GRAEME LOFTS | MERRIN J. EVERGREEN

JACARANDA

SCIENCE QUEST 9

VICTORIAN CURRICULUM | THIRD EDITION

VICTORIAN CURRICULUM v2.0

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All activities in this resource have been written with the safety of both teacher and student in mind. Some, however, involve physical activity or the use of equipment or tools. **All due care should be taken when performing such activities**. To the maximum extent permitted by law, the author and publisher disclaim all responsibility and liability for any injury or loss that may be sustained when completing activities described in this resource.

The publisher acknowledges ongoing discussions related to gender-based population data. At the time of publishing, there was insufficient data available to allow for the meaningful analysis of trends and patterns to broaden our discussion of demographics beyond male and female gender identification.

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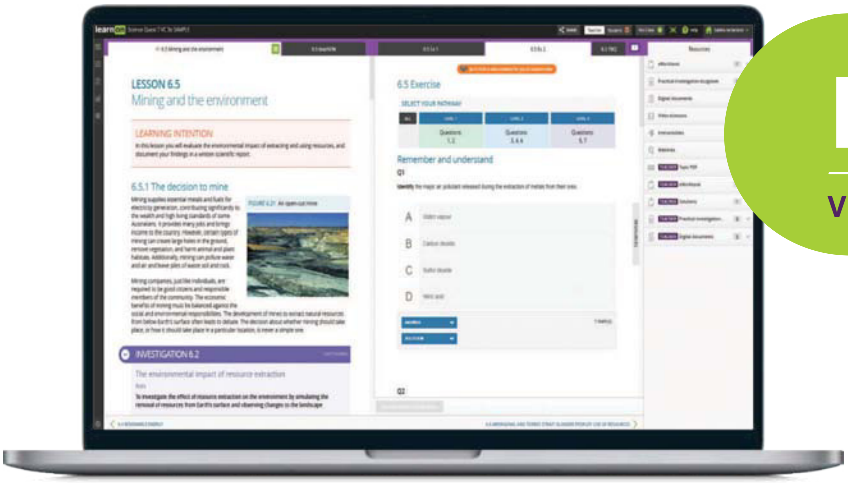

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SCIENCE QUEST 9

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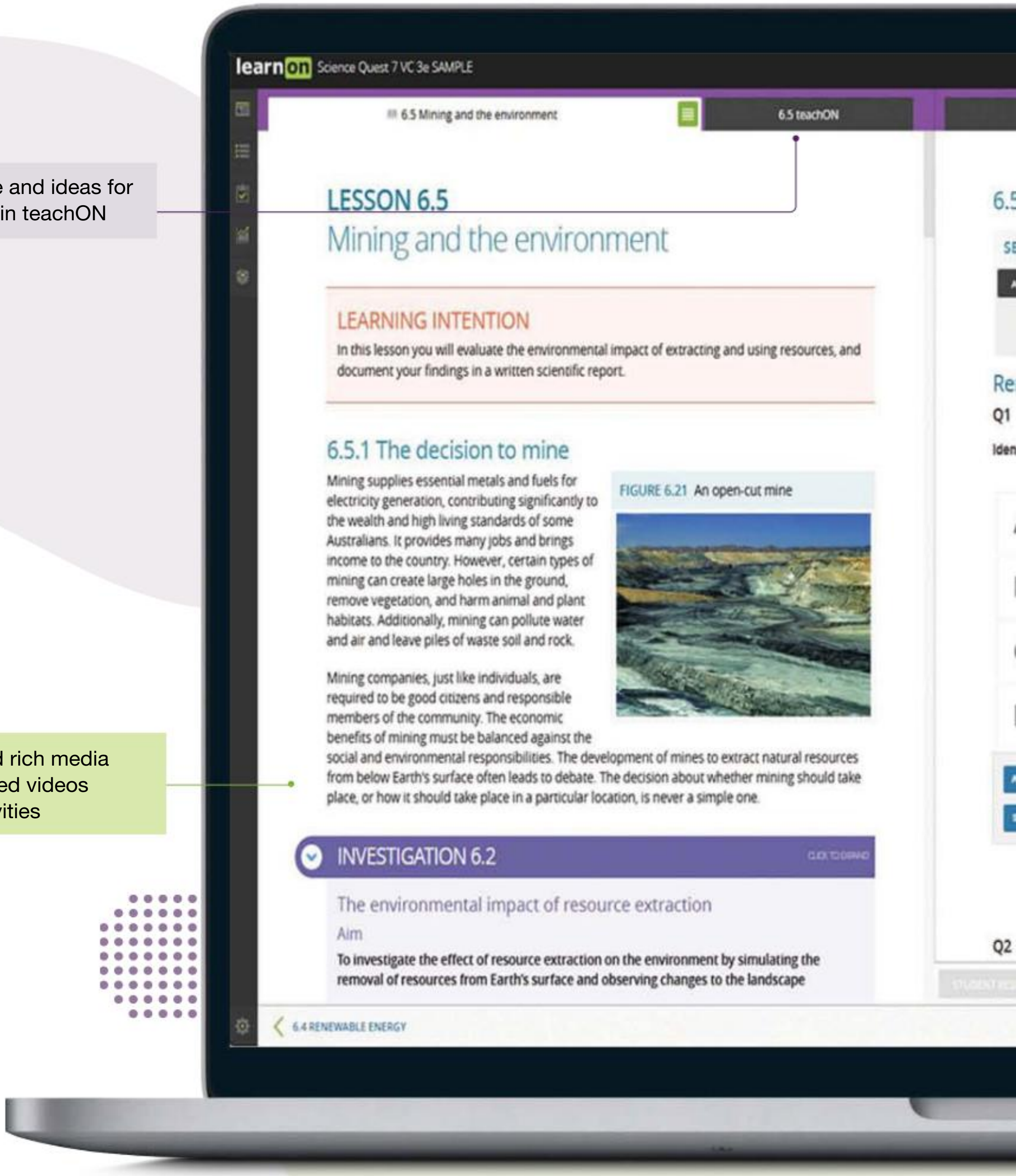

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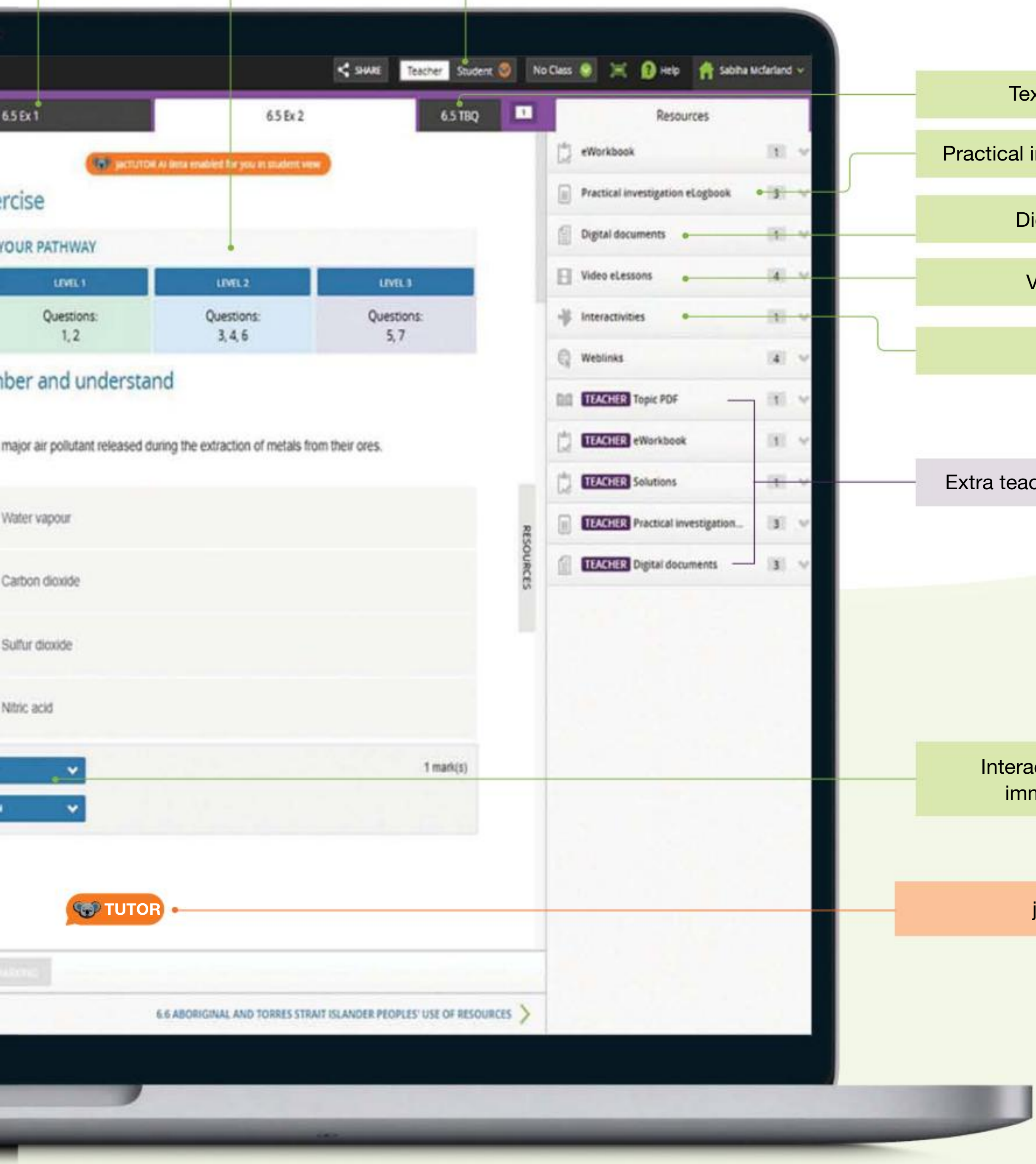

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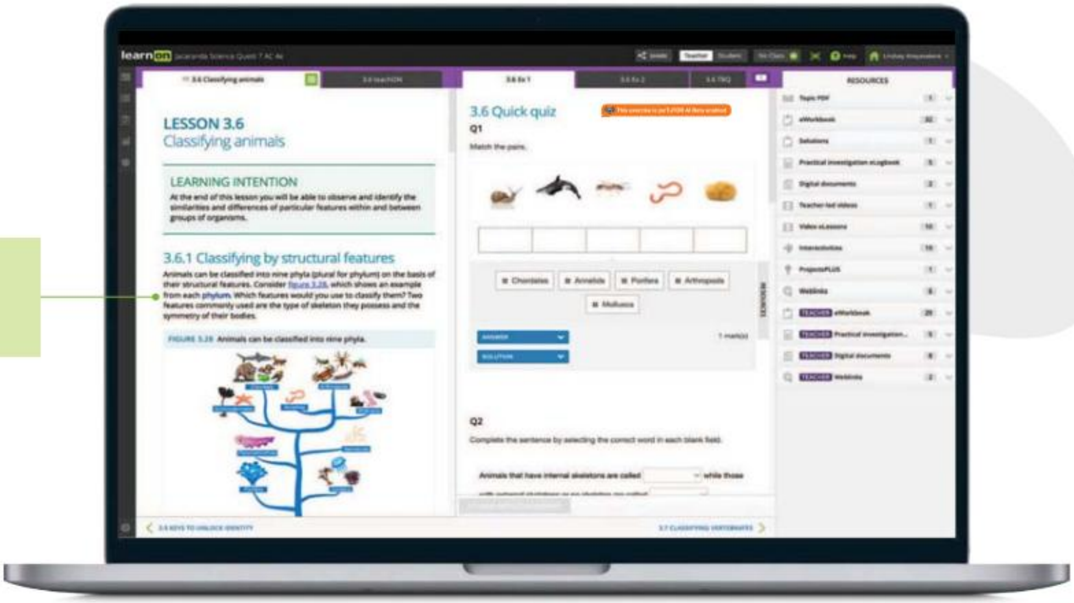

Interactive glossary terms help develop and support scientific literacy.

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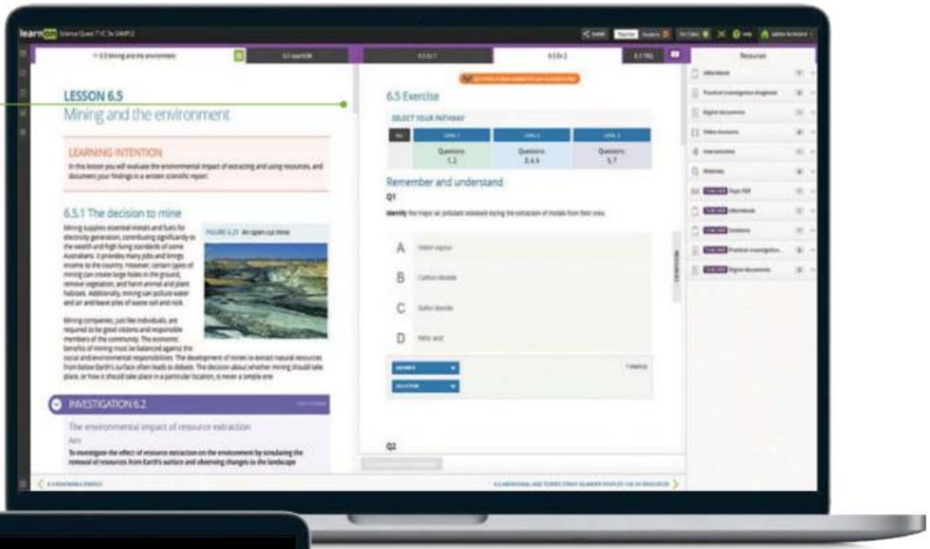
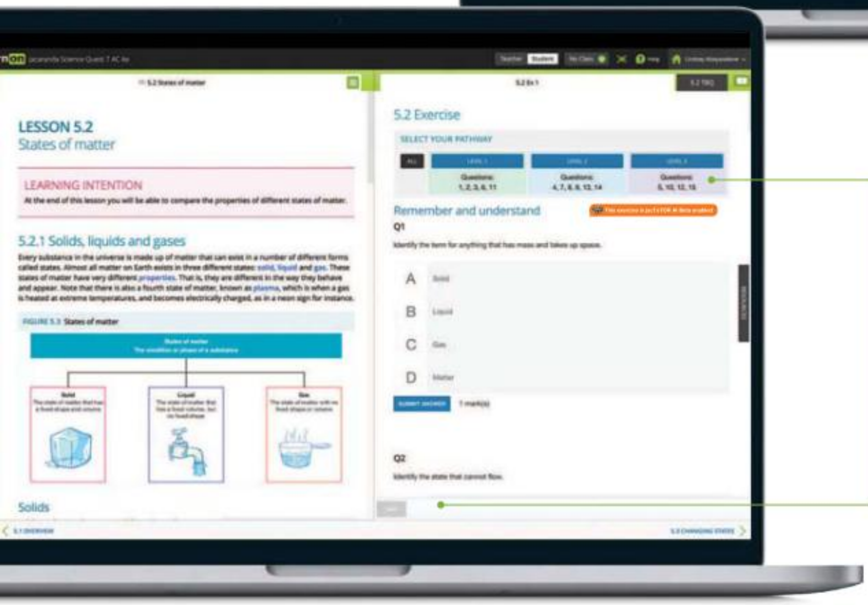
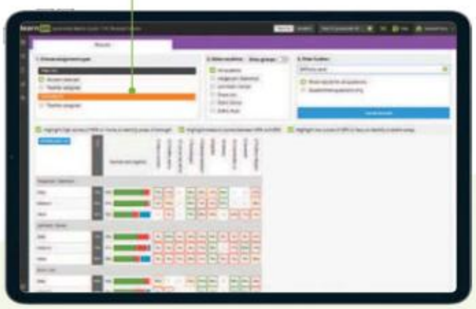
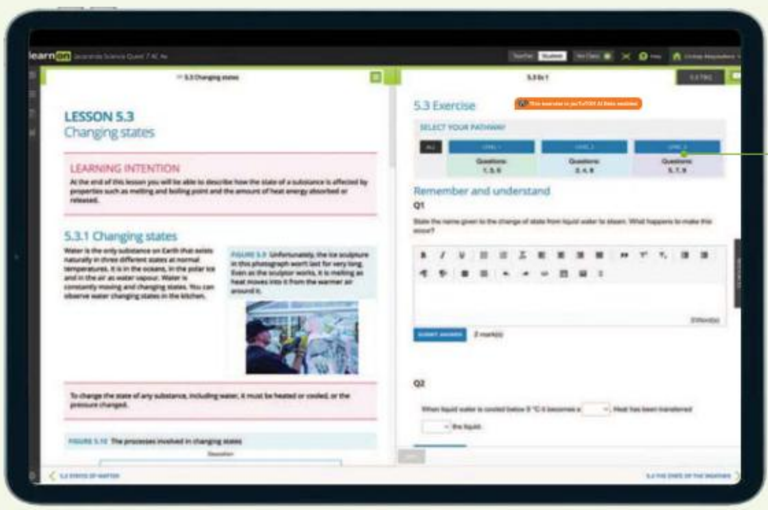




Three differentiated question sets, with immediate feedback in every lesson, enable students to challenge themselves at their own level.

Instant reports give students visibility into progress and performance.

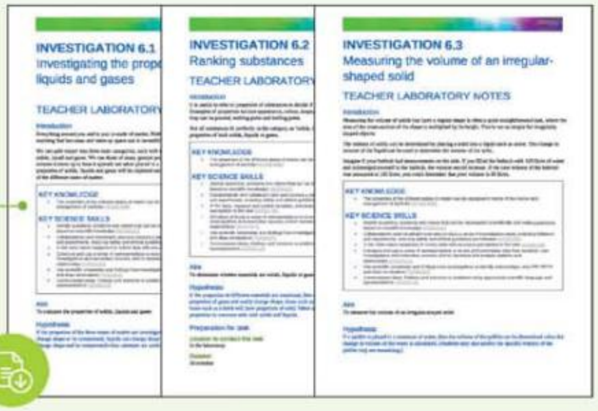




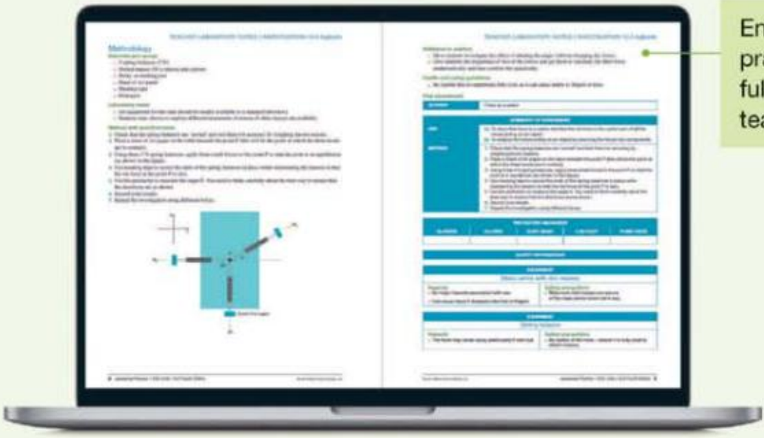
Every question has immediate, corrective feedback to help students overcome misconceptions as they occur and get unstuck as they study independently — in class and at home.

Practical Investigation eLogbook

The **practical investigation eLogbook** ignites curiosity through science investigation work, with an extensive range of exciting and meaningful practical investigations. Aligned with the scientific method, students can develop rich science inquiry skills in conducting scientific investigations and communicating their findings, allowing them to truly think and act like scientists! The practical investigation eLogbook is supported with an unrivalled teacher and laboratory guide, which provides suggestions for differentiation and alteration, risk assessments, expected practical results and exemplary responses.

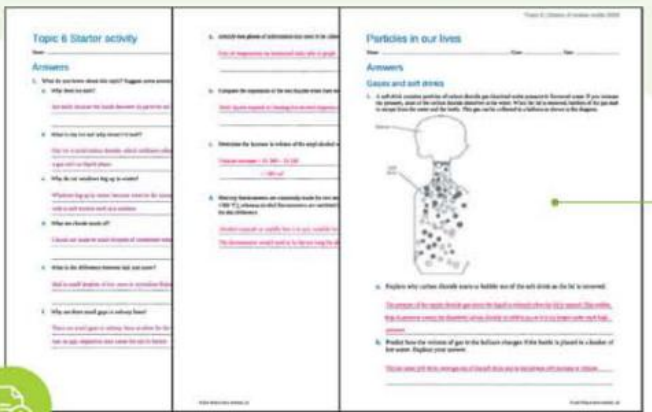


RiskAssess included



Enhanced practical investigation support includes practical investigation videos and an eLogbook with fully customisable practical investigations — including teacher advice and risk assessments.

eWorkbook



The **eWorkbook** is the perfect companion to the series, adding another layer of individualised learning opportunities for students, and catering for multiple entry and exit points in student learning. The eWorkbook also features fun and engaging activities for students of all abilities and offers a space for students to reflect on their own learning. The eWorkbook and eWorkbook solutions are available as a downloadable PDF or customisable Word documents in learnON.

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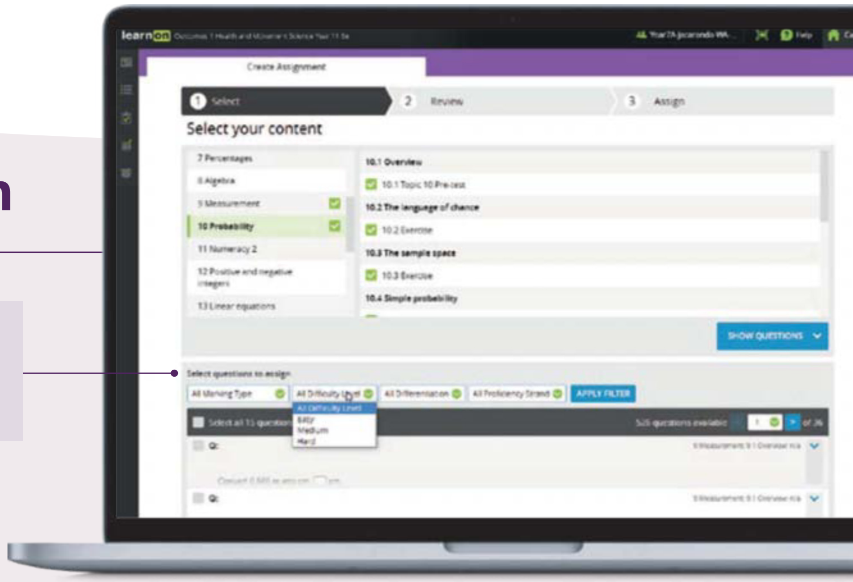
- practical teaching advice
- three levels of differentiated teaching programs
- quarantined topic tests (with solutions)

Customise and assign

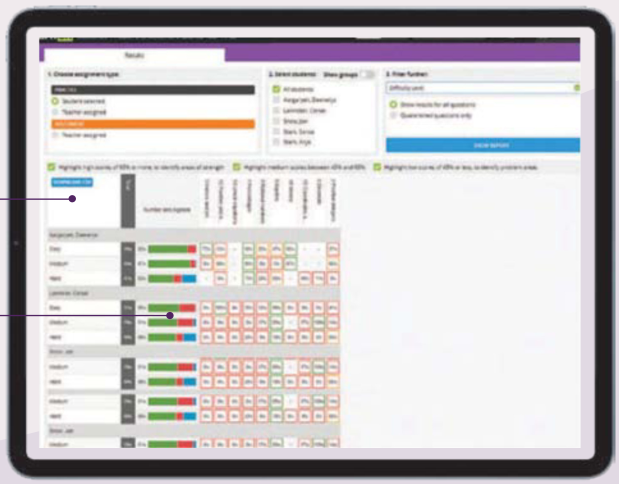
An inbuilt testmaker enables you to create custom assignments and tests from the complete bank of thousands of questions for immediate, spaced and mixed practice.



Reports and results

Data analytics and instant reports provide data-driven insights into progress and performance within each lesson and across the entire course.

Show students (and their parents or carers) their own assessment data in fine detail. You can filter their results to identify areas of strength and weakness.



The new jacTUTOR

Help when students (and teachers) need it — with jacTUTOR

With jacTUTOR, every student can have the help of a personal tutor when they get stuck, in class or at home. This purpose-built tool sits safely within your favourite Jacaranda resource, so guidance will always be specific to that lesson, question and curriculum.

A personal tutor for every student

Now every student can get the help they need, when they need it. jacTUTOR uses AI to create a fair and level playing field for all students.

Get guidance, not the answer

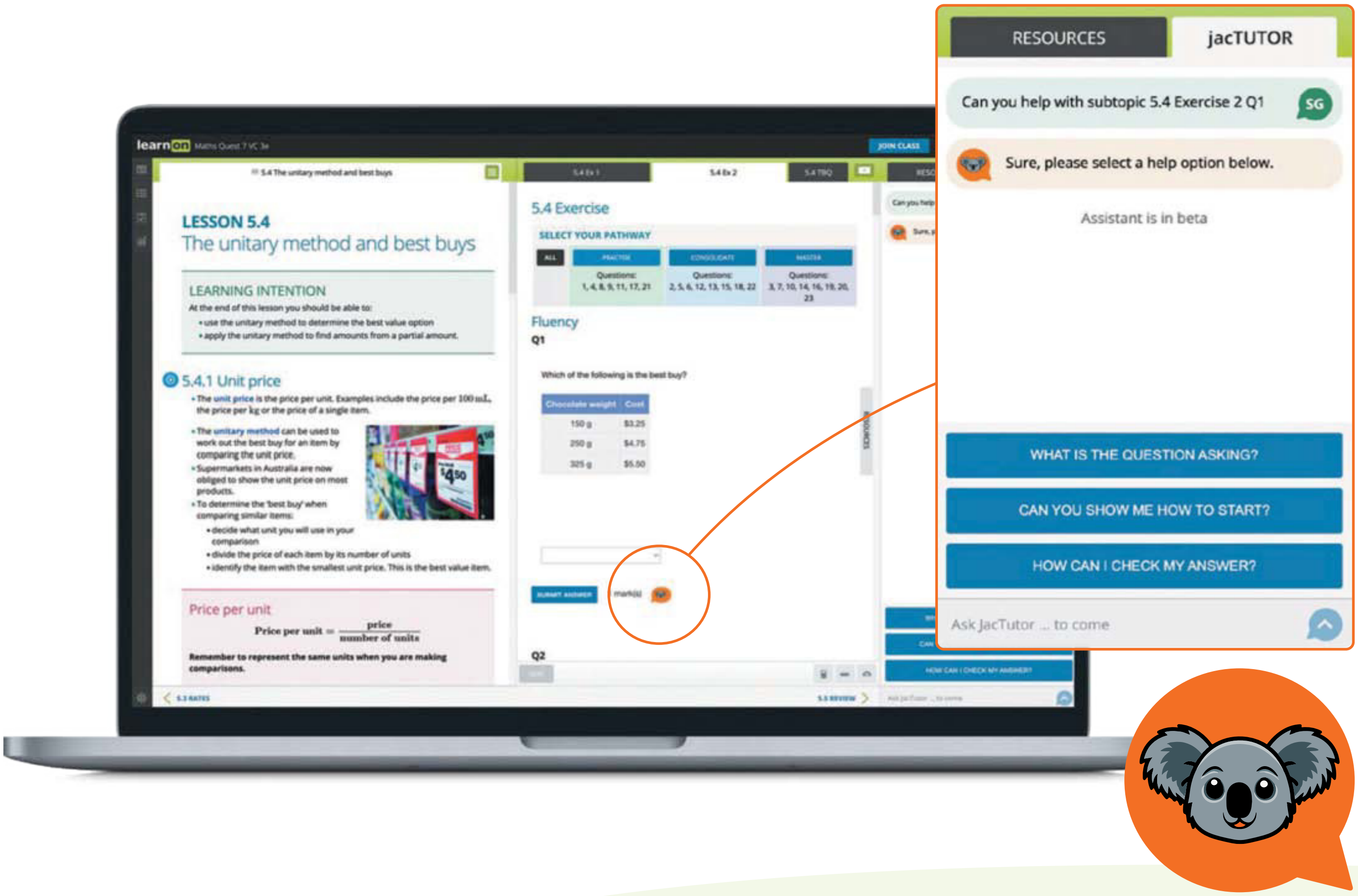
jacTUTOR doesn't just give the answer away. Students are given prompts to help understand what they should be asking to get to a correct answer.

Combat anxiety

Afraid to raise a hand or ask more questions? With jacTUTOR, students will find a safe space to ask questions, get clarification and try again.

A safe space

To keep students safe, any concerning or inappropriate comments are automatically flagged and sent to their teacher.



Meet our author team

Graeme Lofts

Graeme taught Physics, Science and Mathematics at both government and independent schools in Victoria for more than twenty-three years. He has also lectured in Science Education at the University of Melbourne and RMIT University. During his career in science education, Graeme has been honoured with many awards, including an International Teaching Fellowship and the BHP Science Teacher Award.

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Merrin J. Evergreen, PhD, is a distinguished author and educator in the field of science education. With a passion for making science accessible and engaging, Dr Evergreen has contributed to a number of educational texts that are widely used in Australian schools. Her dedication to science education is evident in the clarity and depth of her publications, making complex scientific concepts understandable for students at various levels of their academic journey. Dr Evergreen's commitment to education extends beyond her writing, with a history of active involvement in educational initiatives and endeavours to enhance science literacy.

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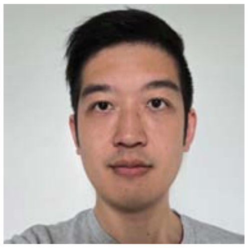

Minhtu Nguyen is a practising Science and Mathematics classroom teacher with over 10 years of experience. He is currently the Head of Mathematics and Numeracy at his school and leads the development of curriculum and teaching excellence. His qualifications include a Bachelor of Engineering (Honors) and Science and a Diploma of Education.

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Luke Williams, Gumbaynggirr

Dr Luke Williams is a proud Gumbaynggirr man of Northern NSW. Luke is a researcher who primarily focuses on the traditional uses of native Australian plants with an emphasis on understanding how these traditional plants can contribute to our modern food and medicine systems. Aside from experimenting with these plants, Luke brings together Indigenous knowledge holders with Western science to explore how these two knowledge systems can add value to our society. Luke is passionate about empowering the next generation of scientist to think holistically about their research.

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Understanding command terms in the Victorian Curriculum

The Victorian Curriculum aims to develop students' disciplinary knowledge, skills, understanding and general capabilities across the curriculum. Students are also expected to progressively develop their thinking skills.

In the Victorian Curriculum, command terms are used as signposts for this depth of thinking. Command terms signify different types of thinking and are already used in the classroom by many teachers and students.

Questions within Jacaranda resources use these command terms to support students in command terms 'thinking'.

For a full list of the command verbs used throughout the *Jacaranda Science Quest* series, visit learnON.

1 Investigating science

LESSON SEQUENCE

LESSON 1.1 Overview

1.1.1 Introduction

Year 9 Science is an exciting journey into understanding how the world works, from the smallest particles in atoms to the systems that keep our planet and bodies functioning. You will explore the scientific methods that help researchers investigate questions and solve problems. This includes learning how to form hypotheses, design experiments, collect and analyse data, and communicate findings clearly. These skills will be at the core of everything you study this year.

FIGURE 1.1 Designing and conducting accurate and precise scientific experiments is an important skill in science.

One of the key topics you will study is reproduction, where you will explore how living things create the next generation. This includes understanding the processes of sexual and asexual reproduction, the role of DNA and how traits are passed from parents to offspring. Closely linked to this is the topic of homeostasis, where you will learn how the body keeps itself balanced by regulating processes like body temperature and blood sugar levels. You will also investigate diseases, discovering the difference between infectious and non-infectious diseases, their causes, and how they are prevented and treated.

In chemistry, you will delve into the structure of atoms, uncovering how scientists have modelled these tiny building blocks over time. You will also learn how chemical reactions occur and how to represent them using word and balanced equations. The energy changes in these reactions, such as exothermic and endothermic processes, will also be explored, helping you understand the chemical transformations happening all around you.

Earth's interrelated systems will be another area of focus. You will explore how the atmosphere, hydrosphere and biosphere interact, and how the carbon cycle affects climate change. This will include investigating strategies for reducing human impacts on the environment. In physics, you will learn about waves, from sound and light to electromagnetic waves, as well as their properties, such as wavelength and frequency. You will also study how electricity is generated from renewable and non-renewable sources, the environmental impact of energy production and ways to improve energy efficiency in our everyday lives.

Science in Year 9 also takes a closer look at people. In psychology, you can explore how the brain works and its influence on our thoughts, emotions and behaviours. You can learn about memory, learning and what happens during different psychological states. Forensics is another fascinating topic in which you can discover the science behind solving crimes, including techniques like fingerprinting, DNA analysis and how evidence is collected and used to identify suspects.

By the end of the year, you will have a deeper understanding of how science explains the world around us and how it is used to address real-world challenges. This knowledge and the skills you develop will not only prepare you for future studies but also help you think critically about the scientific and technological advancements shaping our society.

DISCUSSION

1. Why do you think it is important for scientists to ask questions and test their ideas?
2. Why do you think reproduction is essential for the survival of species?
3. What do you think causes diseases, and why do you think some can spread between people while others cannot?
4. Atoms are the building blocks of everything. Why do you think it is important to understand what atoms are made of and how they behave?

5. Have you ever seen a chemical reaction, like a firework exploding, or baking a cake? What do you think happens to the materials involved during these reactions?
6. Earth's systems — like the air, water and land — are all connected. Why do you think it is important to study how they interact?
7. How do you think human activities, like generating electricity, might affect Earth's systems?

SCIENCE INQUIRY: The importance of science — investigating Galileo's inclined plane experiment

Science is about asking questions and using evidence to find answers. Some of the greatest discoveries in history came from simple experiments that revealed fundamental truths about our world. Galileo Galilei's famous inclined plane experiment is one such example. It showed how objects fall, which laid the groundwork for modern physics. This investigation will help you understand why science is valuable by exploring the ideas behind Galileo's experiment and applying them to real-world scenarios.

Inquiry focus

This activity will explore:

- how Galileo used observation and experimentation to challenge long-held beliefs
- the importance of careful measurement in scientific investigations
- how science helps us understand and predict how things work in everyday life
- how the angle of an inclined plane affects the speed of an object rolling down it.

Hypothesis

As the angle of the inclined plane increases, the object will accelerate more quickly.

Materials

- wooden board
- permanent marker
- small ball
- stopwatch

Method

1. Create an inclined plane using a wooden board and adjust it to three different angles (e.g. 15°, 30° and 45°).
2. Mark equal distances along the plane with a marker (e.g. every 20 cm).
3. Roll a small ball down the plane, starting from the same point each time.
4. Use a stopwatch to measure the time it takes for the ball to travel each marked section. Repeat each trial three times for accuracy.
5. Calculate the ball's average speed for each section by dividing the distance by the time taken.

Data collection

1. Record the times for each trial at each angle in a table.
2. Calculate and graph the relationship between the angle of the incline and the ball's average speed.

Analysis

1. Identify patterns in how the angle affects the speed.
2. Discuss how this experiment helps illustrate the concept of acceleration and the effect of forces on motion.
3. How did Galileo's approach to experimenting differ from earlier methods of understanding the natural world?
4. What does this experiment show about the relationship between observation and theory in science?
5. How does understanding motion help us in everyday life, like in designing vehicles or predicting natural events?
6. Why is repeating experiments and taking accurate measurements important in science?
7. How has this experiment influenced the way we study motion and physics today?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

learnon

Pre-test	Topic 1 Pre-test
eWorkbook	Topic 1 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 1 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 1.2 Observing

LEARNING INTENTION

In this lesson you will:
- explain why instruments can be used to enhance our observation skills
- define the terms quantitative data and qualitative data, and distinguish between precision and accuracy.

1.2.1 Using the senses

Observing involves using our senses to collect information.

TABLE 1.1 The human senses collect different information.

Sense	Sense organ	Example of observation
Sight	Eyes	Colour change
Hearing	Ears	A pop sound is heard
Touch	Skin	The test tube feels warm
Taste	Tongue	Baking powder tastes bitter
Smell	Nose	A pungent odour is produced

FIGURE 1.2 We can use all our senses to collect information about the world around us.

1.2.2 Using instruments

Scientific instruments can improve our ability to make observations.

KEY IDEAS

- Microscopes and telescopes allow us to see objects that our eyes cannot distinguish by magnifying and increasing resolution.
- Magnification means to make bigger. A magnification of ×400 means that the image produced is 400 times larger than the actual object.
- Resolution is the ability to distinguish detail. Better quality microscopes can distinguish two points that are very close together as separate points.
- Many of the instruments used in science convert a signal that cannot be detected by our senses into a display or data that can be interpreted. For example, radio telescopes can detect electromagnetic radiation of longer wavelengths than our eyes can detect.

FIGURE 1.3 Microscopes allow us to see details that cannot be distinguished with our eyes alone.

Instruments can also be used to take measurements, so that we can make quantitative observations.

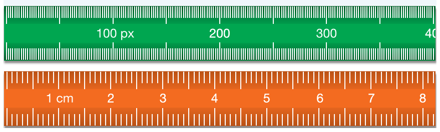
- **Quantitative data** includes measurements, whereas **qualitative data** does not.
- Describing the weather as cold, overcast and rainy is an example of qualitative data.
- Stating that the temperature is 11 °C and 2 mm of rain fell in one hour is an example of quantitative data.

FIGURE 1.4 Precision scales

Using the correct piece of equipment for a particular measurement is important to ensure that an investigation is **valid** and produces **precise** and **accurate** results. One of the criteria of valid experiments is that they must measure what was intended. For instance, using a thermometer to measure whether the pH of a solution changes when carbon dioxide is blown into the solution is not a valid investigation.

Choosing the correct piece of equipment is critical to ensure that your results are precise. Your bathroom scales and the electronic scales in a chemistry laboratory both measure mass, but the laboratory scales are more precise. Your school might have different sets of scales that measure to one or two decimal places. Scales that measure to two decimal places are more precise. High-precision scales are needed for some of the senior Chemistry experiments.

FIGURE 1.5 A ruler with smaller gradations on the scale is generally more precise.



For measuring instruments with a scale, such as thermometers, rulers and measuring cylinders, the gradations (lines) on the scale give an indication of the precision of the instrument. Generally, an instrument with smaller gradations is more precise, so in figure 1.5, the ruler at the top is more precise than the ruler below.

Measurements can be precise but incorrect. Sometimes, service stations overcharge customers due to faulty petrol pumps that give inaccurate readings. For example, a pump might read 1.1 L for each litre dispensed, charging customers more. The machine is precise, but not accurate.

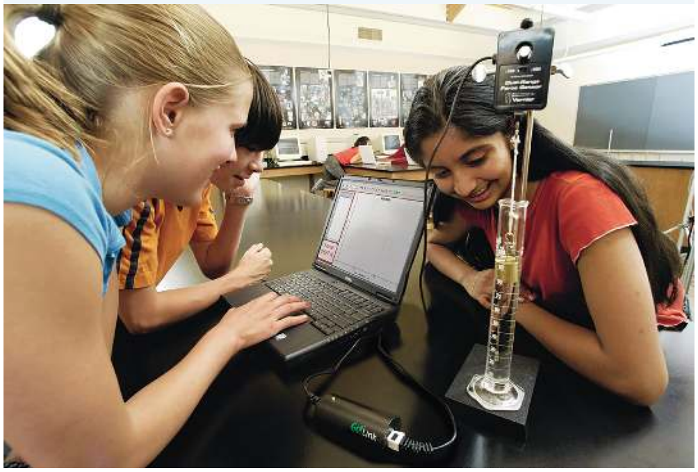
Some instruments need regular calibration to ensure accuracy. A pH meter, which measures acidity, requires frequent calibration. It provides precise readings to one or two decimal places but can lose accuracy over time; for example, it might show 6.25 when the actual pH is 5.38. To **calibrate**, you place the meter in solutions of known pH and adjust it until it reads the correct values for these solutions.

FIGURE 1.6 A pH meter needs to be calibrated regularly to ensure it gives accurate readings.

1.2.3 Data collection probes

Data collection probes can collect many measurements very quickly, or collect data more slowly over a long period of time. There are different types of probes that can measure temperature, pH, salinity, oxygen concentration, light intensity and many other parameters. The probes can connect to either a data logger or a computer. Software can be used to display the data in tables and graphs and analyse the results.

FIGURE 1.7 The probe collects data. Software on the computer displays and analyses the data.



INVESTIGATION 1.1

Using data collection probes

Aim

To investigate the change in pH and temperature involved in some chemical processes

Materials

- pH probe
- ammonium chloride salt
- dropper bottle of dilute sodium hydroxide (a solution of 0.5 mol/L is suitable for this experiment)
- temperature probe
- magnesium ribbon
- dilute hydrochloric acid (a solution of 0.5 mol/L is suitable for this experiment)

Method

CAUTION:
- **Safety glasses must be worn for this investigation.**
- **Do not handle any chemicals with your fingers. Use a spatula to handle salts.**

1. Connect a temperature probe and a pH probe to your data logger or computer. Set up the data logger or computer to collect data every second for 3 minutes (180 seconds).
2. Place 25 mL of hydrochloric acid in a 50 mL beaker.
3. Lower the probes into the acid. You may need to stand the small beaker inside a larger beaker to ensure it does not tip over.
4. Using a dropper, gradually add 50 mL of the sodium hydroxide solution. Try to add the solution evenly over the full 3 minutes if you can.
5. Save the data you collected.
6. Place 50 mL of water in a clean beaker. Place the temperature and pH probe in the water. Again, you may need to stand the small beaker inside a larger beaker to ensure it does not tip over.
7. Add one spoon of ammonium chloride salt to the water. Start the data collection as soon as you add the salt and continue until the salt has completely dissolved. Use the temperature probe to gently stir the water as the salt dissolves, but be careful to avoid bumping the pH probe as it is fragile.
8. Save the data.
9. Place 50 mL of dilute hydrochloric acid in a small clean beaker. Stand the small beaker inside a larger beaker. Place the temperature and pH probe in the acid. Add a 2 cm piece of magnesium to the acid and start the data collection as soon as the magnesium is added to the acid. Continue to collect data until the magnesium has completely reacted.
10. Save the data.

Results

1. Take screenshots of the graphs produced by the data logging software and insert these in the results section of your experiment report.
2. Exothermic processes give off heat whereas endothermic processes take in heat. Identify the exothermic and endothermic processes.

Discussion

1. This experiment could be done with a thermometer and universal indicator or a pH meter instead of a data logger. List some advantages and disadvantages of using a data logger in this instance.
2. In this experiment, which was:
   a. the independent variable
   b. the dependent variable?

Conclusion

Write a sentence to describe the change in pH for each reaction.

1.2 Activities

learnon

1.2 Quick quiz on	1.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 5	2, 3, 6, 9	7, 8

Remember and understand

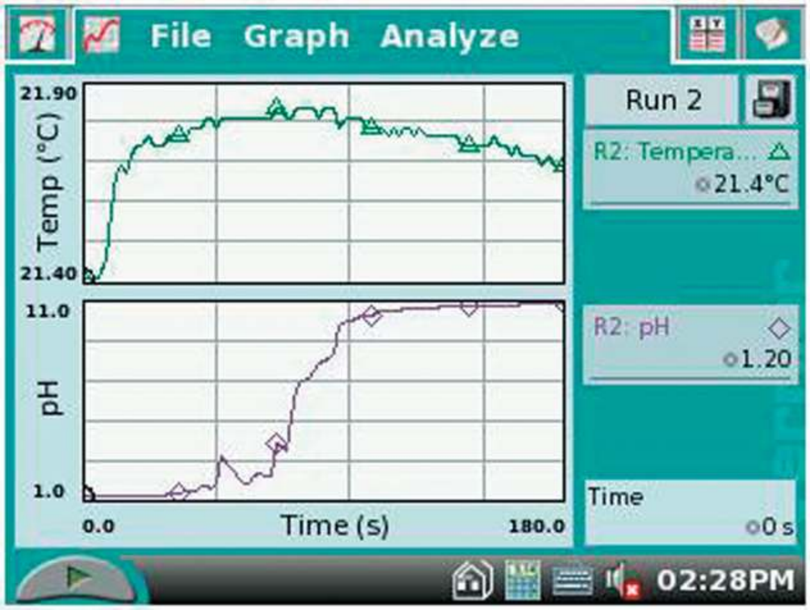
1. MC A Science teacher combines two white powders into a beaker. After a while, the powders look like a slushy mixture and the bottom of the beaker feels cold. The smell of ammonia can be detected.
   Identify the senses that were used to make these observations. (Select all that apply.)
   A. Sight
   B. Sound
   C. Touch
   D. Smell
   E. Taste
2. **Explain** how microscopes and telescopes enhance our ability to make observations.
3. Calibration of equipment is important in scientific experiments. **Outline** what calibrating an instrument involves.
4. **Identify** which of the pieces of equipment on the left matches with each of the functions on the right.

Equipment	Function
a. Data logger	1. Plugged into the data logger, these take measurements
b. Computer	2. A device that can collect and store data from sensors connected to it
c. Data logger software	3. Data needs to be downloaded from the data logger to this
d. Touch screen	4. Allows you to process the data collected by the data logger
e. Data	5. Allows you to input data into the data logger or computer by touching it with your finger or a stylus
f. Sensor	6. Piece of information (or set of pieces of information)

Apply and analyse

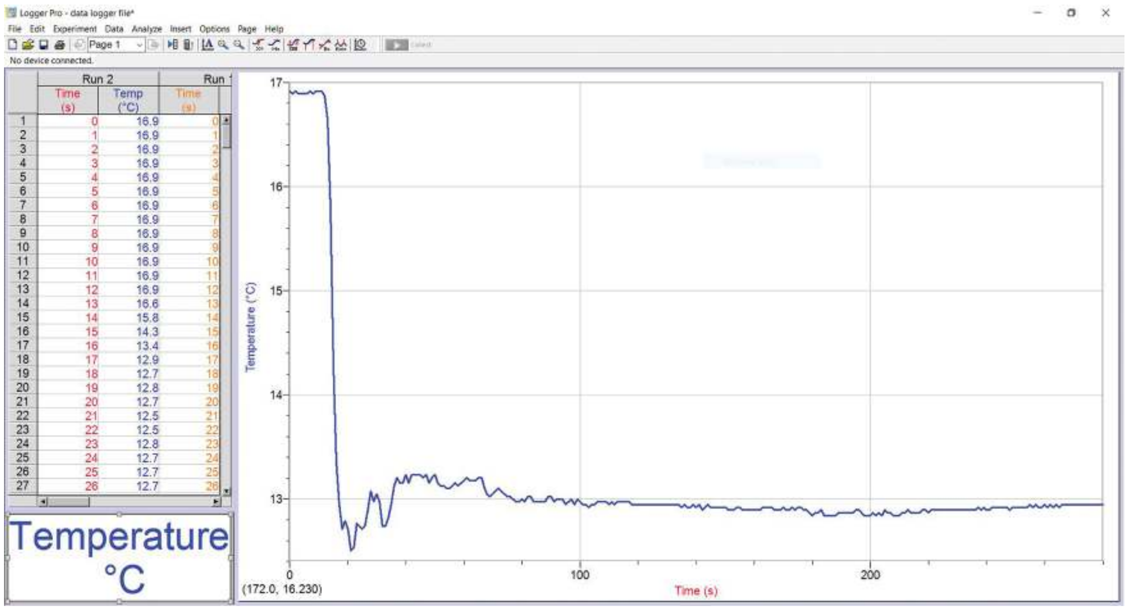
5. MC A student is using a pH probe that has not been calibrated recently. They place the pH probe in a buffer solution that has a pH of 7.0, and it reads 9.2. In a buffer solution with a pH of 4.5, the probe reads 6.7; and in a buffer solution with a pH of 13.0, it reads 15.2.
   Identify the statement that is correct.
   A. The pH probe is accurate and precise.
   B. The pH probe is accurate, but not precise.
   C. The pH probe is precise, but not accurate.
   D. The pH probe is neither accurate nor precise.

6. Observe the figure and complete the following.



a. **Identify** the time that the pH was approximately 5.
b. **Identify** the approximate time that the maximum temperature was reached.
c. **Identify** the approximate pH and temperature values after 180 seconds.

7. The graph shows the change in temperature after 20 g of salt X was added to 100 mL of water. Observe the graph and complete the following.



	Run 2 Time (s)	Run 2 Temp (°C)	Run 1 Time (s)
1	0	16.9	0
2	1	16.9	1
3	2	16.9	2
4	3	16.9	3
5	4	16.9	4
6	5	16.9	5
7	6	16.9	6
8	7	16.9	7
9	8	16.9	8
10	9	16.9	9
11	10	16.9	10
12	11	16.9	11
13	12	16.9	12
14	13	16.6	13
15	14	15.8	14
16	15	14.3	15
17	16	13.4	16
18	17	12.9	17
19	18	12.7	18
20	19	12.8	19
21	20	12.7	20
22	21	12.5	21
23	22	12.5	22
24	23	12.8	23
25	24	12.7	24
26	25	12.7	25
27	26	12.7	26

a. **Identify** the temperature at the start of the experiment.
b. **Identify** what was the lowest temperature that the solution of salt X and water solution reached. **State** how long after first adding the salt X crystals this occurred.
c. **State** whether dissolving salt X in water is an exothermic or endothermic process. **Justify** your response.
d. **Suggest** why the graph line is not smooth. **Discuss** what might have caused the sharp drops in temperature.

8. Ethan wanted to find out whether sand heats up faster than water in the Sun. He filled one beaker with sand and another with water. He placed a temperature probe connected to a data logger in each beaker and placed the two beakers in a sunny area of the playground. Half an hour later, Ethan came back to collect the beakers, probes and data logger. Once back in the lab, he downloaded the results to his computer and analysed.
   a. **Describe** another way this experiment could be carried out if you did not have access to a data logger.
   b. **Discuss** the advantages of using temperature probes and a data logger for this experiment.
   c. When all the groups had finished the experiment, Ethan's teacher asked a student from each group to write the increase in temperature for each beaker on the board. **Explain** why it is a good idea to collect data from all groups.

Evaluate and create

9. As compost decomposes, it releases heat. A student wanted to find out if the composition of compost affects the amount of heat released by compost. She prepared three types of compost in three separate beakers.
   - Compost A consisted of grass clippings.
   - Compost B consisted of shredded leaves from a eucalyptus tree.
   - Compost C consisted of shredded lettuce leaves.

   Explain why the student might decide to use a temperature probe rather than a thermometer to monitor the temperature of the three types of compost.

Answers and sample responses are available in your digital formats.

LESSON 1.3 Measuring and reading scales

LEARNING INTENTION

In this lesson you will read and record measurements accurately.

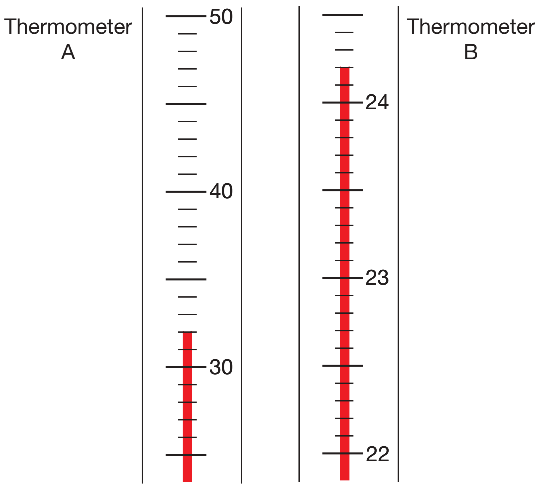
1.3.1 Why do we need to measure and read scales?

When conducting experiments, it is critical that measurements and data are recorded accurately. Whether measuring volume or temperature, or interpreting alternate scales, it is important that they are recorded accurately.

What is the application of measuring and reading scales in science?

In science applications, measuring and reading scales are used to observe and record many variables, including volumes of liquids or gas, mass, length and temperature. It is important that scales are used correctly to reduce random errors and ensure that the data obtained is accurate, in order to obtain valid conclusions.

FIGURE 1.8 The temperatures measured by thermometers A and B are 32 °C and 24.2 °C, respectively.



1.3.2 How do we measure and read scales?

Materials

- thermometer with a liquid column (alcohol or mercury)
- 250 mL measuring cylinder or burette

Method

Step 1

A thermometer with a liquid column should have markings on its scale. Find the top of the measuring column and position your eye so that it is level with the top of the column. This will avoid any parallax errors in reading the temperature. Read the number on the largest scale division below the top of the column.

Step 2

Read the number on the largest scale division above the top of the column and count how many scale divisions there are between the lower and higher scale divisions. Divide the number of divisions into the temperature difference between the upper and lower scale divisions. This will give you the amount each scale division is worth. Count up from the lower scale division and read the correct temperature. If the column is in the middle of two divisions, the reading will be half a scale division above the lower reading.

Step 3

Liquids in containers such as measuring cylinders often have a curved surface at the top edge. The curve is called a meniscus. The edges of the meniscus may curve up or down. Locate the middle flat section of the meniscus and position your eye so it is level with it.

Step 4

Using the procedure in step 2, read the volume of the middle flat section of the meniscus.

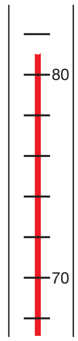
1.3 Activities

learnon

1.3 Quick quiz on	1.3 Exercise

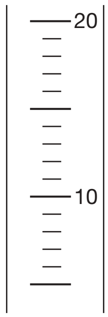
LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	–	–

1. The diagram shows a portion of a thermometer measuring a temperature in degrees Celsius.
   a. **Identify** the value of the lower scale marker.
   b. **Identify** the value of the higher scale marker.
   c. **Calculate** the value of each scale division.
   d. **Identify** the reading of the red column of the thermometer.

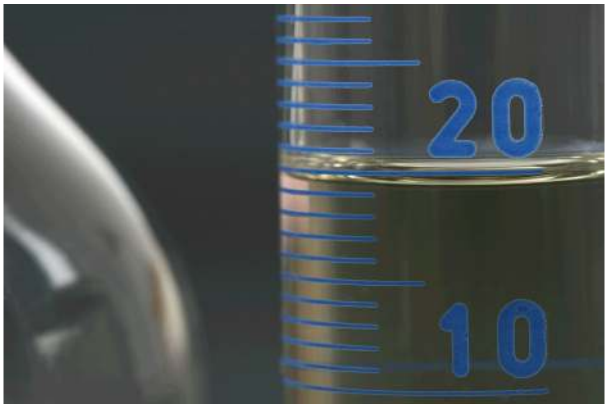


2. The human body temperature is normally around 37 °C. If a person's temperature is different from that, they may be suffering from an illness. The thermometer shows the temperature of a patient. **Identify** the temperature shown.

3. The diagram represents a section of an alcohol thermometer. Copy the figure and draw a central line to show a temperature of 14 °C.



4. The photo shows a measuring cylinder containing some water. Read the scale to determine the volume of water in the measuring cylinder.



   a. MC **Identify** the correct reading.
      A. 19.5 mL
      B. 20.5 mL
      C. 21.0 mL
      D. 22.0 mL
   b. **Explain** how you reached your answer.

Answers and sample responses are available in your digital formats.

LESSON 1.4 Questioning and predicting

LEARNING INTENTION

In this lesson you will describe some of the ways that scientists develop questions and problems to investigate.

1.4.1 It starts with observations

How do scientists decide what to investigate?

Many ideas for scientific investigations start with a simple observation. Some well-known investigations and inventions from the past started that way. The development of **penicillin** was the result of a chance observation of a mould growing in a dish of bacteria. The bacteria near the mould were not multiplying. This observation was made by a Scottish scientist, Sir Alexander Fleming, in 1928. An Australian, Howard Florey, saw the possibility that the mould could be used to treat infections caused by bacteria. After almost 20 years of further investigation, the mould, called *Penicillium*, was used to produce penicillin. This is a powerful drug that can help rid the body of many bacterial infections.

FIGURE 1.9 Sir Alexander Fleming

Danish scientist Hans Oersted discovered the connection between electric current and magnetism when, in 1819, he noticed that a compass needle pointed in the wrong direction every time it was placed near a wire carrying an electric current. His discovery started a flood of inventions, including electric generators and motors.

High school science projects should also start with observations. For example, an investigation by 15-year-old student Catherine Pippos began with an observation that her friends seemed to perform better in track and field events when there was an audience cheering them on. You have probably seen this yourself. Her investigation 'Does an audience affect the performance of an athlete?' involved three different sporting activities and compared the performance of a large group of students under three different conditions:

- No audience
- A quiet audience
- A cheering audience

The sporting activities were:

- goal-shooting in basketball
- sit-ups
- shot put.

Catherine's research investigation resulted from her curiosity, and she chose a topic based on her interests.

1.4.2 Defining the question

Once you have an area of interest, you can determine exactly what you want to investigate. It is better to start with a simple, very specific question than a complicated or broad question. For example, the topic 'earthworms' is very broad. There are many simple questions that could be asked about earthworms, such as:

- Which type of soil do earthworms prefer?
- How much do earthworms eat?
- Do earthworms prefer to eat meat or vegetables?
- How fast does a population of earthworms grow?

In defining the question, you need to consider whether:

- you can obtain the background information that you need
- the equipment that you need is available
- the investigation can be completed in the time you have available
- the question is safe to investigate.

Your chosen question should be expressed in the form of an **aim**. The aim is a statement that outlines the purpose of the the scientific investigation.

1.4.3 From question to hypothesis

Once you have decided on the question you will investigate, you can formulate a hypothesis. A hypothesis is a statement that attempts to answer the question. For instance, if your question was 'does the addition of fluoride to drinking water reduce your risk of tooth decay?', the hypothesis might be 'By the time they reach the age of 50, people who spent their childhood in a city where the tap water is fluoridated have fewer fillings than people who spent their childhood in a city where no fluoride is added to the water'.

In lesson 1.6, we will learn more about writing hypotheses, but some important features are listed in the following key ideas box.

KEY IDEA

A hypothesis:

- is written as a statement
- should be sensible
- should be **testable** through a scientific investigation
- can be written in different formats, but usually includes independent and dependent variables
- is never proven correct. The results of the investigation may *support* the hypothesis. Alternatively, if the results do not support the hypothesis, it may be rejected or modified.

1.4.4 Hypothesis or prediction?

A prediction is a specific statement about what we think will happen in the future or what we anticipate will happen in an experiment. For example, you might notice that the sky is grey and make the prediction that it will rain shortly. Before combining acid and magnesium, you might predict that a gas will form. When testing your friends' heart rates, your prediction could be that James, who is the school cross-country champion, will have the lowest heart rate.

A hypothesis is a more general statement. 'People who exercise regularly have a lower resting heart rate than those who do not exercise' is a hypothesis. Similarly, 'Purple flowers make good acid–base indicators' is also a hypothesis; it is a general statement about all purple flowers. A hypothesis can be used to make a prediction. 'Purple impatiens will make a good acid–base indicator' is a prediction. It is a specific statement about one particular type of flower.

FIGURE 1.10 A hypothesis can be used to make a prediction, such as that purple impatiens will make a good acid–base indicator.

SCIENCE AS A HUMAN ENDEAVOUR: The role of predictions and hypotheses in scientific discovery

Predictions and hypotheses are essential tools in science, helping researchers explore the unknown and test their ideas about the world. By observing patterns and making predictions, scientists develop hypotheses — general statements that provide a foundation for experimentation. These steps drive progress and innovation in science and technology.

FIGURE 1.11 A meteorologist analyses weather data

Meteorologists rely on observations of atmospheric patterns to make predictions about the weather. Using data such as wind speed, temperature and cloud cover, they predict outcomes like rainfall or storms. Behind these predictions are hypotheses about how atmospheric variables interact. Advances in computer modelling and satellite technology have refined these predictions, illustrating the importance of hypothesis-driven research in practical applications.

Predictions and hypotheses play a crucial role beyond everyday science. For example:

- *Medical research.* Scientists may hypothesise that a new drug will be effective against a disease and predict specific outcomes during clinical trials.
- *Environmental science.* Ecologists hypothesise how changes in an ecosystem might impact species and predict how interventions, like reforestation, will affect biodiversity.
- *Engineering and innovation.* Engineers hypothesise how a new material or design will perform and predict its behaviour under different conditions, such as stress or temperature changes.

These examples highlight how making informed predictions and testing hypotheses drive solutions to complex problems.

1. Why is it important for scientists to test their predictions with experiments?
2. What might happen if a hypothesis is proven incorrect? How could this lead to new discoveries?
3. How do tools like weather satellites or computer models improve the accuracy of predictions?
4. What's the difference between a hypothesis and a prediction? Why are both necessary in science?
5. Can you think of a situation in which a hypothesis led to an unexpected discovery?

Scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)

1.4 Activities

learnon

1.4 Quick quiz on	1.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1	2	3

Remember and understand

1. **Identify** whether the following statements are true or false.
   a. The aim of an investigation starts with an idea or problem.
   b. The aim is written as an if–then statement.
   c. The hypothesis is written as a question.
   d. The hypothesis must be able to be tested by experimental results or data.

Apply and analyse

2. A student was interested in investigating how to grow the bushfood warrigal greens, using seeds, to produce a plentiful crop in the shortest amount of time. The student observed that some plant seeds germinate only when soaked in water or exposed to smoke.
  a. **State** an aim for the student's investigation.
  b. From your aim, **state** a hypothesis for an investigation.
  c. **Describe** how your hypothesis could be tested.

Evaluate and create

3. **a.** **Identify** whether each of the following statements is written as an aim, a hypothesis or neither.
  i. To determine how much rubbish is collected from my school in one day
  ii. If the different colours of new cars purchased this year were calculated, then the most popular colour would be black.
  iii. Chocolate is the most popular snack food at my school.
  iv. If the temperature drops below 5 °C for three days in a row, then it will rain on the fourth day.
  v. To investigate how tall a wall mirror should be in order for me to see my full height (185 cm) from 1 m away.
  b. For any statement in part **a** that is neither an aim nor a hypothesis, rewrite it as a possible hypothesis.

Answers and sample responses are available in your digital formats.

LESSON 1.5 Controlled, dependent and independent variables

LEARNING INTENTION

In this lesson you will identify independent, dependent and controlled variables.

1.5.1 What is the difference between controlled, dependent and independent variables?

In order to answer a question scientifically, a controlled investigation needs to be performed. In a controlled investigation, every **variable** except the one being tested is held constant, which stops the results being affected by an uncontrolled factor. The variable that you are investigating is called the **independent variable**. The variable that you are measuring is called the **dependent variable**. The other variables should be controlled (kept the same).

FIGURE 1.12 A controlled investigation is an important part of science.

What is the application of variables in science?

In many branches of scientific research, questions are being asked, such as: What is the best way of doing this? How can this be done faster or more efficiently? How can we cure this disease? In order to answer complicated questions, investigations must be carried out that are well thought out and planned, so that the results can be trusted and repeated.

When creating scientific questions, developing aims and formulating hypotheses, it is vital to know which variables are which. Understanding variables ensures that a **fair test** is created and your questions, aims and hypotheses are specific and targeted.

1.5.2 How do you identify and use controlled, dependent and independent variables?

Materials

- 2 thermometers or temperature probes
- 2 identical glasses or beakers
- ice-cube trays that make cube-shaped ice blocks
- ice-cube trays that make spherical-shaped ice blocks
- 1 L of water
- measuring cylinder

Method

Step 1

Determine which variable you are changing and testing in your investigation; this is the independent variable. In this investigation, the aim is to investigate which ice block's shape is most successful at reducing the temperature of the water.

Therefore, the independent variable is the shape of the ice blocks.

Step 2

Determine which variable you are measuring in your investigation. In this case, it is the temperature of the water.

Step 3

Ensure a fair test is created by making sure all other variables are controlled. Consider all the factors that need to be controlled: the amount of water, the volume of the ice block, the initial temperature of the water, the number of ice blocks and the time.

Step 4

Conduct the investigation.

Determine the volume of water needed to fill the spherical ice-cube tray by filling it using the measuring cylinder and recording the volume.

Using the measuring cylinder, fill the cube-shaped ice-cube tray with the same volume of water as used to fill the spherical ice-cube tray. Freeze both trays overnight for the same amount of time.

Step 5

Fill each glass to half its volume with water using the measuring cylinder to ensure each glass has the same volume in it. Add the thermometer or temperature probe to each glass. At the same time, add two spherical ice blocks to one glass but ensure it does not overflow, and add the same number of cube ice blocks to the other glass ensuring that the water does not overflow.

Step 6

Measure and record the temperature in each glass until it stops falling and starts to rise. Repeat the experiment using the remaining ice blocks.

1.5 Activities

learnon

1.5 Quick quiz on	1.5 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	–	–

1. To investigate various ways of keeping cut flowers alive, several different substances were added to the water in three identical vases. The substances were 5 g of sugar, 5 g of salt and 5 g of vinegar. A fourth vase was set up using only water with nothing added.
   A bunch of flowers was divided up so that there were the same number of individual flowers in each of the four vases.
   a. **Identify** the independent variable.
   b. **Identify** the dependent variable.
   c. **Identify** the two variables that were controlled.
   d. **Explain** why one vase was set up with only water in it.
2. An investigation can be used to determine which shape of ice block cools a drink to the lowest temperature.
   a. **Describe** how this could be done.
   b. **Identify** the dependent variable in this case.
3. A group of scientists wants to test how different types of soil affect the growth of tomato plants. They set up an experiment using soil with large particles (like sand), soil with small particles (like clay) and soil with a mixture of both. Each plant is given the same amount of water, sunlight and fertiliser.
   a. **Identify** the independent and dependent variables.
   b. **Explain** why controlling water, sunlight and fertiliser is important in this experiment.
   c. **Predict** which soil might lead to the best plant growth. **Justify** your reasoning.

Answers and sample responses are available in your digital formats.

LESSON 1.6 Writing an aim and forming a hypothesis

LEARNING INTENTION

In this lesson you will write aims and hypotheses.

1.6.1 Why do we need to write an aim and form a hypothesis?

In science, we conduct investigations to gather data and results and draw conclusions. Every investigation requires an aim — a short statement of what we are trying to achieve. Alongside an aim, the ability to formulate predictions is important in science. This is done through the use of a hypothesis. Being able to write aims and hypotheses are vital skills for any scientist.

FIGURE 1.13 In scientific investigations an aim and a hypothesis are needed.

What is the application of an aim and a hypothesis in science?

A hypothesis is an idea that is based on observation, which can be tested in an investigation by experiment or data. Investigations can involve testing, field work, using models or simulations, finding and using information for various sources and conducting surveys.

The aim is a question or a statement about the direction of the scientific investigation. It provides a purpose of the investigation.

A hypothesis is an educated prediction of the outcome of an investigation, which can be supported or unsupported through the results of an investigation.

1.6.2 How do we write aims and form hypotheses?

The following is an idea for an investigation, based on an area of interest. The purpose of the investigation is to find out whether the bushfood warrigal greens grows best from seeds or cuttings.

Materials

- warrigal green seeds
- warrigal green cuttings
- potting mix
- pots

Method

Step 1

To write an aim, you need to first identify your independent and dependent variables. The independent variable is what you are changing: using seeds or cuttings from warrigal greens.

The dependent variable is what you are examining: the growth of warrigal greens.

Step 2

It often helps to write your idea as a scientific question; for example, how are warrigal greens best grown?

Step 3

Use this to develop your aim. An aim is usually written in one of two formats:

1. To investigate the effect of a change in the independent variable on the dependent variable
2. To investigate how the dependent variable is affected by a change in the independent variable

For this investigation, some example aims may be:

- to compare the difference between the use of seeds and cuttings on the growth of warrigal greens
- to observe whether the growth of warrigal greens is affected by the use of seeds or cuttings during planting
- to determine whether warrigal green seeds or warrigal green cuttings result in the greatest amount of plant growth.

Step 4

Refine your aim into a hypothesis, in this case written as an 'if–then' statement. This should again link your variables. For example, *if* the same number of warrigal seeds and cuttings are planted and the two crops compared after one month, *then* the cuttings will produce a greater weight of picked leaves.

Step 5

Check that your hypothesis is able to be tested or backed up by data. In this case, the two crops of leaves can be weighed and compared.

1.6 Activities

learnon

1.6 Quick quiz on	1.6 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 5	–	–

1. **Identify** the correct terms to complete the following sentences.
   A *prediction* / *hypothesis* / *opinion* is a statement that explains observations. It is measurable and can be tested.

   A *prediction* / *hypothesis* / *opinion* is a guess about what will happen if the hypothesis is true.
2. **Identify** whether each of the following statements is an aim, a hypothesis, an observation or a prediction.
   a. Mould grows fastest in warm and humid environments.
   b. No mould will grow on bread if it is stored in the fridge.
   c. To find out the temperature at which mould grows fastest
   d. After 5 days, 50 per cent of the slice of bread stored at 35 °C was covered in mould.
   e. After 3 minutes, the temperature of the coffee in the ceramic cup had dropped from 80 °C to 63 °C.
   f. Ceramic is a better insulator than plastic.
   g. To find out whether ceramic is a better insulator than plastic
   h. Coffee will cool down faster in the plastic cup than in the ceramic cup.
3. **Identify** whether each of the following statements is a suitable hypothesis. If not, **justify** your answer.
   a. White chocolate tastes better than dark chocolate.
   b. Washing powder X removes tomato sauce stains faster than washing powder Y.
   c. Plants grow faster under red light than under green light.
   d. Sagittarians are nicer people than Leos.
   e. Playing video games increases the muscle strength in your thumbs.
   f. Playing video games affects the development of social skills.
   g. Science teachers are more interesting people than English teachers.
   h. Science teachers perform better in IQ tests than English teachers.
4. **State** a hypothesis for each of the following questions.
   a. Does the size of a dog have an impact on its lifespan?
   b. Are people more likely to use public transport to travel to and from work if they live close to a station?
   c. When magnesium reacts with acid, is the reaction faster when the acid is more concentrated?
5. **Explain** the role of aims and hypotheses in scientific investigations. **Discuss** how they guide the process of inquiry and contribute to developing reliable scientific knowledge. Provide examples to support your explanation.

Answers and sample responses are available in your digital formats.

LESSON 1.7 Planning valid investigations

LEARNING INTENTION

In this lesson you will describe the features of valid investigations.

1.7.1 Valid investigations

A valid experiment measures what it actually sets out to measure. If your aim was to find out whether watering plants with seawater affects their growth rate, comparing the number of radish seeds that germinate after one week when watered with tap water or seawater would not be a valid method because it does not actually measure growth rate. It tests the effect of seawater on seed germination.

Controlling variables

In a valid experiment, only one variable should change at a time. The independent variable is deliberately altered, while the dependent variable is measured.

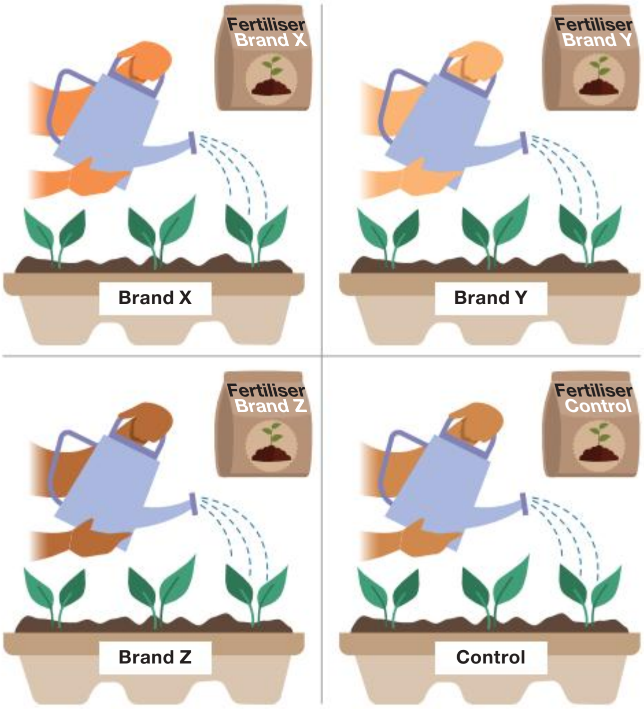
For example, in an experiment testing the effects of different fertilisers on plant growth, the independent variable is the fertiliser brand, and the dependent variable is the plant's height after a set number of days.

When you are testing the effect of an independent variable on a dependent variable, all other variables should be kept constant. Such variables are called **controlled variables**. In the fertiliser experiment, the type of plant, amount of water provided to each plant, soil type, amount of light, temperature and pot size are all controlled variables. The process of controlling variables is also known as fair testing.

The need for a control

Some experiments require a **control** as a point of comparison. A control is needed in the fertiliser experiment to ensure that the result is due to the fertilisers and not something else. The control in this experiment would be a pot of plants to which no fertiliser was added. All other variables would be the same as for the other three pots (see figure 1.14).

FIGURE 1.14 In the fertiliser experiment, a control is needed to show that the results are due only to the fertiliser.



KEY IDEA

To ensure an experiment is valid:

- the independent variable is what you change
- the dependent variable is what you measure or observe
- the other variables should be controlled (kept the same).

1.7.2 Reliable data

The results of an investigation are considered reliable when the experiment has been repeated multiple times and the results are consistent. Similar results are obtained each time the experiment is repeated.

This can involve simply doing the same experiment a few times, or having different groups repeat the same experiment and pooling the data gathered by each group when writing the report.

In plant experiments and medical research, using a large sample size improves reliability. A drug is tested by administering it to many people and monitoring its effects. In the fertiliser experiment, reliability increases by using multiple pots per brand or several seedlings per pot. Results are checked for consistency, and an average is calculated for each fertiliser brand and the control plants.

INVESTIGATION 1.2

Paper helicopter

Aim

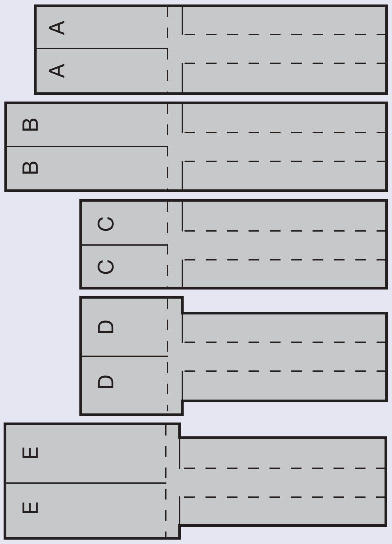
To investigate variables that affect a helicopter's drop speed

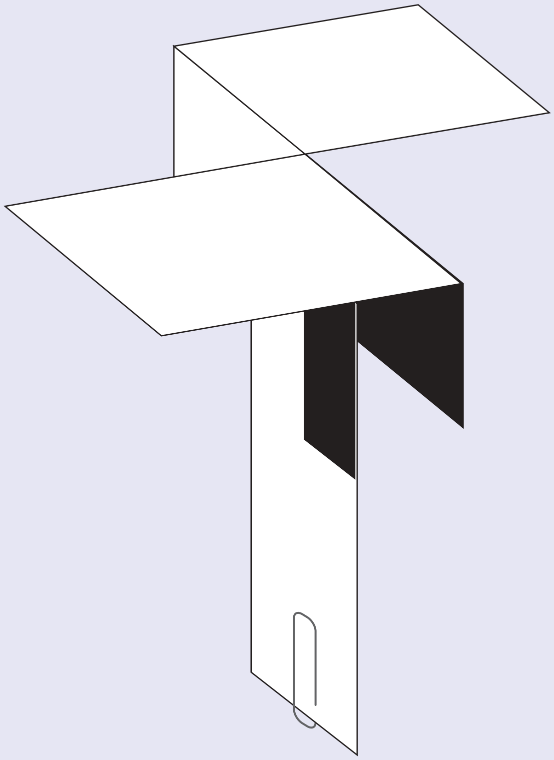
Materials

- stopwatch
- ruler
- paperclip
- a copy of the helicopter template

Method

1. You will need to work in groups of three for this experiment.
2. Before cutting out the helicopters, copy the Results table into your exercise book and fill in the first two columns.
3. Using the template, cut out the five helicopters — cut along solid lines only, then fold along the dotted lines. Fold one blade in one direction and the other in the opposite direction.
4. Attach a paperclip to the bottom of each helicopter. This will weigh it down and hold the flaps in place. The diagram shows what the finished helicopter should look like.





5. Find an elevated place to drop your helicopters. A balcony or open window on the second floor of your school would be ideal. One student from each group should be at the dropping point at the top. Two students from each group will need to be at the landing point at the bottom.
6. Drop the helicopters one at a time and use the stopwatch to time how long it takes for each helicopter to reach the ground. After you have dropped all helicopters, one student will need to take them back upstairs for the next trial. Each helicopter will need to be dropped five times. As the helicopters fall, record any other relevant information. For example, you may wish to record whether the helicopters spin as they fall.

Results

1. Record your results in a table like the one below. Remember to include a title for your table.

Helicopter	Blade width (cm)	Blade length (cm)	Time taken to reach the ground (s)						Other observations
			Trial						
			1	2	3	4	5	Average	
A									
B									
C									
D									
E									

2. Calculate the average time taken for each helicopter to fall.

Discussion

1. In this experiment, two variables were deliberately changed: the length of the blades and the width of the blades. In what way is this different to most science experiments you have done?
2. Which pairs of helicopters could be compared to find out the effect of the width of the blades on the drop time?
3. Which helicopters could be compared to find out how the length of the blades affects drop time?
4. Write two separate conclusions about the effect of blade width and blade length on the helicopter drop time.
5. Discuss the validity of this experiment. (*Hint:* Are there any variables you were not able to control?)
6. Why was the experiment repeated five times?

Conclusion

Write a conclusion for this experiment. It should address the aim.

1.7.3 Surveys

A survey is a list of questions that you ask to a large group of people. Some surveys are read out, sometimes over the phone. Some require participants to fill in a form and increasingly, surveys are done online. Surveys are used to collect census data, for market research, to find out what product characteristics consumers find most appealing, to determine voting intentions and also for scientific purposes. A great deal of data about health and lifestyle has been gathered through the use of surveys, sometimes in combination with other tests. To investigate whether there is a link between diet and blood pressure, researchers might collect data about the participant's diet through the use of a survey. Below are some features of well-designed surveys:

- A large sample size is used. Many participants take part in the survey.
- Questions are unambiguous. Participants can understand the questions.
- A control group is used or, where appropriate, the group should include people with different degrees of exposure to the factor under investigation. An investigation into the impact of loud music on hearing could include a survey in which participants are asked about the number of concerts and dance parties they attended over the last 12 months, and the participants' hearing could be tested. The data would be of little value if all participants had a similar level of exposure to loud music. The participants need to include some people who are exposed to loud music frequently, some occasionally and some rarely.
- Data can be analysed mathematically. Multiple-choice or short-answer questions often lend themselves better to this type of analysis.

1.7 Activities

learnon

1.7 Quick quiz on	1.7 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4, 5, 6, 7	8, 9

Remember and understand

1. A student is investigating whether students who walk to school each day have better aerobic fitness than those who are driven to school. Her experiment involves asking all students in her school how they travel to school and measuring their flexibility using a sit-and-reach test. **Explain** why this experiment is not valid.
2. MC When evaluating the reliability of experiment results, it is important to consider:
   A. whether the experiment was repeated.
   B. the sample size.
   C. whether the results are consistent.
   D. all of the above.
3. **Identify** which type of variable on the left matches each of the definitions on the right.

Type of variable	Definition
a. Independent	1. Factor that is kept the same
b. Dependent	2. Factor that is changed
c. Controlled	3. Factor that is measured

Apply and analyse

For questions 4 to 7, **identify** the independent and dependent variables, and three variables that would need to be controlled.

4. Jessie wanted to find out if the water in her drink bottle would stay cold longer if she wrapped the bottle in foil or a towel.
5. Charlie would like to know if ice blocks made from green-coloured water melt at the same temperature as uncoloured ice blocks.
6. Jayden is testing the hypothesis that tall people are faster long-distance runners than short people.
7. Shinji is testing the myth that plants grow faster if you play them music for at least two hours a day.

Evaluate and create

8. Reliable results are a key part of scientific investigations.
   a. **Define** what makes experimental results reliable.
   b. Imagine you are testing the effectiveness of three different fertilisers on plant growth. **Construct** a simple experiment to ensure your results are reliable, considering aspects such as repetition, sample size and consistency in experimental conditions.
   c. **Discuss** why it might be important to have other groups repeat your experiment, and how their data could contribute to your findings.
9. Yasmine works at a gym. She has noticed that there seem to be more young people at the gym in the evening. She has also noticed that some exercise classes seem to have only female participants, whereas other classes have a mixture of males and females.
   Construct a survey that could be used to investigate:
   - whether there is a relationship between a person's age and the time they visit the gym
   - whether there is a relationship between gender and the type of exercise class people prefer.

Answers and sample responses are available in your digital formats.

LESSON 1.8 Planning safe and ethical investigations

LEARNING INTENTION

In this lesson you will:
- prepare a risk assessment for an experiment
- explain the importance of considering risks and ethics when planning an investigation.

1.8.1 Risk assessments

When planning a scientific investigation there are two very important things to think about: safety and ethical considerations. A risk assessment is usually carried out before a practical investigation. This is a document in which you list the hazards associated with an activity and how you plan to minimise these. Figure 1.15 shows part of a sample risk assessment for a class experiment. It was prepared by a teacher using software called RiskAssess.

1.8.2 Hazards

Hazardous substances

Hazardous substances are chemicals that are harmful to humans. The harmful effects might be seen straight away or over a long period of time. If you get concentrated sulfuric acid on your skin you will feel it burning and blisters will form rapidly. Some substances do not appear harmful at first, but repeated exposure can affect health over time. Carcinogenic substances are substances that cause cancer. Their effect may take many years to show up. Before using any chemical in an investigation you need to be aware of any associated hazards.

Safety data sheet

Manufacturers that supply chemicals to schools and other organisations are required to supply a safety data sheet (SDS) with the chemicals they sell. The SDS is also available online. An SDS provides information about any health risks associated with a chemical, guidelines for safe storage and handling, and information about what to do if the chemical is spilt or comes in contact with the skin or eyes. Disposal information is also provided. Schools and other businesses that use chemicals (including those used for cleaning) are required to have the SDS for the chemicals they store readily available, either in printed form or electronically. When writing a risk assessment you can consult the SDS for any chemical you are intending to use. They are lengthy documents, however, and your school may have a summary of the safety information about chemicals available in other forms, such as risk assessment software.

KEY IDEAS

- A risk assessment identifies the risks associated with an activity and how these can be minimised.
- Hazardous substances are chemicals that are harmful to humans
- A safety data sheet (SDS) provides safety information for a particular chemical.

FIGURE 1.15 A section of a risk assessment prepared using a risk assessment software package

RISK ASSESSMENT

Investigation 13.3

Written by: Pascale Warnant **Commenced on:** 28 Sep 2024 **Expires:** 28 Dec 2025

Classes for which experiment is required

Teacher: Pascale Warnant (user code 1) **Year Group:** 9

Room	Period	Date
Lab 6	7	Mon 3/9/12

Items to be prepared by laboratory technician (user code 2)

- hotplate
- geranium leaves
- methylated spirit
- chromatography paper

Procedure or reference, including variations

p. 392 of CS5

Equipment to be used

chromatography paper

Potential hazards

Flammable.

electric hotplate

Potential hazards

IGNITION SOURCE, unless specially designed and certified. Do not heat flammable liquids on a hotplate that is not certified as sparkproof. Hotplate retains heat; possibility of burns. Damaged electric cord may cause electric shock.

Standard handling procedures

Inspect regularly for signs of damage to cord, cord loose in plug, cord loose at entry to hotplate, or any signs of corrosion or other damage. Test and tag at regular intervals.

Chemicals to be used and produced

ethanol **CH_3CH_2OH**

(ethyl alcohol, alcohol, absolute alcohol, methylated spirits, duplicating fluid, duplicator spirit, Fordiograph fluid)

Class: 3 PG: II **7-12** Users: 1,2,3,4,5 UN: 1170 CAS: 64-17-5

Potential hazards

HIGHLY FLAMMABLE; DO NOT USE NEAR IGNITION SOURCES; slightly toxic; prolonged contact with skin causes irritation. Forms violently explosive mixtures with nitric acid and other oxidising agents. Reaction of ethanol with acidified dichromate solution is highly exothermic. Potassium reacts violently with ethanol. Do not heat ethanol in a container over an open flame; use a water bath that is sparkproof. Any experiments involving the combustion of ethanol are potentially hazardous. If a fuel is required, use metaldehyde or hexamine tablets. Ethanol becomes less flammable as it is diluted with water; 50% ethanol is barely flammable at room temperature and <24% ethanol is not classified as a dangerous good.

Standard handling procedures

Store and use away from ignition sources. Methylated spirits is the usual form in which ethanol is obtained; it contains methanol (5%), water (5%) and small amounts of pyridine and other coal-tar products to make the liquid unpalatable. Methylated spirits is adequate for most experiements carried out in schools.

Others

geranium - should not be eaten

Knowledge

I have read and understood the potential hazards and standard handling procedures of all the equipment, chemicals and living organisms.

I have read and understood the Material Safety Data Sheets for all chemicals used and produced.

I have copies of the Material Safety Data Sheets of all the chemicals available in or near the laboratory.

Risk assessment

I have considered the risks of:

fire	breakage of equipment	electrical shock	radiation
explosion	cuts from equipment	escape of pathogens	waste disposal
chemicals in eyes	sharp objects	heavy lifting	inappropriate behaviour
inhalation of gas/dust	rotating equipment	slipping, tripping, falling	special needs
chemicals on skin	vibration and noise	falling objects	other risks
runaway reaction	pressure	heat and cold	

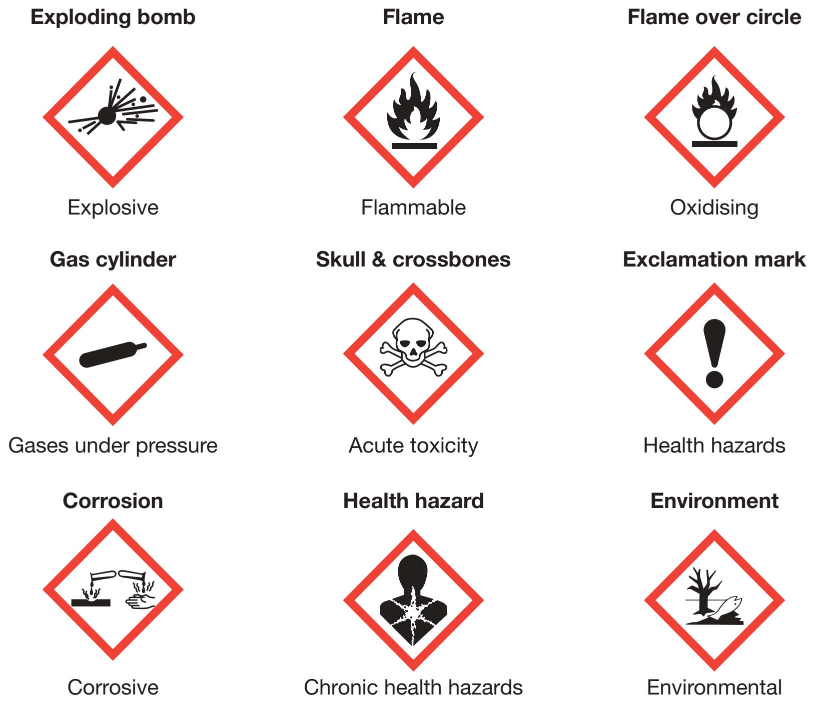
Certification by teacher

I have assessed the risks associated with performing this experiment in the classroom on the basis of likelihood and consequences using the School's risk matrix, according to International Organization for Standardization Standard ISO 31000:2009 and the Risk Management Guidelines, HB 436:2004.

A picture is worth a thousand words

The symbols shown in figure 1.16 are part of the Globally Harmonised System (GHS) of Classification and Labelling of Chemicals. These are internationally agreed pictograms that indicate the type of risk associated with particular chemicals. Hazardous substances must be labelled, and the label should include the relevant pictograms.

FIGURE 1.16 The GHS pictograms



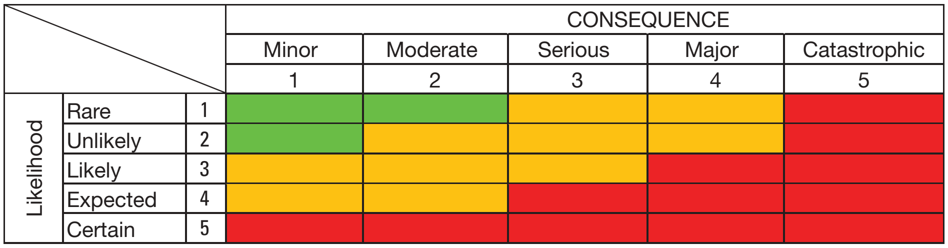
Other hazards

Even if you are not planning to use hazardous substances in your investigation, it is likely that there are other hazards associated with your experiment. Some risks relate to the equipment you use and minimising the risk involves using the equipment in a safe manner. A Bunsen burner, scalpel or even scissors can be hazardous if used incorrectly. When assessing risk, you should consider who will be using the equipment and whether they are properly trained to use it. Risks can also result from the setting up or dismantling of equipment, and from allergic reactions. Using latex gloves to carry out a dissection is a sensible safety precaution for most students, but not for a student who has an allergy to latex. For some investigations, it may also be necessary to consider the emotional impact of the investigation on the test subjects. Testing the impact of horror movies on heart rate may pose too high a risk if the test subjects are primary school students, for example.

1.8.3 Too high a risk?

Once you have identified all the risks associated with your investigation, you should assess the inherent level of risk for the activity. A **matrix** or grid such as the one in figure 1.17 is useful to do this. If you cannot bring the risk level to the acceptable range (by wearing protective gear, for example), then you should modify your investigation plan.

FIGURE 1.17 A risk assessment matrix



Harm occurrence likelihood levels
- Certain: will occur on every occasion
- Expected: is expected to occur in most circumstances (e.g. more than 2 times a year)
- Likely: could occur in many circumstances (e.g. probable to happen up to 2 times a year)
- Unlikely: could occur occasionally (e.g. possibility of happening once a year)
- Rare: not expected to happen, but is possible (even if no occurrence registered)

Harm severity levels
- Catastrophic: multiple deaths
- Major: possibility of death or major permanent loss of function (motor, sensory, physiologic or intellectual)
- Serious: major injury/adverse health outcome (e.g. possibility of permanent lessening of bodily functioning)
- Moderate: moderate injury/adverse health outcome (e.g. increased length of stay)
- Minor: no or minor injury/adverse health outcome

Estimated risk levels: Red: unacceptable risk | Yellow: tolerable risk | Green: acceptable risk

1.8.4 Ethical concerns

Ethics deal with moral values and a sense of what is right or wrong. Some ethical values are fairly universal. This means that they are accepted by most people worldwide. Most people throughout the world would agree that murder is wrong, and looking after the old and sick is right. Many ethical values vary between countries, religions, different groups in societies or even between members of the same family. This is where things become tricky. A scientific investigation or use of technology that may be perfectly acceptable to some people may deeply upset others. The case studies below illustrate some examples.

CASE STUDY: Gene editing

In November 2018, twin girls Lulu and Nana were born in China. Their birth was quite controversial because they were the first human babies to have their genes edited using CRISPR-Cas9 technology. Chinese scientist Dr He Jiankui was responsible for the gene editing, which is illegal in many countries, including Australia.

Dr He's research was investigated to determine whether it broke Chinese laws and he was sent to jail for a period of time. He argued that the gene editing was therapeutic because the **genetic modification** protected the girls from HIV, the virus that causes AIDS. The girls' father is HIV-positive. The girls were conceived through IVF. The gene editing took place before the embryos were implanted into their mother's womb. HIV can only be transmitted through the exchange of body fluids, so the risk of catching HIV from their father was quite low. Was this genetic modification really necessary?

It has been argued that CRISPR-Cas9 is a new technology, and there was not enough known about the long-term effects when Dr He used the technique. Additionally, the type of genetic modification that was made will be passed on to any children Lulu and Nana might have. This raises additional ethical concerns.

Some scientists have argued that Dr He's results should not be published in scientific journals, because his research was unethical. On the other hand, this experiment could be the first step towards treating a whole range of genetic conditions using CRISPR-Cas9 technology.

CASE STUDY: A gut feeling

When Barry Marshall and Robin Warren came to the conclusion that stomach ulcers were probably caused by bacteria, they were faced with some tricky ethical and safety considerations. A stomach ulcer occurs when the lining of the walls of the stomach becomes damaged and the acid inside the stomach eats away at the stomach wall. It is a very painful condition. Previously, it was thought that ulcers were caused by lifestyle factors, including stress, so it was difficult to treat them. People were usually told to avoid stress, such as by changing their job or cutting their work hours, and to cut out particular foods, sometimes with no improvement to their health.

FIGURE 1.18 *Helicobacter pylori* bacteria in the human stomach cause stomach ulcers. They move their cilia (hair-like structures) to travel around the stomach lining.

Barry Marshall and Robin Warren suspected that ulcers were actually caused by bacteria called *Helicobacter pylori*. They had found this bacterium in the stomachs of people suffering from stomach ulcers but not in the stomachs of healthy individuals. They had also studied the bacterium. The only way to know for sure would be to deliberately infect someone with the bacteria and find out if they developed a painful ulcer. There were risks involved; for instance, the bacteria could cause other health problems, or could even kill the patient. There were also ethical issues associated with deliberately trying to make a healthy person sick. Eventually, Barry Marshall carefully weighed up the risks involved and decided to test his hypothesis on himself. He swallowed a solution of the bacteria and soon became ill and developed the early symptoms associated with the development of stomach ulcers. He then treated himself with antibiotics. Now when a patient is diagnosed with a stomach ulcer, treatment is simple — a course of antibiotics usually fixes the problem.

1.8 Activities

learnon

1.8 Quick quiz on	1.8 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4	2, 5, 6, 8	7, 9

Remember and understand

1. MC **Identify** which of the following is a document listing the risks associated with an experiment and how these risks will be minimised.
   A. SDS
   B. Risk assessment
   C. GHS
   D. Hazardous substance
2. **Explain** what 'minimising risks' means.
3. **Identify** which of the terms on the left matches each of the meanings on the right.

Term	Meaning
a. Carcinogenic	1. Causes damage to the skin and eyes
b. Corrosive	2. Can catch on fire
c. Flammable	3. Poisonous
d. Toxic	4. Causes cancer

Apply and analyse

4. MC A teacher has been asked to carry out a risk assessment for an activity students will be doing. She has determined that there is a risk of serious injury, but it is unlikely this would happen.
   Identify the estimated risk level.
   A. Unacceptable
   B. Tolerable
   C. Acceptable
   D. Risk-free
5. Use the risk assessment shown in figure 1.15 to answer the following.
   a. **Identify** the main hazard associated with this experiment.
   b. **Explain** how the teacher will minimise the hazard.
   c. **List** the protective gear that will need to be worn when doing this experiment.
6. **Explain** why it is important for an organisation to have access to the SDS for any chemicals they use and store.
7. The introduction of the Globally Harmonised System of Classification and Labelling of Chemicals in Australia meant that many workplaces had to change their labels and signs. **Outline** some of the advantages and disadvantages of adopting a global system of classification and labelling of chemicals.
8. **Describe** the safety and ethical issues associated with the experiments using *H. pylori* carried out by Barry Marshall.

Evaluate and create

9. **Discuss** the following statements.
   a. Cosmetics should never be tested on animals.
   b. All medical research, including research into new drugs, should be performed by not-for-profit organisations rather than by companies seeking to make a profit.
   c. Food made from genetically modified crops should have a special label to show that it contains GM ingredients.

Answers and sample responses are available in your digital formats.

LESSON 1.9 Conducting investigations

LEARNING INTENTION

In this lesson you will identify and respond to different types of errors in investigations.

1.9.1 Responding to errors

In lesson 1.8, we saw that it is important to have a plan when carrying out an investigation. Safety considerations must be carefully thought out. Variables should be identified and the experiment must be carefully designed to ensure it is valid. However, investigations do not always go according to plan. Responding to potential sources of error and solving problems as they arise are part of the scientific process.

CASE STUDY: Unexpected results lead to invention

In 1946, Percy Spencer was running some tests on a magnetron. He was employed by a company that makes military equipment, and he was working on improving radar technology for the Allied forces. The tests he was running did not produce the results he was hoping for, but when he reached into his pocket to retrieve a peanut cluster bar (a type of snack), he noticed it had melted. The radiation produced by the magnetron had melted the snack bar. He then tested the effect of the magnetron on other foods, including corn, and successfully made popcorn. From this unexpected result, the microwave oven was developed.

FIGURE 1.19 The microwave oven was developed following unexpected observations during testing of a magnetron.

CASE STUDY: A very expensive solution to a problem

When the Hubble telescope was launched into space in 1990, it was hailed as a revolutionary piece of technology that would transform astronomy. The space telescope orbits Earth above the atmosphere, so the gases that make up Earth's atmosphere do not block the wavelengths of light it can detect. There was one problem, however. Shortly after its launch, it was discovered that one of Hubble's mirrors had an imperfection. The curvature of the mirror was off by 2 microns (that's 0.002 mm!), but that was enough to make the images slightly blurry. Once this source of error was discovered, a team went to work to devise a solution. It would not be possible to adjust the curvature of the mirror, but other components were redesigned to correct the image produced, in the same way that glasses can correct people's vision when the structures that make up the eye do not produce a focused image. A unit the size of large refrigerator had to be installed, and this had to be done in space, by astronauts. It was a very expensive solution!

FIGURE 1.20 The same image of galaxy M100 before and after a service mission was sent to make adjustments to Hubble.

1.9.2 Types of errors

There are two main types of errors that can occur when collecting data: systematic and random.

KEY IDEAS

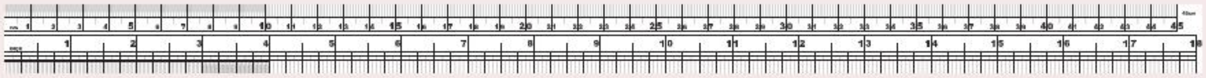
- *Systematic error:* An error in which all measurements are either greater or smaller than the actual value by the same amount each time. An example would be the measurements produced by a scale that has not been zeroed properly. Instead of reading zero when there is nothing on the scale, it might read 0.50 g. All the measurements will be 0.50 g greater than the actual measurement.
- *Random error:* An error that results in measurements that are either greater or less than the actual value, but by a different amount each time. For instance, if you are using a stopwatch to measure the time it takes for a toy car to travel 1 m, your reaction time may affect the accuracy of the measurement.

To reduce errors in your measurements:
- calibrate the measuring device
- use the measuring equipment properly (e.g. read a measuring cylinder at eye level, from the bottom of the meniscus)
- control the necessary variables as much as possible
- use the most precise measuring device available.

KEY IDEA

When reading a scale, there is always some uncertainty in the measurement. The accuracy of the measurement is half of the smallest division on the scale. So, if the lines on a ruler are 1 mm apart, the accuracy of the ruler is +/– 0.05 cm.

FIGURE 1.21 This ruler has an accuracy of +/– 0.05 cm.

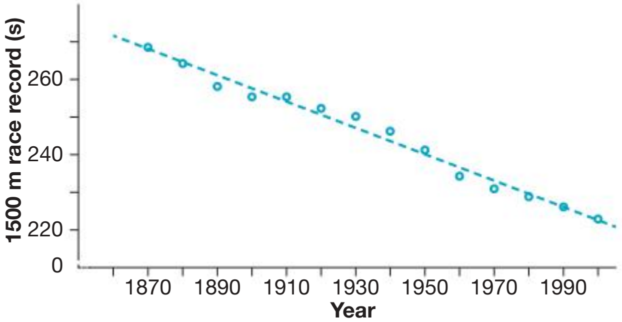


1.9.3 Dealing with errors

Some errors are very obvious. A result that appears very different to the other results is called an outlier. Outliers are not included when calculating an average or graphing data. It is important to determine that a result is truly an outlier before discarding a data point. In some instances, outliers indicate a problem with the design of the investigation and this needs to be addressed.

Random errors, particularly those relating to reaction time or the accuracy of measuring equipment, are difficult to avoid. The best way to deal with these is to take multiple measurements and calculate an average. Repeating the experiment numerous times, or increasing the sample size, reduces the impact of random error. If the results are graphed, using a line of best fit to identify the relationship between the variables also reduces the effect of random error.

FIGURE 1.22 Using a line of best fit to identify the relationship between two variables reduces the effect of random errors.



We can also indicate the degree of uncertainty in a measurement. If there is only one measurement taken, the uncertainty of that measurement is the accuracy of the measuring instrument. If we use a ruler that has graduation lines that are 1 mm apart to determine that a pencil has a length of 6.7 cm, the accuracy of the ruler is 0.05 mm, so the measurement is 6.7 mm +/– 0.05 mm. When multiple measurements are taken, the degree of uncertainty is the difference between the highest and lowest value, divided by 2. For example, a student takes three measurements of the length of a piece of copper wire. Her measurements are 6.5 cm, 6.6 cm and 6.4 cm. The result is reported as 6.5 ± 0.1 mm.

INVESTIGATION 1.3

Gooey liquid races

Aim

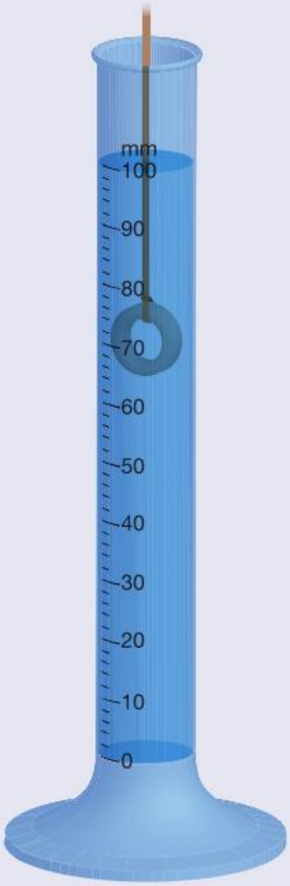
To compare the time taken for objects to fall through a viscous liquid

Materials

- 100 mL cylinder
- a viscous clear liquid (e.g. detergent, shampoo, wallpaper paste, oil or glycerine)
- small objects of different shapes (the objects should all be made of the same metal, and should be able to have a piece of cotton thread attached; e.g. washer, key, nail and bolt)
- cotton thread
- stopwatch

Method

1. Fill the measuring cylinder to the 100 mL mark with the viscous liquid.
2. Attach a piece of cotton thread to one of the small objects.
3. Drop the object into the liquid, keeping hold of the thread loosely so the object is not slowed down as it falls to the bottom of the liquid. Use the stopwatch to measure the time taken for the object to reach the bottom of the cylinder. The thread can be used to retrieve the small object from the liquid.
4. Repeat step 3 a further two times and calculate the average sinking time.
5. Repeat steps 1–4 for another object.
6. To avoid waste and mess, keep the liquid in the measuring cylinder after use and pass it on to another group that might need it. At the very end of the experiment, the liquids can be poured back into bottles so they can be reused the next time this experiment is done.



Results

Record your results in a table like the one below. Remember to include a title for your table.

Object	Time taken to reach the bottom of the liquid (s)			
	Trial 1	Trial 2	Trial 3	Average

Discussion

1. When you filled the measuring cylinder to the 100 mL mark, what was the uncertainty of this measurement?
2. What is the main source of error when measuring the time taken for the object to reach the bottom of the liquid?
3. Did your experiment produce reliable data? Give a reason for your answer.
4. Calculate the uncertainty of the average time for each object.
5. If you did not top up the liquid each time, you probably noticed that the volume of liquid in the measuring cylinder was not 100 mL by the end of the experiment.
   a. Explain why.
   b. How does this affect the results?
6. In this investigation, identify:
   a. the independent variable
   b. the dependent variable
   c. the controlled variables (list at least three).

Conclusion

Summarise the time taken for objects to fall through a viscous liquid and outline the impact of object shape on the rate of descent in viscous fluids.

1.9 Activities

learnon

1.9 Quick quiz on	1.9 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4, 5	6, 7, 8

Remember and understand

1. MC **Identify** the household appliance that was developed following an unexpected result while running tests on a magnetron.
   A. Microwave oven
   B. Induction stove
   C. Remote control
   D. Convection oven
2. MC **Identify** where the Hubble telescope is located.
   A. Los Angeles
   B. At the top of Mount Everest
   C. Parkes, New South Wales
   D. In space
3. A tape measure is damaged. A small piece has been torn off, so all measurements are now 0.4 cm less than the actual reading. **Identify** whether this is a systematic or a random error.

Apply and analyse

4. A student measures the time it takes for a toy car to travel 1 m. Their measurements are: 46 s, 42 s, 48 s and 47 s.
   Calculate the uncertainty of the measurement.
5. **Identify** a way students measuring the bounce height of a tennis ball could reduce random error.
6. A student would like to measure the thickness of a type of rope. They try the following two methods.
   - Method 1: They use a piece of sticky tape to stick a piece of string on top of a minigrid and observe the minigrid (with the string) under a microscope to measure the thickness of the rope. *Note:* A minigrid is a microscope slide with a very fine grid drawn on the slide. The grid lines are 0.1 mm apart.
   - Method 2: They cut 25 pieces of string and bundle them together. They tie the pieces of string together, use a ruler to measure the width of the bunch of strings and divide this number by 25.

   Evaluate the accuracy of the two methods.

Evaluate and create

7. A student has been provided with a small bag of jellybeans. Their teacher asked them to determine the average mass of a jellybean, and to include a measure of the uncertainty of their measurement in their answer. **Construct** a method the student could use.
8. A student weighs a coin three times. His readings are 15.34 g, 15.31 g and 15.35 g. **State** the mass of the coin in a way that indicates the degree of uncertainty.

Answers and sample responses are available in your digital formats.

LESSON 1.10 Presenting data

LEARNING INTENTION

In this lesson you will:
- construct a table to organise data
- select the most appropriate type of graph to display data.

1.10.1 Tables and graphs

Diagrams, photos and videos can be an effective way of providing evidence of your practical work and may form part of the results of your investigation. Analysing your results and identifying trends in your data will usually involve presenting some of your results in the form of tables and graphs.

Tabulating data

A table organises data so that trends are more easily identified. An example of a simple table is shown in figure 1.23; it includes all the features you need to remember when constructing a table.

FIGURE 1.23 An example of a simple table

Always include a title for your table.

The column headings show clearly what has been measured. Include the measurement units in the headings.

The independent variable is usually on the left.

The dependent variable is usually on the right.

Use a ruler to draw lines for rows, columns and borders.

Enter the data in the body of the table. Do not include units in this part of the table.

Temperature of Earth at different depths

Depth (km)	Temperature (°C)
0	15
1	44
2	73
3	102
4	130
5	158
6	187
7	215
8	242

When tabulating the results of an experiment, a more complex table may be required, particularly if there are multiple trials.
- The independent variable should be on the left and the dependent variable on the right. Include units in brackets for both if these variables have units.
- Divide the dependent variable column so that you have a column for each trial, and one for the average. An example for an experiment with three trials is shown in table 1.2.

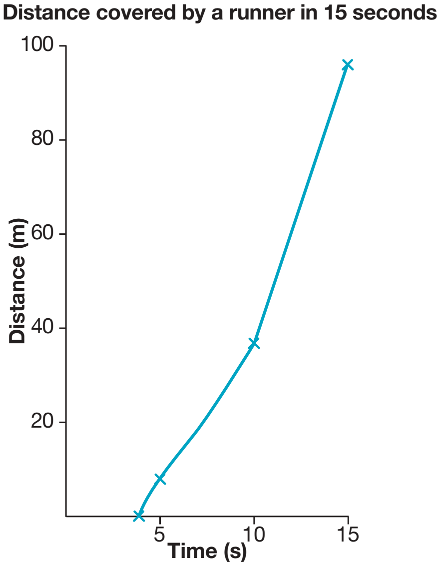
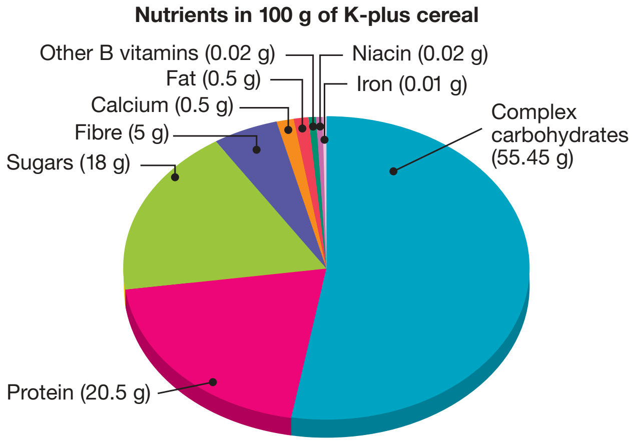
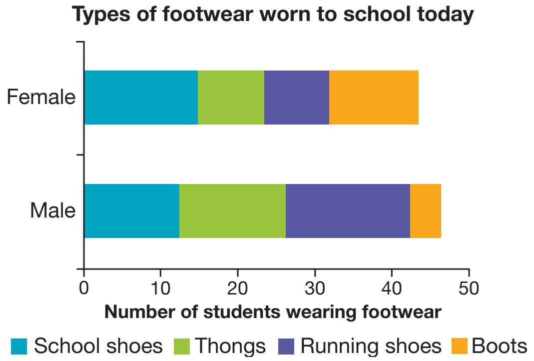
TABLE 1.2 The bounce height of balls

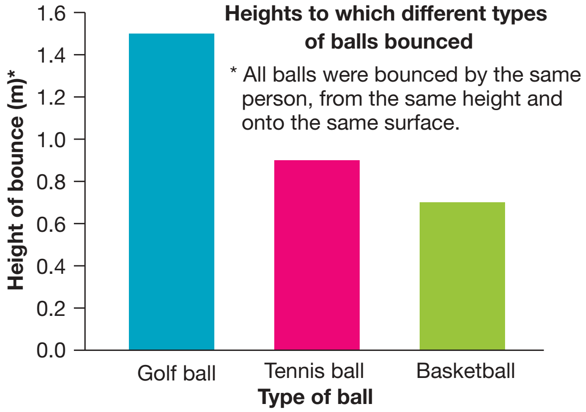
Type of ball	Bounce height (cm)			
	Trial 1	Trial 2	Trial 3	Average
Tennis ball	52	54	54	53
Squash ball	65	62	61	63
Ping pong ball	46	47	48	47

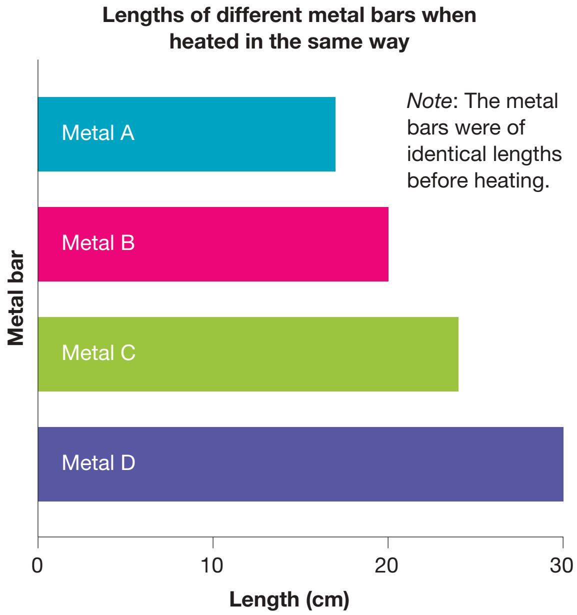
Graphing data

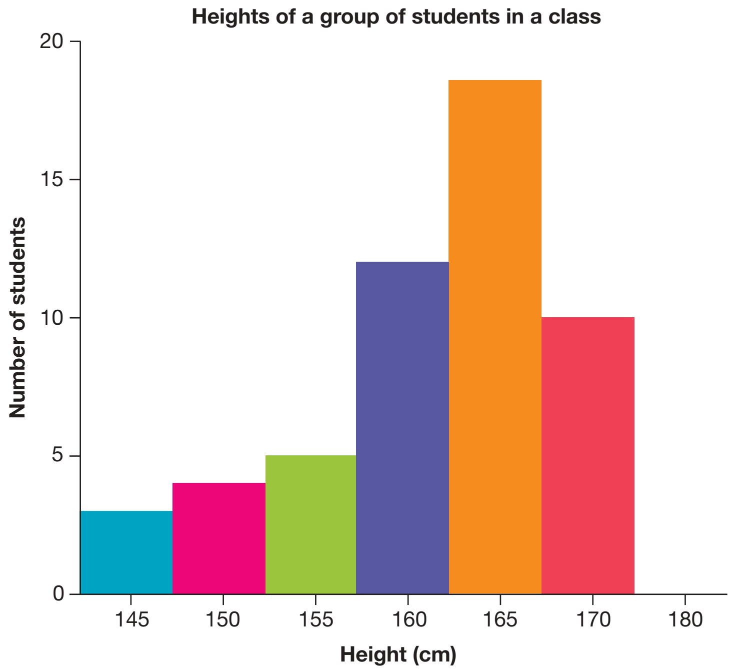
Graphs provide a visual representation of the data, but it is important to select the correct type of graph for your data.

TABLE 1.3 Different types of graphs and their applications

Type of graph	Application	Example
Line graph	To present continuous numerical data where the dependent variable (on the *y*-axis) changes as the independent variable (on the *x*-axis) changes	
Pie chart and divided bar graph	To show the proportions or parts that make up a whole	 

<table>
<tr><td>Column graph and bar graph</td><td>To present data that is not continuous and cannot be connected</td><td>




</td></tr>
<tr><td>Histogram</td><td>Similar to a column graph, but the columns touch each other because the data is continuous</td><td>


</td></tr>
</table>

1.10.2 Data cleansing

In lesson 1.9, we saw that dealing with outliers appropriately is one way that we can improve the quality of data. If a result is very different to the other results, we first need to consider whether there is a reason for the result being different. If there is no apparent reason, it is logical to conclude that the unexpected value is the result of an error and it should be discarded. If possible, that part of the investigation should be repeated to replace the data that was discarded. This may not always be possible, particularly if using a publicly available data set for an investigation.

There are other ways that we can improve the quality of data, or cleanse data, including:

- dealing with missing values. Imagine that you were sick for a whole term and you missed an assessment task due to illness. Should your teacher enter a mark of zero, or calculate an estimate based on your other marks? What if you failed to submit a task because you were too lazy to get the work done? Should your teacher give a mark of zero, or an estimate? These are the types of decisions scientists must make when data is missing. They need to decide whether to enter a zero, simply leave out the data point and use the other values to identify trends and carry out calculations, or estimate the missing value.
- ensuring all data has the same number of decimal places (or significant figures). This can be important for some calculations.

SCIENCE INQUIRY: The impact of data cleansing on investigation quality

In scientific investigations, the quality of the data directly affects the reliability of conclusions. Data cleansing is the process of improving data quality by addressing errors, outliers, missing values and inconsistencies. This inquiry focuses on understanding how data cleansing techniques influence the outcomes of an investigation and why they are a critical part of the scientific process.

Inquiry focus

This activity will explore:

- how handling outliers affects the interpretation of results
- how dealing with missing values changes data trends and calculations
- the importance of consistency in data precision, such as decimal places or significant figures.

Investigation

How do different data cleansing techniques influence the conclusions of an investigation?

Hypothesis

Applying data cleansing techniques, such as handling outliers and missing values, will produce clearer trends and more accurate results in scientific investigations.

Method

1. Create or obtain a dataset that includes intentional errors, such as outliers, missing values and inconsistent decimal places.
2. Analyse the dataset as it is, and record trends and outcomes.

Apply data cleansing techniques

- Identify and handle outliers (e.g. by discarding or adjusting values).
- Address missing values (e.g. by leaving them blank, entering zero or estimating).
- Standardise decimal places across the dataset.
- Reanalyse the cleansed dataset and compare the results to the original analysis.

Data collection

1. Record the trends, calculations and any anomalies observed in both the original and cleansed datasets.
2. Use graphs or tables to illustrate differences between the two analyses.

Analysis

1. Discuss how the data cleansing process affected the reliability and clarity of the results.
2. Evaluate which cleansing methods had the greatest impact on improving data quality.
3. Why is it important to address outliers in a dataset? How might they affect conclusions if left unchecked?
4. What are the advantages and disadvantages of estimating missing values versus leaving them blank?
5. Why is it essential to ensure consistency in the number of decimal places or significant figures in data?
6. How can decisions made during data cleansing introduce bias into an investigation?
7. In what situations might it be impossible to replace missing or erroneous data? How should scientists handle these cases?

Information and processed data can be analysed and compared to identify and explain qualitative and quantitative patterns, trends, relationships and anomalies (VC2S10I05)

INVESTIGATION 1.4

Using graphing skills

Aim

To determine the concentration of an orange drink by measuring its colour

Materials

- Tang orange drink or similar (any coloured drink additive powder is suitable for this experiment)
- 7 identical beakers
- 2 jugs of prepared orange drink of unknown concentration
- colorimeter (optional; schools that own a colorimeter may wish to use this. Use a coloured salt rather than a drink additive to avoid leaving a sticky residue on the colorimeter.)

Method

1. Add 100 mL of water to five of the beakers.
2. Add drink powder to each cup; accurately measure the amounts shown in the table below.

Beaker number	1	2	3	4	5
Mass of powder (g)	2	4	6	8	10

3. Line up the beakers in order from least dilute (strongest) to most dilute (weakest). These are the standards.
4. Pour 100 mL of the drinks of unknown concentration into two separate beakers. Estimate the mass of powder dissolved in each beaker by comparing the intensity of the colour to the standards.

Results

1. A colorimeter is a device that measures the intensity of the colour of a solution. It does this by shining a particular wavelength through the solution and measuring how much light it absorbs. Tang is orange, so it reflects orange light and absorbs mainly blue light. Concentrated Tang is more orange, so it absorbs more blue light than dilute Tang. If your school owns a colorimeter you could use it to measure the absorbance of the standards you prepared and the drinks of unknown concentration. Otherwise, use the results below.

2. The absorbance readings have no meaning unless a calibration curve is produced. Use your own results or the sample results below to produce a calibration curve, which is a graph that shows concentration on the *x*-axis and absorbance on the *y*-axis. The standard solutions should be plotted on the graph.

Mass of powder added to 100 mL water (g)	Absorbance
2	0.15
4	0.30
6	0.45
8	0.60
10	0.75

3. The colorimeter is then used to measure the absorbance of the two orange drinks of unknown concentration. Sample results are shown below.

Drink	Absorbance
A	0.25
B	0.50

4. What is the concentration of drinks A and B? Express your answer in terms of the mass of orange powder dissolved in 100 mL of water.

Discussion

1. Explain why it was necessary to construct a calibration curve.
2. Study the table in Results step 2. Imagine that an absorbance of 0.21 was recorded for the solution containing 8 g of orange powder. How could you deal with this outlier?

Conclusion

Write a conclusion that addresses the aim.

1.10 Activities

learnon

1.10 Quick quiz on	1.10 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5, 6, 7	8, 9

Remember and understand

1. MC **Identify** which of the following is *not* true about displaying data in a table.
   A. The table should have a heading.
   B. The dependent variable should be in the left column and the independent variable in the right column.
   C. The table should be easy to read.
   D. The table should include units in the column headings.

Use the following information to answer questions 2 and 3.

A teacher wanted to find out if her students' test scores were proportional to how much time they studied. The results are shown below.

Student test scores compared with time spent studying

Student	Test score (%)	Time studying (h)
A	82	7.5
B	55	6
C	76	9
D	32	2
E	48	5
F	85	8
G	40	2
H	33	3
I	75	1
J	35	4
K	65	7

2. MC **Identify** which of the following is *not* true when plotting a graph of this data.
   A. Test scores should be represented on the horizontal axis.
   B. Time studying should be represented on the horizontal axis.
   C. It is appropriate to draw a line of best fit through this data.
   D. There is a possible outlier.
3. MC **Identify** which of the following is *not* true of the results of student A.
   A. Student A is an outlier.
   B. Student A achieved a higher test result than the data predicted for a student who only studied for 1 hour.
   C. It is possible that the results for student A might have been recorded incorrectly.
   D. The results of student A are consistent with the general trend of the rest of the data.

Apply and analyse

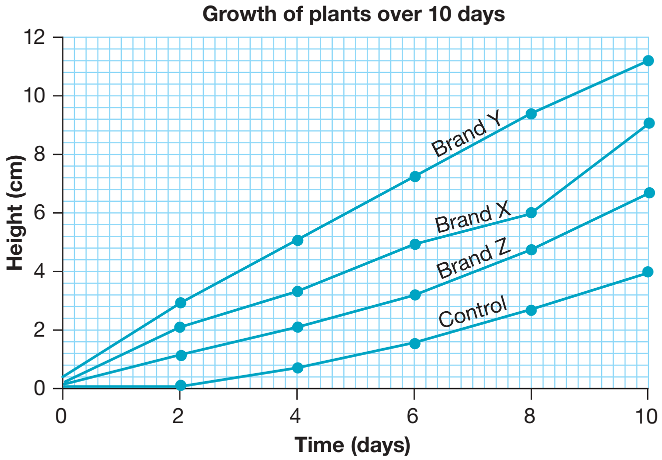
4. A student measured the mass of sugar that can dissolve in 250 mL of water at different temperatures. At 20 °C, 30 g of sugar dissolved; at 40 °C, 60 g of sugar dissolved; and at 80 °C, 120 g of sugar dissolved. **Construct** a table with the student's results.
5. A scientific investigation revealed the following data about nutrients in 100 g of a breakfast cereal.

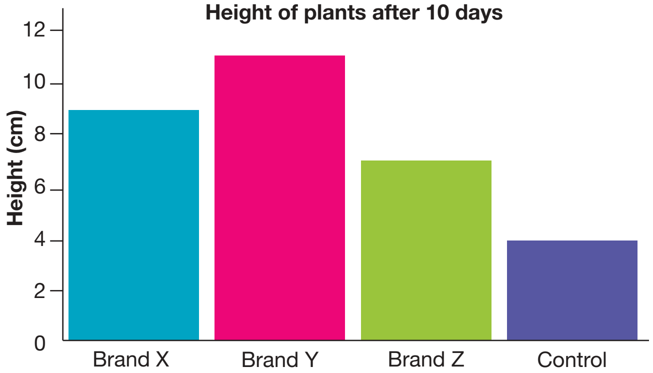
Nutrients in 100 g of a breakfast cereal

Nutrient	Mass (grams)
Complex carbohydrates	55
Protein	21
Sugars	18
Fibre	5
Other nutrients	1

   Identify two types of graph that would be suitable for displaying this data.
6. **Identify** the type of graph that would be most appropriate to display the following data.
   a. Data from Werribee Open Range Zoo showing how the mass of a baby elephant has increased over time
   b. The mass of each elephant at Werribee Open Range Zoo
   c. The proportion of visitors using various modes of transport to travel to Werribee Open Range Zoo
   d. The ratio of cordial to water in a drink
   e. The amount of milk absorbed by different brands of breakfast wheat bars
   f. The relationship between the concentration of salt in a sample of water and its boiling point

7. The following two graphs show data from the same investigation. The student was investigating the effect of different brands of fertiliser on the growth of plants.





a. **State** an aim for the experiment.
b. **Identify** which of the graphs shows more information. **Explain** your answer.
c. **Identify** two problems with the second graph.
d. **State** a conclusion for the experiment.

Evaluate and create

8. A student was investigating the effect of temperature on the action of bleach. They stained some pieces of fabric with red dye and soaked each piece of fabric in a bleach solution at a particular temperature. They then measured the time it took for the fabric to lose its red colour. The results are shown below.

Time taken for fabric to lose red colour at different temperatures

Temperature (°C)	15	20	25	30	35	40
Time (s)	60	40	30	20	15	10

a. **State** which result is an outlier.
b. **Explain** the most appropriate way of dealing with this outlier.

9. MC A student wanted to find out if the number of drinks sold at the school canteen was related to the maximum daily temperature. Their results are shown below.

Number of drinks sold compared with maximum daily temperature

Day	Drinks sold	Maximum daily temperature (ºC)
1	135	26
2	156	28
3	98	19
4	87	17
5	184	32
6	111	39
7	175	33
8	122	23
9	130	24
10	101	18
11	100	17

Identify which of the following is *not* true when plotting a graph of this data.

A. Number of drinks sold should be represented on the horizontal axis.
B. Maximum daily temperature should be represented on the horizontal axis.
C. It is appropriate to draw a line of best fit through this data.
D. There is a possible outlier.

Answers and sample responses are available in your digital formats.

LESSON 1.11 Drawing a line graph

LEARNING INTENTION

In this lesson you will construct line graphs.

1.11.1 What is a line graph?

A line graph displays information as a series of points on a graph that are joined to form a line. Line graphs are very useful to show change over time. They can show a single set of data, or they can show multiple sets, which enables us to compare similarities and differences between two sets of data at a glance.

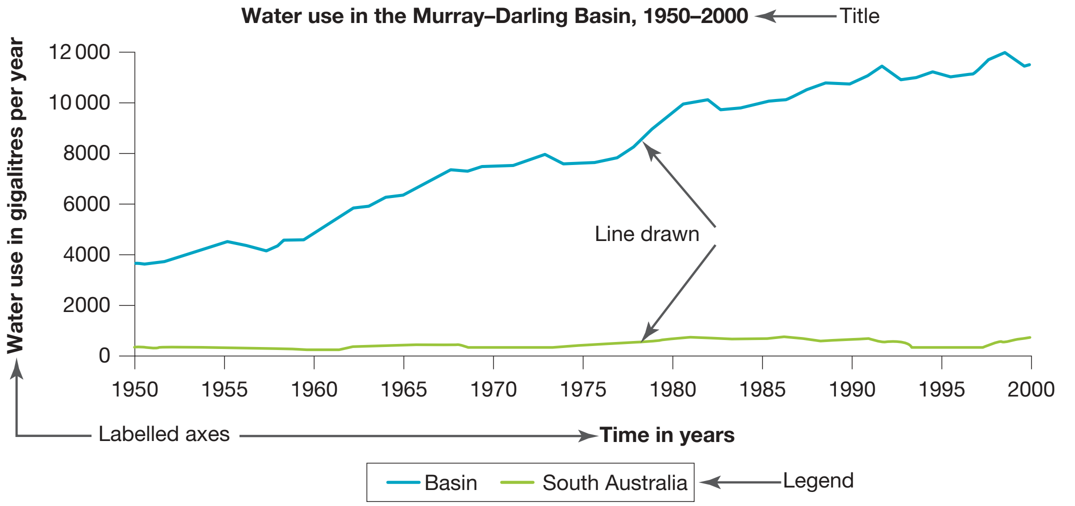
How are line graphs useful?

Line graphs are very useful to show change over time. They can show a single set of data, or they can show multiple sets based on a common theme, such as water use in the Murray–Darling Basin compared to water use in South Australia (see figure 1.24). This enables us to compare similarities and differences between two sets of data at a glance.

A good line graph has:

- been drawn in pencil
- an appropriate scale to show the data clearly
- labelled axes
- small dots joined by a line to make a smooth curve
- a legend, if necessary
- a clear and accurate title that explains the purpose of the graph
- the source of the data.

FIGURE 1.24 Water use in the Murray–Darling Basin



Source: © Department of Environment, Water and Natural Resources, South Australia Government ← Source

What is the application of line graphs in science?

Line graphs are very useful in science to show change over time for continuous data, such as the increase in temperature when heating water with a Bunsen burner. Line graphs can show a single or multiple sets of data, which allows comparison and trends in data to be observed.

1.11.2 How to complete a line graph

Materials

- data
- graph paper
- a pencil
- a ruler

Method

Step 1

Select the data you wish to compare or interpret (table 1.4).

TABLE 1.4 Use of rainwater tanks by household, 2001–10

Year	Use of rainwater tanks by household (%)
2001	16
2004	17
2007	19
2010	26

Source: © Australian Bureau of Statistics.

Draw a horizontal and vertical axis using a ruler.

Evenly space and then label the years along the horizontal axis. Look carefully at your range of data and work out appropriate increments for the vertical axis, then evenly space and label this information on the axis. Start at zero where the axes join. For table 1.4 data, an increment of 5 percentage points would be appropriate.

Step 2

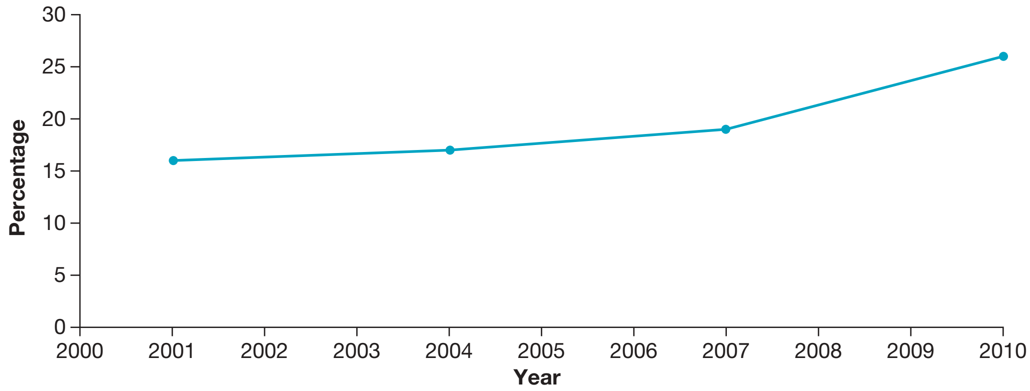
Label the x- and y-axes. In this case, the x-axis would be labelled 'Year', and the y-axis would be labelled 'Percentage'.

Plot the statistics. Draw a dot at the point where the year on the horizontal axis meets the relevant position on the vertical axis. Once you have plotted all the statistics, join the dots. This can be done freehand or using a ruler.

Step 3

Add a title and a source to the graph.

FIGURE 1.25 Use of rainwater tanks by household, 2001–10



Source: © Australian Bureau of Statistics

1.11 Activities

learnon

1.11 Quick quiz on	1.11 Exercise

Learning pathways

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	–	–

1. Use the data in the table below to **construct** a line graph.

Daily residential water consumption for South Australia

Year	Daily residential water consumption (L)
2001	539
2002	502
2003	532
2004	460
2005	465
2006	440
2007	413
2008	410
2009	395

Source: SA Water, Annual Reports.

2. Referring to your graph, apply your skills to answer the following.
   a. **State** the year that water consumption is lowest.
   b. **Describe** the pattern shown by the graph.
   c. **Suggest** some reasons that might explain the changes from 2001 to 2009?
   d. When water restrictions were lifted in 2011, **predict** what happened to water consumption.
   e. If the government made every household adopt water saving measures in 2022, **predict** what might happen to water consumption.
   f. **Explain** how useful the graph was in helping you understand the changes that occurred to water consumption in South Australia compared to reading a table of figures.

Answers and sample responses are available in your digital formats.

LESSON 1.12 Creating a simple column or bar graph

LEARNING INTENTION

In this lesson you will construct simple column or bar graphs.

1.12.1 What is a column or bar graph?

Column graphs show information or data in columns. In bar graphs, the bars are drawn horizontally, and in column graphs they are drawn vertically. They can be hand-drawn or constructed using computer spreadsheets.

How are column graphs useful?

Column and bar graphs are useful for comparing quantities. They can help us understand and visualise data, see patterns and gain information.

FIGURE 1.26 A column graph

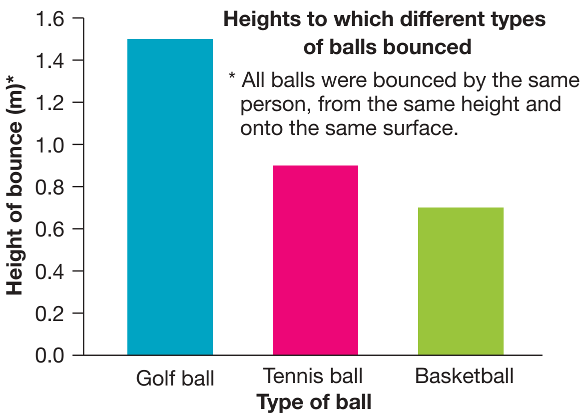
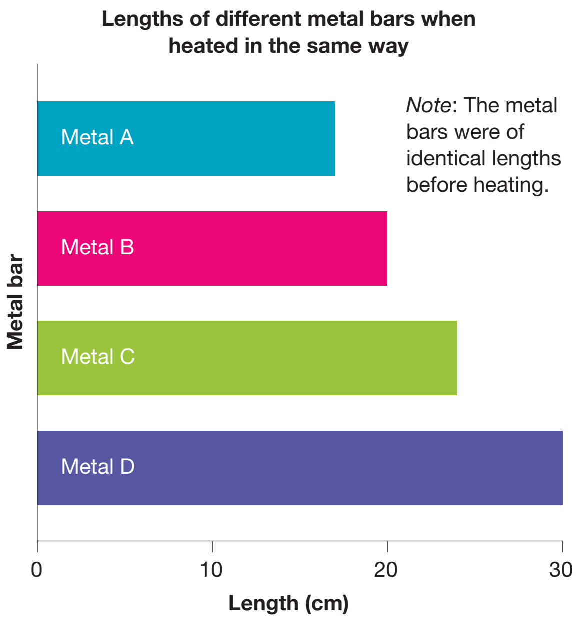


FIGURE 1.27 A bar graph



A good column or bar graph has:

- ruled axes
- labelled axes
- a space between each column
- a title
- the source of information.

What is the application of column or bar graphs in science?

Column or bar graphs are useful to compare or investigate one or more numerical variables across different categories. There are different types of column or bar graphs, including individual, clustered and stacked.

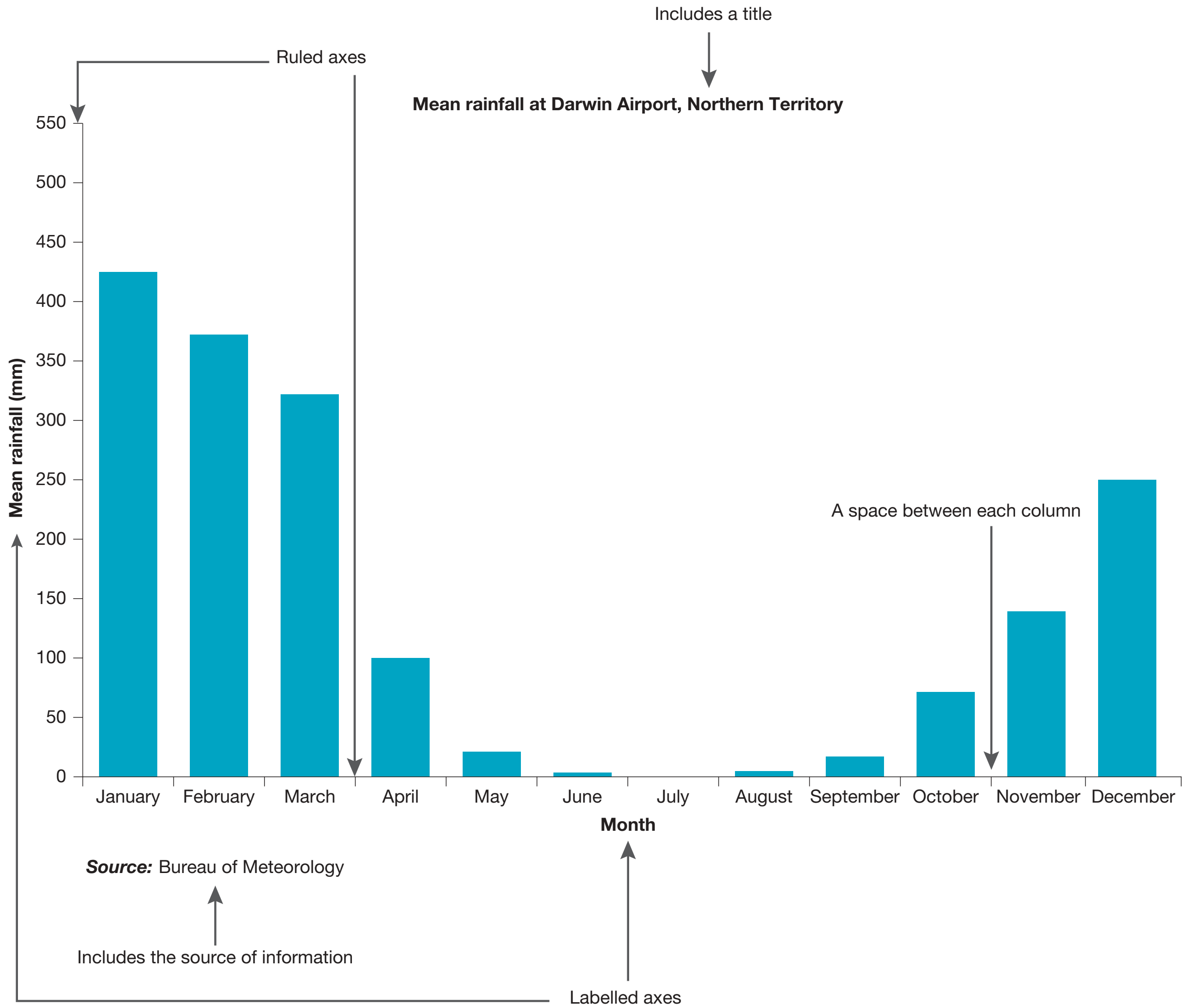
1.12.2 How to complete a column graph

Materials

- table of data (table 1.5)
- graph paper
- a pencil
- a ruler

Model

FIGURE 1.28 A labelled column graph



Method

Step 1

Examine the data. Decide on the scale to use for your vertical axis. For this example, the vertical axis should start at zero and increase at intervals to suit the data. As the highest rainfall for any month for Cardwell is 465.9 mm, intervals of 50 would be suitable. For this exercise, you could use 1 cm to represent 50 mm of rainfall. Draw your vertical axis according to the scale you have devised.

TABLE 1.5 Mean monthly rainfall for the years 1871 to 2016, Cardwell, Queensland

Statistics	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean rainfall (mm), 1871 to 2016	438.5	465.9	400	208.6	94.7	47	32.4	29.2	38.5	54.4	115.2	193.5

Source: © Bureau of Meteorology.

Step 2

Decide on the width and spacing of the columns and draw your horizontal axis to fit. Ensure that each column is the same width.

Step 3

For each column, mark the meeting point of the two pieces of information with a dot, then use your ruler to neatly complete the column. Shade it in using colour.

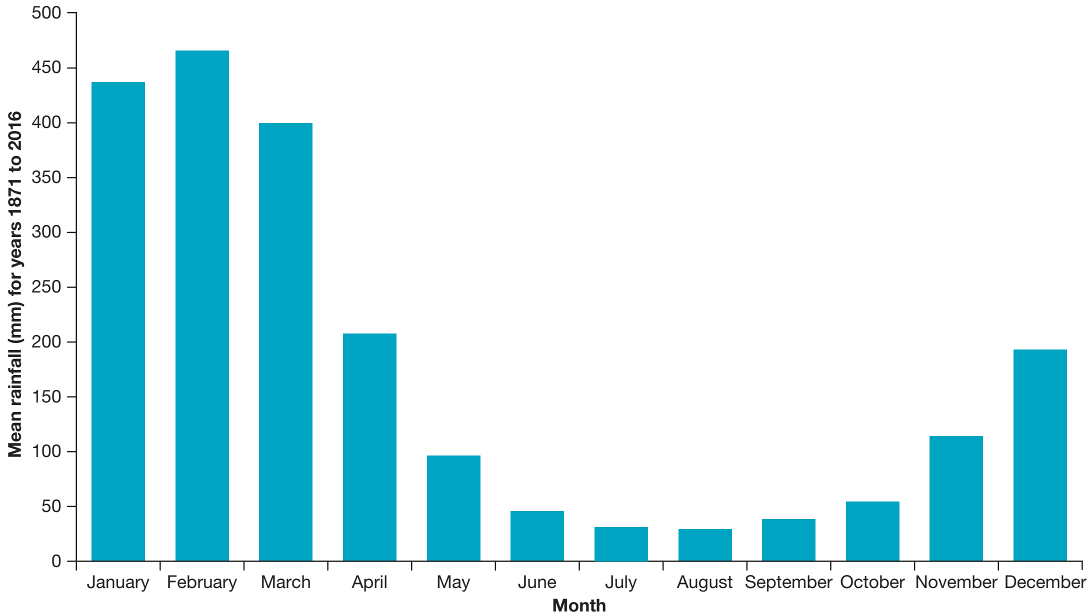
Step 4

Label the vertical and horizontal axes and give the graph a title. Include a key if necessary.

Step 5

Provide the source beneath your graph, to enable the reader to locate the source data if they wish.

FIGURE 1.29 Mean monthly rainfall for the years 1871 to 2016, Cardwell, Queensland



Source: © Bureau of Meteorology.

Step 6

This same data could also be represented using a bar graph. In a bar graph, the columns would be oriented horizontally rather than vertically, but the ruled axes, labels, spacing, title and source would remain essential elements.

1.12 Activities

learnon

1.12 Quick quiz on	1.12 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	–	–

1. Using the data in the table below, **construct** your own graph of average monthly rainfall for Innisfail, Queensland.

Mean rainfall (mm) for the years 1881 to 2016, Innisfail, Queensland

Statistics	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean rainfall (mm), 1881 to 2016	507.3	590.1	662.2	456.3	302.2	189	137.6	116.9	86.1	87.7	157.9	262.6

2. Once you have constructed your graph, answer the following.
   a. **Identify** which month has the most rainfall.
   b. **Identify** which month is the driest.
   c. Imagine you are a filmmaker, planning to film on location in Innisfail for three months. As rain would cause problems for your filming schedule, **identify** which months would be best for your requirements.

Answers and sample responses are available in your digital formats.

LESSON 1.13 Using a spreadsheet

LEARNING INTENTION

In this lesson you will:
- create, label and use formulas in a spreadsheet
- insert and label graphs to analyse data.

1.13.1 How do you use a spreadsheet to record, analyse and graph your results?

Spreadsheets, through programs such as Microsoft Excel, provide very powerful ways to identify trends and patterns in your data. They allow data to be recorded in cells to format tables, and allow quick analysis of data and the creation of different types of graphs.

Why is it important to use spreadsheets?

Spreadsheets are a way of effectively recording data gathered during science investigations. This data can then be represented as a graph in the spreadsheet to show results and trends. These graphs make the results more easily understood and analysed.

What is the application of spreadsheets in science?

Spreadsheets are used in science applications to record and analyse large amounts of data. This data is often recorded from various types of electronic probes, such as temperature, mass or pressure probes. Spreadsheets are used in the medical field to record patient data and show it graphically. Many industrial processes are also continually monitored and the readings recorded in a spreadsheet.

1.13.2 How do we use a spreadsheet?

Materials

- data from an investigation or another secondary source
- a spreadsheet

Method

Step 1

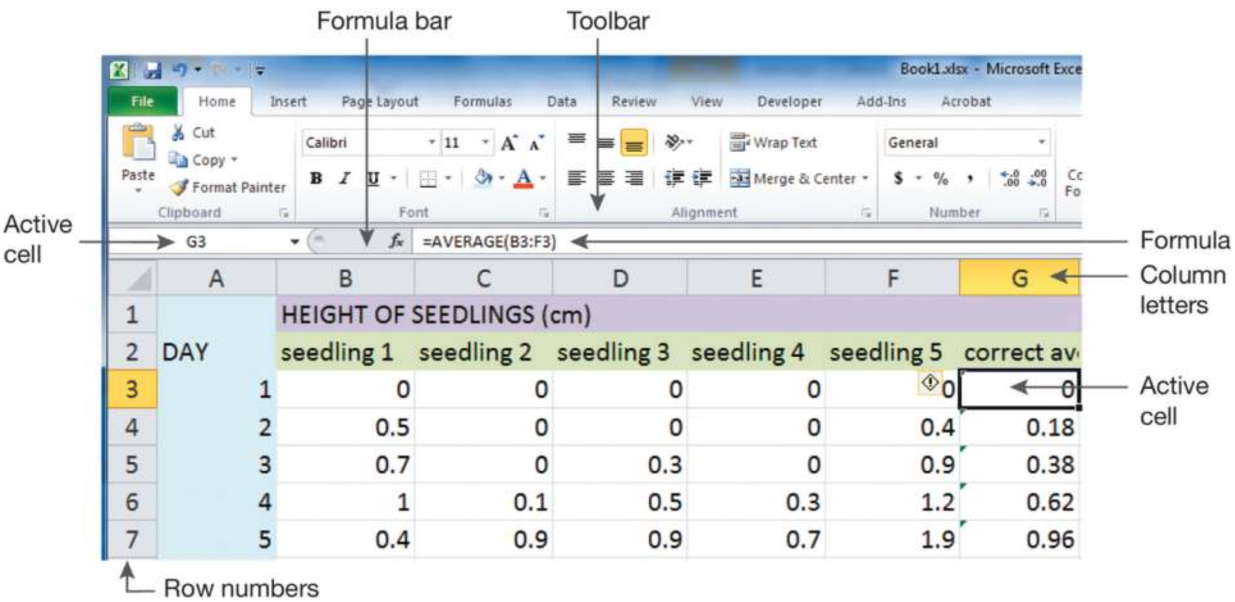
Change the title of your spreadsheet by selecting the tab at the bottom of the spreadsheet labelled 'Sheet 1'.

Step 2

Decide on titles for the rows (1, 2, 3, etc.) and columns (A, B, C, etc.) of your spreadsheet.

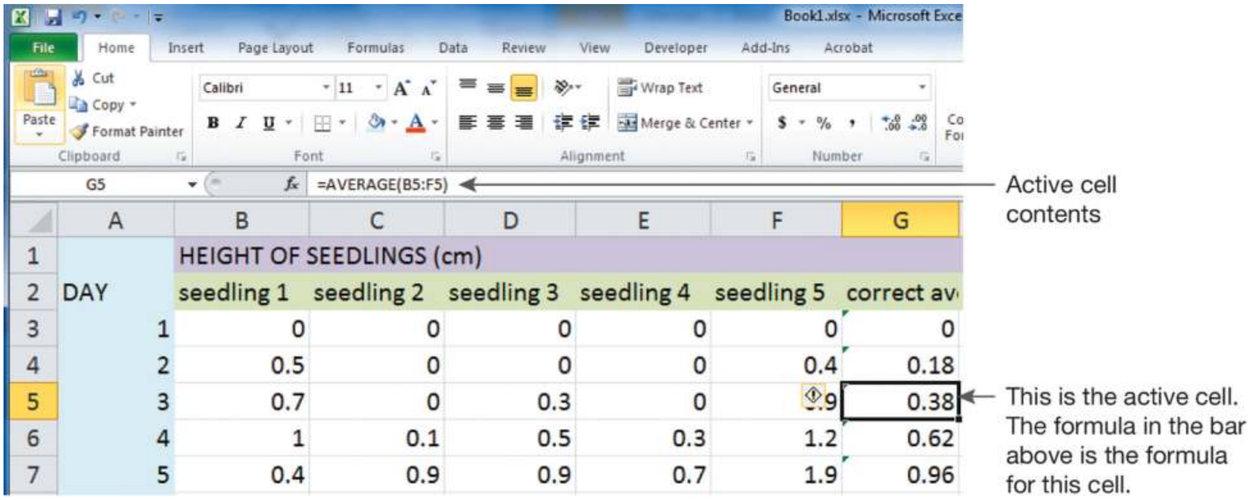
Step 3

Transfer your data into the spreadsheet.



Step 4

If you want to do calculations on the data in a spreadsheet, you need to enter a formula. In most spreadsheet programs, a formula starts with an equal sign (=). If you want the total of cell A2 and cell B2 to appear in cell C2, you would type the formula '=A2+B2' in cell C2, and then press the Enter key. If you want to calculate the average of a set of cells — for example, cells B5, C5, D5, E5 and F5 — you would type =AVERAGE(B5:F5).



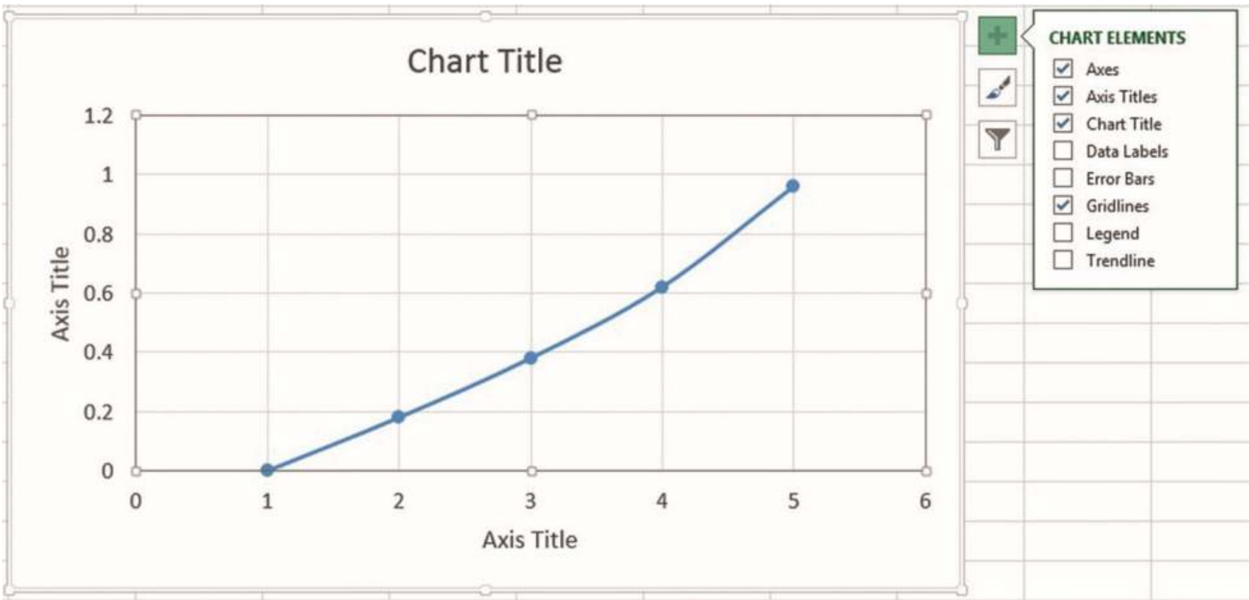
There are many other formulas that can be used, depending on your requirements.

The symbols used for mathematical operations in spreadsheets are:

- + for addition
- – for subtraction
- * for multiplication
- / for division.

Step 5

Create graphs by selecting the data, then clicking Insert and selecting the type of graph you want to produce. Once the graph has been created, use the Layout tab to add axis labels and a title for your graph.



1.13 Activities

learnon

1.13 Quick quiz on	1.13 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 5	–	–

1. **Identify** the correct terms to complete the following passage.
   A *formula* / *function* / *spreadsheet* is a computer program that can be used to organise data into *cells* / *columns* / *formulas* and rows.
   Once the data are entered, *manual* / *mathematical* calculations, such as adding, multiplying and averaging, can be carried out easily using the spreadsheet functions.
2. **Identify** which of the spreadsheet features on the left matches with each of the meanings on the right.

Feature	Meaning
a. Row numbers	**1.** Letters at the top of the worksheet identifying vertical columns
b. Active cell	**2.** Displays the contents of the active cell and allows editing of formulas or data
c. Column letters	**3.** The currently selected cell where data can be entered or edited
d. Formula bar	**4.** Numbers on the left of the worksheet identifying horizontal rows

3. **Identify** whether the following statements are true or false.
   a. A *row* is identified by a letter.
   b. A *column* is identified by a number.
   c. A *cell* is identified by its column and row address.
   d. A *range* is a block of cells.
4. **MC** Consider the section of a spreadsheet presented below.

H6 fx =AVERAGE($B$3:$F$3)

A	B	C	D	E	F	G	H
	HEIGHT OF SEEDLING (cm)						
DAY	seedling 1	seedling 2	seedling 3	seedling 4	seedling 5	correct av	incorrect av
1	0	0	0	0	0	0	0
2	0.5	0	0	0	0.4	0.18	0
3	0.7	0	0.3	0	0.9	0.38	0

   Identify what cell D3 contains.
   A. 0
   B. 0.3
   C. 0.9
   D. seedling 3
5. **MC** **Identify** which of the following symbols is used for division in spreadsheets.
   A. +
   B. –
   C. *
   D. /

Answers and sample responses are available in your digital formats.

LESSON 1.14 Processing and analysing data

LEARNING INTENTION

In this lesson you will:
- analyse data using simple descriptive statistics
- identify trends in data displayed as a scatter graph, and use a line graph to interpolate and extrapolate.

Once you have collected your data, it is time to process and analyse it. This might involve carrying out calculations and interpreting graphs to identify trends.

1.14.1 Descriptive statistics

Imagine that your teacher set you the task of determining whether the hot chips sold at the corner shop are longer than the chips sold at the fast-food store up the road. You could buy a serve of chips from each shop, measure each chip and calculate the average, or mean, length of a chip from each of the shops. Would this give you an indication of the length of a typical chip from each shop? What if one of the serves included a couple of really long chips? Would this skew the results? The mean is not always the best indication of the central tendency, or the middle results.

FIGURE 1.30 Is the average length of potato chips a good indication of central tendency?

Sometimes the median or mode are more useful.
- *Mean (or average):* The sum of the values divided by the number of values. This is the most commonly used measure of central tendency.
- *Median:* The middle value when values are organised in order from smallest to largest. If there is an even number of values, the median is the average of the two middle values.
- *Mode:* The most common value; that is, the value with the highest frequency

SAMPLE PROBLEM 1 Calculating the mean, median and mode

The following quiz results (out of 10) were achieved by students in a Science class:

10, 5, 9, 8, 6, 5, 9, 8, 7, 6, 5, 6.

Work out the mean, median and mode for the set of results.

THINK	WRITE
1. The mean is the average.	$\text{Mean} = \frac{(10+5+9+8+6+5+9+8+7+6+5+6)}{12} = 7$
2. To determine the median, write the values in order.	5, 5, 5, 6, 6, 6, 7, 8, 8, 9, 9, 10
Since there is an even number of values, the median is the mean of the two middle values (6 and 7).	$\text{Median} = \frac{6+7}{2} = 6.5$
3. The values 5 and 6 are the most common, so there are two modes.	Mode = 5 and 6

ACTIVITY: PhET simulation

Access the **PhET simulation: Centre and variability** interactivity in the Resources panel and use the simulation to identify and predict the mean and median, and explore and compare measures of centre and variability.

When comparing the hot chips from the two shops, it is also useful to know whether the chips from a particular store all have a similar length, or whether the length of the chips varies greatly. This is another type of descriptive statistics: how spread out the values are. There are four ways we can describe the spread of values: using range, quartiles, variance and standard deviation.

- *Range:* The difference between the highest and lowest values. This does not always provide a good indication of the variability in the data, particularly if there are outliers.
- *Quartiles:* Useful to describe the spread of the data. If values are placed in rank order, the top 25 per cent are the upper quartile, and the bottom 25 per cent are the lower quartile.
  A box-and-whisker plot can be used as a visual representation of the spread of data. An example is shown in figure 1.31. Each set of data is represented by a box with two whiskers. The box extends the length of the two middle quartiles. The whiskers extend the length of the lower and upper quartiles, and the median is shown with a line across the box.

FIGURE 1.31 A box-and-whisker plot

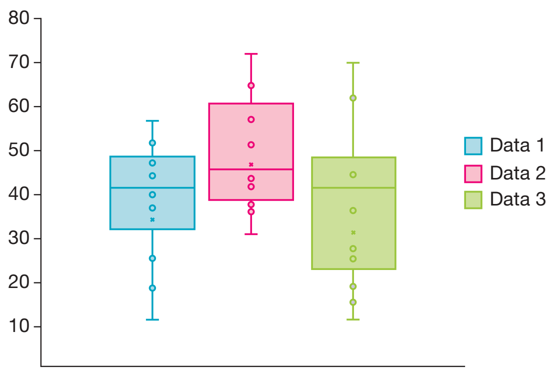
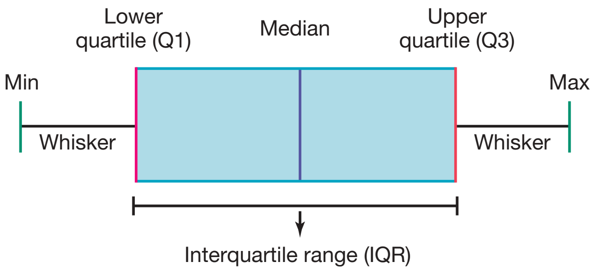


FIGURE 1.32 The box shows the two middle quartiles, and the whiskers show the upper and lower quartiles.



- If the data has a normal distribution (see the following Extension box), variance and standard deviation are two other measures of the spread of data.
  - *Variance:* A measure of how much individual scores vary from the mean
  - *Standard deviation:* The square root of variance. Data that has a high standard deviation is very spread out. Data that has a small standard variation is bunched up close to the mean. Scientific calculators and spreadsheet software can do this calculation as well.

EXTENSION: Normal distribution

In statistics, when we say that data has a normal distribution, it means that a frequency distribution graph of the data has a bell shape, with most of the values bunched up around the mean and only a few values far from the mean. For instance, if we constructed a frequency distribution graph of birth weight for Australian babies, it would have a bell shape. Most babies have a birth weight that is quite close to the mean birth weight, but a few have a birth weight that is much higher or lower than the mean.

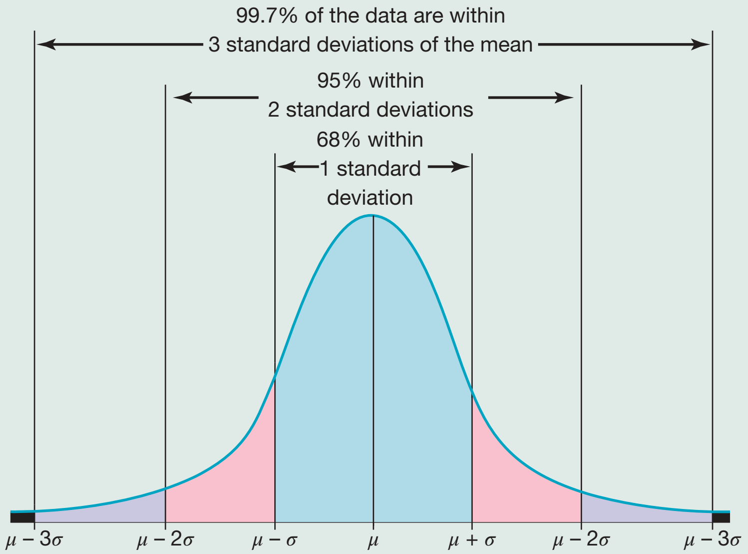
Variance is a measure of how much individual scores vary from the mean. It is the average squared difference between the scores and the mean. To calculate variance you can use the formula below, but there are easier ways to do this calculation with a scientific calculator or spreadsheet software.

$$\text{Variance} = \frac{\sum (X - \mu)^2}{N}$$

where X is an individual score, μ is the mean and N is the number of scores.

Standard deviation gives an indication of the spread of the data. The deviations are fixed intervals on either side of the mean where a certain percentage of values exist when the data has a normal distribution. For instance, 68 per cent of the values fall within one standard deviation of the mean.

FIGURE 1.33 Standard deviation gives an indication of the spread of data.



1.14.2 SI units

You might have noticed that older people often describe height in feet and mass in pounds, whereas you probably use metres and kilograms for the same quantities. SI units are a set of internationally agreed units that are used by scientists to ensure there is uniformity between countries, as shown in table 1.6.

TABLE 1.6 SI units

Measurement	Instruments used	SI unit	Other units
Length	Ruler, trundle wheel, tape measure	Metre (m)	Inches, feet, miles
Mass	Scales	Gram (g)	Pound, stone, ounce
Temperature	Thermometer	Degree Celsius (°C)	Degree Fahrenheit
Volume	Measuring cylinder, pipette	Litre (l), cubic metre (m^3)	Cups, gallons

The International System of Units includes a set of prefixes, as shown in table 1.7.

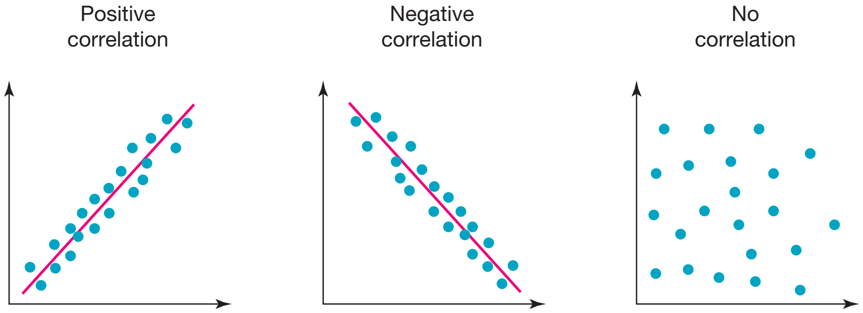
TABLE 1.7 Prefixes of SI units

Prefix	Abbreviation	Meaning
Nano	n	0.000 000 001
Micro	μ	0.000 001
Milli	m	0.001
Centi	c	0.01
Deci	d	0.1
Deca	da	10
Hecto	h	100
Kilo	k	1000
Mega	M	1000 000
Giga	G	1000 000 000
Tera	T	1000 000 000 000

1.14.3 Identifying trends

Graphs can be useful to identify trends in data. A scatter graph (or scatter plot) can indicate whether there is a relationship (correlation) between the independent and dependent variable. If the correlation is positive, that means that the dependent variable increases when the independent variable increases. The opposite is true for a negative correlation.

FIGURE 1.34 Scatter graphs can show if there is a correlation between the independent and dependent variables.



1.14.4 Interpolating and extrapolating

Interpolation

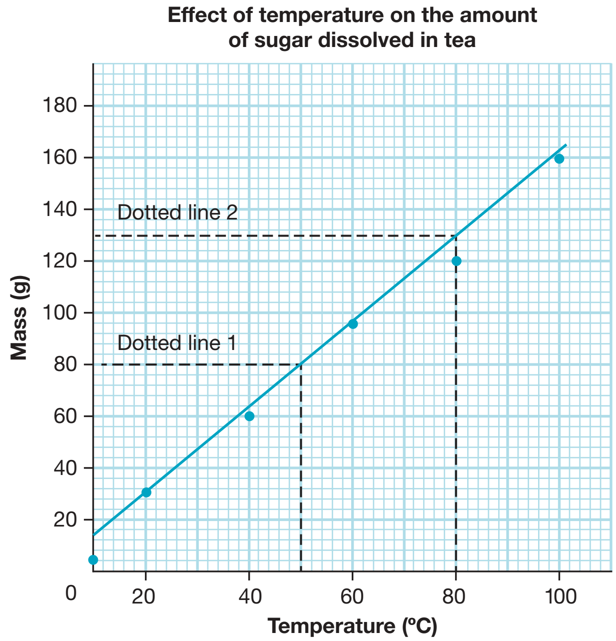
Line graphs can be used to estimate measurements that were not actually in an experiment. Table 1.8 shows the results of an experiment in which a student measured how many spoons of sugar dissolved in a cup of tea at various temperatures.

The student did not measure how much sugar dissolved at 50 °C, but we can work this out by **interpolation**. First we need to plot the data collected in the experiment. Then we read off the graph the amount of sugar that would dissolve at 50 °C. The same procedure can be used to work out the water temperature that would be needed to dissolve 130 g sugar in one cup of tea. This is shown in figure 1.35.

TABLE 1.8 Amount of sugar that dissolves in one cup of tea at different temperatures

Temperature (°C)	Mass of sugar dissolved (g)
0	4
20	30
40	60
60	98
80	120
100	160

FIGURE 1.35 Using a line graph for interpolation



1.14.5 Extrapolation

In many cases it is also possible to assume that the two variables will hold the same relationship beyond the values that have been plotted. This is called **extrapolation**. Consider table 1.9, which shows the results obtained when different masses were attached to a spring and the increase in length of the spring was measured.

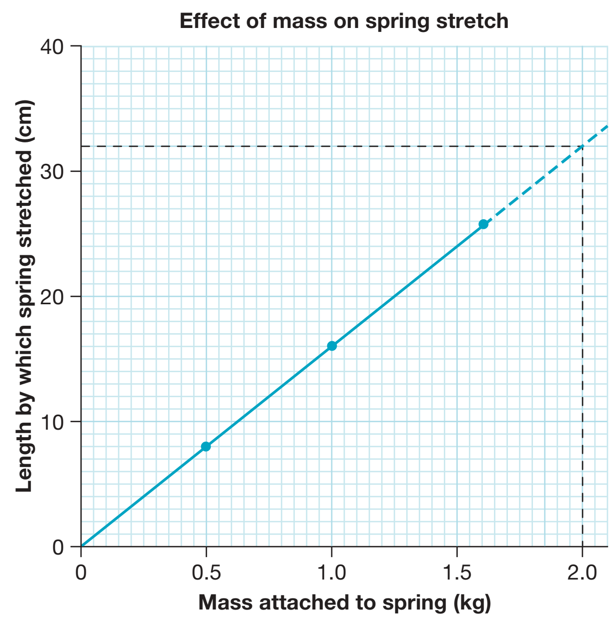
If you want to predict the mass needed to stretch the spring by 32 cm, you need to plot the data on a graph and extrapolate the value.

The data in table 1.9 has been plotted on the graph shown in figure 1.36. Values have been plotted up to a mass of 1.6 kg and an increase in length of 26 cm. The line on the graph has been projected onwards (as the dotted lines show). This extrapolation shows that a mass of 2 kg will stretch the spring 32 cm.

TABLE 1.9 Amount that a spring stretched when various masses were attached to it

Mass attached to the spring (kg)	Length by which spring stretched (cm)
0	0
0.5	8
1.0	16
1.6	26
?	32

FIGURE 1.36 Using a line graph for extrapolation



INVESTIGATION 1.5

Jellybean science

Aim

To use descriptive statistics to compare the mass of two brands of jellybeans

Materials

- 2 different brands of jelly beans (you will need at least 20 of each brand of jellybean)
- electronic scales that can measure to at least two decimal places

Method

1. Set up a spreadsheet with two columns titled 'Mass of brand X jellybeans' and 'Mass of brand Y jellybeans'.
2. Weigh each jellybean and enter the results in the appropriate column.
3. Calculate the mean and median mass for each brand of jellybean. You could do this on a calculator, or enter a formula into the spreadsheet to carry out this calculation. If you are using an Excel spreadsheet, the formula =AVERAGE(A2:A21) would return the mean of the values in cells A2 to A21. The formula =MEDIAN(A2:A21) would return the median of the same cells.
4. Sort the data values in order from smallest to largest for one type of jellybean using the Sort function. If you weighed 20 jellybeans, the top 5 masses are the top quartile and the bottom 5 are the lowest quartile. Identify the values that correspond to each of these quartiles.
5. Display the mass of each type of jellybean as a box-and-whisker plot using the information provided in this lesson.
6. Calculate the standard deviation for each type of jellybean. Again, you could use the statistics mode on your calculator, or enter a formula into the spreadsheet. If using Excel, the formula =STDEV.P(A2:A21) will calculate the standard deviation of the values in cells A2 to A21.

Results

Save a copy of your spreadsheet, including all calculations and the box-and-whisker plot.

Discussion

1. Which brand of jellybean had the highest average mass?
2. Which brand of jellybean had the most variation in mass? Justify your answer using the calculations you carried out.

Conclusion

Write a conclusion that addresses the aim.

1.14 Activities

learnon

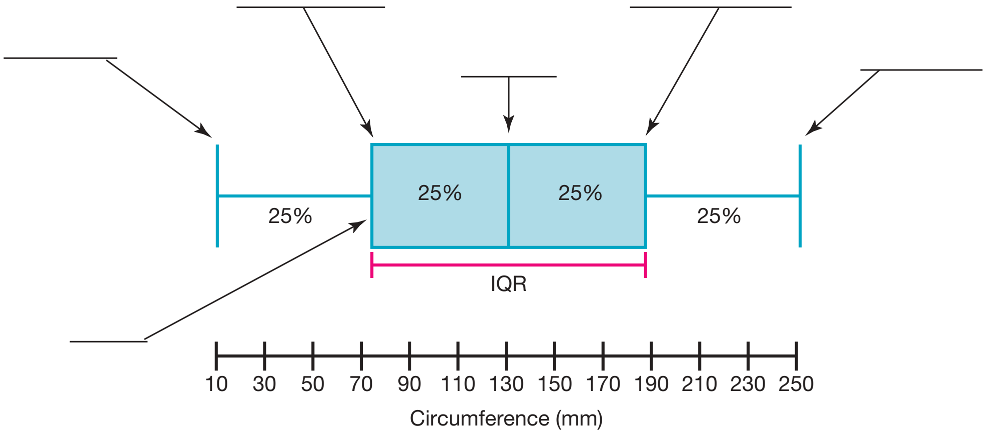
1.14 Quick quiz on	1.14 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4, 5, 6	7, 8, 9

Remember and understand

1. **State** whether the following statement is true or false.

   Data that is very spread out has a small standard deviation.
2. MC **Identify** which of the following statements is *not* true about SI units.
   A. They are internationally agreed units
   B. Prefixes such as centi, milli and kilo can be used to multiply or divide units by factors of 10.
   C. They are the preferred units in scientific reports.
   D. They are only used in English-speaking countries.
3. Label the box-and-whisker plot shown.



Apply and analyse

4. A student measured the mass of 10 pebbles. Their results were: 4.5 g, 4.5 g, 7.5 g, 8.2 g, 5.7 g, 5.7 g, 4.4 g, 8.2 g, 4.5 g, 6.2 g.
   a. **State** the average mass of the pebbles.
   b. **State** the median mass of the pebbles.
   c. **State** the mode of the pebbles.
   Give all answers rounded to one decimal place.
5. MC A vet weighs all the animals that visit their surgery and enters the data into a spreadsheet. She then calculates the average mass of the cats and dogs that visited the surgery.
   Identify which statement is most likely to be correct.
   A. The dogs will have a greater average mass than the cats, and the standard deviation will be greater for dogs than for cats.
   B. The dogs will have a lower average mass than the cats, and the standard deviation will be greater for dogs than for cats.
   C. The dogs will have a greater average mass than the cats, and the standard deviation will be smaller for dogs than for cats.
   D. The dogs will have a lower average mass than the cats, and the standard deviation will be smaller for dogs than for cats.

6. The table shows the temperature of Earth at different depths.

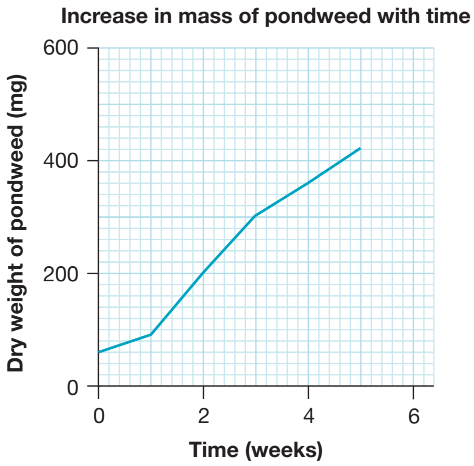
Earth's temperature at different depths

Depth (km)	Temperature (°C)
0	15
1	44
2	73
3	102
4	130
5	158
6	187
7	215
8	242

a. **Construct** a line graph for the data shown in the table.
b. Use your graph to interpolate the temperature at a depth of:
  i. 4.5 km
  ii. 7.5 km.

Evaluate and create

7. The graph shows the increase in mass of pondweed (a type of plant that grows in ponds).



a. **Identify** the mass of the pondweed after 3.5 weeks of growth.
b. **Identify** how long it took for the pondweed to reach a mass of 250 g.
c. **Predict** the mass of pondweed after 6 weeks of growth. Can you be sure that your extrapolation is valid? **Justify** your answer.
d. **Identify** whether interpolations be more valid than extrapolations. **Justify** your answer.

8. **Evaluate** the benefits of having an internationally agreed system of units.
9. In 2024, the average yearly income in Australia was $89 122, but the median income was only $67 600. **Explain** why these two measures of central tendency can be so different.

Answers and sample responses are available in your digital formats.

LESSON 1.15 Using information to solve problems

LEARNING INTENTION

In this lesson you will:
- describe the scientific method
- distinguish between correlation and causation
- analyse the validity of information.

1.15.1 Taking a scientific approach to solve problems

Tasmanian devils are under threat. A deadly disease called devil facial tumour disease (DFTD) is spreading through the population (figure 1.37). Within a few months of developing the first signs of the tumours, the animals usually die, as they find it difficult to eat.

FIGURE 1.37 Devil facial tumour disease is a deadly disease spreading through the Tasmanian devil population.

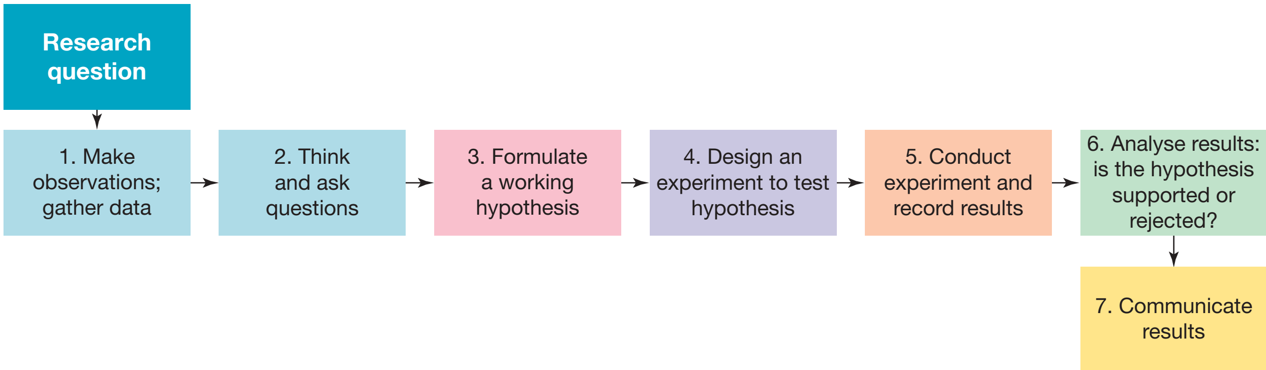
Attempting to solve this problem has required a scientific approach. First, the cause of the tumours had to be identified. It was discovered that the disease is a type of cancer, but unlike most cancers it is caused by a virus and is therefore contagious. It is passed on when the animals bite each other.

Once it was known that the tumours were caused by a viral infection, researchers could work towards developing a vaccine. A vaccine is currently in the testing phase.

Taking a scientific approach to a problem involves putting forward a hypothesis, such as ‘the disease can be transmitted between devils’, then designing and carrying out an experiment to test the hypothesis. The results may support the hypothesis. If they do not, scientists may formulate a different hypothesis. Scientific knowledge is built up gradually through investigations and the knowledge is shared and built upon by others over time.

Figure 1.38 represents what is often described as the **scientific method**.

FIGURE 1.38 The scientific method



There are many instances in which scientists will follow these steps in their quest to solve problems and develop new knowledge. You will probably use these steps if you carry out a practical depth study. There are also instances that require a less linear process. A scientist might design an investigation only to realise mid-way through that their approach is not working, and go back to the drawing board. Chance encounters and conversations with colleagues in other teams might result in a rethinking of hypotheses, and unexpected results might send research in a completely different direction.

SCIENCE AS A HUMAN ENDEAVOUR: Tackling wildlife diseases — insights from scientific collaboration

The Tasmanian devil's battle with devil facial tumour disease (DFTD) highlights how science can address urgent environmental and health challenges. Beyond Tasmania, wildlife diseases have prompted scientists worldwide to develop innovative solutions, combining research, collaboration and creative problem-solving.

One example is the fight against chytridiomycosis, a fungal disease devastating amphibian populations globally. Scientists discovered that the chytrid fungus infects amphibian skin, interfering with their ability to regulate water and electrolytes. This has led to population declines and extinctions. To combat this, researchers have been testing antifungal treatments and conducting breeding programs for resistant individuals, aiming to safeguard amphibian species.

Similarly, scientists studying bovine tuberculosis (bTB), a disease affecting cattle and wildlife such as badgers, have worked to develop vaccines and methods for controlling its spread. This includes conducting field studies to monitor disease transmission, and advances in genetic research to identify resistant traits.

The effort to address diseases like DFTD often involves large, multidisciplinary teams. For instance:

- *Tasmanian researchers.* Scientists from institutions like the University of Tasmania and the Save the Tasmanian Devil Program collaborate to develop vaccines and implement conservation strategies.
- *Global expertise.* Specialists in immunology, genetics and ecology work together, sharing insights to accelerate breakthroughs.
- *Field studies.* Field biologists monitor populations to track the spread of diseases and test interventions, such as releasing devils raised in captivity into disease-free areas.

Unexpected discoveries also play a key role. For example, while working on DFTD, researchers identified a second, unrelated transmissible cancer in Tasmanian devils. This finding reshaped their understanding of how these cancers evolve and spread, influencing strategies to combat the disease.

1. Why is collaboration between scientists from different fields important in solving complex problems like DFTD?
2. How can research on diseases in animals help us understand and address human diseases?
3. What challenges do scientists face when trying to develop vaccines or treatments for wildlife diseases?
4. How might studying transmissible cancers in Tasmanian devils help scientists learn more about cancer in humans?
5. What role does fieldwork play in the study and prevention of wildlife diseases?

Scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)

1.15.2 Evaluating conclusions and evidence

Scientific investigations generate data. From this data, we draw conclusions, but are these conclusions always correct? In lesson 1.14, we introduced the idea of correlation. If we plot a scatter graph of a dependent variable against an independent variable and the points form a line, this indicates a relationship, or correlation, between the independent and dependent variables. For instance, if we measured the mass, in grams, and the weight, in newtons, of various objects, the points on a scatter graph would form a straight line. If we measured students' foot length and their height, the points would not form a perfect straight line, but they also would not be spread out randomly. There would be some correlation, but not as strong as the correlation between mass and weight.

Establishing causation is more difficult than identifying correlation. Causation refers to when one thing causes another. A number of studies have shown that children who spend more time outdoors are less likely to be short-sighted than those who spend little time outdoors. This is a correlation. Is it actually spending time outdoors that reduces the chance of becoming short-sighted, or is there another explanation? Perhaps the children who spend less time outdoors spend more time reading, looking at a screen or doing other close work. Perhaps the children who spend more time outdoors have more opportunity to look at landscapes and distant objects, and this is what prevents short sight. Or perhaps the children who spend more time outdoors are also more physically active.

It turned out that exposure to bright outdoor light was the critical factor (see the following case study). In this case, something about the time spent outdoors (exposure to bright light) did cause the reduced risk of myopia.

FIGURE 1.39 Is there a correlation between foot length and height?

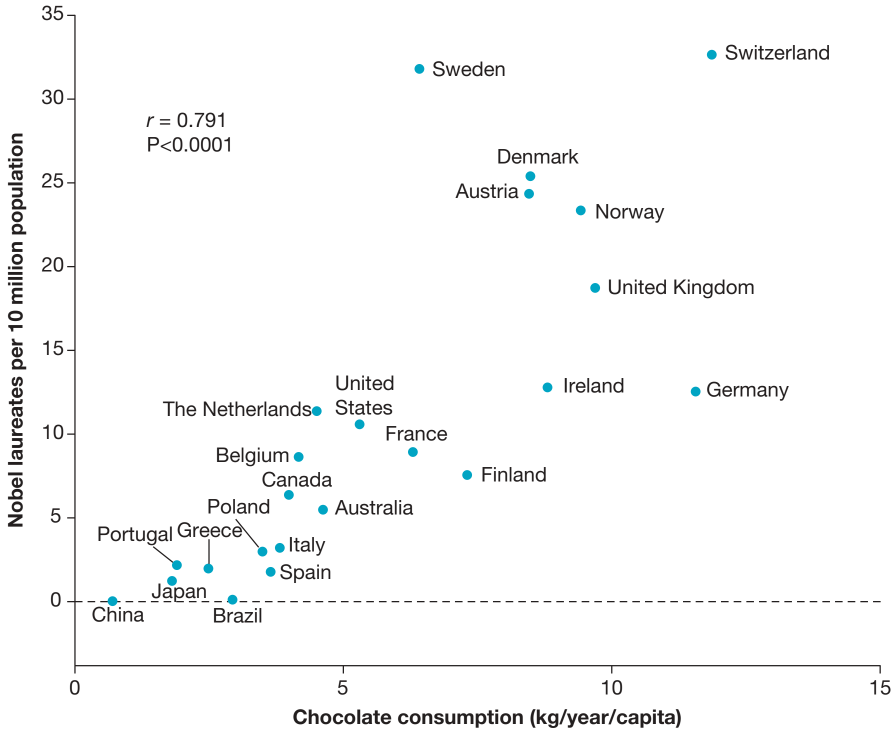
FIGURE 1.40 Does spending time outdoors decrease the risk of becoming short-sighted?

CASE STUDY: Does bright outdoor light reduce the risk of myopia?

To investigate whether exposure to bright outdoor light reduces the risk of myopia (short-sightedness), researchers carried out an investigation involving chickens. First, they used special lenses to try to induce myopia in chicks. Then they separated the chicks into three groups, with each group exposed to different light levels for 15 minutes per day. By the end of the trial, the chicks that had been exposed to the brighter light were less short-sighted than those exposed to light that was not as bright. It appears that bright outdoor light is important for eye development.

In other instances, causation cannot be established. Figure 1.41 shows that there appears to be a correlation between a country's chocolate consumption and the number of Nobel Prize winners the country has produced. But does chocolate consumption actually increase your chance of winning a Nobel Prize? Can you think of another explanation for the correlation?

FIGURE 1.41 Correlation between countries' annual per capita chocolate consumption and the number of Nobel laureates per 10 million population



1.15.3 Analysing the validity of information

Formulating sensible hypotheses, analysing evidence, arriving at valid conclusions and developing evidence-based arguments are some of the components of the science process that involves using secondary sources. A secondary source is information that you did not generate yourself. When you carry out a science investigation, the report you write is a primary source. Data obtained by another person and published in a research paper, and information from a website, textbook or video, are all examples of secondary sources. When accessing information from secondary sources, it is important to consider whether the information can be trusted. A research paper published in a reputable science journal, an article in a popular science magazine and your science textbook are more likely to contain correct information about a scientific issue than a video from a YouTuber with a reputation for peddling conspiracy theories. To decide whether you can trust a source of information, you can use the CRAAP test (figure 1.42).

FIGURE 1.42 The CRAAP test is useful to evaluate information.

C	**Currency:** The timeliness of the information
R	**Relevance:** The importance of the information for your needs
A	**Authority:** The source of the information
A	**Accuracy:** The reliability, truthfulness and correctness of the content
P	**Purpose:** The reason the information exists

Table 1.10 lists some questions you can ask yourself to gauge whether the information passes the CRAAP test.

TABLE 1.10 Examples of questions to evaluate whether information passes the CRAAP test

Currency	When was the information published? Have there been major developments in this field since it was published?
Relevance	Does this information relate to the question you are researching?
Authority	Who is the author? Do they have relevant qualifications or expertise?
Accuracy	Is this information correct? How can you tell? Have you found the same or similar information on other reputable sites?
Purpose	Why has the author published this information? Are they likely to have a bias? Do they stand to gain anything from people believing this information?

1.15 Activities

learnon

1.15 Quick quiz on | **1.15 Exercise**

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	2, 4, 5, 6	7, 8, 9

Remember and understand

1. MC Tasmanian devils are under threat from a disease that causes facial tumours and make it difficult for the animals to eat. Attempting to solve this problem has involved all of the following except
   A. identifying the cause of the disease.
   B. working out that the disease is contagious.
   C. developing a vaccine.
   D. finding a cure for the facial tumours.
2. Refer to figure 1.38, which shows the steps involved in the scientific method. **Describe** an instance in which a scientist may not follow this exact sequence of steps.
3. MC **Identify** which of the following is a secondary source of information.
   A. A first-hand account or original document
   B. An analysis or interpretation of primary sources
   C. A direct observation or experiment
   D. A personal opinion
4. MC **Identify** the reason that secondary sources are valuable in scientific research.
   A. They provide direct evidence.
   B. They offer personal opinions.
   C. They synthesise information from multiple primary sources.
   D. They are always more reliable than primary sources.

Apply and analyse

5. **Identify** whether the following statements are true or false.
   a. A primary source is created by someone who was present at an event.
   b. An interview with a scientist discussing their research findings is considered a primary source.
   c. A photograph taken during a scientific experiment is an example of a primary source.
   d. Secondary sources often draw from one or more primary sources.
   e. A lab report detailing the results of an experiment is a primary source.

6. MC Imagine you are researching the impact of plastic pollution on marine ecosystems.

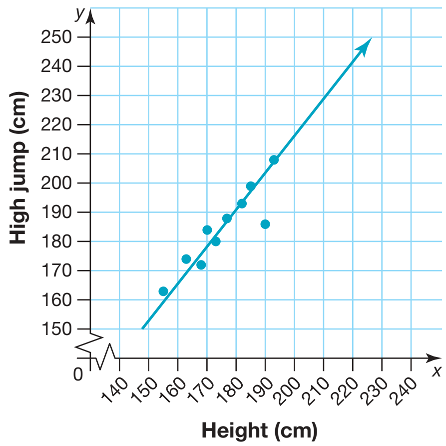
Identify which of the following sources would be most helpful for understanding the broader context.
A. A blog post by an environmental activist
B. A scientific review article on plastic pollution
C. A YouTube video showing beach clean-up efforts
D. A personal diary entry about a beach visit

7. A sports scientist is looking at data comparing the heights of athletes and their performance in the high jump.

The following table and scatter graph represent the data they have collected. A trend line of best fit by eye has been drawn on the scatter graph.

Heights of athletes versus their performance in the high jump

Height (cm)	168	173	155	182	170	193	177	185	163	190
High jump (cm)	172	180	163	193	184	208	188	199	174	186



a. **Identify** whether there is a correlation between the two variables shown.
b. **State** whether we can establish causation between the variables shown. **Explain** your answer.

8. **Explain** why you might also use secondary evidence in a scientific report if you have already gathered primary evidence.

Evaluate and create

9. A student has used the following sources of information for their secondary evidence to support findings they made in an investigation. **Evaluate** each of the sources of secondary evidence, summarising assumptions that can be made about their reliability and validity.
a. Three peer-reviewed journals
b. An article on the Australian government Department of Health website
c. A social media post by a well-known immunologist
d. Two articles from the *Sydney Morning Herald* website.

Answers and sample responses are available in your digital formats.

LESSON 1.16 Communicating

LEARNING INTENTION

In this lesson you will:
- outline some of the ways that scientists share their research findings
- describe the structure of an experiment report.

Effective communication is critical to the progress of science. It allows scientists to share their own research findings, and to learn from others.

1.16.1 Research papers

Scientific research is most often communicated in a research paper published in a journal. The most reputable science journals are peer-reviewed. The research papers published in these journals go through a peer-review process that involves other scientists in the field reviewing the paper and making sure that it meets certain criteria before it can be published.

The experiment reports you write at school are based on the same format as a research paper, although you may not be required to include all the sections typically found in a published paper.

Table 1.11 lists some of the sections that are usually included in a school experiment report, although you should check with your teacher to find out exactly what is required as your school may use a slightly different format. The left-hand side of the table describes the features of the different sections of the report. The right-hand side shows a partially completed example. In this report, the method is written in the past tense passive voice, but the present tense may be preferred at your school. You could work through the experiment described and complete the report to practise your scientific-report-writing skills.

TABLE 1.11 What to include in experimental reports

Report section	Example
Heading • Write down the problem you are investigating as a question.	*Which flowers produce the best acid–base indicators? Can you predict whether a flower will make a suitable acid–base indicator from its colour?*
Abstract • Write this last. • An abstract gives an overview of the project. The abstract allows the reader to decide whether the research paper will be useful to them. • In scientific journals, abstracts are usually written in the past tense and in the passive voice; that is, rather than writing 'I poured 50 mL of water into a beaker', you should write '50 mL of water was poured into a beaker'.	This abstract may not match your results. Modify it to match the data you obtain when you do this experiment. *The purpose of this experiment was to find out whether there is a relationship between the colour of flowers and whether certain flowers are suitable to make acid–base indicators. A range of flowers of various colours were used to make indicators. The flowers were ground up with a small amount of methylated spirits to extract the pigment. The coloured extract was then added to solutions of various pH levels. The extract from most flowers except yellow flowers was a different colour in acid and alkalis, although the colour change did not occur at the same pH for all flowers tested. All the purple flowers tested were suitable for making indicators. Some of the purple flowers went through a number of colour changes as the pH was changed.*

(continued)

TABLE 1.11 What to include in experimental reports *(continued)*

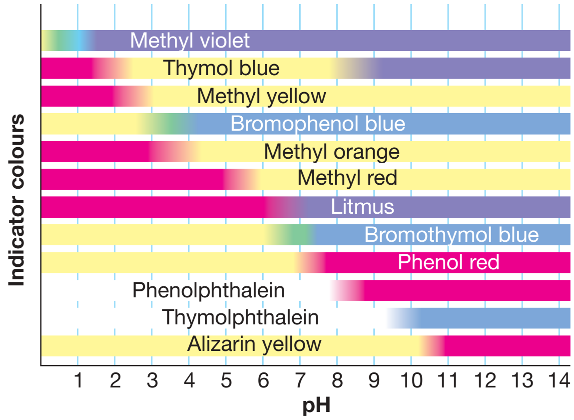
<table>
<tr><th>Report section</th><th>Example</th></tr>
<tr><td>Hypothesis
A testable statement that explains a set of observations</td><td>Pigments extracted from purple and red flowers work as acid–base indicators, whereas pigments extracted from yellow and white flowers do not.</td></tr>
<tr><td>Apparatus
A list of equipment used in the experiment</td><td>You should read the method below and write your own list of equipment.</td></tr>
<tr><td>Method
A list of steps that explain how to do the experiment
In scientific journals, methods are written in the past tense and passive voice. At school, methods are sometimes called ‘procedure’ and the present tense may be used. Check with your teacher how you should write your method.</td><td>A range of flowers of various colours was collected.
The petals of each flower were removed and ground up with 20 mL methylated spirits in a mortar and pestle.
Small amounts of 1 mol/L hydrochloric acid, citric acid powder, water, baking soda and 1 mol/L sodium hydroxide were placed on a sheet of plastic.
A few drops of the coloured extract obtained from each flower were added to each substance.
The colour of the indicator in each substance was recorded.
Universal indicator solution was used to measure the pH of the hydrochloric acid, citric acid, water, baking soda and sodium hydroxide. Two drops of universal indicator solution were added to each substance and the colour produced was compared to the colour chart provided with the universal indicator solution.</td></tr>
<tr><td>Results
Include your observations and measurements.
Where possible, present the results in a way that allows the reader to identify trends and patterns easily (e.g. as a table or graph).</td><td>A table with the headings shown below could be used to present the results for this experiment. You will also need another table to record the pH of the solutions tested.

Table 1: Colour of flower extracts in a range of substances
<table>
<tr><th>Flower used</th><th>Hydrochloric acid</th><th>Citric acid</th><th>Water</th><th>Baking soda</th><th>Sodium hydroxide</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 2: pH of substances that were combined with the flower extracts
<table>
<tr><th>Substance</th><th>pH</th></tr>
<tr><td>Hydrochloric acid</td><td></td></tr>
<tr><td>Citric acid</td><td></td></tr>
<tr><td>Water</td><td></td></tr>
<tr><td>Baking soda</td><td></td></tr>
<tr><td>Sodium hydroxide</td><td></td></tr>
</table></td></tr>
</table>

A graph is another way to present your results, although in this example the names of the flowers you use should replace the names of the indicators.

Figure 1: Colours of common indicators at various pH levels



Discussion

In this section you should:
- identify general trends in your results
- explain how your results might be useful
- identify sources of error
- suggest improvements to your experiment
- suggest further experiments that might be carried out in this field.

To complete this section, write a paragraph that answers the questions below.

1. Can you identify any trends in your results (which colour flowers tended to work as indicators, which ones didn't work)?
2. Were there any problems or limitations with your method? For example:
   - Were you able to test a large number of flowers of each colour?
   - Did you follow exactly the same method to make the indicator each time?
3. How could your method be improved in terms of its validity, accuracy and reliability? *Note:* Remember that a valid experiment measures what it set out to measure and is a fair test with all the necessary variables controlled. In this instance, the validity of the experiment could be improved by ensuring that the same weight of flower petals and the same amount of solution and powders were used for each flower. Reliability means that the same results will be obtained consistently if the experiment is repeated. For instance, an experiment where only two purple flowers were tested is not a reliable way to check whether most purple flowers make good acid–base indicators. Repeating the experiment and including many flowers of each colour would improve the reliability of the experiment. You should also discuss the accuracy and precision of the measurements. How could pH have been measured more accurately and precisely in this experiment?
4. Are there further experiments that could be performed to gather more knowledge about this problem (e.g. obtaining pure samples of the coloured chemicals found in flower petals and testing whether they work as acid–base indicators)?

Conclusion

- An overall statement that summarises the trends in your results and relates back to the aim
- Your conclusion should state whether your results support your hypothesis.

Can you write your own conclusion?

(continued)

TABLE 1.11 What to include in experimental reports *(continued)*

Report section	Example
References • A list of all the books, journal articles, websites and so on that you used as a source of information for your SRP. There are a few different formats used for reference lists (also called **bibliographies**), so you should check the format required by your school. • You may also wish to have an acknowledgements section where you thank people who helped you.	The Harvard referencing format for books is as follows: Author(s), date of publication, title (in *italics* if typed or underlined if handwritten), publisher, city where published. If you wanted to include the book you are reading now in a reference list you would write it as: Lofts, G. and Evergreen, M.J. (2025) *Jacaranda Science Quest for the Victorian Curriculum*, 3rd edn, John Wiley and Sons, Melbourne, Vic., Australia.

1.16.2 Other ways scientists communicate

Another way that scientists share their research formally is through presentations at conferences. A conference is a meeting of people working in a particular field. For scientists, it is an opportunity to present their research, listen to other researchers and have informal conversations with others in their field.

FIGURE 1.43 Scientists can present their research at conferences.

The target audience for research papers and conference presentations consists of other scientists, but researchers are often keen to share their findings with the general public, particularly if their research has important implications. In these instances, television or radio interviews and social media posts may be a more effective way of reaching their audience.

Some scientists have roles in which communication with the public is a key part of their job. During the COVID-19 pandemic, the state Chief Health Officers regularly appeared on television with the state premiers to communicate the latest health orders.

CASE STUDY: Expert science communicators

Professor Brett Sutton

Professor Brett Sutton served as Victoria's Chief Health Officer during the COVID-19 pandemic, becoming one of the most prominent public figures in the state. With a background in public health and infectious diseases, Professor Sutton was instrumental in guiding the state's response to the crisis. His role involved providing expert advice on measures to control the virus, including lockdowns, mask mandates and vaccination strategies.

Dr Karl Kruszelnicki

With his brightly coloured shirts, Dr Karl Kruszelnicki is one of the most recognised people in Australian science. He has multiple qualifications, including a medical degree, and worked as a doctor at a children's hospital early in his career, but these days he is a science communicator. He has worked in television and radio and written for newspapers, and has also written a number of books. Dr Karl, as he is often referred to, is passionate about communicating accurate scientific information to the public and addressing myths around key scientific issues such as vaccination and climate change.

FIGURE 1.44 Professor Brett Sutton

FIGURE 1.45 Dr Karl Kruszelnicki

1.16 Activities

learnon

1.16 Quick quiz on	1.16 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4, 5, 7, 8	6, 9, 10, 11

Remember and understand

1. MC **Identify** the target audience for research published by scientists in science journals.
   A. Members of the public
   B. Other scientists who work in the same field
   C. School students
   D. Science teachers
2. MC **Identify** the section of a report in which you should describe possible improvements to your experiments.
   A. Method
   B. Results
   C. Discussion
   D. Conclusion
3. MC **Identify** the section of a report in which you should list the steps you followed in your investigation.
   A. Abstract
   B. Method
   C. Results
   D. Discussion
4. **Explain** why it is important for researchers to publish their investigations in scientific journals and to read reports written by other scientists.

Apply and analyse

5. **Describe** why it is important to write a risk assessment before you conduct an investigation.
6. **Explain** why it is better to write the abstract of a scientific report last, even though it appears at the beginning.
7. Write the following instructions in the past tense and passive voice. An example has been done for you. Example: *Read the book.* The book was read.
   a. Chop up some flower petals.
   b. Combine 20 mL hydrochloric acid with 40 mL sodium hydroxide.
   c. Add three spoons of sugar to 100 mL water.
   d. Use a stopwatch to measure the time taken for the sugar to dissolve.
   e. Wrap some aluminium foil around a test tube.
8. Many researchers choose to have their reports published in journals written in English, even if English is not their first language. **Suggest** why.

Evaluate and create

9. When scientists write their investigations for publication in a scientific journal, the abstract is one of the most important parts of the report. **Explain** why the abstract is usually read by many more people than the full report.
10. **Justify** why it is important for scientists to clearly describe the method they used when they write a report of their investigation.
11. There have been instances where scientists have faked their results or committed other types of scientific misconduct.
    a. **Outline** why you think that some scientists might be tempted to fake or fabricate their results.
    b. **Explain** why cases of scientific misconduct are damaging to all scientists.
    c. **Propose** what you think might happen to scientists who are found to have faked their results.

Answers and sample responses are available in your digital formats.

LESSON 1.17 Review

1.17 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
1.2	I can explain why instruments can be used to enhance our observation skills.			
	I can define the terms quantitative data and qualitative data, and distinguish between precision and accuracy.			
1.3	I can read and record measurements accurately.			
1.4	I can describe some of the ways that scientists develop questions and problems to investigate.			
1.5	I can identify independent, dependent and controlled variables.			
1.6	I can write aims and hypotheses.			
1.7	I can describe the features of valid investigations.			
1.8	I can prepare a risk assessment for an experiment.			
	I can explain the importance of considering risks and ethics when planning an investigation.			
1.9	I can identify and respond to different types of errors in investigations.			
1.10	I can construct a table to organise data.			
	I can select the most appropriate type of graph to display data.			
1.11	I can construct line graphs.			
1.12	I can construct simple column or bar graphs.			
1.13	I can create, label and use formulas in a spreadsheet.			
	I can insert and label graphs to analyse data.			
1.14	I can analyse data using simple descriptive statistics.			
	I can identify trends in data displayed as a scatter graph, and use a line graph to interpolate and extrapolate.			
1.15	I can describe the scientific method.			
	I can distinguish between correlation and causation.			
	I can analyse the validity of information.			
1.16	I can outline some of the ways that scientists share their research findings.			
	I can describe the structure of an experiment report.			

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Post-test	Topic 1 Post-test
eWorkbook	Topic 1 eWorkbook
Digital document	Key terms glossary

1.17 Activities

learnon

1.17 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5, 6, 7	8, 9

Remember and understand

1. **Identify** which of the terms on the left matches each of the definitions on the right.

Term	Definition
a. Risk assessment	1. The answer to the aim or the problem
b. Hypothesis	2. The part of a journal article where a brief overview of the article is given
c. Independent variable	3. The part of a report where problems with the experiment and suggestions for improvements are discussed
d. Abstract	4. States what was seen or measured during an experiment; may be presented in the form of a table or graph
e. Conclusion	5. Testable statement that explains a set of observations
f. Results	6. A document that lists the risks associated with an activity and steps that must be taken to minimise these risks
g. Dependent variable	7. Concerns that deal with what is morally right or wrong
h. Apparatus	8. The variable that is deliberately changed in an experiment
i. Method	9. The variable that is measured in an experiment
j. Ethical considerations	10. A list of steps to follow in an experiment
k. Discussion	11. A list of equipment needed for the experiment

2. **Explain** the difference between qualitative and quantitative data.
3. MC **Identify** which of the following is the best description of ethics.
   A. A system of moral principles
   B. Communication between scientists
   C. A method of scientific enquiry
   D. The genetic modification of crops
4. **Outline** some of the information that needs to be included in a risk assessment for an experiment.

Apply and analyse

5. **Identify** the part of a scientific report on the left that matches the information that would be included within it on the right.

Part of scientific report	Information
a. Materials and method	1. A list of books and websites to which you have referred
b. Bibliography	2. Observations and measurements
c. Discussion	3. A statement about why the experiment was performed
d. Conclusion	4. A list and diagrams of the equipment used
e. Results	5. Your thoughts about the results and suggestions for improvements
f. Aim	6. A clear statement of what you found out

6. Miranda wanted to test the following hypothesis: 'Hot soapy water washes out tomato sauce stains better than cold soapy water.'
   a. **List** the equipment she will need.
   b. **Identify** the independent and dependent variables in this investigation.
   c. **List** five variables that will need to be controlled.
   d. **Outline** a method that could be used to test the hypothesis.
   e. Miranda's results are shown in the table below.

Results of Miranda's experiment

Water temperature (°C)	Observations
40	Faint stain left after washing
60	No stain left after washing
80	No stain left after washing

Write a conclusion based on Miranda's results.

7. Gemina and Habib wanted to investigate whether the type of surface affects how high a ball bounces. Habib thought the ball would probably bounce highest off a concrete floor. They dropped tennis balls from different heights onto a concrete floor, a wooden floor and carpet. Their results are shown in the table.

Results of Gemina and Habib's experiment

Distance ball dropped (cm)	Average height of bounce (cm)		
	Concrete	Wood	Carpet
25	22	14	8
50	46	34	18
75	70	50	26
100	94	66	34
125	X	85	Z
150	128	94	48
175	129	Y	50
200	130	100	51

   a. Write a hypothesis for this experiment.
   b. **List** the equipment needed for this experiment.
   c. **Construct** a line graph of Gemina and Habib's results.
   d. Use your graph to **estimate** the values of X, Y and Z.
   e. **Identify** two variables that had to be kept constant in this experiment.
   f. **Identify** two trends in the results.
   g. **State** whether the results support the hypothesis you wrote in part a.
   h. **Predict** how high the tennis ball would bounce off each floor if it was dropped from a height of 225 cm.

Evaluate and create

8. Design an experiment to test the following hypothesis: 'Lemon juice and vinegar can prevent sliced apple from turning brown.'
   Outline a suitable method and **describe** the observations that would be recorded. **Construct** a suitable table that could be used to enter the results.
9. It has been proposed that adding iron sulfate to the oceans could reduce atmospheric carbon dioxide levels and thus bring global warming under control. The iron sulfate would promote the growth of algae. As algae carry out photosynthesis, they take up carbon dioxide.
   State whether you think it would be ethical to test this idea by dumping large quantities of iron sulfate in all the world's oceans. **Justify** your response.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

2 Reproduction

CONTENT DESCRIPTION

The structures of reproductive cells and organs in plants and animals are related to their functions; processes of sexual and asexual reproduction enable survival of a species (VC2S10U01)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 2.1 Overview

2.1.1 Introduction

Reproduction is essential for life on Earth to continue. Living things, or **organisms**, must reproduce to create **offspring** for their species to survive for future generations. Humans and all animals reproduce, as do plants, fungi and bacteria, but all in different ways. Many animals reproduce sexually, having both male and female individuals just as humans do. However, did you know that many plants also have male and female reproductive cells and reproduce sexually? Some animals, such as the garden snail, have both male and female reproductive organs. In addition, the akoya pearl oyster can change gender many times throughout its life, beginning as a male and then becoming female; the oysters switch genders over and over again to improve their chances of successful reproduction. Although many animals and plants reproduce sexually, there are lots of others that reproduce by simply dividing into two identical offspring or by breaking off part of their body to give rise to the next generation. In this topic, you will explore the fascinating area of reproduction in different organisms and develop an ability to discuss reproduction using the correct scientific terminology.

FIGURE 2.1 Dandelions use the wind to help them to disperse their seeds.

DISCUSSION

1. Why is reproduction important for the survival of species on Earth?
2. What are the differences between sexual and asexual reproduction?
3. How do plants reproduce sexually, and how is this similar to animals?
4. Why might some animals, like the akoya pearl oyster, change genders?
5. What are the advantages of garden snails having both male and female organs?
6. Can you give examples of organisms that reproduce asexually?
7. Would you design an organism to reproduce sexually or asexually, and why?

SCIENCE INQUIRY: Reproductive strategies in organisms

In this science inquiry, you will investigate the reproductive strategies of different organisms, focusing on the conditions that influence reproductive success. You will compare sexual and asexual reproduction in various species and explore how environmental factors, such as temperature or resource availability, might affect reproduction.

Formulate investigable questions

Examples:
- How does the method of reproduction (sexual or asexual) affect the survival rate of offspring in different environments?
- What environmental conditions (e.g. temperature and humidity) impact the reproductive success of organisms?

Develop hypotheses

Example: Organisms that reproduce asexually will have a higher reproductive success rate in stable environments compared to those that reproduce sexually.

Plan and conduct investigations

- Use secondary sources to gather data on reproductive success in various organisms (e.g. bacteria, plants, garden snails and akoya pearl oysters).
- Examine existing studies or create models showing how reproduction strategies vary with environmental changes.

Identify variables

- Independent variable: Type of reproduction (sexual versus asexual)
- Dependent variable: Reproductive success rate (measured as offspring survival or population growth)
- Controlled variables: Environmental conditions like temperature, light and resource availability

Analyse data

- Compare survival rates of offspring in different environmental contexts.
- Look for patterns or relationships between reproduction method and environmental stability.

Draw conclusions

- Determine which reproductive strategy provides an advantage in various environments.
- Evaluate the reliability of the data and consider alternative explanations.

1. What hypothesis can you form about how asexual and sexual reproduction respond to environmental changes?
2. What variables would you need to control to ensure the validity of your investigation?
3. How could models or representations, such as graphs or diagrams, help explain the relationship between reproduction methods and reproductive success?
4. What patterns or trends might you expect to find in organisms that reproduce sexually versus asexually?
5. How could you evaluate the reliability of the data collected from secondary sources for this investigation?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

EXTENSION: Hermaphrodites

Did you know that not all plants or animals have separate sexes? Some invertebrates are both male and female at once. They are called **hermaphrodites**. This enables an individual to achieve greater reproductive efficiency than if it was just the one sex.

FIGURE 2.2 Garden snail *Cornu aspersum*

Snails have been around for 600 million years and have developed intriguing methods of reproduction. Each snail has an organ called an ovotestis, which makes both sperm and eggs, and a single tube to carry both the sperm and the eggs.

After a complex courtship in which hermaphrodite snails rear up, each pressing its muscular foot against its partner, and stroking each other with their tentacles, they simultaneously insert their sex organ into the other's body. In this manner, each snail gives sperm to the other and each has its eggs fertilised.

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Pre-test	Topic 2 Pre-test
eWorkbook	Topic 2 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 2 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 2.2 Asexual reproduction

LEARNING INTENTION

In this lesson you will describe how some organisms reproduce asexually with examples of some of the main strategies, such as binary fission, budding and spores.

2.2.1 Asexual reproduction

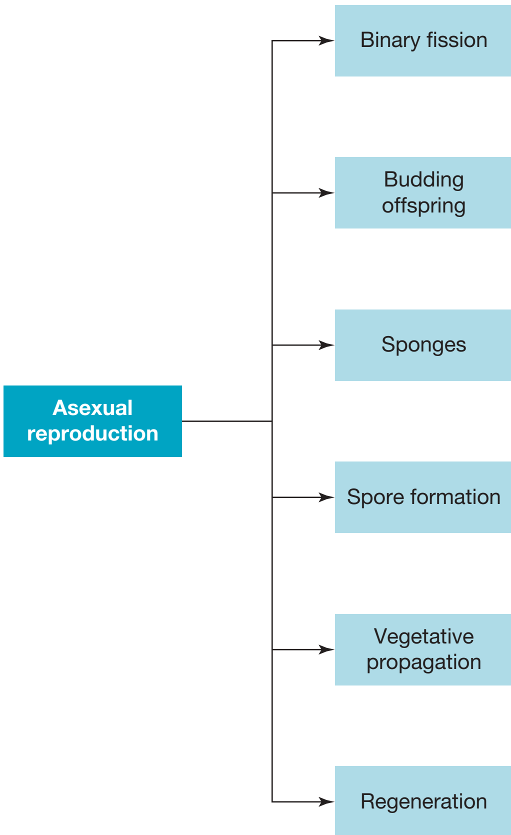
Imagine looking exactly like your parent — and all of the rest of your family!

Not all organisms reproduce by sexual methods. In some types of organisms, a single parent produces one or more genetically identical offspring. This is called **asexual reproduction**. Binary fission, spore formation, budding and vegetative propagation are examples of this type of reproduction.

Asexual means 'without sex'. Asexual reproduction does not use specialised sex cells (**gametes**) to bring information from two parents together. Instead, all the information (**genes**) comes from one parent. This means that all the offspring produced are identical to each other — and to their parent. However, there are some issues that can arise from being genetically identical. Because there is a lack of variation in the genetic information, a disease would be detrimental to the whole population, not just some. Also, any errors that occur in the genetic information would be passed on to all offspring.

Individuals that have identical genetic information to each other are called **clones**. As well as occurring in nature, technology has also used **cloning** to produce genetically identical organisms.

FIGURE 2.3 Examples of asexual reproduction



SCIENCE AS A HUMAN ENDEAVOUR: Advanced understanding

Scientific understanding of asexual reproduction has developed and changed as new technologies and methods have allowed scientists to observe microscopic processes more closely. Early scientists could only study visible examples of asexual reproduction, such as budding in *Hydra* or spores in fungi. However, with the invention of the microscope in the 1600s, scientists like Antonie van Leeuwenhoek were able to observe single-celled organisms — such as bacteria and amoebas — reproducing through binary fission for the first time.

Modern advancements, including electron microscopes and DNA analysis, have helped scientists refine their understanding of how genetic material is replicated and passed down in asexual reproduction. For example, researchers discovered that some bacteria can exchange genetic material through processes like conjugation (direct contact), which challenges the idea that asexual reproduction only produces identical offspring.

Scientific knowledge about asexual reproduction continues to evolve. Cloning technologies, such as those involved in the cloning of Dolly the sheep in 1996, have expanded our understanding of how genetic material can be copied artificially. This knowledge raises important ethical and environmental questions, such as whether cloning should be used to save endangered species or produce food.

This ongoing research shows how scientific ideas are refined and challenged as new methods are developed, and results are reviewed and tested by other scientists. It highlights the importance of peer review and consensus in ensuring that scientific knowledge is reliable and trustworthy.

1. How did the invention of the microscope change the way scientists study asexual reproduction?
2. Why is peer review important when scientists develop new theories about reproduction?
3. How might advances in technology, such as cloning, challenge or refine our understanding of asexual reproduction?
4. What ethical concerns might arise from technologies that allow artificial reproduction, such as cloning?
5. Why is it important for scientific knowledge about reproduction to be refined and updated over time?

Scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)

2.2.2 Binary fission

Some unicellular organisms reproduce by **binary fission**. In this type of asexual reproduction, when an organism has grown to a certain size, it divides into offspring of equal size to the parental cell. Prior to this division, the genetic material in the cell is replicated. The cytoplasm then divides, producing two cells with identical genetic information.

Binary fission can occur in both prokaryotes (such as bacteria) and eukaryotes (such as amoeba, *Euglena* and *Paramecium*). While the same term is used, the actual processes involved for these different types of organisms differ. In eukaryotes, a type of cell division called mitosis is involved. The process in prokaryotes is less complex and faster. For example, one bacterial cell could produce about 16 million offspring in eight hours. Some types of bacteria can also produce more than two cells per division. This is called **multiple fission**. Multiple fission is very efficient and allows for an even greater increase in numbers within a short time frame.

FIGURE 2.4 Amoebas are unicellular eukaryotic organisms. They have no need for complex tissues or systems, and lead a highly successful life by engulfing their food and expelling their waste products as a single cell.

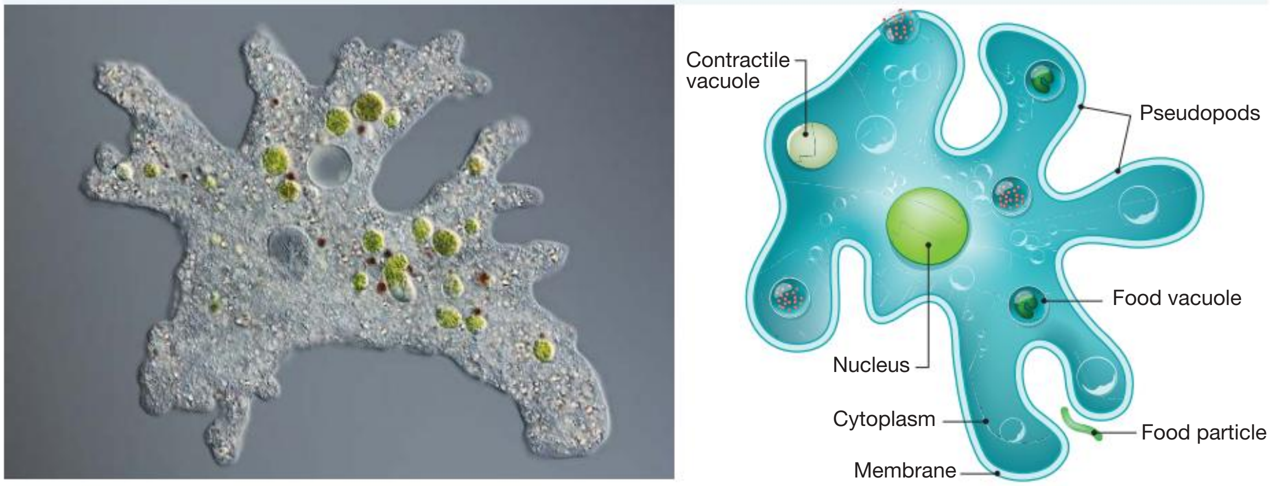
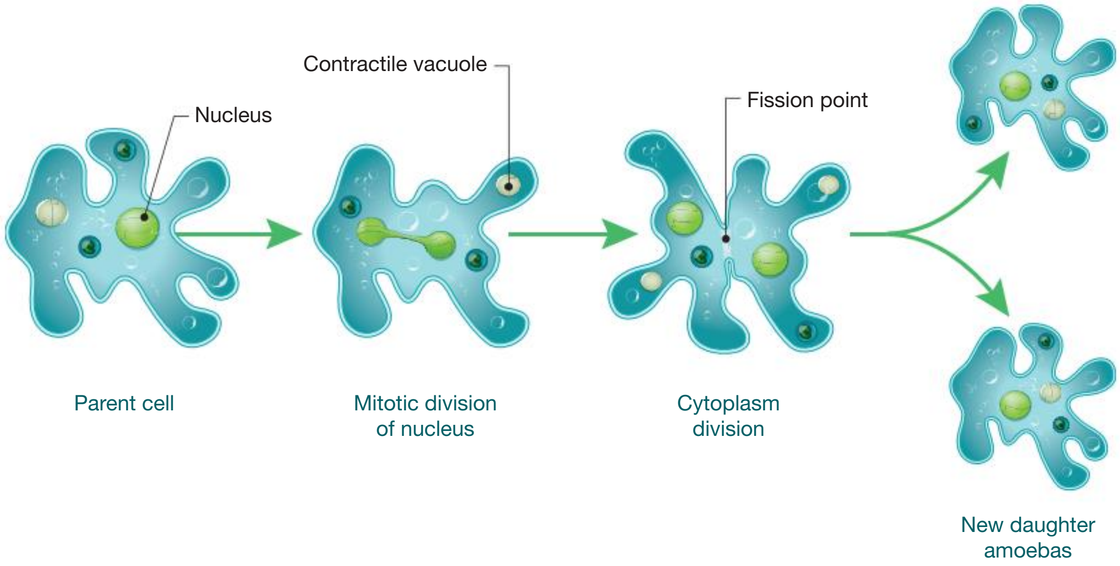


FIGURE 2.5 Binary fission in an amoeba. This organism duplicates essential cell parts, like the nucleus and mitochondria, to ensure offspring have genetic information and energy production capabilities. It then splits into two identical daughter cells.



2.2.3 Budding offspring

Imagine your offspring beginning as a simple swelling on your side and then developing its own mouth and features. When its development is complete, it merely detaches itself and independently continues its own life. This is the sequence of events that happens in yeast (figure 2.6) and in freshwater *Hydra* (figure 2.7). The initial swelling is called a bud and hence this process is often called **budding**.

FIGURE 2.6 Yeast are unicellular organisms from the same kingdom as mushrooms and mould — kingdom Fungi. Yeast reproduce by budding off their offspring from the parent cell.

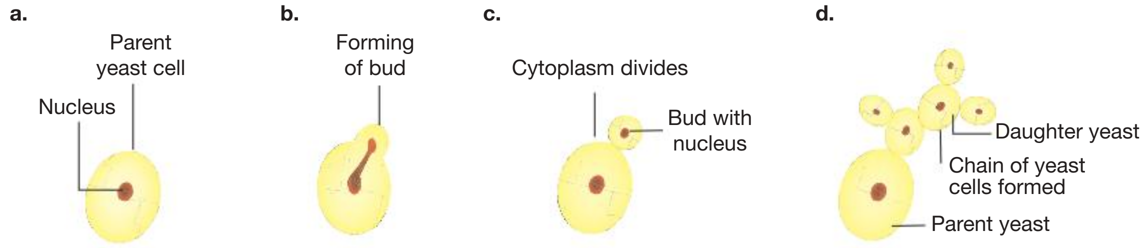
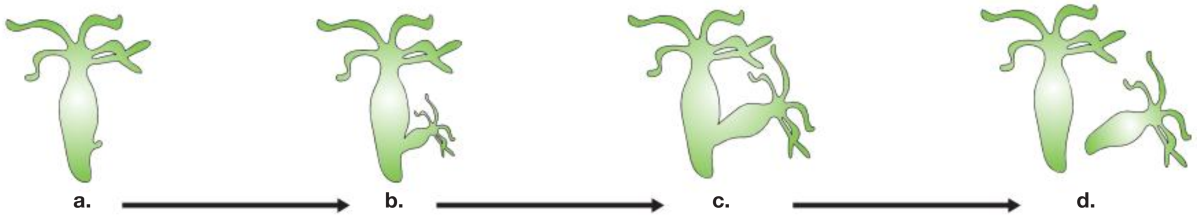
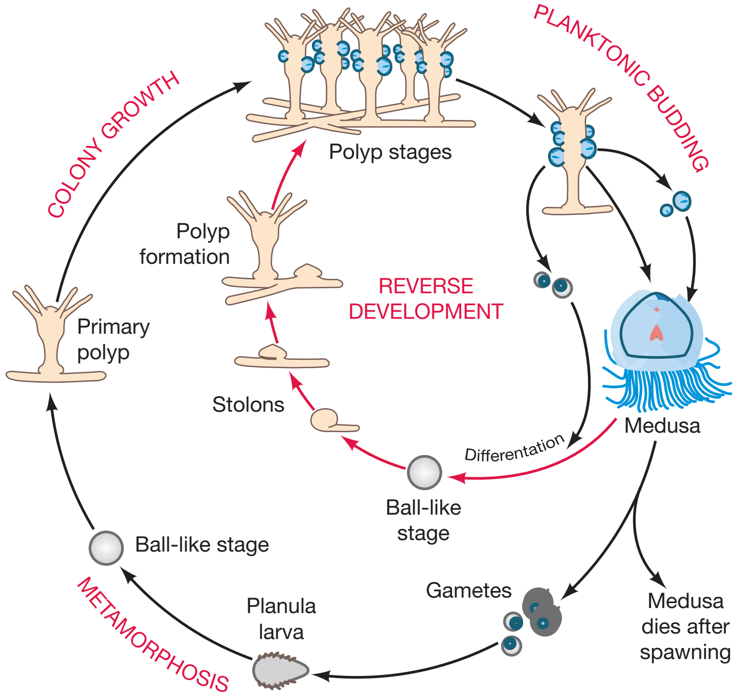


FIGURE 2.7 *Hydra* are small multicellular freshwater organisms from the phylum Cnidaria that also reproduce by budding.



Jellyfish, such as the common *Aurelia aurita*, reproduce both sexually and asexually (figure 2.8). The mature medusae are the familiar free-floating organisms with round transparent bodies. These adults release **eggs** and **sperm** into the environment that, once successfully fertilised, result in offspring known as polyps. The polyps attach to hard rocky surfaces to grow and reproduce by budding, as each polyp will release many small disc-like jellyfish into the water in the form of miniature medusae.

FIGURE 2.8 Jellyfish reproduce both sexually and asexually.



2.2.4 Sponges

Some fungi (such as mushrooms, and bread and fruit mould) have **spores** that, when released, may develop into offspring identical to the parent fungi. These spores are merely a group of unspecialised body cells, combined with a source of nutrients and packaged in a resistant coat. They can provide an effective means of dispersing future generations and may also overcome adverse conditions by waiting until conditions are favourable before they begin to grow.

FIGURE 2.9 Mould spores on berries, which may develop into offspring genetically identical to the parent fungi.

2.2.5 Fragmentation and regeneration

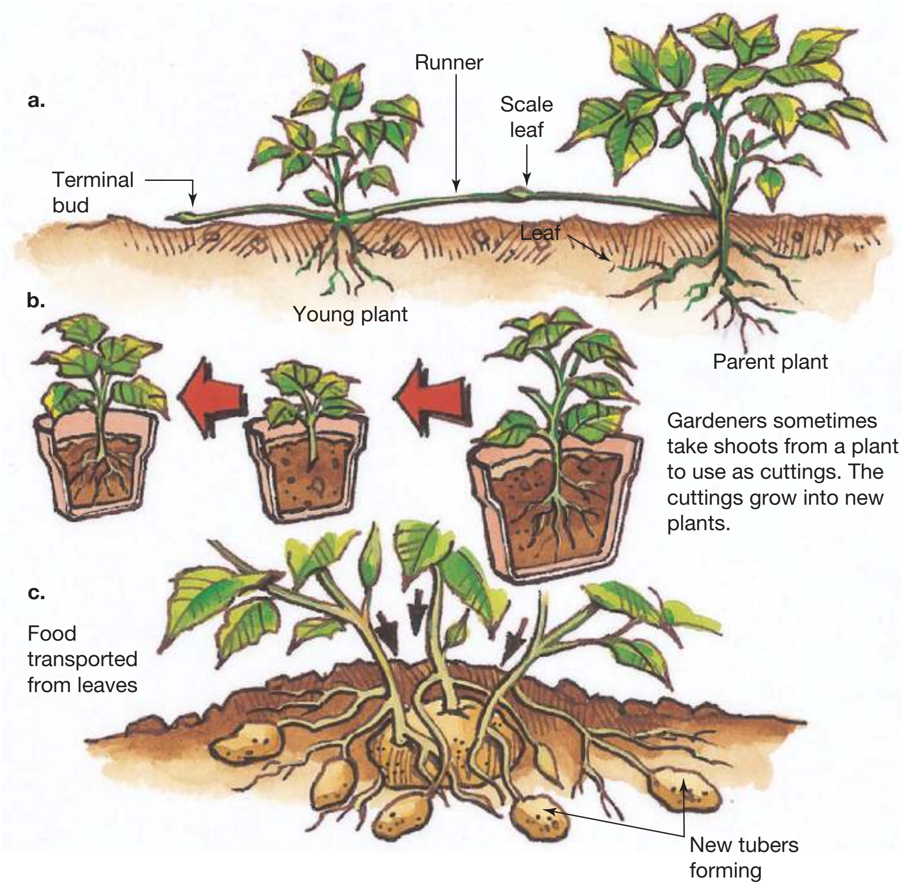
Flatworms and starfish are animals with some strange reproductive abilities. Fragmentation is commonly observed in flatworms. During this type of reproduction, the parent flatworm breaks into several pieces and, over time, each piece develops into a new adult flatworm. Regeneration is a similar type of reproduction that can be seen in starfish. While some starfish can regenerate replacement new limbs, others — such as the *Linckia* starfish — can regenerate completely new organisms from a severed arm.

FIGURE 2.10 Tiny new starfish growing at the end of a discarded *Linckia* starfish arm

2.2.6 Vegetative propagation

In **vegetative propagation**, the non-sexual parts of the plant are used to develop new individuals of the same type. Examples include bulbs (e.g. daffodils), stem tubers (e.g. potatoes), runners (e.g. native violets) and cuttings (e.g. roses).

FIGURE 2.11 Examples of vegetative propagation: **a.** runners, **b.** cuttings **c.** tubers



2.2.7 Parthenogenesis

In some animals, the females produce eggs, but these develop into **embryos** without fertilisation taking place. The scientific name for the development of new individuals from an unfertilised egg is **parthenogenesis**. Worker bees, for example, develop from unfertilised eggs laid by the queen bee (figure 2.12a). This allows the most number of offspring to be produced in the least amount of time.

Some gecko lizard groups are parthenogenetic and form all-female families. An example is Bynoe's gecko (*Heteronotia binoei*), which is found only in Australia (figure 2.12b). A population of these geckos would contain only females. Births that result without any meeting between eggs and sperm are often referred to as **virgin births**.

FIGURE 2.12 a. Worker bees develop from unfertilised eggs laid by the queen bee (parthenogenesis). **b.** Bynoe's gecko

INVESTIGATION 2.1

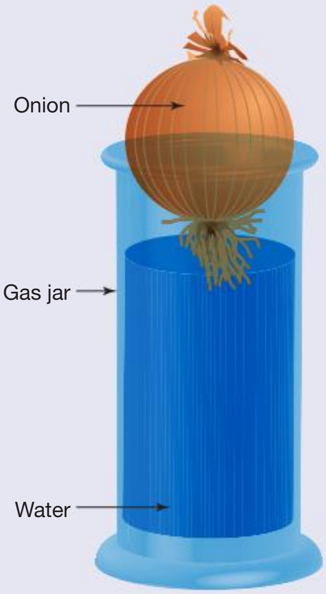
Asexual reproduction

Aim

To observe asexual reproduction in plants

Materials

- gas jar
- large onion
- potato
- grass runner
- beaker or glass jar
- leaf–stem cutting from geranium or impatiens
  Note: A leaf–stem cutting is a piece of the plant's stem that is cut just below a joint or growing point and has at least three leaves.
- leaf from an African violet, jade plant or snake plant
- plant pot
- rooting medium (this can be purchased from a nursery)



Method

1. Fill a gas jar almost to the top with water and place the onion in the mouth of the gas jar so that its base is sitting in the water as shown in the diagram.
2. Leave the potato in a dark cupboard.
3. Remove the lower leaves from the leaf–stem cutting. Quarter fill a beaker or glass jar with water and place the cutting in the water.
4. Place some rooting medium in a pot. Add water to the rooting medium until it feels moist. Cut a 3 cm section from the leaf of the African violet, jade or snake plant. Stand the piece of leaf upright in the rooting medium.
5. Cut a piece of the grass runner. Ensure the section you have cut has at least one growing point. Press the piece of grass runner into the rooting medium (laying it flat on the surface).
6. Leave all the plant parts undisturbed for two weeks. You may need to top up the water over that time.

Results

Copy and complete the table shown, and remember to include a title for your table. You may need to dig the leaf–stem cutting and the runner from the rooting medium and wash them to see what has happened to them.

Plant part	Description after two weeks	Diagram
Onion		
Potato		
Leaf–stem cutting		
Leaf		
Runner		

Discussion

1. In your own words, summarise your observations for each of the plant parts.
2. Explain why each of the examples in the table are forms of asexual reproduction.
3. What are the advantages of growing plants using one of the techniques described in this investigation, rather than growing them from seeds?
4. Suggest improvements to the design of the investigation.

Conclusion

Summarise the findings from this investigation about asexual reproduction.

2.2 Activities

learnon

2.2 Quick quiz on	2.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4, 6, 10	3, 5, 7, 11	8, 9, 12

Remember and understand

1. **Define** the term *asexual reproduction*. **State** some examples.
2. **Identify** the missing words to complete the following sentences.
   a. When a single parent produces one or more genetically identical offspring, this is called _________ reproduction.
   b. Unlike sexual reproduction, asexual reproduction does not require the _________ of sex cells or sex cells from _________ organism because the single parent contributes _________ of the genetic information to their offspring.
   c. In organisms that use _________ reproduction, the _________ are genetically identical to each other as well as being genetically _________ to the parent.
   d. Individuals that have identical genetic information to each other are called __________.

3. **Identify** the type of asexual reproduction that is occurring in each of the following descriptions.
   a. When a cell reaches a certain size, it replicates its genetic material and then divides in two.
   b. When a cell reaches a certain size, it replicates its genetic material and then divides into more than two cells.
   c. Involves the growth and development of a swelling on the parent, which, when completed, detaches itself and lives independently of the parent
   d. Involves the release of a group of unspecialised body cells, combined with a source of nutrients and packaged in a resistant coat
   e. Uses the non-sexual parts of a plant to develop new individuals of the same type
   f. Involves parts of the parent breaking into pieces, and each piece developing into a separate organism
   g. Has embryos that develop from unfertilised eggs
4. **Identify** the type of asexual reproduction used by the following organisms by ticking the correct boxes in the table.

Types of asexual reproduction in various organisms

	Starfish	Yeast	Amoeba	Mushrooms
Budding				
Spores				
Binary fission				
Regeneration				

5. a. **Identify** whether each of the following statements is true or false.
      i. The processes involved in binary fission in prokaryotes and eukaryotes are the same.
      ii. A population of Bynoe's gecko lizards (*Heteronotia binoei*) would contain only males.
      iii. Worker bees develop from unfertilised eggs laid by the queen bee.
      iv. Births that result without any meeting between eggs and sperm are often referred to as virgin births.
   b. Rewrite any false statements to make them true.
6. **Identify** which of the plant types on the left matches each of the types of vegetative propagation on the right.

Vegetative propagation used in different plant types

Type of plant	Type of vegetative propagation
a. Daffodils	1. Cuttings
b. Native violets	2. Bulbs
c. Potatoes	3. Runners
d. Roses	4. Tubers

Apply and analyse

7. **Compare** the advantages and disadvantages of using asexual reproduction methods, such as vegetative propagation and parthenogenesis, in ensuring the survival of species. How does the lack of genetic variation impact the long-term survival of these organisms?
8. SI Sexual reproduction results in variation among the offspring, whereas asexual reproduction does not. **Summarise** the advantages and disadvantages for each type of reproduction in a table format as shown.

Advantages and disadvantages of asexual reproduction

Advantages of asexual reproduction	Disadvantages of asexual reproduction

9. **Suggest** why many insects that would usually reproduce sexually use parthenogenesis to produce offspring in favourable conditions.

Evaluate and create

10. How does binary fission compare to other asexual reproduction methods in terms of efficiency and speed? **Discuss** the advantages and disadvantages of this strategy for unicellular organisms like bacteria.
11. Design an infographic or diagram that demonstrates how budding works in yeast and jellyfish. Include an explanation of why this method of reproduction might be beneficial in certain environments.
12. In what ways is regeneration an advantage for survival and reproduction in starfish and flatworms? **Discuss** how this ability compares to other asexual reproduction strategies.

Answers and sample responses are available in your digital formats.

LESSON 2.3 Sexual reproduction in flowering plants

LEARNING INTENTION

In this lesson you will:
- describe how some plants reproduce sexually with pollen and ovules as their reproductive cells
- explain how seeds are dispersed and germinate.

2.3.1 Flowers and pollination

Like animals, many plants can reproduce sexually. Flowering plants (**angiosperms**) have their reproductive structures located in their flowers.

Flowers are involved in reproduction. As plants are not mobile and cannot go looking for a suitable mate, they rely on other ways to bring the male and female gametes together. The **petals** and **nectaries** are often used to lure insects and other animals to assist in the delivery of 'sperm' or **pollen**. Flowers are designed to increase the chances of pollen grains making contact with the sticky **stigma**.

Pollination describes the way in which pollen grains reach the stigma. Plants may pollinate themselves (**self-pollination**). More often, however, they obtain the pollen from the flower of a different plant of the same species (**cross-pollination**). Cross-pollination increases the genetic variation among the offspring and gives them a better chance of survival. This is because if a disease passes through the population, some may have natural immunity that will allow them to survive and pass this resistance on to their offspring. The pollen grains may be transferred to other flowers by wind, insects or other animals.

FIGURE 2.13 Flowering plants — angiosperms — reproduce sexually using male and female sex cells, similar to animals. Many plants rely on insects to spread pollen and seeds. For example, the bee shown collects nectar while transferring pollen between flowers.

FIGURE 2.14 Each part of a flower has a specific function that allows the flower to bloom, fruit or seed.

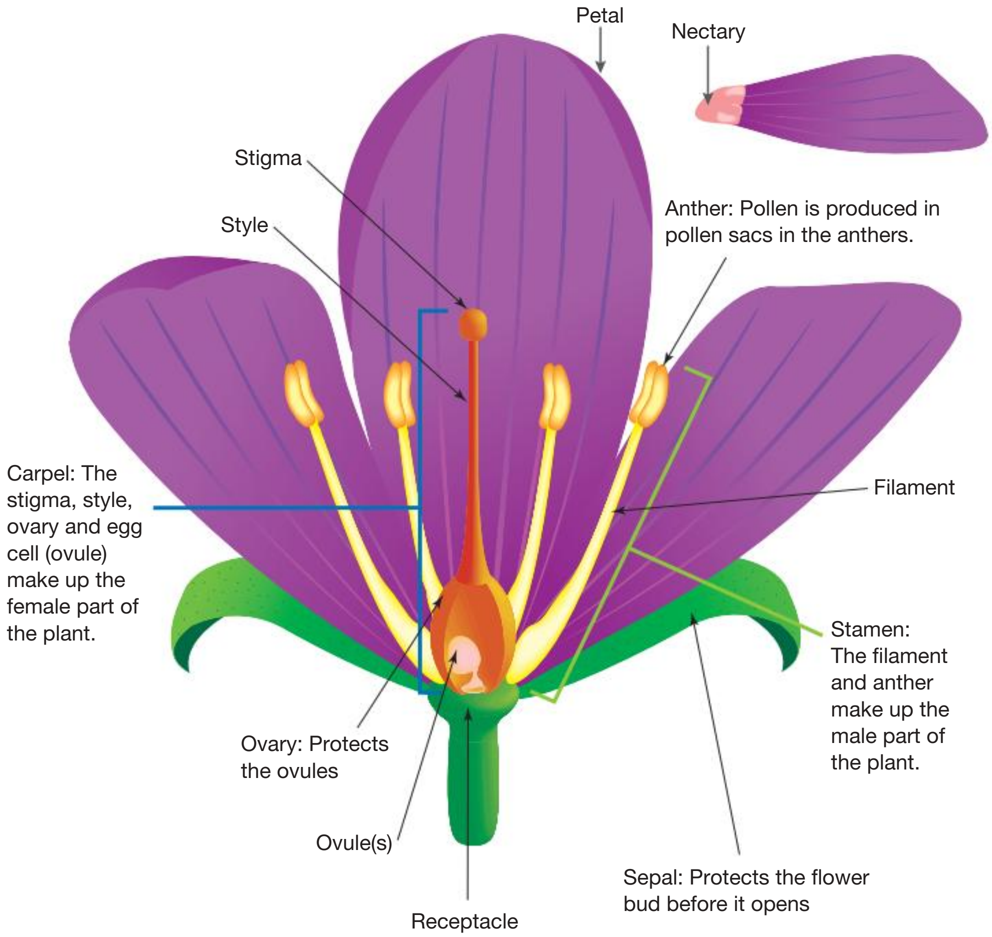
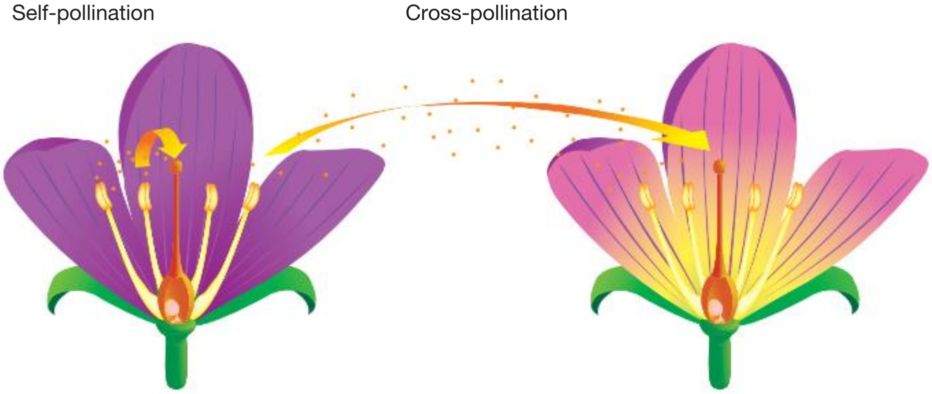


FIGURE 2.15 The difference between self-pollination and cross-pollination



Insect-pollinated flowers usually have attractive, brightly coloured petals and nectaries. The pollen grains themselves may be in a shape that makes them become easily attached to the insect.

Wind-pollinated flowers are usually less conspicuous and have no large scented petals or nectar. Their shape enables small, light pollen grains to be shaken from the plant and carried away with even the slightest gust of wind. The **anthers** hang outside the flower and the feathery stigmas spread out to catch airborne pollen grains.

FIGURE 2.16 A sunflower is an example of an insect-pollinated flower.

FIGURE 2.17 A wind-pollinated flower receives pollen carried by the wind from another flower.

TABLE 2.1 Comparing flowers that are pollinated by insects versus flowers pollinated using wind

Part of flower	Insect pollination	Wind pollination
Petals	• Large • Scented • Contain nectaries • Brightly coloured	• Maybe none, or small • No scent • No nectaries • Dull colours
Anthers	• Positioned where insects might brush against them	• Hang loosely on thin filaments • Shake easily in the wind to distribute pollen
Stigma	• Positioned where insects might brush against them • Sticky and flat or lobe-shaped to capture pollen	• Long branching and feathery • Reaches out into air to catch pollen blowing in the wind
Pollen	• Rough or sticky surface to stick to insects • Small amounts produced • Grains are large	• Small, light grains • Large amounts produced • Easily carried in wind

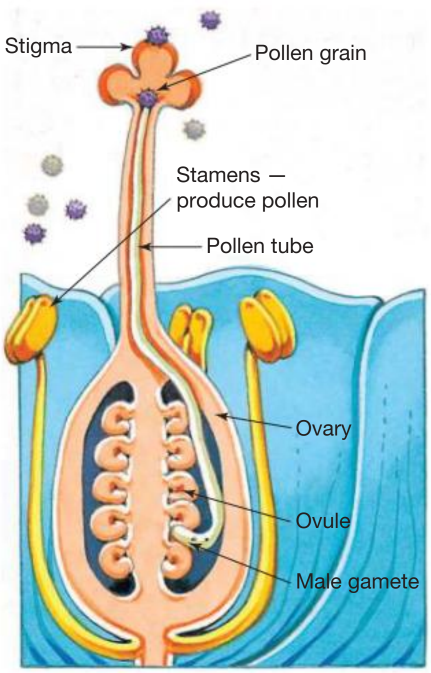
The titan arum (*Amorphophallus titanum*) is a rare plant, native to Sumatra, that has a two-metre flower that smells of rotting flesh, giving it the nickname the 'corpse flower' (figure 2.18). The smell of this flower, although repulsive to humans, attracts insects that take its pollen — the male sex cells — and deliver it to another plant, resulting in fruit and seeds to begin the next generation.

FIGURE 2.18 The corpse flower

2.3.2 Fertilisation

As in animals, only a few of the **pollen grains** produced actually fertilise an egg cell. After pollen grains are on the stigma of a flower, a long hollow tube called a **pollen tube** is formed. This pollen tube grows down the **style**. Male gametes (sex cells) travel down these tubes to the **ovules** inside the **ovary**, where they fuse with the **ovum** (female gamete or egg). This joining of male and female gametes is called **fertilisation**. The fertilised egg is called a **zygote**.

FIGURE 2.19 Fertilisation



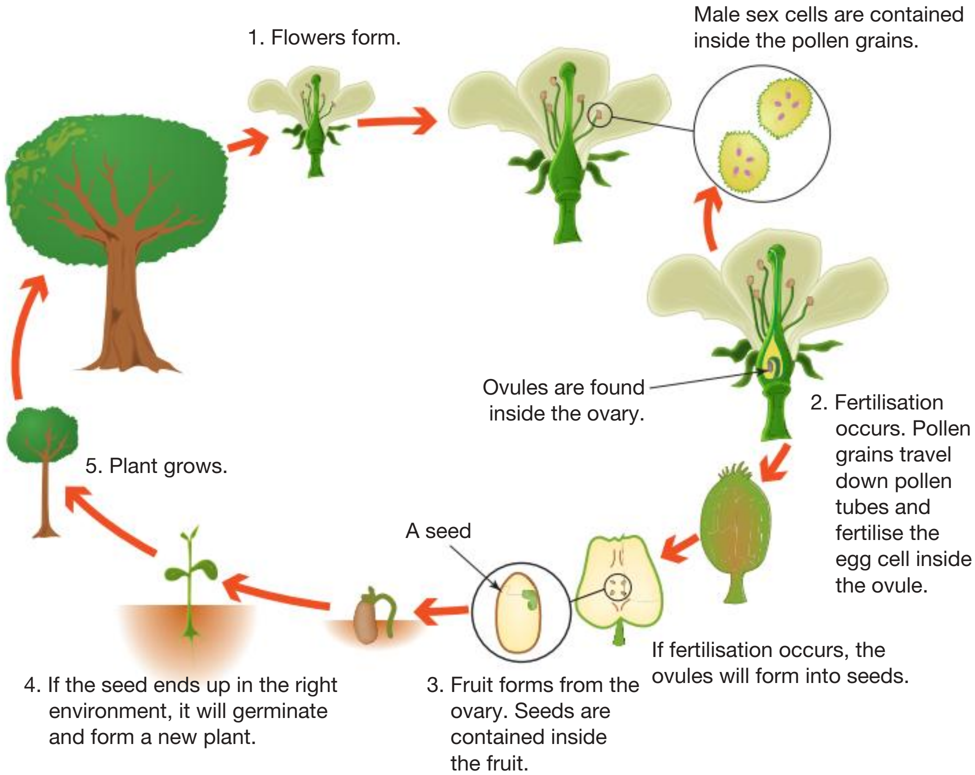
2.3.3 Plant babies

Once the flower has done its job and the egg cell has been fertilised by the pollen nucleus, another sequence of events takes place. Inside the ovule, the fertilised egg — or zygote — divides into a little ball of cells that becomes an embryo. Special tissue called **endosperm** surrounds the embryo and supplies it with food. The ovule becomes the **seed**, and tissue forms around it to provide a protective **seed coat**.

Are you aware that when you bite into an apple, cherry or orange you are actually eating the enlarged ovary of the plant? Did you know that these swollen ovaries contain the plant's 'babies' in their embryonic form? The plants are using you as a way of distributing their 'young' out into the world.

During the formation of the seed, the ovary expands and turns into a **fruit**. The fruit of some plants can be sweet, which makes them attractive to animals, including humans, as a source of food. The animals that eat the fruit aid the plant by dispersing the seeds over a much wider area than the plant could achieve by itself.

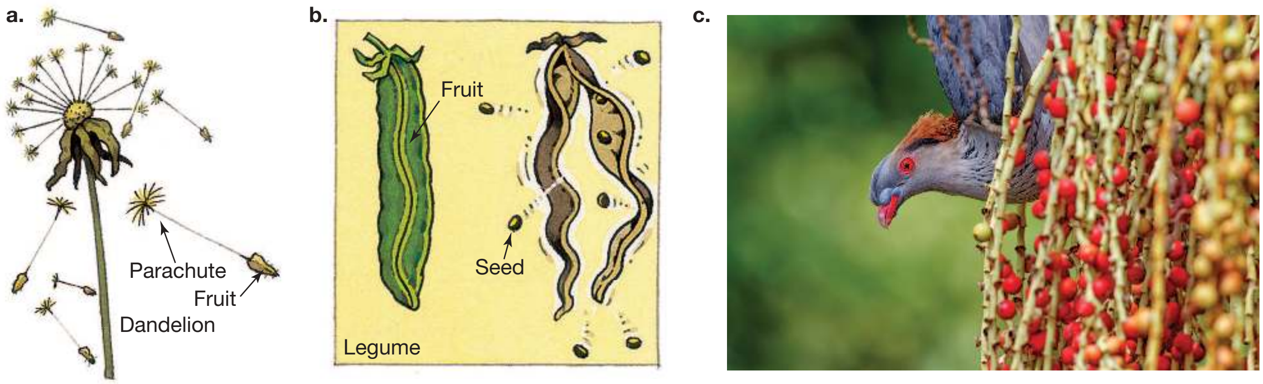
FIGURE 2.20 The life cycle of a flowering plant



2.3.4 Seed dispersal

One of the main jobs that fruits do is to help **disperse** or spread the seeds. Plants disperse their seeds in a variety of ways: dispersal may involve animals, including birds (such as for tomatoes, grapes and apples); water (such as for coconuts); or wind (such as for grasses and dandelions). Some plants can disperse their seeds by themselves. For example, the fruits of some plants in the pea family (legumes) split open suddenly when they are ripe and dry, throwing the seeds long distances.

FIGURE 2.21 Seed dispersal can use **a.** wind, rain and rivers or **b.** seeds can be propelled out of the pod or **c.** fruit can be eaten by animals and the seeds distributed in droppings. The Australian topknot pigeon, *Lopholaimus antarcticus*, is a frugivore (a fruit-eating bird) found in rainforest areas of northern and eastern Australia. This bird plays a critical role in distributing seeds from native plants by helping to regenerate deforested areas, as well as helping to increase the number of native plants compared to introduced plants in these areas.



SCIENCE AS A HUMAN ENDEAVOUR: How technology advances seed research and agriculture

The study of plant reproduction has been transformed by technological advances in agriculture and biology. Scientists have long observed that plants reproduce sexually using pollen and ovules to form seeds, which then disperse and grow through germination. However, modern technologies have allowed researchers to investigate these processes in much greater detail.

For example, microscopes and staining techniques enable scientists to study pollen grains and ovules at the cellular level, helping them understand fertilisation and seed formation. DNA sequencing technologies allow scientists to analyse plant genes and identify traits linked to better seed production, disease resistance and drought tolerance.

In agriculture, selective breeding and genetic engineering have been used to develop crops with improved seed production and higher yields. Technologies such as seed coating protect seeds from pests and diseases, increasing their chances of survival during germination. Farmers also use satellite imaging and drones to monitor crops, ensuring seeds are planted in the best conditions for growth.

These advancements not only help farmers grow more food but also address global challenges like climate change and food security. By improving seed quality and dispersal methods, scientists and engineers are helping to ensure a sustainable future for agriculture.

1. How have technologies such as microscopes and DNA sequencing improved our understanding of plant reproduction?
2. What are some ways genetic engineering has helped farmers improve crop yields and seed quality?
3. How do technologies like seed coatings and drones support sustainable farming practices?

4. Why is it important to develop crops that can grow in difficult conditions, such as droughts or poor soils?
5. How might further advances in technology continue to change the way seeds are dispersed, planted and grown in the future?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

2.3.5 Seed germination

The embryo, inside the seed, is made up of three different parts: the baby shoot (**plumule**), the baby root (**radicle**) and one or two thick, wing-like **cotyledons**.

When the conditions are right, the seed bursts open and a new plant grows out. This process is called germination. When **germination** is complete, the embryo has become a young plant or **seedling**.

FIGURE 2.22 Parts of a seed

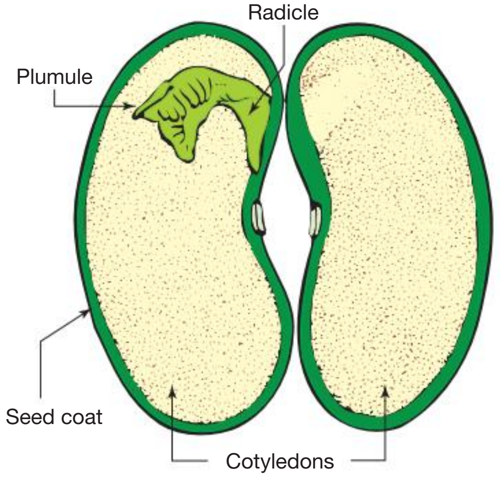
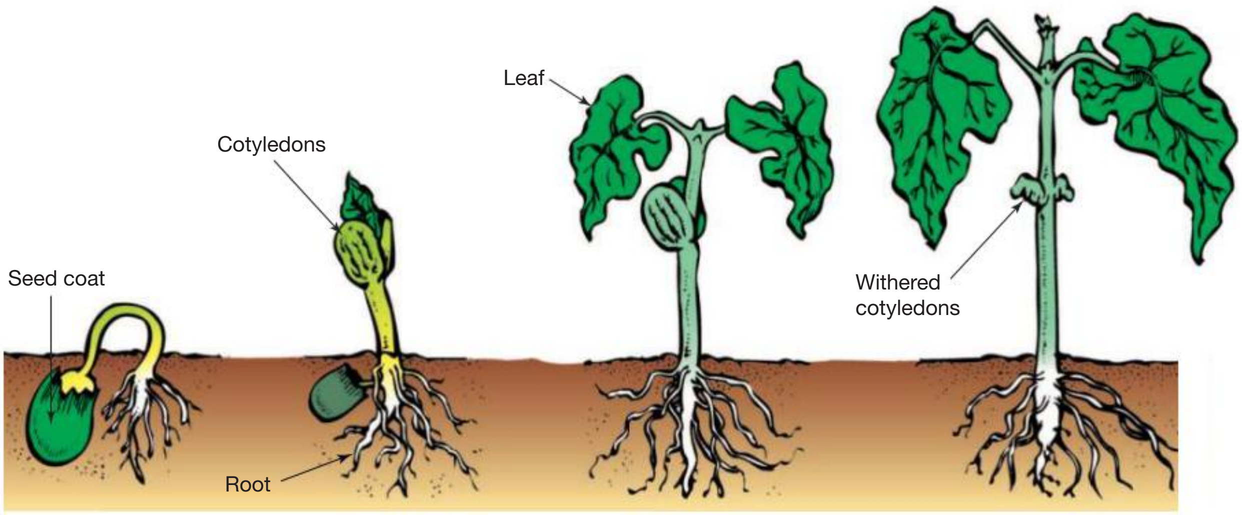


FIGURE 2.23 Germination of a broad bean



INVESTIGATION 2.2

What's in a flower?

Aim

To identify the parts of a flower and relate their structure to their function

Materials

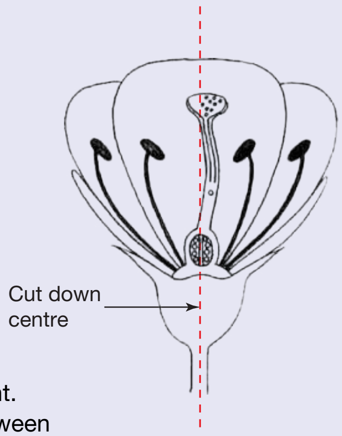
- flowers
- sharp knife or razor blade
- cutting board
- hand lens
- tweezers

Method

1. Draw a diagram of your first flower before dissection.
2. Identify and label the male and female parts you can see.
3. Place the flower on the cutting board and hold it with the tweezers.
4. Carefully cut the flower in half down the middle (a vertical cross-section).
5. Use the hand lens to look at the ovary and eggs.
6. Repeat for each flower.

Results

1. Draw a diagram of each flower prior to dissection. Locate, count and label the petals and sepals.
2. Draw the cross-section and label the female parts inside each flower.



Discussion

1. Identify ways in which the flowers you observed were (a) similar and (b) different.
2. Suggest reasons for (a) similarities between the flowers and (b) differences between the flowers.
3. a. Predict which parts of the flower become seeds and may grow into fruit.
   b. Justify your predictions.
   c. Check references to see if your predictions were accurate and comment on your findings.
4. Describe possible relationships between the parts of the flower in your diagram.
5. Describe how the various structures of the flower that you have observed assist the plant in reproduction.
6. Suggest how the investigation could be improved.
7. Identify a limitation in the investigation and suggest how it could be improved.

Conclusion

Write a conclusion summarising your results. Remember to refer to the aim.

INVESTIGATION 2.3

Investigating features of flowers

Aim

To identify a feature of a flowering plant and investigate its relationship to reproduction

CAUTION: Be responsible in your fieldwork and handle the plant parts very gently and carefully. Do not pick, break, tread, trample or climb the plants. Remember that you are dealing with living things.

Materials

- 5 pieces of blank A4 paper
- pencil
- flowering plants growing in local environment

Method

1. Identify a research question that relates to either the structure or a feature of a flower that may increase its chances or effectiveness of pollination.
2. Find five plants, each with a different type of flower.
3. Using a separate page for each plant, at the top of the page:
   a. record your name and the date
   b. record the plant's name, or, if unknown, record it as 'specimen A, B, C' and so on
   c. give a general description of the location in which the plant is found.
4. Divide the rest of your A4 sheet into three sections.
   a. Draw a half-page sketch of a flower.
      - Try to show the parts listed in table 2.1 and label them.
      - Count or estimate how many stamens, stigma, petals and sepals are present.
   b. Draw a quarter-page sketch of a leaf — include any veins that you see.
   c. Draw a quarter-page sketch of the plant's overall appearance.

Results

Record the structure or feature of your flower identified in your research question from the method.

Discussion

1. In regard to your chosen floral structure or feature, identify ways in which the flowers you observed were (a) similar and (b) different.
2. Suggest reasons for (a) similarities between the flowers and (b) differences between the flowers.
3. Research your observed plants using databases and the internet. Construct a table, field guide, cluster map or multimedia format to summarise your findings on the following:
   a. Possible identification
   b. Labelled sketch or image of flower and fruit
   c. Type of pollination and type of seed dispersal
   d. An interesting fact
4. Based on your observations and your research:
   a. suggest how your chosen floral structure or feature may influence the effectiveness of the pollination of the plant to which it belongs
   b. construct a relevant hypothesis that may be investigated.
5. Identify strengths and limitations of this investigation and suggest possible improvements.

Conclusion

Write a conclusion summarising your results. Remember to refer to the aim.

2.3 Activities

learnon

2.3 Quick quiz on	2.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 7	4, 5, 8, 10, 13	6, 9, 11, 12, 14

Remember and understand

1. **Identify** the missing words to complete the following sentences.
   a. Flowering plants (_________) have their _________ structures located in their _________.
   b. Flowers are designed to increase the chances of _________ grains making contact with the _________.

2. **MC** **Identify** the term used to describe the way in which pollen grains reach the stigma.
   A. Fertilisation
   B. Germination
   C. Pollination
   D. Seed dispersal
3. **Identify** the term used to describe the following processes.
   a. The process in which plants pollinate themselves
   b. The process in which pollen from the flower of a different plant of the same species is used to pollinate the plant
   c. The process that increases the variation among offspring, potentially giving them a better chance of survival
4. **Identify** the plant part on the left that matches each of the alternative terms or descriptions on the right.

Alternative terms or descriptions for different plant parts

Part of the plant	Alternative term or description
a. Sepal	1. Sperm
b. Petal	2. Sugar
c. Pollen	3. Leaflet
d. Nectary	4. Colour
e. Ovule	5. Egg cell

5. **Describe** the relationship between:
   a. stigma and stamen
   b. ovule and seed
   c. ovary and fruit
   d. pollen and anthers.

Apply and analyse

6. **Distinguish** between the following terms:
   a. Self-pollination and cross-pollination
   b. Pollination and fertilisation
   c. Plumule and radicle
   d. Germination and fertilisation
7. Organise the following terms to construct a flowchart that shows the correct sequence for flowering plants: reproduction, fertilisation, seed dispersal, germination, pollination.
8. **Suggest** why some orchid flowers closely resemble female wasps.
9. **Construct** storyboards or timelines to summarise how plants reproduce.

Evaluate and create

10. How do flowering plants ensure fertilisation occurs? **Suggest** ways plants could evolve to improve fertilisation success, particularly in changing environments.
11. Imagine you are designing a public awareness campaign about hayfever. Develop an infographic explaining the role of pollen in triggering hayfever and **suggest** ways to reduce exposure.
12. **Assess** why certain conditions are essential for germination. Which of these conditions would you prioritise to ensure successful germination in harsh environments? **Justify** your choice.
13. Design a simple experiment to compare the success rates of cross-pollination versus self-pollination in a specific plant species. Include predictions based on your understanding of their benefits and methods.
14. Why are fruits significant in seed dispersal? Using your observations, **propose** an innovative way fruits could be adapted to improve seed dispersal in areas affected by climate change.

Answers and sample responses are available in your digital formats.

LESSON 2.4 Comparing reproductive strategies in animals

LEARNING INTENTION

In this lesson you will describe some different reproductive strategies seen in the animal kingdom.

2.4.1 Sexual reproduction

All animal cells (except mature red blood cells) have a nucleus, which contains the full set of genetic instructions to build that animal. In sexual reproduction, the new organisms produced received a mixture of instructions from both parents — which is why you might look a bit like your dad and a bit like your mum, but not exactly like either of them.

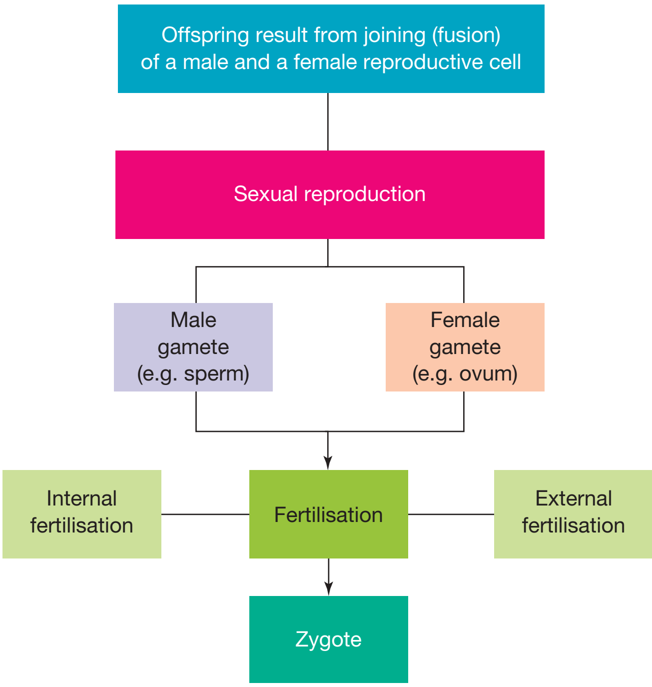
For this process to work, animals need specialised sex cells, or gametes. These cells have a nucleus that only contains half a set of instructions. When a male gamete and a female gamete join, a complete set of instructions is formed, and a new organism can develop and grow.

The female sex cell is called the egg, or ovum. Ova (the plural of ovum) are the largest cells in the human body, large enough to be just visible without the help of a microscope. They are big because they contain the energy needed for the early stages of the new baby's development.

Sperm cells are very small — about 10 000 times smaller than an ovum. They have a head section containing a nucleus with half a set of instructions, and a cell membrane that contains special chemicals to allow it to get through the membrane of the ovum.

When a sperm joins with an ovum, it is called fertilisation. The fertilised ovum then divides into two identical copies of itself; these then divide into four, then eight and so on. As the number of cells increases, they specialise and form tissues, organs and systems until a complete baby is formed.

FIGURE 2.24 Sexual reproduction involves fusion of gametes.



Internal fertilisation

In **internal fertilisation**, reproduction occurs when the egg remains in the female and is fertilised by sperm inserted into the female. The offspring may develop inside the female's body until it is ready to be born, or the female may lay a fertilised egg outside the body, where it will develop until it hatches.

In most cases, organisms that undergo internal fertilisation reproduce through K-selection. K-selected species produce small numbers of offspring but invest a lot of time and effort into caring for them. This results in the production of fewer young, but greatly increases their chances of survival. This becomes a more successful strategy in complex organisms that have a long life span and take time to reach sexual maturity.

Organisms that undergo internal fertilisation include mammals (such as humans, lions, whales), birds (such as eagles, penguins), reptiles (such as snakes, lizards) and insects (such as bees, butterflies).

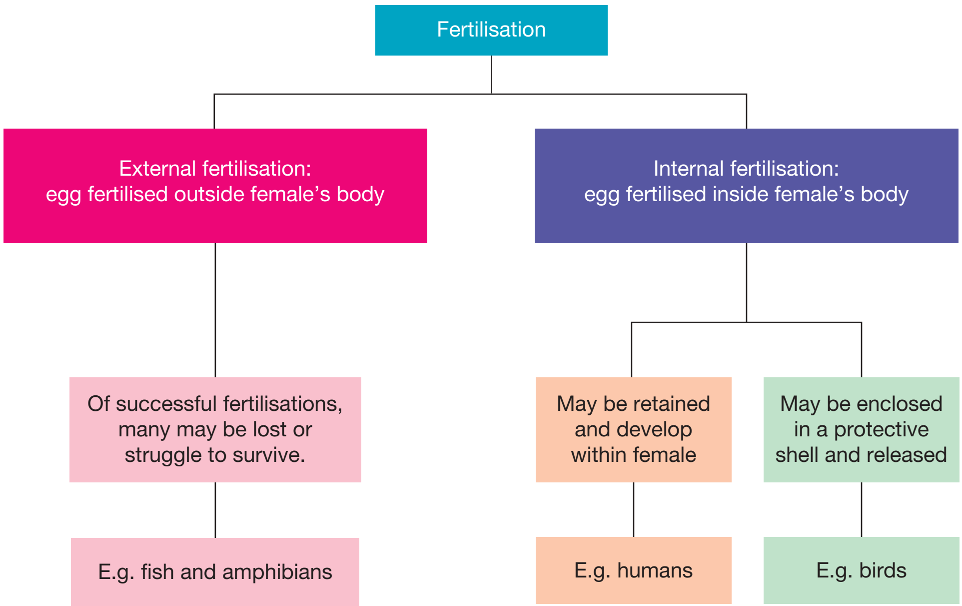
External fertilisation

In **external fertilisation**, reproduction occurs when the eggs are released by the female into water and fertilised by sperm released nearby. The eggs are left to develop outside the mother's body.

In most cases, organisms that undergo external fertilisation reproduce through r-selection. These species produce large numbers of offspring, but provide little, if any, parental care. This results in only a very small percentage of young surviving long enough to reach sexual maturity. This is a successful strategy in organisms that have a short life span and reach sexual maturity quickly, but becomes less and less effective the longer it takes to become mature, as the chances of dying before reproducing increase.

Organisms that undergo external fertilisation include fish (such as salmon, goldfish), amphibians (such as frogs, salamanders), corals, sea urchins and mollusks (such as oysters, clams).

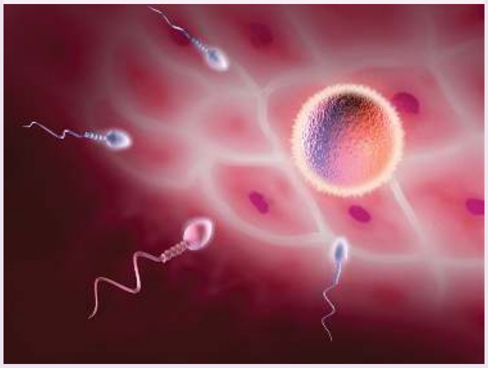
FIGURE 2.25 Some differences between internal and external fertilisation



SCIENCE INQUIRY: Investigating reproductive strategies — internal versus external fertilisation

In this science inquiry, you will investigate the differences between internal and external fertilisation in animals, exploring how these reproductive strategies affect survival rates, offspring numbers and parental care. The investigation will focus on identifying patterns and relationships between environment, reproductive strategies and offspring survival.

FIGURE 2.26 Internal fertilisation within the human body



Formulate investigable questions

Examples:

- How does internal fertilisation improve offspring survival rates compared to external fertilisation?
- Why do r-selected species produce more offspring, and what challenges do they face in survival?
- What environmental conditions influence the success of internal and external fertilisation?

Develop hypotheses

Examples:

- Organisms that use internal fertilisation have higher survival rates due to parental care.
- Species that use external fertilisation must produce large numbers of offspring to compensate for environmental risks.

Plan the investigation

- Use secondary data to compare survival rates of species that use internal fertilisation (e.g. mammals and reptiles) and external fertilisation (e.g. fish and amphibians).
- Model fertilisation methods using diagrams or digital simulations to visualise processes.

Collect and analyse data

- Examine case studies of species with different reproductive strategies.
- Create tables or graphs to compare survival rates, offspring numbers and maturity times.

Draw conclusions

- Evaluate patterns in the data to explain how reproductive strategies are adapted to different environments.
- Discuss how fertilisation strategies contribute to population growth and survival.

1. Why do species that use internal fertilisation tend to produce fewer offspring but invest more in parental care?
2. How do environmental factors, like water availability, influence whether a species uses internal or external fertilisation?
3. What advantages and disadvantages do r-selected and K-selected species have in terms of survival and reproduction?
4. How could models or graphs be used to explain differences between internal and external fertilisation strategies?
5. What patterns might we see when comparing offspring survival rates between organisms using internal and external fertilisation?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

EXTENSION: Interesting facts

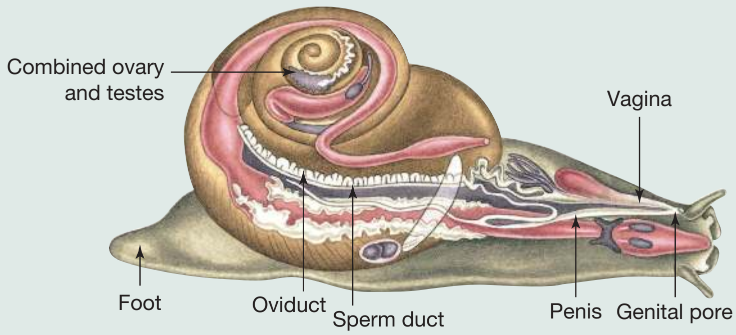
- Some reptiles and rodents actually 'cement' up the female's genitalia by using some of the semen, which sets into a hard plug, not allowing other sperm to get in.
- Male starworms are 'live-in lovers', spending their entire lives within the female's vagina. Her eggs are fertilised by these parasitic males (which live off her vaginal fluids) as soon as they are released.
- Some butterflies have eyes on their genitals to help guide the hooks and claspers of the male to the appropriate nooks and crannies in the female during copulation.
- The Australian gastric brooding frog (now thought to be extinct) swallowed its externally fertilised eggs and then developed them in its stomach. A special chemical produced by the eggs stopped them from being digested. More than 25 baby frogs would crawl out of the female's stomach and into her mouth.
- Leadbeater's possums are tiny marsupials endemic to the Victorian high country. The mother gives birth two weeks after mating and keeps her two offspring in her pouch for another 12 weeks. The young stay with the mother for up to ten months but are not reproductively mature until about two years of age. The lifespan of a Leadbeater's possum is approximately six years.

FIGURE 2.27 Some male damselflies have a penis with a special hook on the end. He uses it to remove other sperm left inside his mate by previous lovers before he makes his own deposit.

FIGURE 2.28 Leadbeater's possum. After emerging from the pouch, young stay with the mother for up to ten months but are not reproductively mature until about two years of age.

Did you know that ancestral reptiles were the first vertebrates to have a penis, and that snails contain both male and female reproductive organs? While there is considerable diversity in the organisation of reproductive systems in organisms, there are also patterns and similarities. Although reproductive organs may appear structurally different, they often perform similar specialised functions that enable their species to survive and reproduce. In figure 2.29, can you identify similarities to our human reproductive systems? If so, what are they?

FIGURE 2.29 Snails are hermaphrodites because they have both egg-producing and sperm-producing organs.



CASE STUDY: Green sea turtles

Green sea turtles, *Chelonia mydas*, reach reproductive maturity between 30 and 50 years of age and will continue to breed and nest every five years for the next 30 years. In a nesting year, a turtle will nest in the sand every two weeks, laying 100–200 eggs per nest. The adult turtle then leaves the nest and never returns. About two months later the hatchlings start to appear, scrambling to the water hoping to avoid a predator. Only an estimated 1 in 1000 hatchlings survive to become adult turtles. Although this sounds like a poor reproductive strategy, you might argue that it is exactly the opposite as these animals have survived on Earth for 110 million years.

FIGURE 2.30 Green turtles lay thousands of eggs every year.

CASE STUDY: Seahorses

Seahorses are very unusual fish, especially when it comes to making babies! It is the female that inserts part of her body (an ovipositor) into the male. She pumps eggs into a pouch at the front of his body and he then fertilises them with his sperm. Labour can sometimes take two days. The male gives birth to 50–100 little seahorses, squeezing them out one at a time. No wonder he's called a big-bellied seahorse!

There are some amazing stories to tell about other types of seahorses. The male *Photocorynus* seahorse never grows larger than 10 cm and leads a parasitic life in which he is permanently attached to the female, hanging on by his mouth! This is useful to the female because it means that she doesn't have to search dark ocean depths to find a mate when her eggs are ready for fertilisation.

FIGURE 2.31 Male *Hippocampus abdominalis* seahorses try to get females to select them to carry eggs by inflating their pouches into a white balloon.

SCIENCE AS A HUMAN ENDEAVOUR: Male Australian redback spiders

Dr Maydianne Andrade is a distinguished ecologist and professor at the University of Toronto Scarborough, renowned for her research on the mating behaviours of spiders, particularly the Australian redback spider (*Latrodectus hasselti*). Her work has significantly advanced our understanding of sexual selection and reproductive strategies in these arachnids.

The male Australian redback spider exhibits several distinctive characteristics and behaviours:

- *Size and appearance*. Males are significantly smaller than females, measuring about 3–4 mm in body length, compared to the female's approximate 1 cm Males typically have a light brown body with white markings on the upper side of the abdomen and a pale hourglass marking on the underside.
- *Web association*. Males do not construct their own webs but are often found on the periphery of a female's web, especially during the summer mating season.
- *Courtship rituals*. To initiate mating, the male performs specific behaviours to signal his presence and intentions to the female, reducing the risk of being mistaken for prey. This includes a unique 'somersault' behaviour, where the male positions his abdomen near the female's mouthparts during copulation.

FIGURE 2.32 The male Australian redback spider is usually eaten by his sexual partner while mating with her.

- *Sexual cannibalism*. In over 60 per cent of mating instances, the female consumes the male after he inserts his second palpus into her genital opening. This act may increase the male's reproductive success by providing the female with nutrition, potentially enhancing the survival of his offspring.
- *Venom potency*. Male redback spiders possess venom glands; however, their fangs are typically too small to effectively penetrate human skin, rendering their bites harmless to humans. In contrast, female redbacks have more potent venom and larger fangs capable of delivering medically significant bites.

1. How might advancements in technology, such as high-speed cameras or genetic analysis tools, have supported Dr Maydianne Andrade's research on the mating behaviours of the Australian redback spider, including its unique 'somersault' behaviour?
2. In what ways could Dr Andrade's findings about the reproductive strategies of redback spiders, such as sexual cannibalism, inspire technological developments in fields like robotics or behavioural modelling?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

2.4.2 Sending out signals

Using smell

Chemicals called **pheromones** can play an important role in communication between members of the same species. This type of communication makes it very easy for animals to locate a mate, even in sparsely populated areas.

When a female dog is about to ovulate, she comes 'on heat'. During this time she releases a pheromone into her urine to notify male dogs that she is ready for mating. Likewise, female moths use scented chemicals that sexually attract male moths from as far as 8 km away.

Using light

Fireflies can make parts of their body glow different colours (figure 2.33). A chemical reaction produces a bright yellow, green or blue colour, which is used to help males and females find each other so that they can mate. Not all females, however, have reproduction on their minds. Females of a particular type of firefly have a different activity in mind. They flash their glowing abdomens on and off in a particular pattern, usually suggestive of a mating invitation. Sadly, instead of a romantic rendezvous, the males become a tasty meal.

Using sound

Whales may become separated by long distances, so in order to reproduce it is important that they can communicate. The male humpback whale sings a song during the mating season to advertise his sexual availability to females.

Birds also use their songs to attract potential mates. Frogs and crickets may not sound so melodic, but they have their own way of making it known that they are available for sex. Male crickets make their chirping song by rubbing their forewings together. Often they build their own version of a stereo amplifier by digging an underground nest with a twin-horned tunnel entrance. By sitting at the junction of the horns, they can beam out their message loud and clear for all to hear.

FIGURE 2.33 A chemical reaction in fireflies produces a bright yellow, green or blue colour to help males and females find each other so that they can mate.

FIGURE 2.34 The male humpback whale sings a song during the mating season to advertise his sexual availability to females.

2.4.3 Tammar trends

Researchers are studying the reproductive biology of the tammar wallaby, a marsupial mammal native to South and Western Australia; this research may help us to understand more about ourselves.

A baby tammar wallaby is born about 26 days after **conception**. At birth, it weighs only 400 mg, is about the size of the end of your little finger, and is blind and hairless. After leaving the birth canal, it crawls up into its mother's pouch and attaches itself to one of her teats. At this stage, its external sex organs have not yet developed; researchers already know that these develop in stages quite different from those in many other mammals.

FIGURE 2.35 A newborn tammar wallaby sucking on its mother's teat

After suckling for about five months, it emerges from the pouch as a young joey. Although a joey can continue to suckle for up to a year, the mother can suckle another wallaby at a different stage of development at the same time. She does this by simultaneously producing two different types of milk. Research on how she does this could help us to improve milk production in farmed animals and our own human nutrition.

The mother tammar wallaby can suspend the development of a fertilised egg until its older brother or sister has left the pouch, or until environmental conditions are more suitable. Finding out how she achieves this may help us develop new fertility and development technologies for other mammals, including humans.

FIGURE 2.36 Will tammar wallabies provide clues to our future reproductive technologies?

INVESTIGATION 2.4

Relationship between seed number and seed size

The intended outcome of reproduction is to produce enough healthy offspring to maintain the survival of the species. There are two distinct strategies adopted to achieve this:

1. **r-selected species** produce large numbers of young, but provide little parental care
2. **K-selected species** produce small numbers of young, but the parents care for and protect them.

We can investigate similar strategies in plants. Seeds contain a food store to sustain the new plant through germination until it has developed enough to start to photosynthesise its own food. Some plants produce small numbers of large seeds, increasing the chances of that individual seed surviving, while others produce large numbers of smaller seeds, increasing the chances of at least one or two of the many seeds surviving.

Aim

To investigate the relationship between seed number and seed size in a range of fruits

Materials

- chopping board
- kitchen knife
- paper towel
- variety of fresh fruits (such as tomato, apple, peach, watermelon, chilli pepper)
- 15 cm ruler

Method

1. Cut open a fruit.
2. Remove all the seeds and wipe them clean with the paper towel.
3. Count the number of seeds and record this in a results table.
4. Measure the size of five seeds.
5. Calculate the average size of one seed by adding the 5 values from step 4, then dividing by 5.
6. Repeat for a range of fruits.

Results

1. Record your results in a suitable table. Remember to include a title for your table.
2. Plot a scattergraph of the number of seeds against the average size of one seed.

Discussion

1. Is there a relationship between the number of seeds and seed size? Explain.
2. Discuss any limitations experienced during this investigation and how they were overcome.

Conclusion

Summarise your findings about the relationship between seed number and seed size.

ACTIVITY: Survival strategies — internal versus external fertilisation

- Why do animals that use internal fertilisation (such as mammals) usually have fewer offspring compared to animals that use external fertilisation (such as fish)?
- How does parental care in K-selected species increase the survival chances of their offspring? Can you think of examples of animals that show high levels of parental care?
- What challenges might animals that use external fertilisation face in ensuring the survival of their offspring, and how do they overcome these challenges?

2.4 Activities

learnon

2.4 Quick quiz on | **2.4 Exercise**

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 6	2, 4, 7, 10, 13	5, 8, 9, 11, 12

Remember and understand

1. **Identify** the missing words to complete the following sentence.
   Environmental factors, ___________ and ___________ for food and resources can result in the death of many ___________ before they get a chance to develop to the stage at which they can ___________.
2. a. **Identify** whether each of the following statements is true or false.
      i. Many organisms produce more eggs than can survive.
      ii. In seahorses, the father can give birth to the young.
      iii. Some male damselflies have a penis with a special hook on the end to remove sperm left inside his mate by previous sexual partners before he makes his own deposit.
      iv. If eaten by his sexual partner, the male redback spider has an increased chance of fertilising her eggs.
      v. Some reptiles 'cement' up the female's genitalia by using semen that sets into a hard plug so that other sperm cannot get in.
      vi. Pheromones are a group of chemicals that play an important role in communication between members of the same species.
      vii. Hermaphrodites are animals that have both egg-producing and sperm-producing organs.
      viii. Fireflies make part of their body glow different colours to help find mates, but never to lure mates and then eat them.
      ix. The male humpback whale sings a song during mating season to advertise his sexual availability to females.
      x. The tammar wallaby can only suckle one infant at a time.
   b. Rewrite any false statements to make them true.
3. **Identify** the term on the left that matches each of the definitions on the right.

Features of sexual reproduction

Term	Definition
a. Pheromones	1. Name given to reproductive cells
b. Fertilisation	2. Male reproductive cell
c. Sperm	3. Female reproductive cell
d. Ovum (ova)	4. Name of early embryo just following fertilisation
e. Gametes	5. Chemical signal released outside of the body to communicate to other members of the species
f. Zygote	6. The joining of a male and female reproductive cell to form an embryo

4. **Identify** the name of the group of chemicals that can play an important role in communications between members of the same species.
5. **Suggest** three ways in which smell is important to reproduction.
6. **Describe** what it means when a dog is 'on heat'.

Apply and analyse

7. **Compare** internal and external fertilisation using an example of each one, ensuring you use comparative language.
8. **Describe** one way in which the following males may increase the chances of their sperm fertilising the female's ova.
   a. Redback spider
   b. Starworms
   c. Damselflies
   d. Some reptiles and rodents
9. SI **Identify** the reproductive strategy that you think is more successful in terms of ensuring the survival of a species. **Justify** your answer.

Evaluate and create

10. How does the ability of the tammar wallaby to pause the development of a fertilised embryo benefit both the mother and offspring in challenging environmental conditions? Could similar strategies evolve in other mammals? **Justify** your response.
11. Develop a short story or comic illustrating an animal overcoming the risks associated with reproduction. Highlight why these risks are essential for the survival of the species.
12. SI **Assess** current methods used to support endangered species. **Suggest** some strategies that could be improved or introduced to ensure their survival for future generations.
13. SI Design a visual comparison (such as a chart or infographic) that compares internal and external fertilisation in animals. Include an evaluation of how these strategies impact offspring survival, and **suggest** why specific adaptations might favour one method over the other.

Answers and sample responses are available in your digital formats.

LESSON 2.5 Human reproduction and contraception

LEARNING INTENTION

In this lesson you will:
- explain the role of gametes in human reproduction, including where they are produced and how they combine to result in a pregnancy and birth
- describe a range of reproductive technologies, including those used to avoid conception (contraceptives) and those used to help couples conceive, as well as how and when genetic testing can be performed.

Human reproduction is a complex and intriguing process. Its success is determined by a range of factors and manipulated by people wishing to control the timing of reproduction as well as the number of offspring they have. It is a dynamic and fascinating area of research that links biology to many other fields within science and medicine.

2.5.1 Gonads and gametes

Gonads are the site of gamete production. They are specialised organs that contain many different specialised cells needed to support growth and development of healthy gametes. In human males, the gametes (sperm cells) are produced continuously for most of the adult life. The female gametes (ova or egg cells), however, are all present at birth in an immature state. Throughout a female's reproductive years, a complex cycle called the **menstrual cycle** supports the growth and maturation of an ovum and its release.

2.5.2 Female reproductive system

The female gonads are called ovaries, and this is the site for production of the female gametes (sex cells), the ova. There are two ovaries, each connected to the **uterus** via their own **fallopian tube**.

Human ova are produced during development of the female **fetus** before birth, and once the baby is born no more ova can be produced. From birth to **puberty** the number of ova decline; by the time a young female enters puberty, there are usually about 400 000 ova in each ovary, although it is likely that only two or three of these will become new offspring.

Each month a small number of ova grow within a fluid-filled follicle in the ovary. Usually only one follicle completes its growth and releases a mature ovum during the process of **ovulation** into the fallopian tube.

A mature ovum is a large cell (approximately 100 μm) that contains half of the genetic material needed to begin embryonic development, but nearly all of the cellular machinery needed. A single human ovum contains approximately 100 000 mitochondria needed to meet the energy demands of fertilisation and early embryo development. In addition, the ova can produce proteins in its ribosomes, absorb nutrients and break them down, and remove waste.

FIGURE 2.37 The human female reproductive system

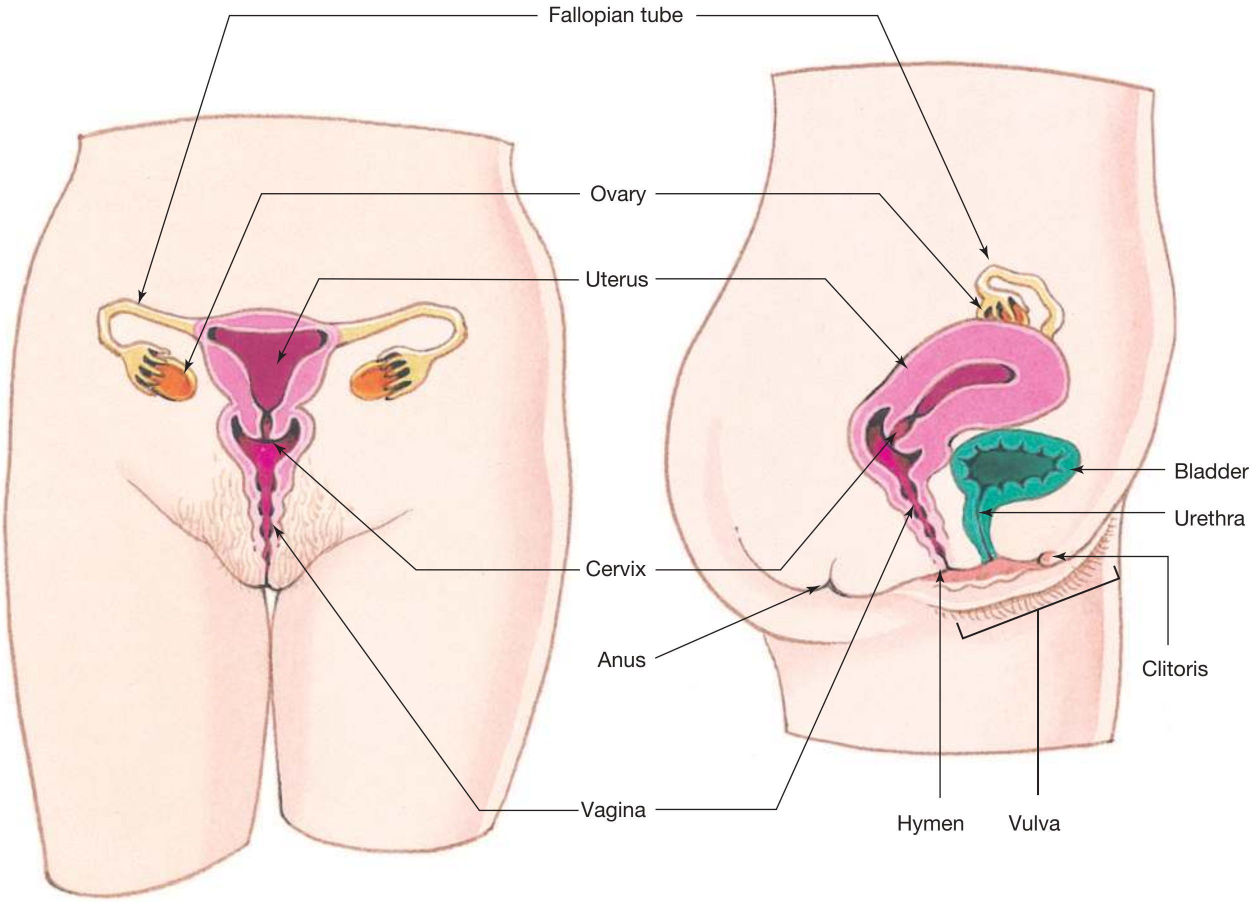


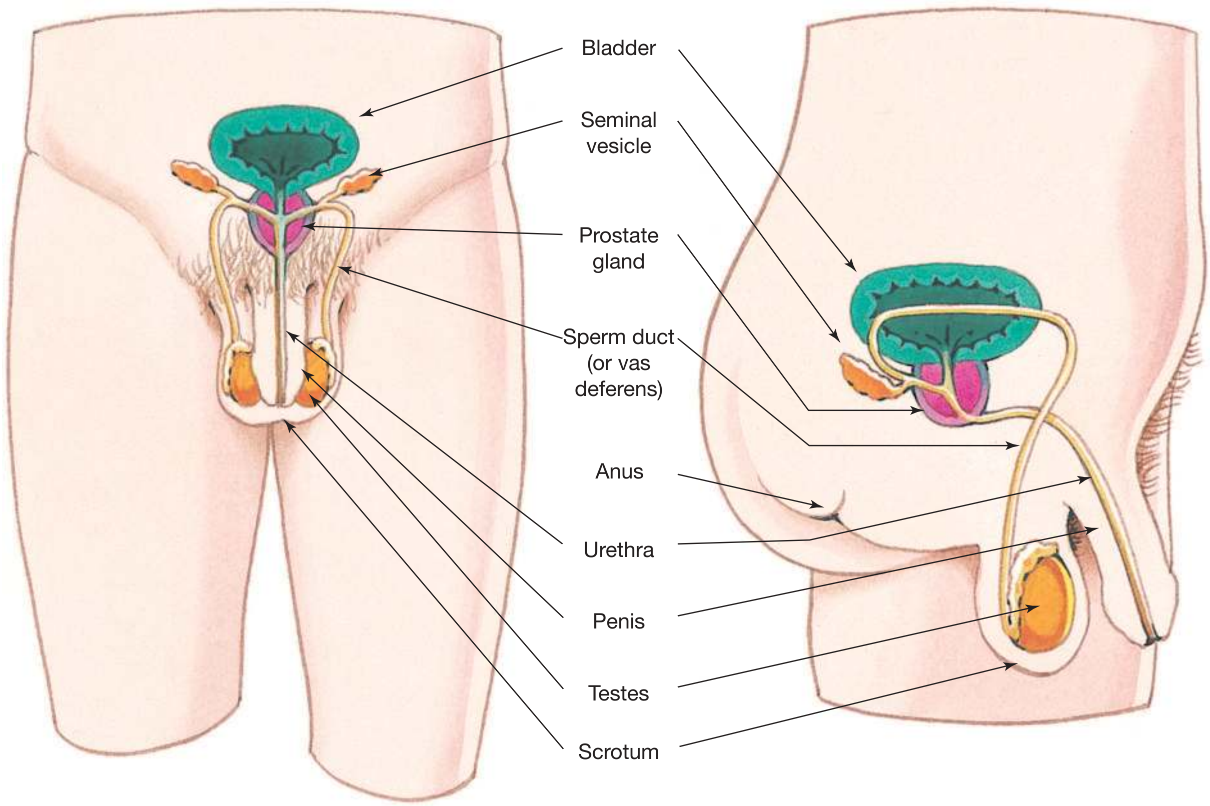
TABLE 2.2 Summary of the human female reproductive system

Part	Function
Ova (plural), ovum (singular)	Female gamete; egg
Ovaries	Female gonads; one ovum matures and is released on a monthly basis from one of the two ovaries
Fallopian tubes/oviducts	Tubes through which the ovum must travel to reach the uterus; the site of fertilisation if sperm is present after **sexual intercourse**
Uterus	The site of embryo implantation; supports the developing fetus from implantation to birth; about the size of a pear if not pregnant
Endometrium	The lining of the uterus; is shed during menstrual bleeding, or period, if an embryo does not implant
Cervix	The passageway between the vagina and the uterus; dilates during childbirth to allow the baby to be delivered through the vagina
Vagina	Elastic entry to the female reproductive system; the site for both semen to enter during intercourse and delivery of a baby during childbirth
Clitoris	A small accessory organ that swells during sexual arousal

2.5.3 Male reproductive system

The male gonads are called **testes**, and they are suspended outside of the body to keep the temperature 3 °C cooler than body temperature, which is optimal for producing sperm. The testes are continuously producing gametes from puberty for most of the male's lifetime.

FIGURE 2.38 The human male reproductive system



A typical ejaculation can contain 300 million sperm cells in a sticky fluid called **semen**. Sperm are about one-twentieth the size of a human ovum and are much simpler cells containing less organelles and cytoplasm than the ovum. This reflects their role, which is simply to deliver the genetic information to the ovum. Sperm are motile cells that have the ability to swim by beating their long flagella and propelling themselves forwards, and therefore need mitochondria to provide the energy for swimming. Only sperm with the correct-shaped head and a good level of motility will be able to reach the fallopian tube and fertilise the ovum. It is common for only 5 per cent of sperm cells to have the correct shape to fertilise an ovum.

Most sperm cells do not progress through the cervix and into the uterus; even less make it into the fallopian tube where a mature ovum may be waiting. Only one sperm cell can fertilise an ovum in the fallopian tube and contribute its genetic material to the offspring.

FIGURE 2.39 Human sperm cells surround an ovum.

TABLE 2.3 Summary of the human male reproductive system

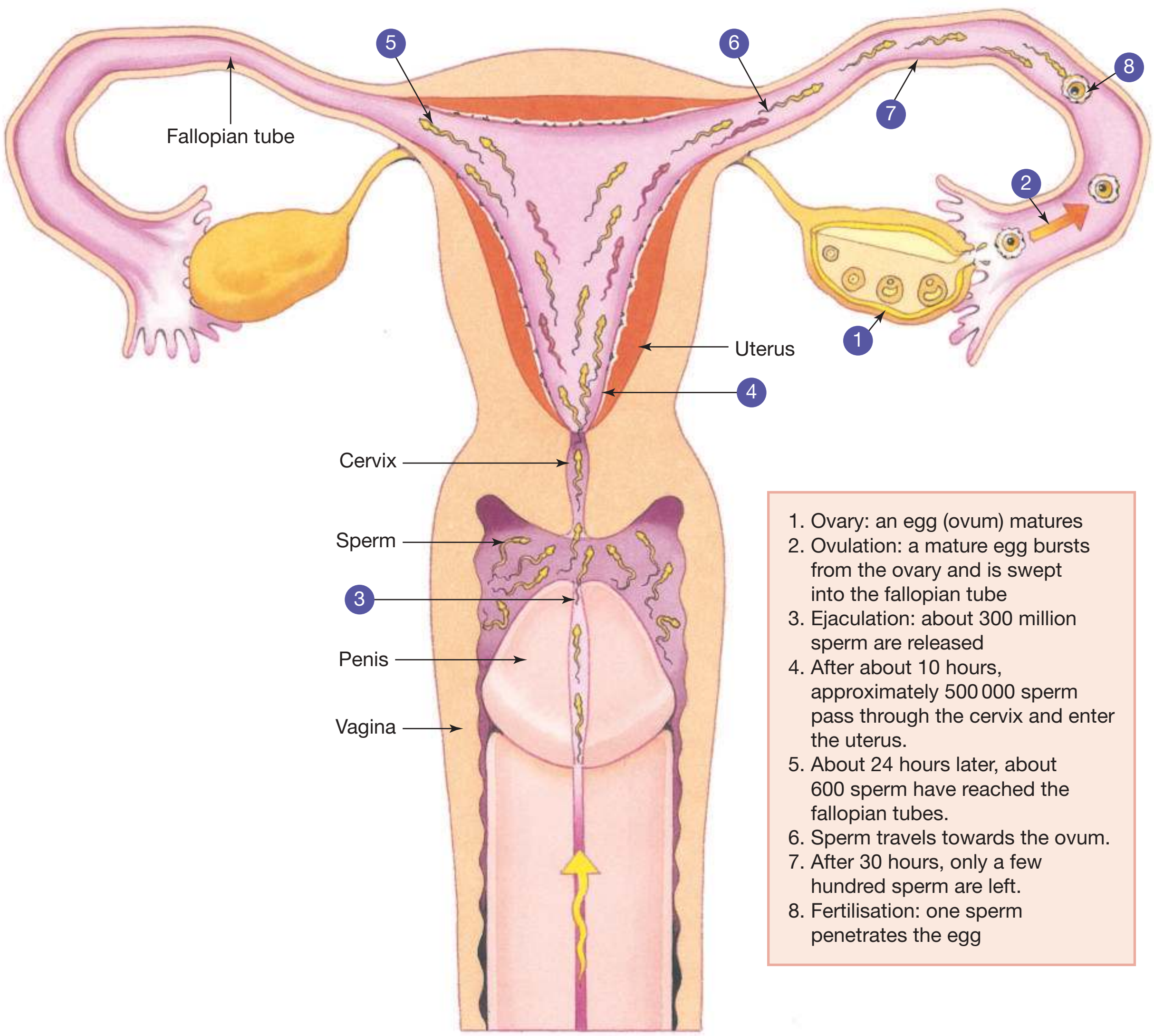
Part	Function
Sperm	Male gamete
Testes	Males produce sperm cells continuously throughout reproductive life
Scrotum	Surround the testes and keep them suspended outside of the body to keep the testes at about 34 °C, about 3 °C cooler than core body temperature
Seminal fluid, semen	A liquid containing sperm cells produced in the testes and fluids from the prostate and seminal vesicle; highly viscous to support delivery of sperm into the reproductive system
Vas deferens	The tube through which mature sperm cells travel from the testes to the penis
Prostate gland	About the size of a walnut, the prostate secretes fluid to support sperm function and maintain the pH of the semen
Seminal vesicle	Provides sugar and nutrients to the semen to support sperm function
Urethra	Tube inside the penis through which urine and semen leave the body
Penis	External sexual organ that swells during arousal; semen containing sperm cells are released, or ejaculated, into the vagina during sexual intercourse

2.5.4 Conception

For sexual reproduction to be successful in humans, a number of things need to occur at the same time. First, there must be a mature egg in the fallopian tube, although the egg cannot be more than a few hours old. Second, a healthy sperm must be in exactly the same place as the ovum, release enzymes to digest through a large number of cells surrounding the ovum, and then bind to the outside shell — or **zona pellucida** — of the ovum. The single sperm must then successfully penetrate the zona and fuse with the cell while initiating a block to other sperm preventing them from entering the ovum.

If this happens correctly then the nucleus of the sperm, with its half set of genes, can join the nucleus of the egg, with its half set of genes, and the egg is fertilised. This is the first stage of a new life, called a zygote.

FIGURE 2.40 Sexual intercourse — getting the sperm to the egg



2.5.5 Giving birth

Three stages are involved in giving birth to a baby. Giving birth is referred to as **labour** because it can be a lot of hard work for the mother. During the first stage, the cervix gradually widens. In the second stage, the woman feels a strong urge to push with each contraction of the uterus. During this stage the baby is born through the vagina, or birth canal.

Usually, the baby is born head first. Sometimes the baby is born bottom or feet first; this is referred to as a **breech** birth and is often more difficult. The third stage lasts from the baby's delivery until the **placenta** is delivered.

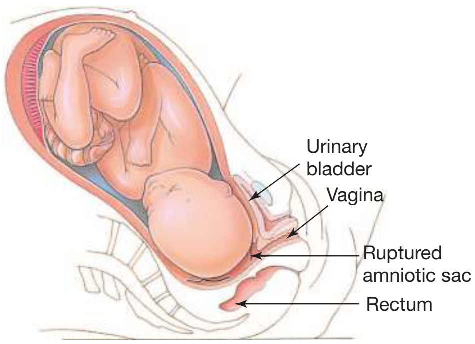
In some cases, the baby or mother needs extra assistance. A **caesarean** may be performed in which doctors surgically remove the baby by cutting through the mother's abdomen to her uterus.

FIGURE 2.41 Stages of giving birth

First stage

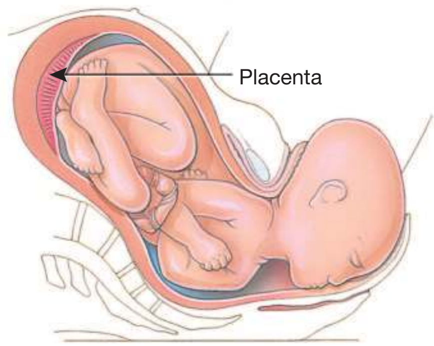
Uterus begins to contract at regular intervals that get closer and closer together. These contractions begin pushing down on the baby. At some point, the sac holding the amniotic fluid breaks; the fluid leaks out of the mother's vagina.

As contractions continue, the cervix stretches open, until it is about 10 cm wide. This stage can last for many hours, especially for first-time mothers.



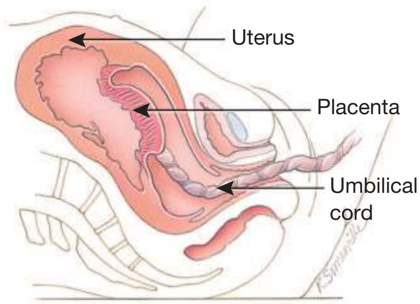
Second stage

The mother gets a fierce urge to push (a bit like with a bowel motion) every time the uterus contracts. Bit by bit, this pushes the baby further down the vagina (birth canal).



Third stage

The placenta is delivered after the baby is born. By this stage of the pregnancy it is a flattish, dinner-plate-shaped organ that looks a bit like a large piece of liver.



2.5.6 Contraception

Conception involves the fertilisation of an ovum and its implantation into the wall of the uterus where it can develop into a fetus. Techniques that prevent this happening are called **contraception**.

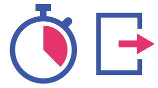
Contraceptives are the devices or substances used to prevent unplanned pregnancies. There are two main types of contraceptives: those that prevent fertilisation taking place and those that prevent the fertilised ovum from implanting in the uterus.

The effectiveness of contraceptive devices varies. Some are expensive and long term — perhaps even irreversible — while others are cheaper and easy to reverse but perhaps less effective. The different contraceptives and their effectiveness can be seen in table 2.4.

TABLE 2.4 Effectiveness of different contraceptive methods

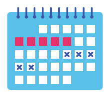
Least effective

- **Withdrawal method (coitus interruptus)**
  - Involves removal of the penis prior to ejaculation
  - Not effective, as some sperm are released before ejaculation
- **Vaginal douche**
  - Flushing the vagina with a chemical that may damage sperm cells



Withdrawal every time

- **Spermicides**
  - Cream or jelly containing chemicals that kill sperm
  - Introduced to the vagina before intercourse
- **Rhythm method**
  - Abstaining from intercourse during the most fertile stages of the menstrual cycle (around the time of ovulation)



Fertility awareness every time

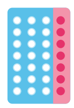
Highly effective

- **Condom**
  - Made of thin, strong latex
  - Male condom rolled onto erect penis just prior to intercourse
  - Female condom inserted into vagina prior to intercourse
  - Barrier to STIs
  - Most effective if used with spermicide
- **Diaphragm**
  - Thin rubber dome placed in vagina
  - Prevents sperm from reaching the cervix
  - Most effective if used with spermicide
- **Hormonal medications**
  - Hormonal control used by women administered as a daily tablet, patch, injection or implant just under the skin
  - Prevents ova developing and prevents ovulation
- **Intrauterine device (IUD) (coil)**
  - Interferes with sperm movement and implantation
  - Also often contains progesterone, a hormone that interferes with ovulation
- **Morning-after pill**
  - Emergency contraception
  - Prevents implantation if taken within 72 hours of intercourse

Male condom single use

Cervical cap every time

Diaphragm every time

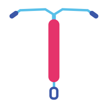


Pills every day

Vaginal ring every month

Patch every week

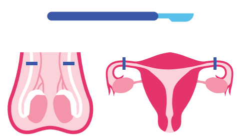
Injection 1–3 months



IUD 3–10 years

Most effective

- **Abstinence**
  - No intercourse
- **Vasectomy**
  - Cutting and sealing of the male's vas deferens
  - Sperm production continues; however, sperm are blocked and cannot be ejaculated
- **Tubal ligation**
  - Fallopian tubes are cut and sealed, preventing fertilisation
  - Irreversible



Sterilisation for men and women — it can be reversed but does not guarantee success in having a child after

SCIENCE INQUIRY: Investigating human reproduction and contraceptive effectiveness

This science inquiry investigates the effectiveness of contraceptive methods and explores how scientific research has contributed to their development. You will analyse how contraception impacts human reproduction and evaluate factors that influence contraceptive success rates, including accuracy, proper use and biological factors.

The investigation will also consider the ethical and social implications of contraception use, and how scientific advancements have improved access to reliable family-planning methods.

FIGURE 2.42 Different contraceptive devices

Formulate investigable questions

Examples:

- What factors influence the effectiveness of different contraceptive methods?
- How do biological processes, such as ovulation and sperm motility, impact the timing and success of fertilisation?
- What are the ethical considerations surrounding the use of contraceptives?

Develop hypotheses

Examples:

- Hormonal contraceptives are more effective than barrier methods in preventing fertilisation due to their ability to stop ovulation.
- Barrier methods are less effective than hormonal contraceptives because they rely on consistent and correct use.

Plan and conduct investigations

- Research the failure rates of different contraceptive methods (e.g. condoms, birth control pills, IUDs).
- Compare real-life effectiveness versus theoretical effectiveness based on correct use.
- Examine data and studies on factors affecting success, such as user error and access to resources.

Control variables and identify biases

- Consider sample size, age groups and health conditions that may influence contraceptive effectiveness.
- Account for human error, cultural differences and availability of methods in different populations.

Organise and analyse data

- Construct tables and graphs comparing contraceptive methods, their failure rates and costs.
- Analyse trends to identify which methods are most reliable and why.

Draw conclusions and evaluate limitations

- Explain which methods are most effective and under what circumstances.
- Assess ethical considerations, including access to contraception and the role of education in promoting responsible use.

1. How have advances in technology improved contraceptive methods, and what impact has this had on human reproduction?
2. Why is it important to test the effectiveness of contraceptives under both perfect and typical use?
3. What ethical considerations should scientists take into account when developing and testing contraceptives?
4. How might cultural beliefs and societal values influence the adoption of contraceptive methods in different regions?
5. What risks and biases might affect the data collected in studies about contraceptive effectiveness?

Valid, reproducible investigations to answer questions and test hypotheses can be planned and conducted, including identifying and controlling for possible sources of error and bias in sampling or in making observations; safe, ethical investigations include undertaking risk assessments and following protocols (VC2S10I02)

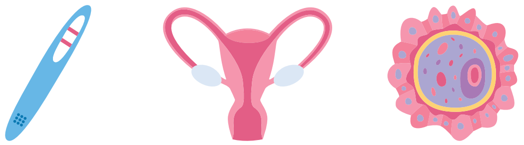
2.5.7 Infertility

Causes of infertility can be diagnosed by a medical doctor following a range of investigations. About one-third of cases of infertility are identified as female factor infertility associated with ova production, ova quality, a blockage preventing the ovum being fertilised or an endometrial factor; about one-third of cases are identified as male factor infertility resulting from sperm production, quality or function; while the other third of cases cannot be explained following the usual investigations.

FIGURE 2.43 Infertility can sometimes result from factors in the male or in the female; however, it is common for both partners to contribute to infertility or for the exact cause to be unknown.

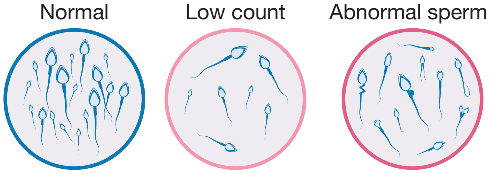
Female fertility can be affected by:

- a woman's age
- tubal disease or problems with the fallopian tubes
- ovulation disorders
- endometriosis
- polycystic ovarian syndrome
- fibroids
- salpingitis (pelvic inflammatory disease) caused by sexually transmitted infection.



Male fertility can be affected by:

- physical problems with the testes
- blockages in the ducts that carry sperm
- hormone problems
- a history of high fevers or mumps
- genetic disorders
- lifestyle or environmental factors.



2.5.8 Treatment options

There are many options for couples who need infertility treatment. The most appropriate treatment is chosen by their infertility specialist and may be a simple, inexpensive treatment or require a long, costly period of medical management. Unfortunately, despite many years of research and advances in this field, the success rates for a couple beginning fertility treatment are still low, with only 20–30 per cent of patient cycles resulting in a baby.

TABLE 2.5 Different treatment options for infertility

Treatment option	Description
Artificial insemination	The least-invasive treatment for infertility is assisted or artificial insemination. This usually involves monitoring ovulation to ensure the follicles containing an ovum are developing correctly, followed by injecting a washed sperm sample into the uterus just before ovulation. Sperm can last for many days in the female reproductive tract. Sometimes the female partner may be given medication to help ovulation to happen. Artificial insemination is a technique used in agriculture and animal breeding programs to control the timing and parentage of offspring.
IVF	In the 1970s, research into infertility resulted in the first successful fertilisation of a human ovum outside of the body, known as **IVF (in vitro fertilisation)**. The first child born from this treatment was in 1978 in Cambridge, UK — the world's first 'test-tube baby'. The birth was the result of a 20-year collaboration between Dr Steptoe, a gynaecologist, and Dr Robert Edwards, a biologist. Since then, more than 3 million births have resulted from IVF treatment. Steptoe developed a method of retrieving the ova from the follicles in the ovaries of a patient, and Edwards developed a method of fertilising ova in a laboratory environment.

Cyropreservation	It is common for there to be excess gametes and embryos in an IVF treatment cycle. **Cryopreservation** is the freezing of gametes or embryos. It is a delicate process that removes water from the cells and replaces the water with a special chemical called cryoprotectant, which does not form damaging ice crystals and helps to keep the cells intact during cooling. Gametes and embryos are cooled in a controlled manner in a freezing machine or using specific devices that result in a high level of cells surviving. Once the gametes or embryos are frozen they can be stored in liquid nitrogen for many years without ageing. The gametes or embryos can be warmed up at any stage and used for treatment. Patients choose to freeze their gametes or embryos for later use or for donating to another couple at a later date.
Gamete or embryo donation	Sometimes people need to use a donor to achieve a family of their own. This may be due to the person having no gametes, being **sterile**, or having poor quality gametes that cannot produce a healthy embryo. In these cases, a person can seek a gamete (sperm or ovum) donor who will give them gametes to use in fertility treatment. The person receiving the gametes or embryos is known as the **recipient**. The female recipient will have an embryo transferred into her uterus and carry the pregnancy herself. The recipient is the legal parent of any children born, although they may have different genetics to the children and are not biologically related. In Australia, donors are not paid for their gametes or embryos; however, in other countries a gamete donor can be paid significant amounts of money.

SCIENCE AS A HUMAN ENDEAVOUR: Understanding human reproduction through scientific advances

Scientific advancements have greatly improved our understanding of human reproduction, from the development of specialised reproductive cells (gametes), to the processes of fertilisation and embryo development.

The invention of the microscope allowed scientists to observe sperm and eggs for the first time, revolutionising our understanding of how life begins. Modern technologies, such as ultrasound imaging, enable us to monitor fetal development during pregnancy, improving maternal health care and reducing complications.

Advances in cell biology have revealed the complexity of sperm and egg cells. For example, scientists discovered that sperm are highly motile, relying on flagella powered by mitochondria to reach and fertilise the egg. Meanwhile, eggs are much larger and store the nutrients needed to support early development.

FIGURE 2.44 Ultrasound involves the use of sound waves to produce images of an unborn child inside the mother’s body.

Genetic research has also transformed our knowledge of fertilisation. Scientists can now study DNA sequencing to understand how genetic material is passed from parents to offspring, leading to breakthroughs in genetic screening and IVF techniques. These discoveries have improved fertility treatments and helped families overcome reproductive challenges.

The study of reproduction has also led to advances in surgical technologies such as caesarean sections, which can safely deliver babies in high-risk pregnancies. Research into reproductive biology continues to develop stem cell therapies and artificial womb technologies, potentially transforming medicine and fertility treatments in the future.

This progress highlights how science and technology work hand-in-hand to expand knowledge, improve health outcomes and support families, while also raising ethical and societal questions about the use of reproductive technologies.

1. How have technological advances, such as microscopes and ultrasounds, improved our understanding of human reproduction?
2. What role does DNA research play in helping scientists understand fertilisation and embryo development?
3. How might future technologies, such as artificial wombs, impact reproduction and fertility treatments?
4. Why is it important for scientists to consider ethical and societal impacts when developing reproductive technologies?
5. How have scientific discoveries about gametes and fertilisation contributed to improvements in reproductive health care?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

2.5 Activities

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2.5 Quick quiz on	2.5 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4	3, 5, 8	6, 7, 9, 10

Remember and understand

1. **Identify** the part of the female reproductive system:
   a. that produces ova
   b. through which the ova must travel to reach the uterus
   c. in which fertilisation of an ovum by a sperm occurs
   d. in which an embryo implants and is 'home' for the developing baby
   e. that is the passageway between the vagina and the uterus
   f. through which semen containing sperm enters during sexual intercourse
   g. through which babies pass through from the uterus during birth.
2. **Identify** the part of the male reproductive system:
   a. that produces sperm
   b. through which sperm travel from the testes to the penis
   c. in which the testes are located
   d. through which semen travels through the penis to leave the male's body
   e. that swells during sexual arousal and through which semen containing sperm is ejaculated.

3. **Construct** sentences using the following words.
   a. Testes, scrotum, sperm
   b. Ovaries, ova, follicles
   c. Vas deferens, fallopian tube, ovaries, testes
   d. Ovum, fallopian tube, sperm, fertilisation, ovary
4. Observe the following list of contraceptives and techniques. **List** them in order of most effective to least effective:
   abstinence, condom, daily contraceptive pill, intrauterine device (IUD), rhythm method, vasectomy, withdrawal method.

Apply and analyse

5. **Explain** why it is important for only one sperm to fertilise an egg, and what mechanism prevents multiple sperm from entering the ovum.
6. Trace the journey of the sperm and egg from their production to the formation of a zygote. **Discuss** how timing and environmental conditions influence the likelihood of successful fertilisation.
7. Break down the three stages of labour during childbirth, identifying the key events and their importance. **Explain** how medical interventions, such as a caesarean section, address complications and ensure the safety of both the baby and the mother.

Evaluate and create

8. **Assess** the significance of three factors that can affect male fertility. Which factor do you think has the greatest impact on sperm production or function? **Justify** your response.
9. Imagine you are a health educator. Design an engaging pamphlet, with visuals, that provides practical tips for young people on maintaining reproductive health. Include at least three key pieces of advice and **explain** their importance.
10. **Analyse** the effectiveness of artificial insemination and IVF as infertility treatments. Based on your analysis, **propose** a scenario in which each method might be the most suitable choice. **Justify** your response.

Answers and sample responses are available in your digital formats.

LESSON 2.6 Review

2.6 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
2.2	I can describe how some organisms reproduce asexually with examples of some of the main strategies, such as binary fission, budding and spores.			
2.3	I can describe how some plants reproduce sexually with pollen and ovules as their reproductive cells.			
	I can explain how seeds are dispersed and germinate.			
2.4	I can describe some different reproductive strategies seen in the animal kingdom.			
2.5	I can explain the role of gametes in human reproduction, including where they are produced and how they combine to result in a pregnancy and birth.			
	I can describe a range of reproductive technologies, including those used to avoid conception (contraceptives) and those used to help couples conceive, as well as how and when genetic testing can be performed.			

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Post-test Topic 2 Post-test
eWorkbook Topic 2 eWorkbook
Digital document Key terms glossary

2.6 Activities

learnon

2.6 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 7, 10, 13, 20	3, 4, 5, 8, 11, 12	6, 9, 14, 15, 16, 17, 18, 19

Remember and understand

1. a. **Identify** whether each of the following statements is true or false.
   i. Pollination in plants is the equivalent of fertilisation in animals.
   ii. Gametes are reproductive sex cells.
   iii. Binary fission in prokaryotes involves mitosis.
   iv. Sperm production in humans is controlled by hormones.
   b. Rewrite any false statements to make them true.

2. **Identify** which of the terms on the left matches each of the descriptions on the right.

Different types of gametes	
Term	**Description**
a. Sperm	1. Female gamete
b. Ova	2. Male gamete(s) in animals
c. Ovum	3. Female gametes
d. Pollen grain	4. Male gamete in plants

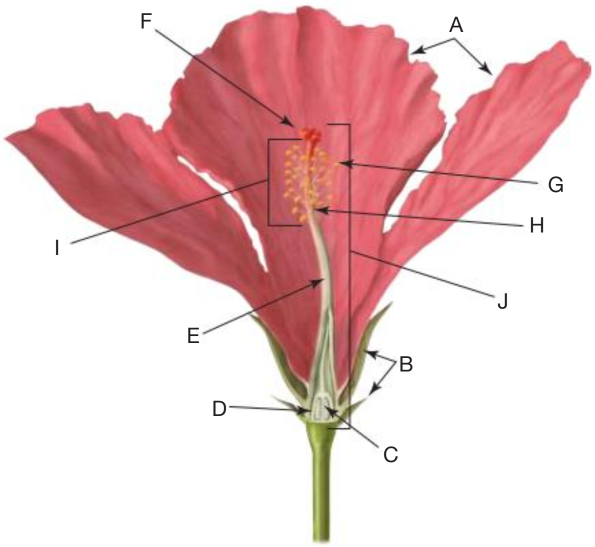
3. **Identify** which of the terms on the left matches each of the descriptions on the right.

Different methods of reproduction	
Term	**Description**
a. Pollination	1. Fusion of male and female gametes
b. Ejaculation	2. Process in which the embryo completely embeds itself in the uterus lining
c. Germination	3. Release of semen from the male's penis
d. Fertilisation	4. Way in which the pollen grains reach the stigma of a plant
e. Implantation	5. When the seed bursts open and a new plant grows old

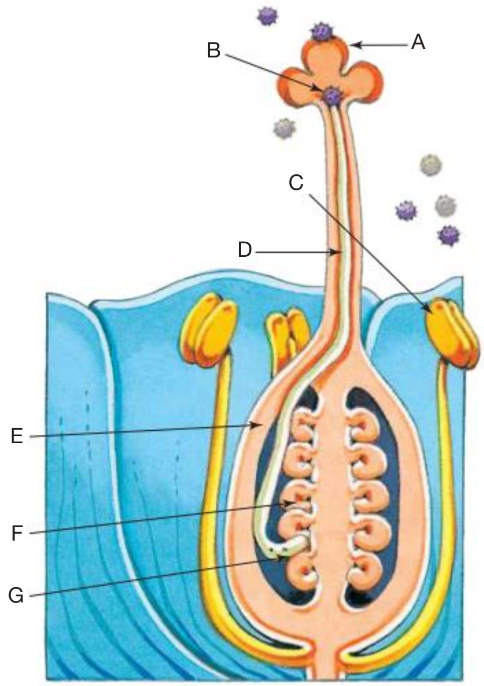
4. **Identify** which of the flower parts on the left matches each of the functions on the right.

Functions of the different parts of a flower	
Part of flower	**Function**
a. Style	1. Produces pollen
b. Ovule	2. Supports the anther
c. Stigma	3. Contains ovule and becomes the fruit
d. Anther	4. When pollen lands here, pollination has occurred
e. Ovary	5. Site of fertilisation of egg cell
f. Filament	6. Supports the stigma and is the structure through which the pollen tube grows

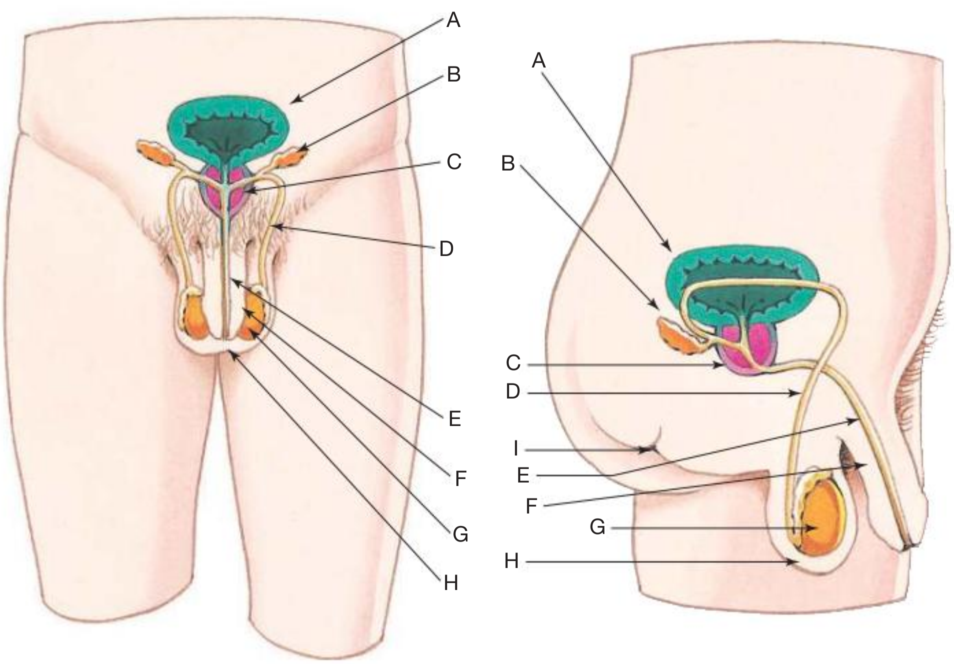
5. **Identify** the letter in the following diagram that corresponds to each of these terms: ovules, sepals, filament, style, stigma, ovary, anther, petals, stamen, carpel.

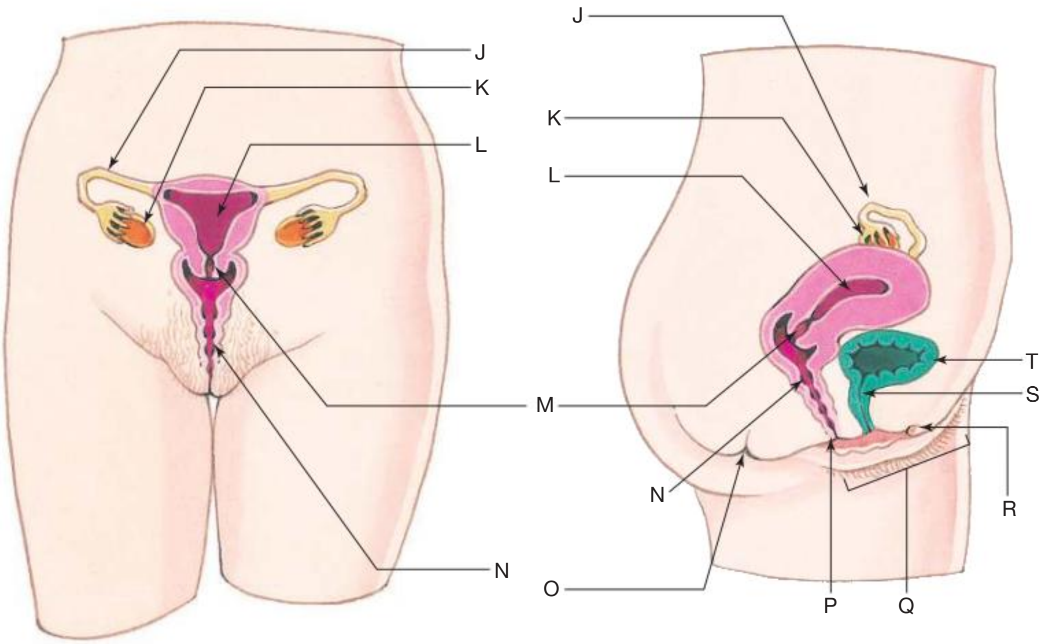


6. **Identify** the letter in the following plant diagram that corresponds to each of these terms: stigma, male gamete, pollen grain, pollen tube, stamen, ovary, ovule.



7. **Identify** the parts labelled A–T in the diagrams shown. **Describe** one function of at least two parts in each diagram.



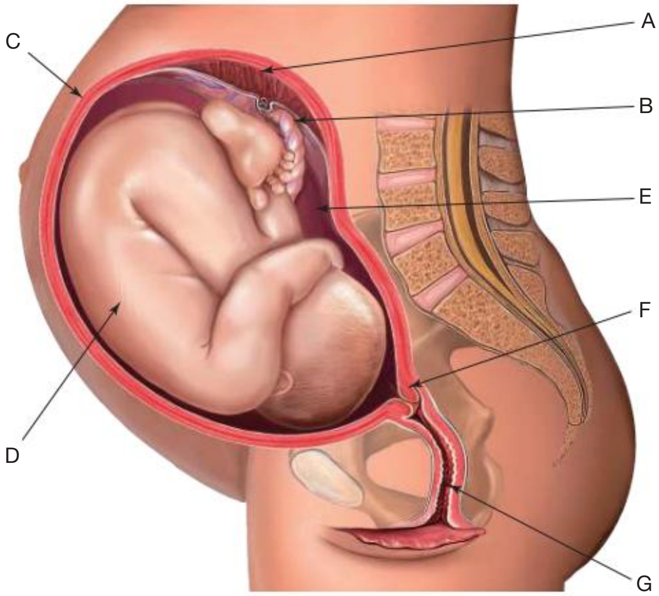


8. **Summarise** the disadvantages and advantages of sexual and asexual reproduction.
9. A *Paramecium* is a single-celled organism that reproduces asexually. **List** the advantages and disadvantages of reproducing in this way.
10. Match each of the contraceptives with how it prevents conception and its effectiveness.

The effectiveness of different contraceptives

Contraceptive	How it prevents conception	Effectiveness
a. Condom with spermicide	1. Prevents ova from developing	i. Extremely effective
b. Diaphragm without spermicide	2. The fallopian tubes or vas deferens are cut and sealed	ii. Unreliable
c. Daily contraceptive pill	3. Keeps sperm and semen from entering the woman's vagina after ejaculation	iii. Highly effective
d. Surgical: vasectomy and tubal ligation	4. Removal of male's penis from the vagina before ejaculation	iv. Highly effective
e. Coitus interruptus (withdrawal method)	5. Prevents sperm cells from reaching the cervix	v. Moderately effective

11. **Identify** the parts A–G in the diagram shown.



12. **Construct** a table naming the organs of the human male and female reproductive systems. For each organ, **describe** its structure and function.

Apply and analyse

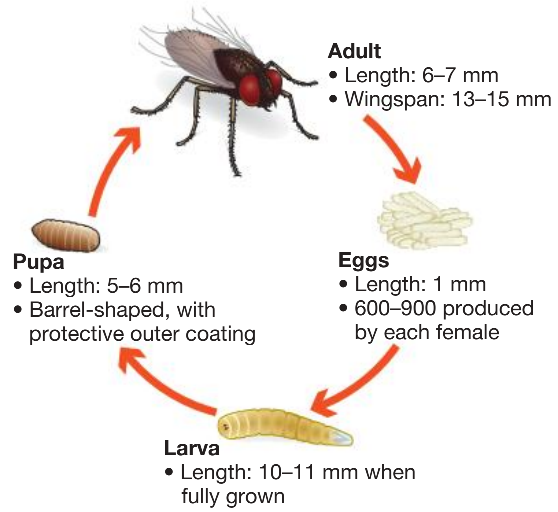
13. **Suggest** responses to the following questions.
    a. How can there be weeds in the garden if you didn't plant them there?
    b. Why don't twins always look the same?
    c. Why doesn't a caged bird lay eggs that can hatch into baby birds?
14. SI Charlotte wanted to find out if temperature affects the growth of plants. She bought four seedlings. She put one seedling in the fridge and one in her garage (which has no windows so is dark and cooler than her house). She put the third seedling on the windowsill (in full Sun) and the fourth seedling on her desk (out of the Sun but in daylight). Charlotte measured the height of each seedling every day for ten days. Her results are shown in the table.

Heights (cm) of seedlings

Position	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Fridge	5.0	5.5	6.0	6.2	6.6	7.0	7.3	7.5	7.7	8.0
Garage	5.0	5.6	6.2	6.6	7.0	7.3	7.6	7.9	8.4	8.8
Windowsill	5.0	6.0	6.7	7.5	8.0	8.5	9.0	9.6	10.2	10.6
Desk	5.0	5.8	6.3	7.0	7.5	8.0	8.5	9.1	9.6	10.0

a. **State** an aim for Charlotte's experiment.
b. **Suggest** three improvements to Charlotte's experiment.
c. **Construct** a graph of Charlotte's results.
d. **State** a conclusion for this experiment.

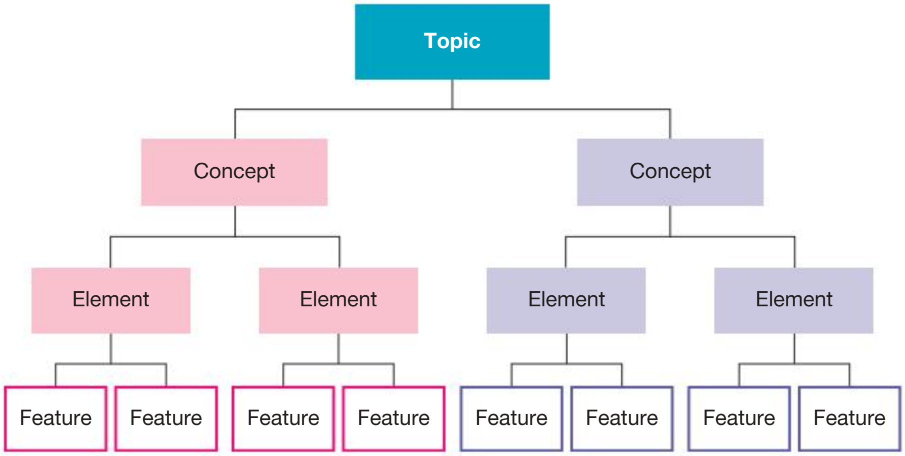
15. **SI** Refer to the diagram shown to answer the following questions.



a. **Construct** a table to show differences between the sizes, shapes and structures of a fly during each stage of its life cycle.
b. **Construct** a graph to show the differences in length during the adult, egg, larval and pupal stages of the life cycle.
c. **Suggest** possible survival advantages for the differences throughout the life cycle.

Evaluate and create

16. **Suggest** how scientific knowledge about the life cycles of plants and animals can be used to develop regulations about importation of foodstuffs into Australia. Suggest reasons for these regulations.
17. **Suggest** how knowledge of the life cycle of a particular plant or animal may influence the practices of an agriculturalist.
18. **Construct** a flowchart to show an example of a life cycle of a flowering plant. Include pollination, fertilisation, development, seed dispersal and germination.
19. **Construct** a tree map to show two sides of a discussion about plant reproduction and animal reproduction. An example of the structure of a tree map is shown.



20. Increased knowledge and understanding of reproductive processes have led to the development of new reproductive technologies. **Construct** a PMI chart for issues associated with one of these technologies.

Answers and sample responses are available in your digital formats.

To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

3 Homeostasis

CONTENT DESCRIPTION

The nervous and endocrine systems work together to regulate and coordinate the body's response to stimuli, ensuring homeostasis, including through negative feedback mechanisms (VC2S10U02)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 3.1 Overview

3.1.1 Introduction

Living things are organised from simple to complex structures: **cells** form **tissues**, tissues form **organs**, organs are part of body **systems** and all the systems work together to create a complete **organism**. We have previously learned about some body systems in detail, including their structure and function.

It is important to understand that none of our body's systems work in isolation. They are all interconnected and work together. A key example of this is **cellular respiration**, a fundamental process used by all systems to produce energy.

Within the muscular system, **glucose** combines with oxygen inside cells to produce the energy needed for movement and other activities. The digestive system breaks down carbohydrates to release glucose, while the respiratory system ensures oxygen enters the body from the air. The circulatory system then transports both glucose and oxygen to the cells where they are needed.

Meanwhile, the nervous system continuously monitors the body's oxygen and glucose demands, adjusting heart and breathing rates accordingly.

FIGURE 3.1 Athletes rely on coordinated body systems to supply the energy they need to stay strong and healthy, and perform at their best.

This process of body systems working together is known as a *coordinated response to stimuli*. It is the basis on which complex multicellular organisms are able to survive. None of our cells, tissues, organs or systems could survive on their own. They all rely on each other.

DISCUSSION

1. Is it the amount of oxygen or carbon dioxide in your blood that influences your breathing rate?
2. How fast can a body react to threatening situations?
3. Can your reactions be consciously controlled in all situations?
4. Which body systems are used for a fight-or-flight response?
5. Which hormones regulate blood glucose levels?
6. What's the link between hormones and the menstrual cycle?
7. Which senses allow our body to detect changes to our environment?

SCIENCE INQUIRY: Design an organism

Have you ever wondered what the recipe for life is? Which ingredients would you blend together to make up a living thing? How could this mixture result in life?

Scientists have developed a whole range of different instruments and technologies to discover more about life processes. This has helped develop our knowledge and understanding of the structure of living things and how they work. Investigations give us more information about chemical processes that occur in cells and keep living things alive.

1. a. Identify an environment in which your organism will live.
   b. Describe the temperature, light intensity, water availability, food sources and other factors that you consider to be important to the survival of your organism.
2. Design your organism.
   a. Identify how your organism:
      i. obtains nutrients
      ii. obtains oxygen
      iii. removes its wastes.
   b. Identify how nutrients, oxygen and its wastes are transported within its body.
   c. Identify how the organism senses and responds to its environment.
3. Draw labelled diagrams of your organism's cells, tissues, organs and systems. Remember to think about the function of each of these when you are designing its structure.
4. Describe how each of your organism's systems work together to keep it alive.
5. Construct a model of your organism.
6. Construct a brochure that advertises what a magnificent life form your organism is. Think about who you are advertising your organism to. Is your target audience a zoo, a documentary film-maker or someone else?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (*VC2S10I01*)

FIGURE 3.2 *Grimpoteuthis,* also known as an umbrella (or dumbo) octopus, lives in the deep sea in very cold water and without sunlight.

FIGURE 3.3 Tardigrades are half-a-millimetre-long water animals that have been found in rainforests, the Antarctic, in mud volcanoes and in the deep sea.

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Pre-test	Topic 3 Pre-test
eWorkbook	Topic 3 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 3 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 3.2 The respiratory and circulatory systems

LEARNING INTENTION

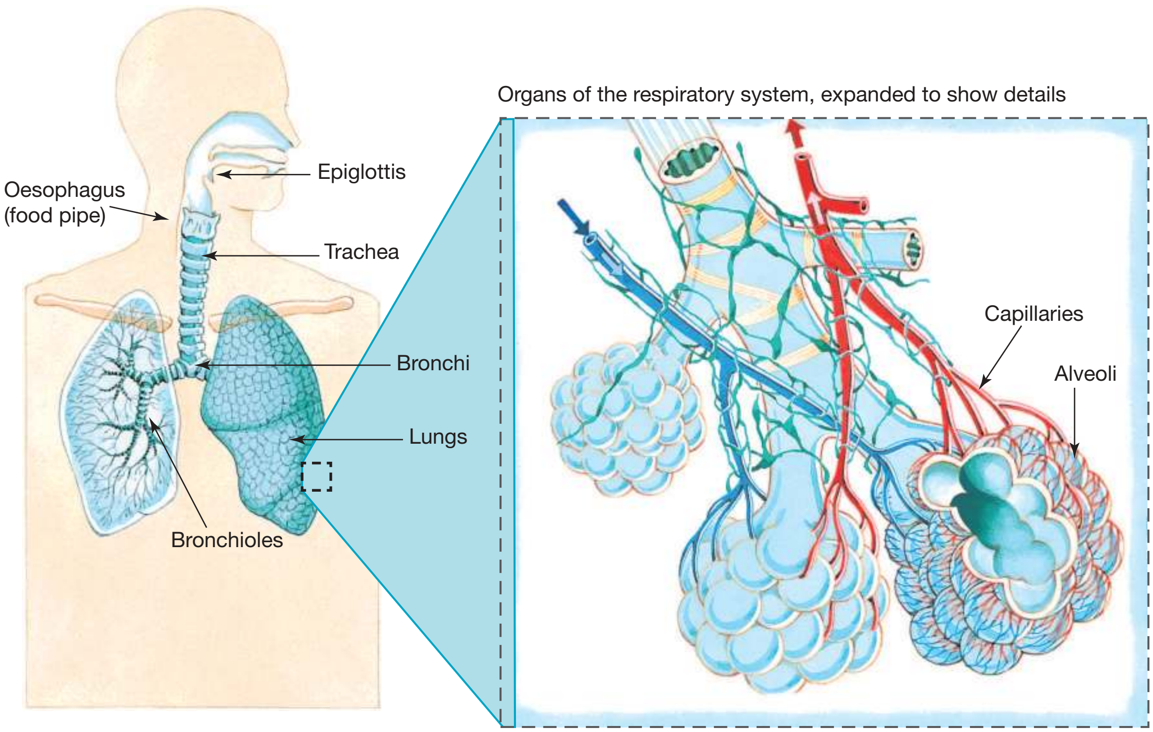
In this lesson you will understand how the respiratory and circulatory systems work together to supply oxygen to your cells and remove carbon dioxide from them.

3.2.1 The respiratory system and the circulatory system

The respiratory system

The **respiratory system** is responsible for getting **oxygen** into your body and removing **carbon dioxide**, a waste product, from your body. This happens when you inhale (breathe in) and exhale (breathe out). The main organ in this system is the **lungs**. Gas exchange occurs in the alveoli — tiny air sacs in the lungs where oxygen enters the blood and carbon dioxide is removed from it (figure 3.4).

FIGURE 3.4 The human respiratory system



The circulatory system

The **circulatory system**, also called the cardiovascular system, is responsible for transporting oxygen and nutrients to your body's cells, and for removing waste products like carbon dioxide. Blood cells travel through blood vessels — arteries, veins and capillaries — with the **heart** acting as the pump that keeps blood moving around the body. **Arteries** transport blood from the heart and veins transport blood back to the heart. Arteries are narrower and more muscular than **veins**, which means blood is under higher pressure in the arteries than in the veins. **Capillaries** are the site at which exchange of materials with the cells occurs (figure 3.6).

The heart is actually two pumps. One side pumps **oxygenated blood** and the other pumps **deoxygenated blood**.

FIGURE 3.5 Heart and blood vessel flowchart

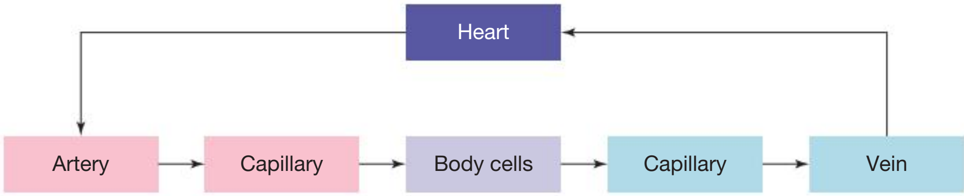
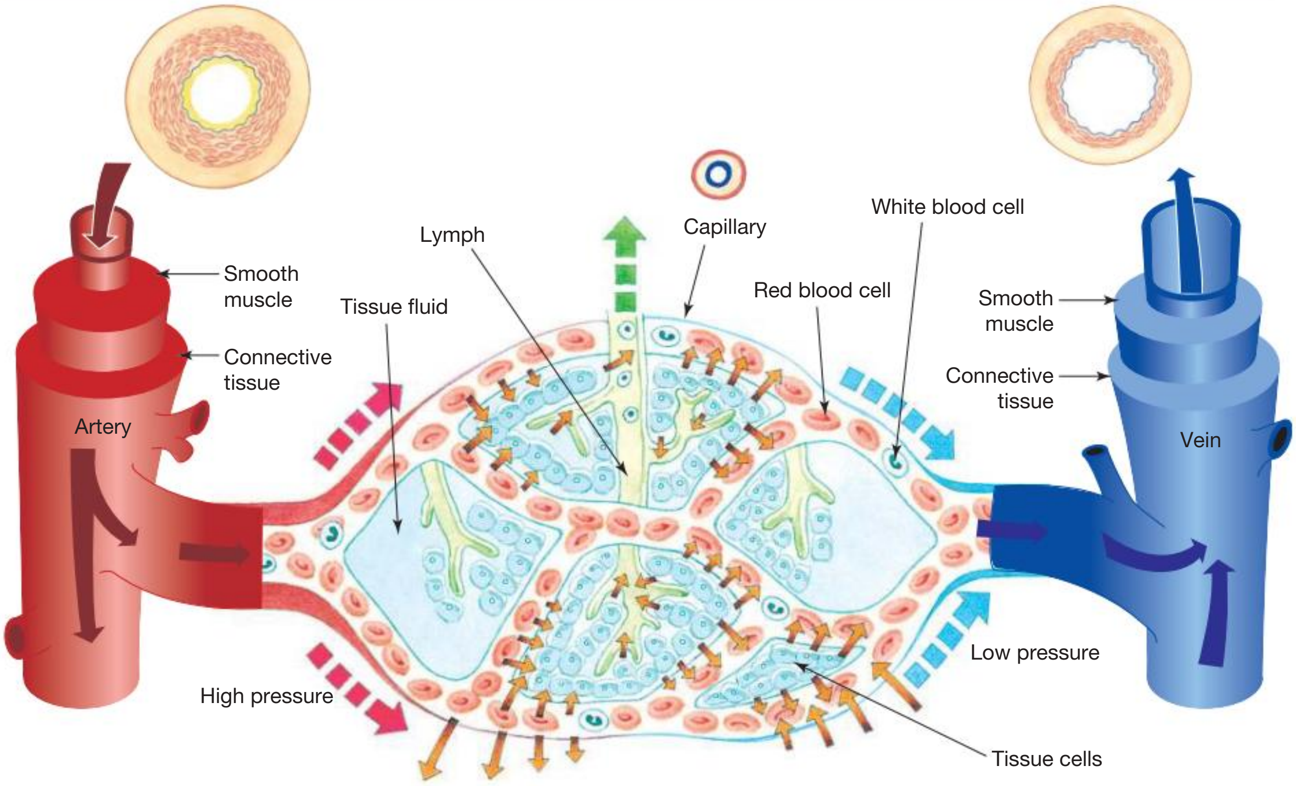


FIGURE 3.6 The oxygenated blood coming from the artery (red) moves into the finer capillaries, where the thin walls allow an exchange of gases into the tissues. Carbon dioxide is released from the tissues to the bloodstream, where the veins take the deoxygenated blood (blue) back to the heart and lungs.



3.2.2 Cells need energy!

Your circulatory and respiratory systems work together to provide your cells with oxygen, which is essential for making energy. This process is called cellular respiration. During cellular respiration, glucose is broken down to release energy in a form that cells can use. As shown in the cellular respiration equation, carbon dioxide is produced as a waste product. This carbon dioxide must be removed from the cells, as its build-up can damage or even kill them.

KEY IDEA

Cellular respiration is the breakdown of food (glucose) in the presence of oxygen, which releases energy that can be transformed into a form that cells can use. Carbon dioxide is a waste product.

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

EXTENSION: Details of cellular respiration

Cellular respiration actually occurs through a complex series of biochemical equations. It can be simplified as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow CO_2 + H_2O + (ATP)$$

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

As this series of reactions give out energy, they are known as exergonic reactions, and the energy released is used to produce a usable form of energy known as adenosine triphosphate (ATP).

3.2.3 Transport in the respiratory and circulatory systems

Transport through your circulatory system

Your circulatory system is responsible for:

- transporting oxygen and nutrients to your cells
- transporting wastes such as carbon dioxide away from your cells.

This involves blood cells that are transported in your blood vessels and heart. The three major types of blood vessels are:

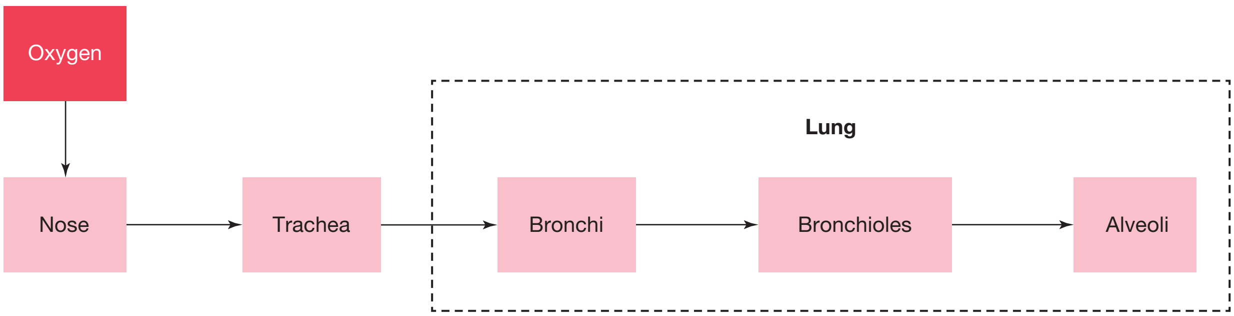
- arteries — transport blood from the heart
- capillaries — where materials are exchanged with cells
- veins — transport blood back to the heart.

Inhaling — to get oxygen into your respiratory system

Your respiratory system is responsible for getting oxygen into your body and carbon dioxide out. This occurs when you inhale (breathe in) and exhale (breathe out).

To get oxygen into your respiratory system you breathe in, but you actually take in a mixture of gases (of which about 21 per cent is oxygen) from the air around you. The air moves down your **trachea** (or windpipe), then down into one of two narrower tubes called **bronchi** (bronchus), then into smaller branching tubes called **bronchioles**, which end in tiny air sacs called **alveoli** (alveolus).

FIGURE 3.7 Flowchart of the human respiratory system



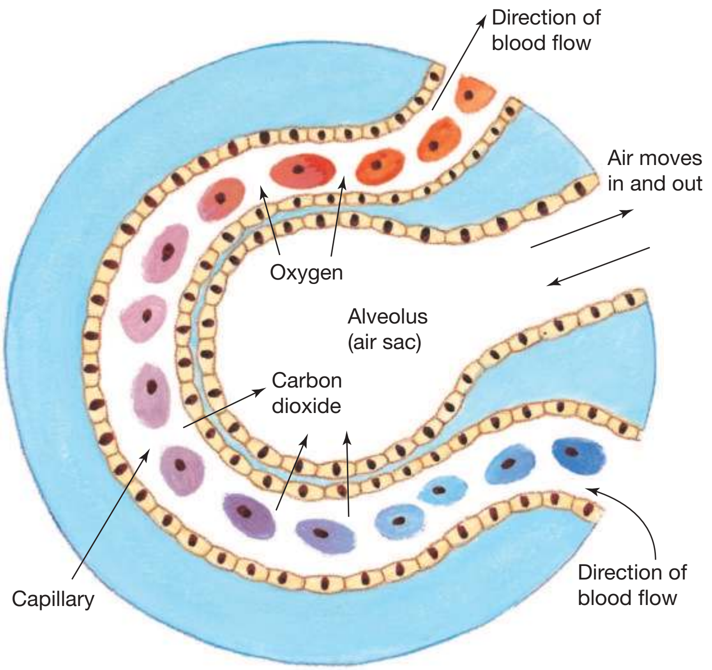
Getting oxygen into your circulatory system

Your alveoli are surrounded by a network of capillaries. The walls of the alveoli and the capillaries are both only one cell thick. This thin barrier allows oxygen and carbon dioxide to move easily between the lungs and the bloodstream by diffusion. The capillaries contain **red blood cells** (or **erythrocytes**) that contain **haemoglobin**, an iron-based pigment that gives your blood its red colour. Oxygen moves from the alveoli into the red blood cells in the surrounding capillaries and binds to the haemoglobin to form oxyhaemoglobin. It is in this form that the oxygen is transported to your body cells.

FIGURE 3.8 Flowchart of oxygen moving into the circulatory system

Oxygen → Alveoli → Capillary → Erythrocyte → Haemoglobin

FIGURE 3.9 In an alveolus, oxygen diffuses into the blood and carbon dioxide diffuses out of the blood.



Transporting oxygen to your cells

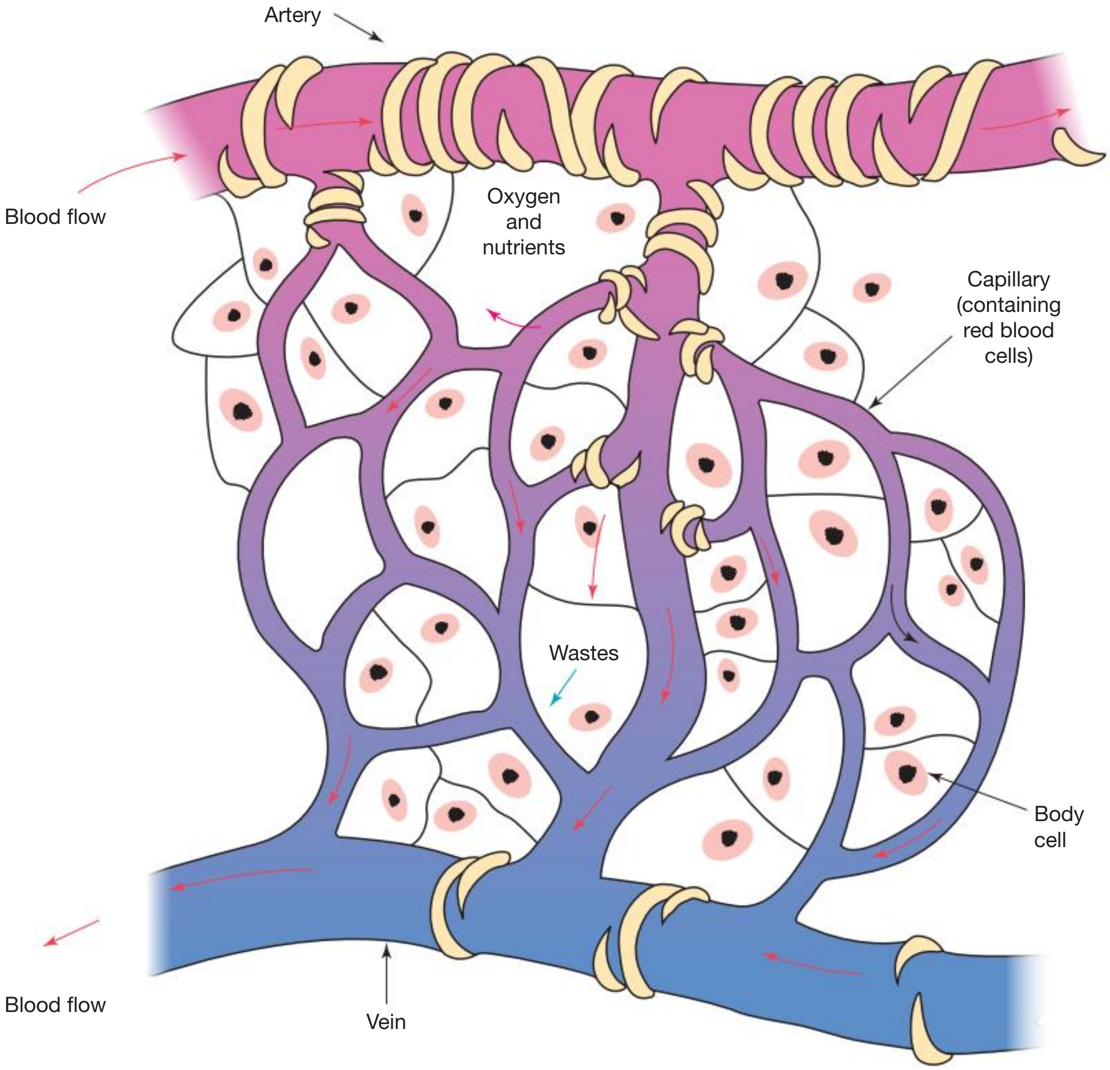
Oxygenated blood travels in a path, as shown in figures 3.10 and 3.12. It travels from your lungs via the **pulmonary vein** to the **left atrium** of your heart. From here the blood moves into the **left ventricle**, where it is pumped under high pressure through the **aorta** — the largest artery in the body — to the rest of the body.

The arteries transport the oxygenated blood to smaller vessels called **arterioles** and finally to capillaries, through which oxygen diffuses into body cells for use in cellular respiration (figure 3.11).

FIGURE 3.10 Flowchart of oxygen moving through the circulatory system to the body's cells

Oxygenated blood → Pulmonary vein → Left atrium of heart → Left ventricle of heart → Aorta → Arterioles → Capillary → Body cell

FIGURE 3.11 In the capillaries, oxygen diffuses out of the blood, and waste produced by cells diffuses into the bloodstream.



Transporting carbon dioxide away from your cells

Once oxygen has diffused into the cell and carbon dioxide — the waste product of cellular respiration — has diffused out of the cell into the capillary, the blood is now called deoxygenated blood. This is because it has lost most of its oxygen and gained carbon dioxide.

The waste-carrying deoxygenated blood travels in a path (figures 3.12 and 3.13). It is transported via capillaries to **venules** (small veins), then to increasingly larger veins, before the largest veins — called the **vena cava** — deliver it to the **right atrium** of the heart. From here it travels to the **right ventricle**, where it is pumped to your lungs through the **pulmonary artery** (so-called because it is associated with your lungs). The pulmonary artery is the only artery that does not contain oxygenated blood.

FIGURE 3.12 The path of oxygenated (red) and deoxygenated (blue) blood through the heart

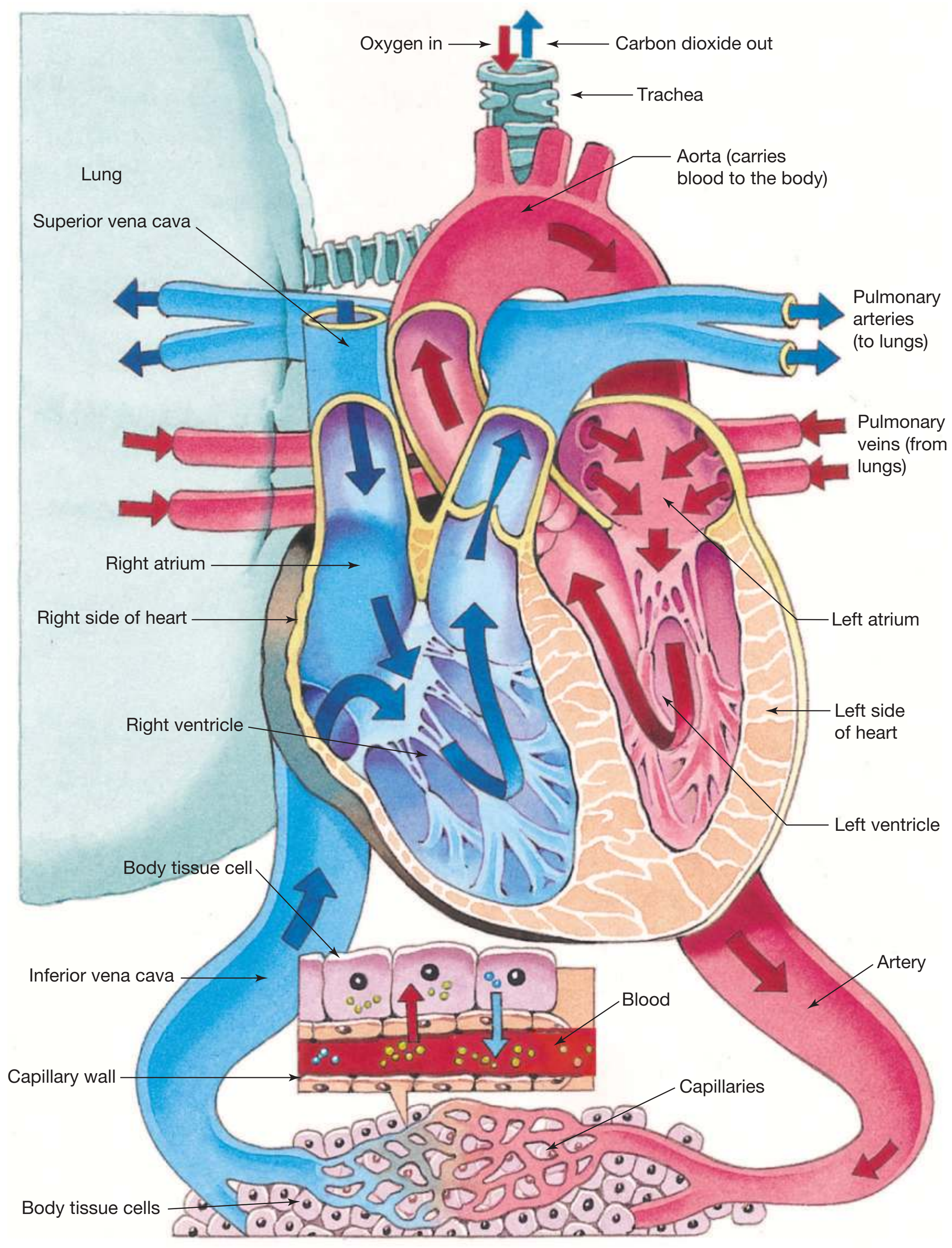
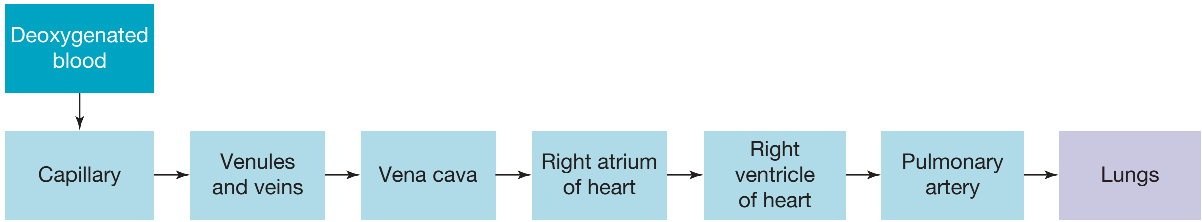


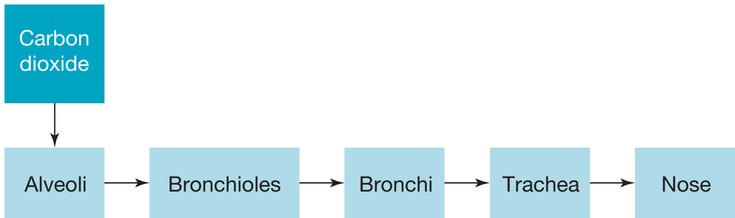
FIGURE 3.13 Flowchart of deoxygenated blood moving back to the lungs



Exhaling — to remove carbon dioxide from your respiratory system

To remove carbon dioxide from deoxygenated blood, your body needs to transfer the carbon dioxide into the respiratory system so it can be exhaled from the body. Carbon dioxide within your capillaries diffuses into the alveoli in your lungs. It is then transported into your bronchioles, then your bronchi and then into your trachea. From here, carbon dioxide is exhaled through your nose (or mouth) when you breathe out (figure 3.14).

FIGURE 3.14 Flowchart of carbon dioxide being released from the body



3.2.4 Working together

The respiratory and circulatory systems work closely together to keep your cells alive and functioning. The respiratory system provides oxygen, while the circulatory system transports it to the cells for cellular respiration. At the same time, carbon dioxide — the waste product — is carried back to the lungs to be removed from the body. Throughout this lesson, you have explored the pathway of oxygenated and deoxygenated blood through the heart and blood vessels, and learned how gas exchange takes place between the lungs, blood and body cells.

FIGURE 3.15 The respiratory and circulatory systems work together.

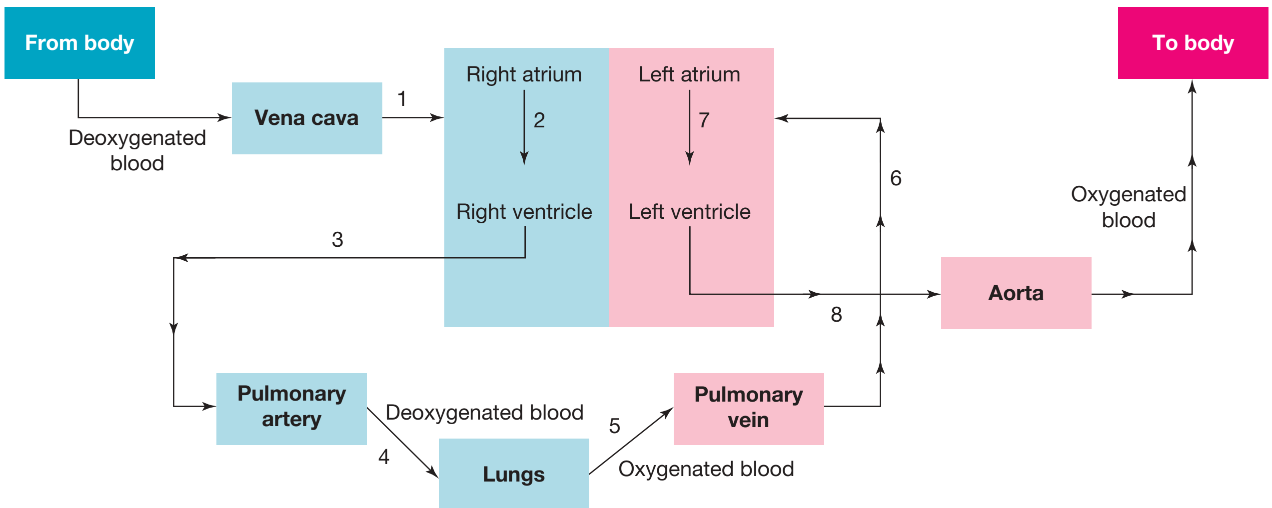
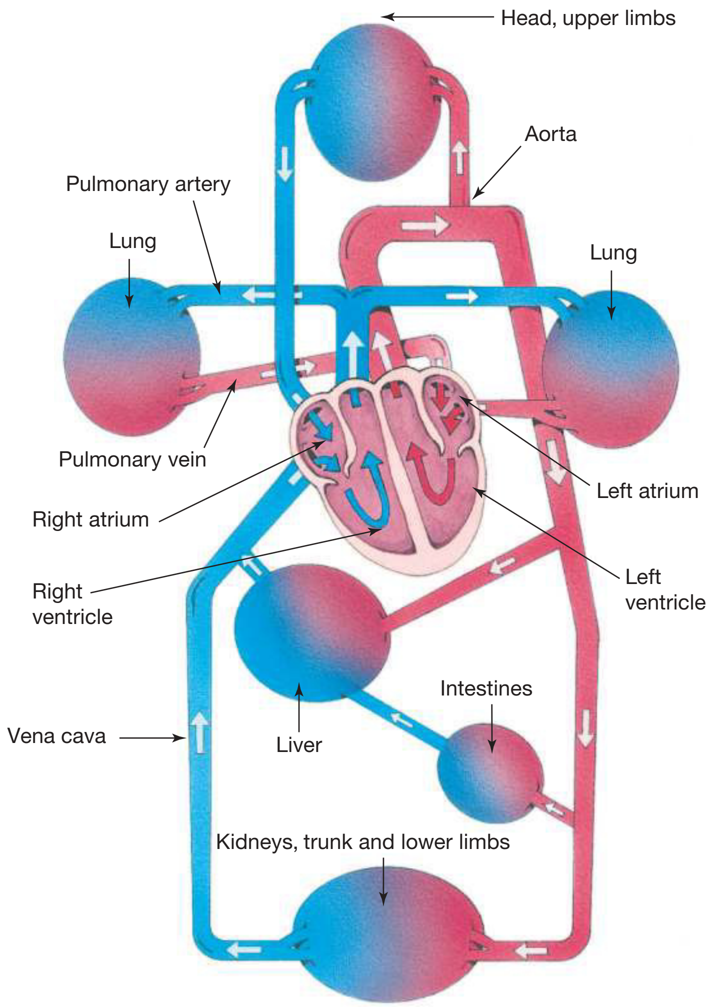


FIGURE 3.16 Connected highways — the routes for blood circulations



INVESTIGATION 3.1

The effect of exercise on the circulatory and respiratory systems

Aim

To investigate the response of the circulatory and respiratory systems to increasing levels of physical activity

Background

As the heart beats it sends a surge, or pulse, of blood through your blood vessels. The elastic walls of the arteries stretch and then relax as each surge of blood passes through them. We can feel each pulse passing through an artery wherever we have arteries close to the surface of the skin and can count these pulses to measure how fast our heart is beating. This is called our 'pulse rate' and is recorded in beats per minute.

A strong pulse can usually be felt in either the inside of the wrist, to the outside of the two tendons running up the inside of your arm near the base of your thumb, or in the neck, just below the hinge of the jaw. To record your pulse, you should place the tips of your first and second fingers (NOT your thumb, as there is a faint pulse in your thumb that will interfere with your counting and give a false reading) where you can feel the pulse, count the number of pulses in 30 seconds and then double this number to calculate the number of beats in 1 minute.

A normal resting pulse rate can be anywhere between 50 and 100 beats per minute (bpm).

Prediction

Predict what you think will happen to your pulse rate and breathing rate as you increase your level of activity. Explain why you think this will happen.

Materials

- stopwatch
- oximeter (optional)

Method

1. Sit quietly at your desk for 2 minutes. Try to be as calm and relaxed as possible.
2. Have your partner count the number of breaths you take during the second minute and record this in your results table. Use the oximeter to record your pulse rate (if using).
3. At the end of your 2 minutes of 'activity', your partner will count your breathing rate for 30 seconds. Double this answer to get your breaths per minute and record it in your results table.
4. In a suitable, safe, open space, such as the school yard, walk slowly for 2 minutes.
5. Repeat steps 2 and 3.
6. In a suitable, safe, open space, such as the school yard, walk briskly for 2 minutes.
7. Repeat steps 2 and 3.
8. In a suitable, safe, open space, such as the school yard, jog for 2 minutes.
9. Repeat steps 2 and 3.
10. In a suitable, safe, open space, such as the school yard, run at approximately 50 to 75 per cent of your maximum pace for 2 minutes.
11. Repeat steps 2 and 3.
12. In a suitable, safe, open space, such as the school yard, run at full pace for 2 minutes.
13. Repeat steps 2 and 3.

Results

1. Construct a table with the headings shown and record your results. Remember to include a title for your table.

Level of activity	Breathing rate (breaths per minute)	Pulse rate (beats per minute)
Resting		
Slow walking		
Fast walking		
Jogging		
Running		
Sprinting		

2. Create a bar graph of your results. This could be two separate graphs for breathing rate and pulse rate, or a single graph with two alternative *y*-axes and two sets of bars on the same graph.

Discussion

1. Discuss what happened to your pulse rate as you increased your level of exercise.
2. Discuss what happened to your breathing rate as you increased your level of exercise.
3. What else changed about your breathing as you increased your level of exercise?
4. Explain why these things occurred.
5. Responding to changes in activity involves far more than just your respiratory and circulatory systems. Research the immediate, short-term responses to exercise of the musculoskeletal, digestive, excretory, nervous and endocrine systems.

Conclusion

Summarise the findings of this investigation about the effect of exercise on the circulatory and respiratory systems.

3.2 Activities

learnon

3.2 Quick quiz on	3.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 7, 11	3, 4, 5, 10, 12	6, 8, 9, 13

Remember and understand

1. **Identify** the missing words to complete the sentence, using the word bank provided.
   alveoli, bronchi, bronchioles, trachea
   When you breathe in, air moves down your ________, then through the ________, then through ________ to tiny air sacs called ________.
2. **Identify** the missing words to complete the sentence.
   The process of cellular respiration requires ________ and glucose, and produces energy in a form that the cell can use and ________ as a waste product.
3. **State** the word equation for cellular respiration.
4. **Identify** the molecule that the respiratory system and circulatory system work together to:
   a. supply to your cells
   b. remove from your cells.
5. a. MC **Identify** the name given to the blood vessel that takes oxygenated blood from the lungs to the left atrium of your heart.
      A. Pulmonary artery
      B. Pulmonary vein
      C. Aorta
      D. Vena cava

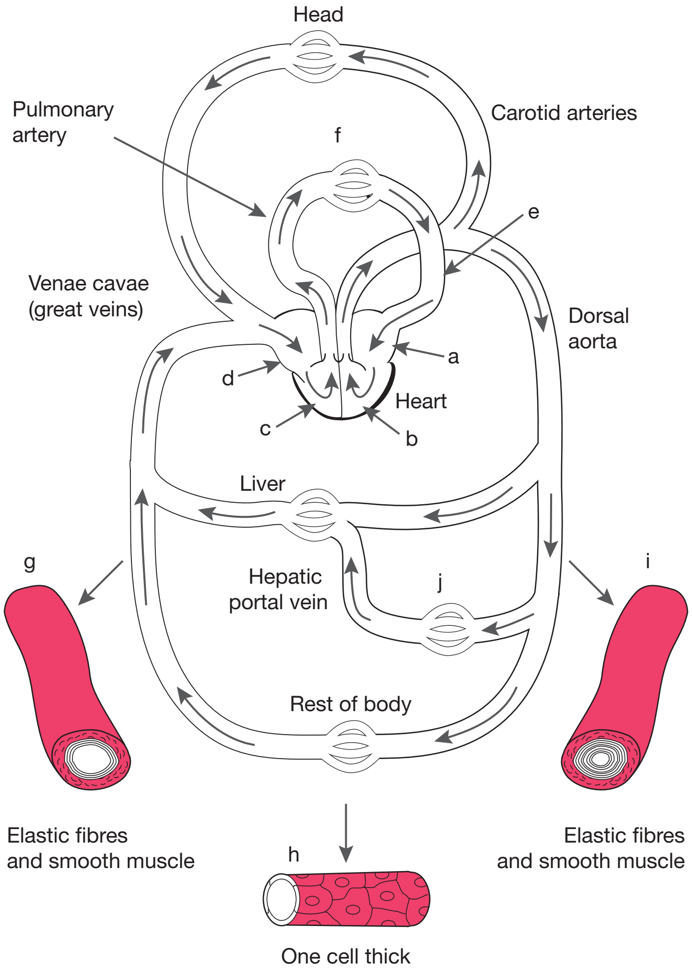
   b. MC **Identify** the name given to the blood vessel that takes deoxygenated blood from the right ventricle of your heart to your lungs.
      A. Pulmonary artery
      B. Pulmonary vein
      C. Aorta
      D. Vena cava

6. **List** the following components in order to show the pathway that carbon dioxide travels from your body cells to your lungs:
   a. Body cell
   b. Capillary
   c. Pulmonary artery
   d. Right atrium
   e. Right ventricle
   f. Vena cava
   g. Venules
   h. Lungs
   i. Arterioles
   j. Capillary
7. a. **Identify** whether each of the following statements is true or false.
      i. Oxygen is a product of cellular respiration.
      ii. Arteries have thicker, more muscular walls than veins.
      iii. Blood travels to the heart in arteries.
      iv. Blood in the aorta is oxygenated.
      v. Deoxygenated blood travels from your heart to your lungs in your pulmonary vein.

   b. Rewrite any false statements to make them true.

Apply and analyse

8. **Identify** the parts labelled a to j in the figure.



9. **SI** **Construct** a flowchart to show how oxygen travels through the body.
10. **SI** **Construct** a flowchart to show how deoxygenated blood travels from body cells to the lungs.
11. **SI** **Construct** a flowchart to show how carbon dioxide travels from the lungs to be exhaled through the nose.

Evaluate and create

12. **Compare**:
    a. the right atrium and left atrium of the heart
    b. the right ventricle and left ventricle of the heart
    c. the left atrium and left ventricle of the heart
    d. oxygenated blood and deoxygenated blood.
13. **Compare**:
    a. arteries and veins
    b. oxygen and carbon dioxide
    c. the pulmonary artery and pulmonary vein
    d. the aorta and vena cava.

Answers and sample responses are available in your digital formats.

LESSON 3.3 Homeostasis in action

LEARNING INTENTION

In this lesson you will:
- recall the five key features of a stimulus–response model
- define homeostasis
- explain the difference between negative and positive feedback mechanisms.

3.3.1 Stimulus–response model

Much of what sustains life is the result of many chemical processes (like cellular respiration and protein synthesis) and physical processes (such as the diffusion of oxygen and glucose) working together in balance. Factors such as temperature, pH or the concentration of dissolved molecules can affect the rate of these processes. If these conditions change too much, it can disrupt how these processes connect, and interfere with the body's ability to maintain life. For this reason, it is essential that we maintain a constant internal environment. Maintenance of this constant internal environment is called **homeostasis.**

To maintain homeostasis, changes within the environment (**stimuli**) need to be detected (by **receptors**), interpreted by a **control centre** (such as the brain) and then, if necessary, action taken by the appropriate body part (an **effector**) to return the environment to more suitable conditions (a **response**). This sequence is referred to as the **stimulus–response model** and involves two major functioning systems in the body: the **nervous system** and the **endocrine system.**

FIGURE 3.17 The stimulus–response model

Stimuli

There are various stimuli that your body needs to detect and, if necessary, respond to. Some of these stimuli may be outside of your body, such as environmental temperature or potentially dangerous (e.g. hot or sharp) objects. Other stimuli may be inside your body, such as changes in body temperature and blood sugar, pH or water levels.

Receptors

Receptors detect changes both inside and outside your body. These specialised nerve cells are found in sense organs such as your eyes, ears, nose, tongue and skin (figure 3.18).

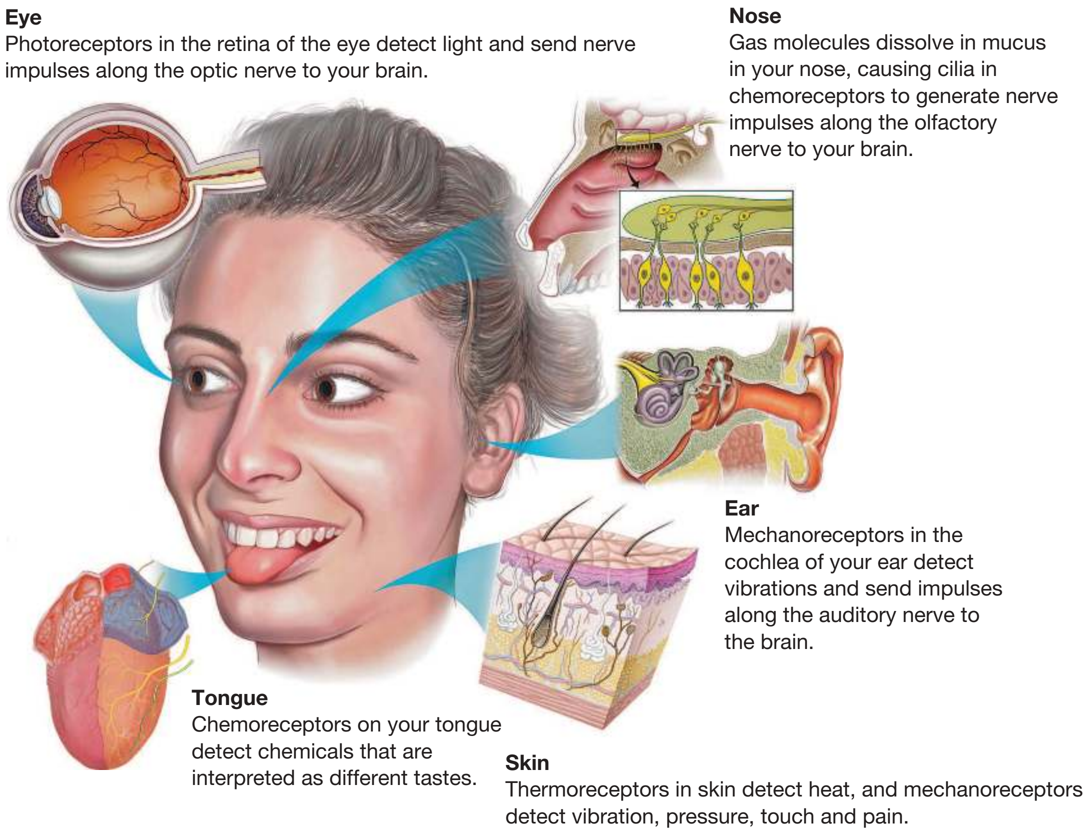
Control centre/modulator

Once a stimulus is detected by a receptor, a message — called a nerve impulse — is sent to the central nervous system, which includes the brain and spinal cord. It is here that the message is processed to determine which response will be appropriate. A message is then sent to the appropriate effector.

Effectors

Effectors such as muscles or glands receive the message from the central nervous system to respond in a particular way. Their response depends on the original stimulus. For example, if your hand is too close to a candle flame, then muscles in your arm may respond to move your hand away from it. If your body temperature increases too much, your sweat glands produce sweat to help cool you down.

FIGURE 3.18 Examples of the receptors in the human body



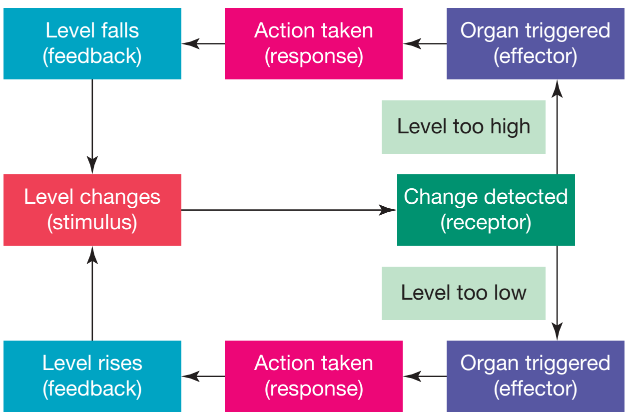
3.3.2 Feedback mechanisms

Stimulus–response models can also involve negative or positive feedback. Most biological feedback systems involve negative feedback.

Negative feedback

Negative feedback occurs when the response is in an opposite direction to the stimulus. It is a homeostatic mechanism that allows for the maintenance of variables within a set range. For example, if levels of a particular chemical in the blood were too high, such as glucose, then the response would be to lower them. Likewise, if the levels were too low, then they would be increased. The response is ‘fed back’ into the system, allowing for further adjustments to be made if required. The key stages of a negative feedback loop are shown in figure 3.19.

FIGURE 3.19 The key stages of a negative feedback loop in the body



SCIENCE AS A HUMAN ENDEAVOUR: Advancing knowledge of negative feedback systems

Negative feedback mechanisms play a crucial role in maintaining homeostasis in living organisms, ensuring that internal conditions remain stable within a specific range. The study and understanding of these processes has significantly advanced through the development of technologies in both neuroscience and endocrinology.

For example, breakthroughs in imaging technologies like functional MRI (fMRI) and advanced microscopy have allowed scientists to observe how **neurons** transmit electrical impulses and communicate using neurotransmitters in real-time. Similarly, developments in hormone assay techniques have enabled precise measurement of hormone levels in blood and tissues, providing insights into how the endocrine system regulates homeostasis.

FIGURE 3.20 Functional MRI (fMRI) allows scientists to observe brain activity.

Scientific knowledge of negative feedback mechanisms is continually refined. For instance, research into diabetes has expanded our understanding of glucose regulation. Scientists have studied how insulin (a hormone) lowers blood glucose levels, while glucagon increases it, both working through negative feedback loops. These insights have led to the development of technologies like continuous glucose monitors and artificial pancreas devices, which mimic these natural processes to manage diabetes more effectively.

The knowledge gained through this research has profound implications for addressing health issues, improving medical treatments and designing bioengineered systems that replicate natural feedback mechanisms.

1. Define negative feedback. Why is it essential for maintaining homeostasis in living organisms?
2. Explain how the nervous and endocrine systems interact to regulate homeostasis through negative feedback.
3. How have imaging technologies, like fMRI, improved our understanding of how the nervous system communicates?
4. Discuss the role that advancements in hormone assay techniques have played in studying endocrine system feedback loops.
5. How has research into negative feedback mechanisms contributed to medical advancements, such as managing diabetes?
6. Hypothesise some ways that future technologies, such as bioengineered feedback systems, could improve health outcomes.

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

Positive feedback

Positive feedback occurs when a response needs to be amplified or increased. In the human body, examples include blood clotting to seal a wound and the stimulation of muscle contractions during childbirth.

3.3.3 How messages are sent in the body

To work together effectively, these mechanisms require coordination. The two systems with this responsibility are the nervous system and the endocrine system. Both of these systems require signalling molecules to communicate messages throughout the body. They use different methods to achieve this. The nervous system uses a combination of electrical and chemical signals. The endocrine system uses hormones.

TABLE 3.1 Comparison of messages sent through the endocrine and nervous systems

Feature	Endocrine system	Nervous system
Speed of message	Slow	Fast
Speed of response	Usually slow	Immediate
Duration of response	Long-lasting	Short
Spread of response	Through whole body, but only acts on the target organ	Very localised
How message travels through the body	In circulatory system — in bloodstream	In nervous system — along nerves and across synapses
Types of message	Hormones (chemicals)	Electrical impulses and neurotransmitters (chemicals)

ACTIVITY: Homeostasis challenge

In groups, ask students to prepare a brief skit demonstrating a stimulus–response model example, including how negative or positive feedback mechanisms play a role. Perform the skit in front of the class.

3.3 Activities

learnon

3.3 Quick quiz on | 3.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 7, 9	3, 5, 8	4, 6, 10

Remember and understand

1. **Identify** which of the terms on the left matches each of the definitions on the right.

Components involved in homeostasis

Term	Definition
a. Hormone	1. Command system of the body: brain, spinal cord and nerves
b. Neurotransmitter	2. The glands and organs that make hormones
c. Nervous system	3. Chemical responsible for controlling and regulating the activities of certain cells and organs
d. Endocrine system	4. Chemical messenger released by neurons

2. MC **Identify** which of the following detects or identifies changes or variations on the inside or outside of your body.
   A. Effectors B. Receptors C. Response D. Stimuli
3. MC **Identify** which of the following would bring about a response to changes or variations in the internal environment of your body.
   A. Effectors B. Receptors C. Response D. Stimuli
4. **Outline** an example of homeostasis in regard to the human body.
5. **Define** each of the following terms.
   a. Stimulus–response model
   b. Control centre
   c. Effector
   d. Receptor

Apply and analyse

6. **Identify** each of the following as positive or negative feedback.
   a. Blood glucose levels increase and insulin returns this back to normal levels.
   b. During a fever, your body's temperature continues to increase away from the set body temperature.
   c. When your body temperature decreases, thyroxine acts to increase your metabolism and body temperature.
7. **Identify** the missing words to complete the sentence, using the word bank provided.
   effectors, receptors, response, stimuli
   The stimulus–response model describes how __________, such as changes in the internal environment of your body, are detected by __________, which may communicate the message to __________ to bring about some kind of __________ so that conditions are brought back to normal.
8. **Outline** an example of a negative feedback mechanism in the human body.

Evaluate and create

9. **Construct** a flowchart to show the relationship between the following: effector, response, control centre, stimulus, receptor.
10. Produce a negative feedback loop diagram to illustrate the stimulus–response process for something that occurs in the body.

Answers and sample responses are available in your digital formats.

LESSON 3.4 Sense organs

LEARNING INTENTION

In this lesson you will describe the links and differences between the senses and different types of receptors in the human body.

3.4.1 Your senses

Your survival can depend on detecting changes in your environment.

Imagine not being able to see, hear, feel, taste or smell the world around you. No sound, no colour, no flavour or scent — just darkness and silence. Without your senses, you would not even be aware of what you were missing.

Sense organs are used to detect stimuli (such as light, sound, touch, taste and smell) in your environment. Examples of human sense organs are your eyes, ears, skin, tongue and nose. These sense organs contain special cells called receptors. These receptors are named according to the type of stimuli that they respond to (as shown in table 3.2).

TABLE 3.2 Examples of different types of receptors

Sense	Sense organ	Stimulus	Receptor	Type of receptor
Sight	Eye	Light	Rods and cones in the retina	Photoreceptor
Hearing	Ear	Sound	Hairs in the cochlea	Mechanoreceptor
Touch	Skin	Heat, cold, pressure, movement	Separate receptors for each type of stimulus	Thermoreceptor Mechanoreceptor
Taste	Tongue	Chemical substances: sweet, salty, bitter and sour	Tastebuds	Chemoreceptors
Smell	Nose	Chemicals: odours	Olfactory nerves inside the nose	Chemoreceptors

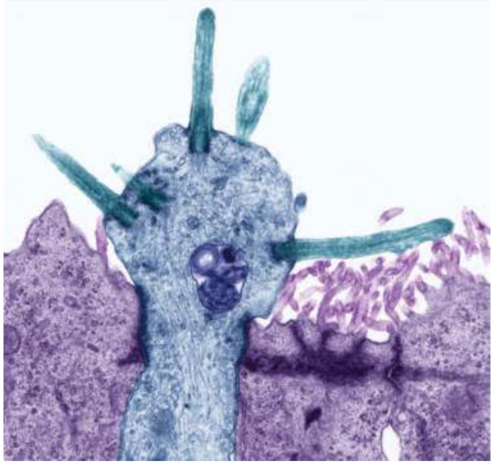
The five receptors

There are five different types of receptors in the body.

1. **Thermoreceptors** enable you to detect variations in temperature and are located in your skin, body core and part of your brain, called the hypothalamus.
2. **Mechanoreceptors** are sensitive to touch, pressure, sound, motion and muscle movement, and are located in your skin, skeletal muscles and inner ear.
3. **Chemoreceptors** are sensitive to particular chemicals and are located in your nose and tastebuds (see figure 3.21).
4. **Photoreceptors** are sensitive to light and are located only in your eyes.
5. **Pain receptors** enable you to respond to chemicals released by damaged cells. Detection of pain is important because it generally indicates danger, injury or disease. Although these receptors are located throughout your body, they are not found in your brain.

Each type of receptor is a different shape as they are specialised to respond to a different stimulus as listed in table 3.2.

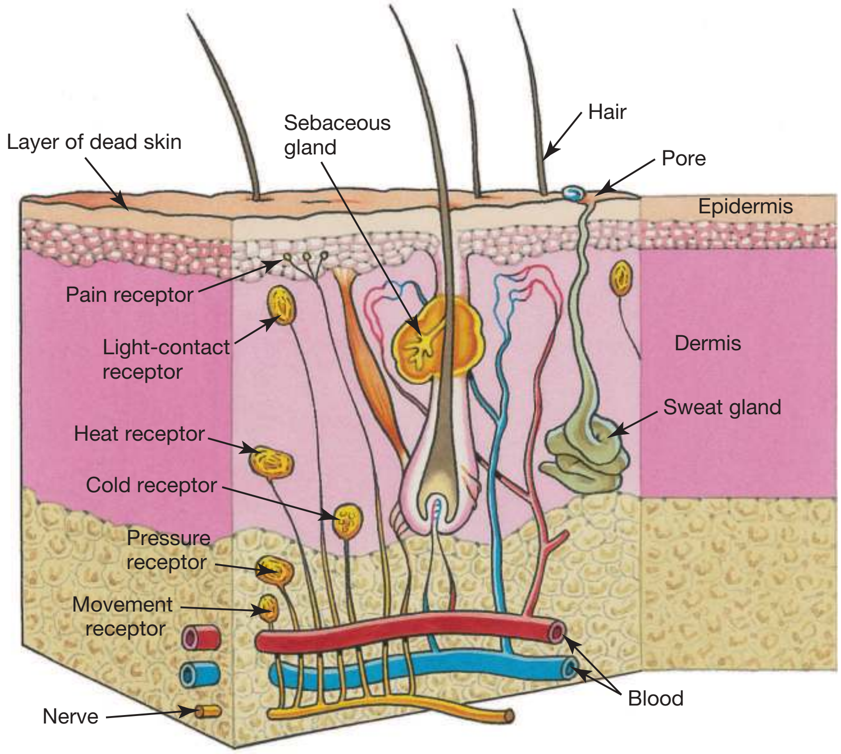
FIGURE 3.21 Transmission electron microscope (TEM) image of a chemoreceptor



3.4.2 Touch receptors

Your skin contains different types of receptors (figure 3.22). Pain receptors and mechanoreceptors enable you to detect whether objects are sharp and potentially dangerous. There are also hot thermoreceptors that detect an increase in skin temperature above the normal body temperature (37 °C) and cold thermoreceptors that detect a decrease below 35.8 °C. These thermoreceptors can also protect you from burning or damaging your skin. The sensitivity of these receptors can depend on how close together they are and their location in your skin.

FIGURE 3.22 Your skin contains a variety of receptors that provide you with a sense of touch.



INVESTIGATION 3.2

Touch receptors in your skin

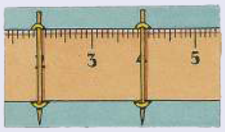
Aim

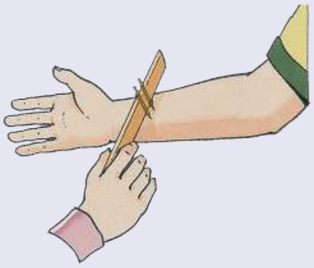
To detect where the skin is most sensitive to light contact

Materials

- 2 toothpicks
- ruler
- 2 rubber bands
- blindfold

Method





1. Use rubber bands to attach two toothpicks to a ruler so that they are 2 cm apart.
2. Predict in which areas of the body the skin will be most and least sensitive.
3. Blindfold your partner. Gently touch your partner's inside forearm with the points of the two toothpicks. Ask your partner whether two points were felt.
4. Move one toothpick towards the other in small steps until your partner is unable to feel both points. To make sure that there is no guesswork, use just one point from time to time.
5. Record the distance between the toothpicks when your partner can feel only one point when there are really two points in contact.
6. Repeat this procedure on the palm of one hand, a calf (back of lower leg), a finger and the back of the neck.
7. Swap roles with your partner and repeat the experiment.

Results

1. Construct a table with the headings shown and record your observations. Include a title for your table.

Part of the skin	Distance (cm) between two points when only one point is felt	
	Your partner	You
Inside forearm		
Palm of hand		
Calf		
Finger		
Back of neck		

2. Construct a graph to represent your data.

Discussion

1. Identify which type of touch receptors were being used in this experiment.
2. Comment on any observed patterns in your graph.
3. Identify which area of the skin was (a) most sensitive and (b) least sensitive.
4. Suggest why the skin is not equally sensitive all over the body.
5. Identify and list which parts of the skin are likely to have the most contact receptors.
6. Discuss how your predictions compared to your experimental results.

Conclusion

Summarise the findings of this investigation about touch receptors.

3.4.3 Smell receptors

Imagine the sweet smell of a rose or the unpleasant stink of rubbish. Tiny gaseous molecules from the air enter your nose as you breathe. When these molecules dissolve in the mucus lining of your nasal cavity, they stimulate the hair-like cilia of chemoreceptors. These receptors send a message along the **olfactory nerve** to the brain, where the smell is identified and interpreted (figure 3.23).

FIGURE 3.23 A flowchart of how we process smell

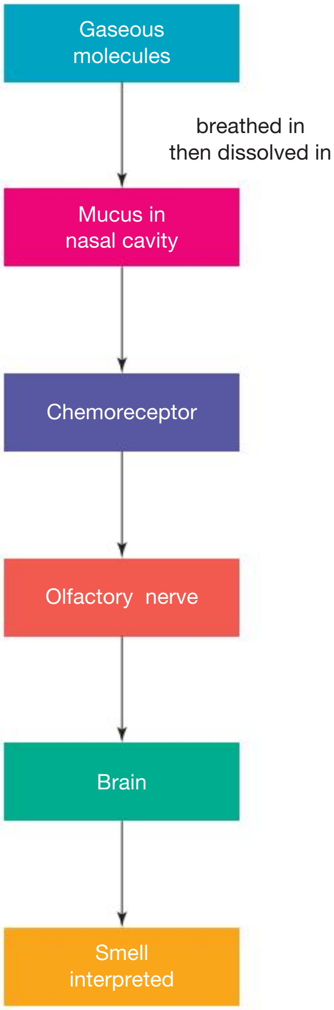
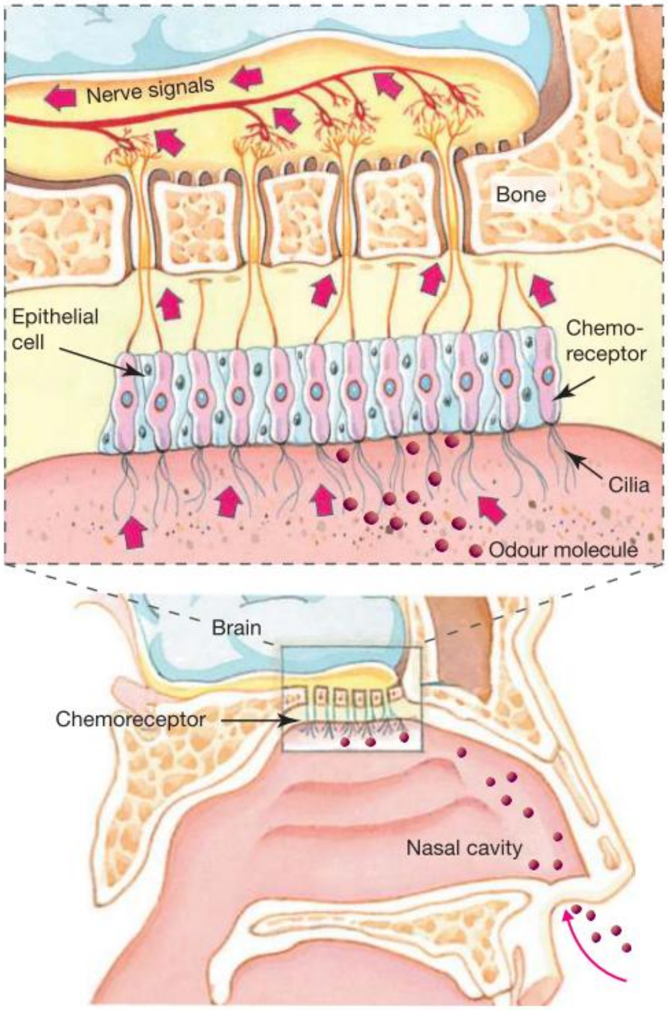


FIGURE 3.24 Chemoreceptors in your nose enable you to have a sense of smell.

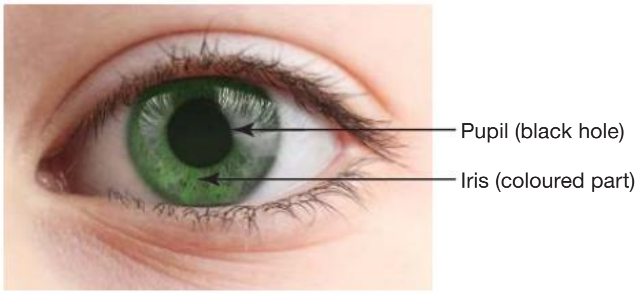


3.4.4 Sight receptors

The images you see are created when light waves enter the eye and reach the **retina** — a layer lining the inside of the eye that contains photoreceptors. These receptors detect light and send messages to the brain, allowing us to see. When you look at your eye in the mirror, you will see:

- the **iris**, the coloured part of your eye, which is a ring of muscle
- the **pupil**, the dark spot in the centre of your eye. Your pupil is simply a hole in the iris.

FIGURE 3.25 The iris and the pupil in the eye



The iris controls the amount of light entering the eye. When the iris relaxes, the pupil appears bigger, letting more light into the eye; and when it contracts, the pupil looks smaller, letting less light into the eye. In a dark room, your pupil is large so that as much light as possible can enter your eye. If you were to move outside into bright light, your pupil would become smaller. This reflex action helps to protect your eyes from being damaged from too much light.

Structure of the eye

The **cornea** is the clear outer 'skin' of your eye. It is curved so that the light approaching your eye is bent towards the pupil. The clear, jelly-like **lens** bends or focuses light onto a thin sheet of tissue that lines the inside of the back of your eye called the retina. The lens is connected to muscles, which can make it thick or thin. This allows your retina to receive a sharp image of distant or nearby objects. Your retina contains photoreceptor cells called **cones** and **rods**. The rod cells detect light intensity and the cone cells respond specifically to colour (figure 3.26).

FIGURE 3.26 A view of the cones and rods in your eye

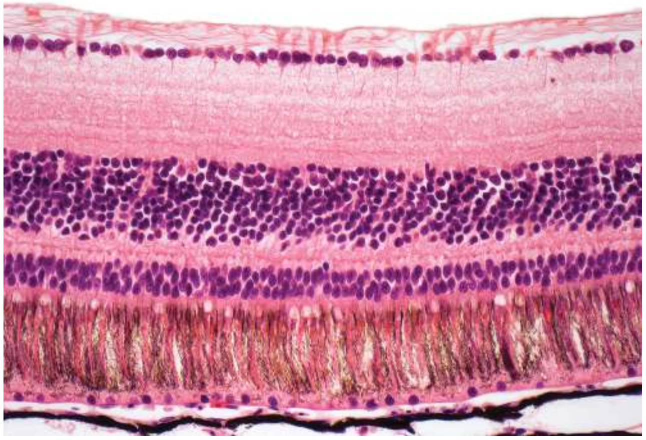
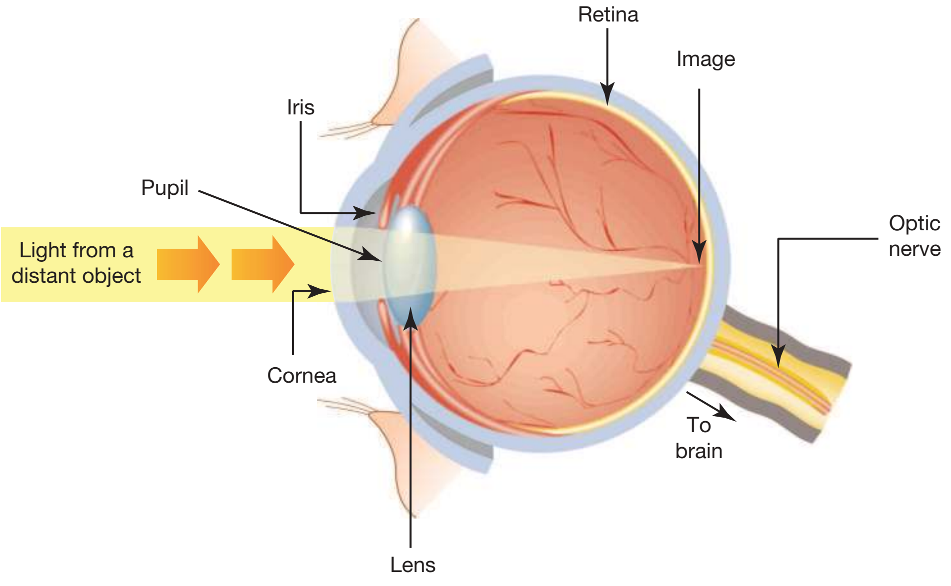
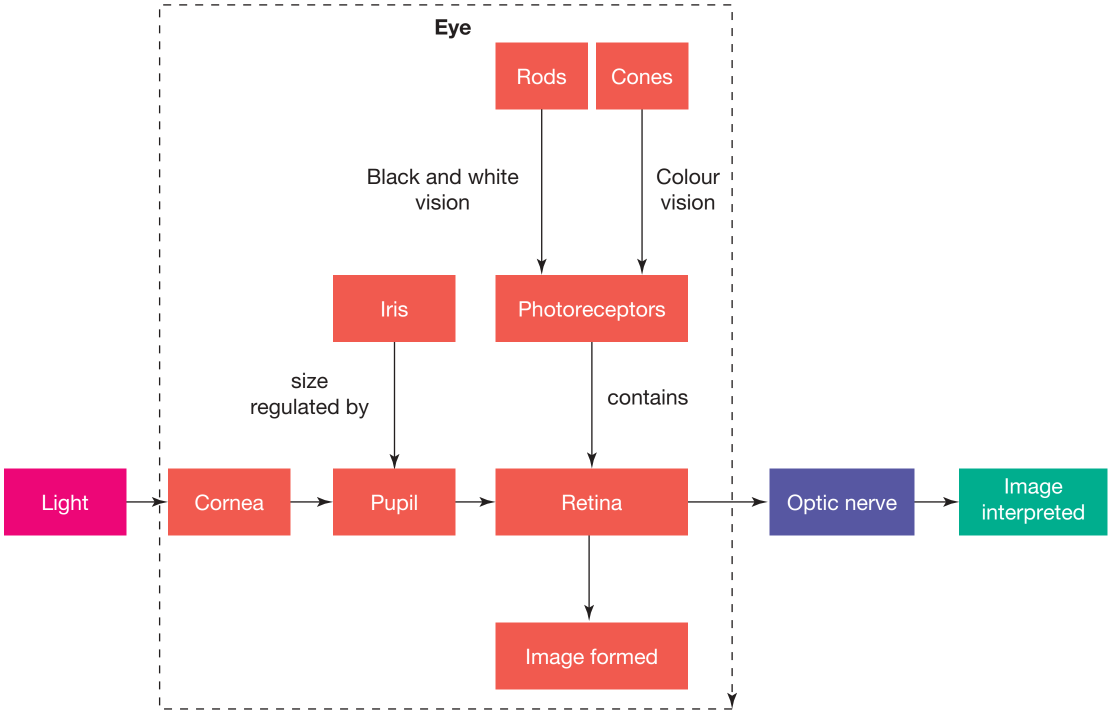


FIGURE 3.27 There are a number of structures within your eyes that function together so that you can detect and respond to light.



Although your eye receives light and produces an image of what you see, it is your brain that interprets and makes sense of the image. The photoreceptors in the retina respond to the light stimuli by sending signals to your **optic nerve**, which then forwards them to your brain for interpretation. The process is outlined in figure 3.28.

FIGURE 3.28 Flowchart of how cells and nerves work together to allow us to see



ACTIVITIES: The eye

Blind spot

The retina is covered in light-sensitive photoreceptors — except for the point where the optic nerve leaves the retina to go to the brain. Light falling on this area is not detected and produces a blind spot in our vision. Follow the steps to find your blind spot.

1. Draw a circle and a cross on a piece of paper a few centimetres apart.

2. Close or cover your left eye and look at the circle with your right eye from directly above it.
3. Without moving position, look slightly left with your right eye to focus on the cross.
4. Slowly move your head backwards and forwards, away from and towards the paper — there should be a point at which the circle disappears from your peripheral vision. This is when light reflected from the circle is falling on your blind spot.
5. Repeat by closing your right eye and looking at the circle with your left. There should be a position where the cross disappears.

Colour vision

The cone cells in our retina that are designed to detect colour are concentrated in a spot directly behind the lens, called the fovea, where we create the sharp, colour image of the things directly in front of us. Around the rest of the retina we have rod cells. These provide us with our peripheral vision. Rod cells are more sensitive to light but do not detect colour, and mostly warn us about movement to the side of where we are focused ('I spotted it out the corner of my eye').

1. Look straight ahead.
2. Have a partner sit behind you with a brightly coloured object — a colouring pen or pencil is ideal — held between their fingers.

3. Have your partner slowly bring their object forward past the side of your head, approximately 15 cm out from your right ear. They should wiggle the object as they do so to provide movement.
4. As soon as you are aware of the movement, and without turning to look at it, try to identify the colour of the object.
5. Repeat on the left side of your head.

You should find that you become aware of the movement as the object enters the very edge of your vision, but cannot identify the colour until it is much further forward.

Judging distance

Having two eyes in the front of our head, a few centimetres apart, allows us to judge distances. The brain receives information from a slightly different angle from each eye and uses this information to judge how far away the object you are looking at is. This is a typical feature in predatory animals, allowing them to judge how far away a prey organism is before pouncing on it.

1. Close or cover one eye.
2. Have a partner hold a pencil with the point upwards in front of you.
3. Attempt to place the tip of your finger on the point of the pencil.

How did you get on? Was it easier with one eye than the other?

Dominant eyes

You will be aware of people being right- or left-handed, and probably aware of them being right- or left-footed, but did you know that people can be right- or left-eyed?

1. Pick an object in the near distance, such as the classroom door, a window frame or the edge of the whiteboard.
2. With both eyes open, hold one finger up at arm's length (as if you are giving someone the sign for 'out' at the cricket) and line it up as best you can with your distant object — your finger will appear a bit blurry and it may seem like you are holding up two fingers.
3. Now close one eye at a time. Your finger will remain lined up with one eye but appear to jump off to the side with the other. The eye that is open when your finger remains lined up is your dominant eye.

Are you right- or left-eyed?

INVESTIGATION 3.3

Dissection of a mammal's eye

Aim

To investigate the structure of an eye

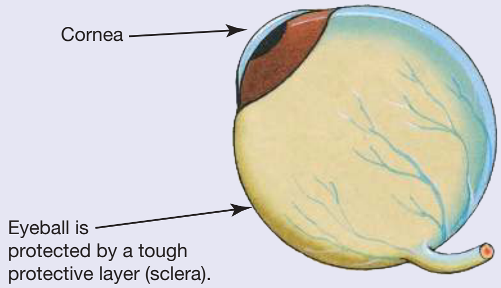
CAUTION: Handle dissecting instruments with care and ensure they are placed in a sterilising solution after use. Wear safety glasses and disposable gloves throughout the dissection and wash your hands thoroughly at the end.

Materials

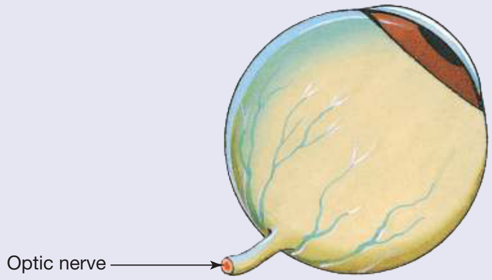
- bull's eye or similar
- dissection board
- newspaper
- paper towelling
- scalpel or razor blade
- safety glasses
- forceps
- stereo microscope
- water
- disposable gloves

Method

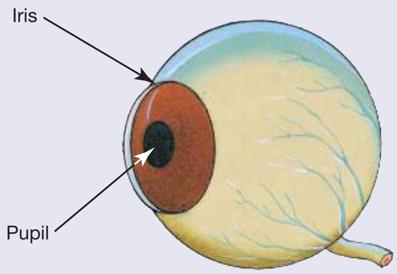
1. Put on safety glasses just in case any of the aqueous or vitreous humour squirts out at you. Aqueous and vitreous humour are jelly-like liquids that give eyes their shape.
2. Carefully place the bull's eye on a dissection board covered with newspaper and paper towelling. Locate the transparent skin of the cornea. Draw and label the structures of the bull's eye before and after your dissection. (Use the diagrams provided to help you to label your drawing.)



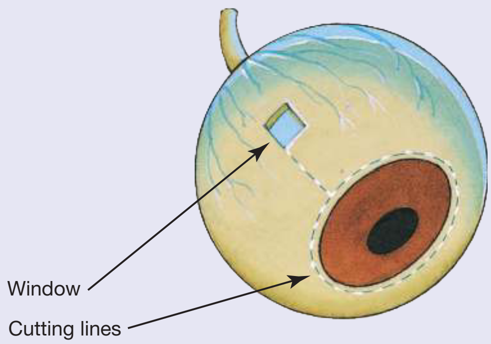
3. Locate the optic nerve. It is a hard, white, solid tube at the back of the eye. You may have to remove some fat to see it. Add descriptive comments to your labels as you make your observations throughout this activity.



4. Look at the coloured part of the eye (iris) and the black part in the centre (pupil).



5. Cut a small window in the eyeball. Be careful that the vitreous humour does not run out. Starting from this window, cut forward and around the iris. Record your observations regarding the toughness of the sclerotic coating.



6. From this window, cut towards and then all the way around the iris so that you have cut the eye into two parts.
7. Lift off the top part of the eye and examine the iris.
8. Remove the lens with forceps and see if you can read the print on the newspaper through it.
9. Use water to rinse out the jelly-like material (humour) from inside the eye and examine the retina. Record your observations.
10. Follow your teacher's instructions regarding the cleaning of equipment and disposal of the dissected eye.

Results

Draw labelled diagrams of the eye before and after the dissection.

Discussion

1. What is the black part in the middle of the iris? Describe its function.
2. Describe what you observed when you looked at the newspaper through the lens.
3. Describe what the retina looked like. Could you find the optic nerve?
4. State what the diaphragm in a microscope does.
5. Which part of the eye does the diaphragm in a monocular microscope most resemble?
6. Summarise your findings in a table.

Conclusion

Summarise the findings of this investigation about the structure of the eye.

ACTIVITY: In the dark

Investigate the effect of light intensity on the iris of a human eye.

- Cup your hands loosely over both eyes so that you cannot see anything but your hands. Keep your eyes open. Look at the insides of your hands.
- After about one minute, have your partner look carefully at your pupils.

1. What happens to the iris as your hands are removed?
2. Explain your observations.

3.4.5 Hearing receptors

The ear is your sense organ that detects sound. The steps involved in the detection of sound and the process of hearing are as follows:

1. Sound travels by waves, which are vibrations in the air.
2. When the air inside your **ear canal** vibrates, it causes your **eardrum** to vibrate at the same rate.
3. Three tiny bones known as **ossicles** in your **middle ear** receive this vibration from your eardrum and then pass it to your inner ear.
4. Inside your inner ear, thousands of tiny hairs attached to nerve cells of the snail-shaped **cochlea** detect the vibration and send a message to your brain via your **auditory nerve**.
5. Your brain interprets the message as hearing sounds.

FIGURE 3.29 An electron micrograph of hair cells in the cochlea

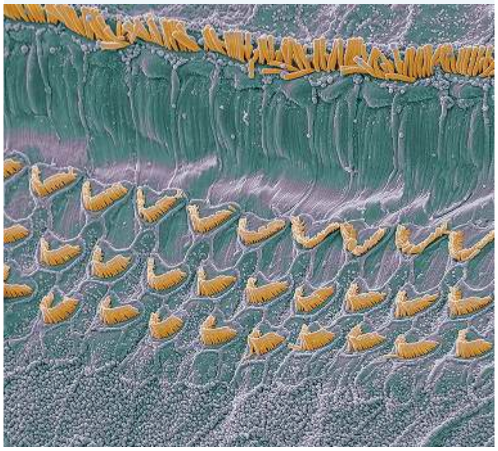


FIGURE 3.30 Your ear contains specialised structures that help you to detect sound.

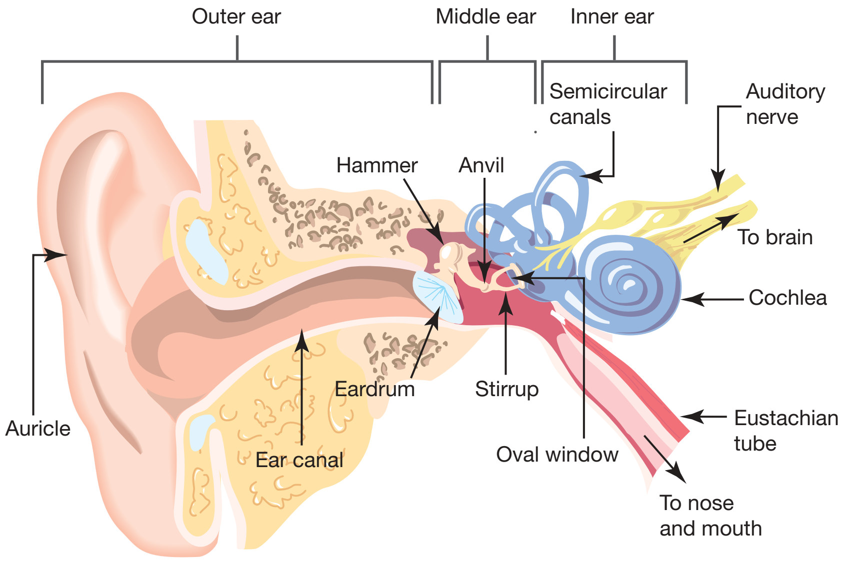
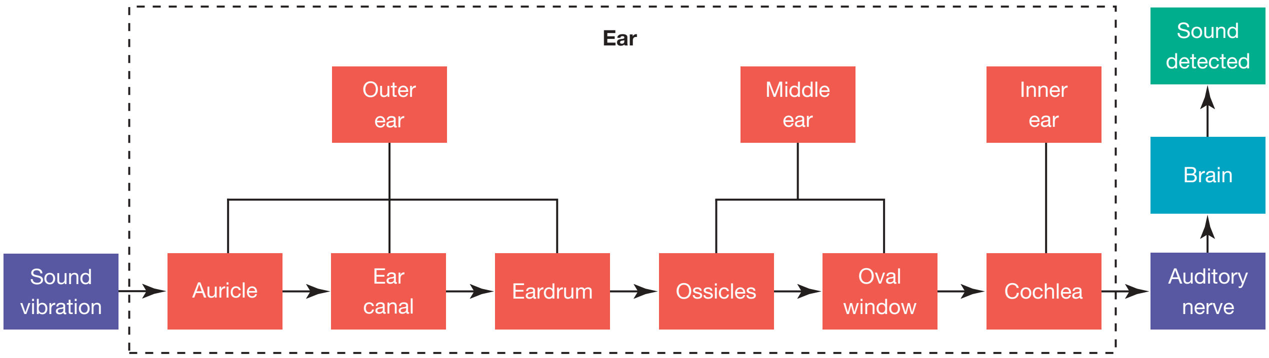


FIGURE 3.31 Flowchart of the steps that allow us to hear



SCIENCE AS A HUMAN ENDEAVOUR: Cochlear implant — the ‘bionic ear’

In the 1960s, Australian surgeon and researcher Professor Graeme Clark led the development of the first multi-channel cochlear implant, known as the bionic ear. This groundbreaking innovation was first implanted in a patient in 1978 at Melbourne’s Royal Eye and Ear Hospital. Since then, cochlear implants have transformed the lives of hundreds of thousands of people globally, restoring hearing and enabling communication for those with severe hearing loss.

A cochlear implant is an electronic device that bypasses damaged parts of the ear to directly stimulate the auditory nerve. It consists of:

- the headpiece — worn externally, it contains the transmitter, microphone and speech processor
- the receiver — implanted under the skin near the ear, it receives signals from the headpiece.

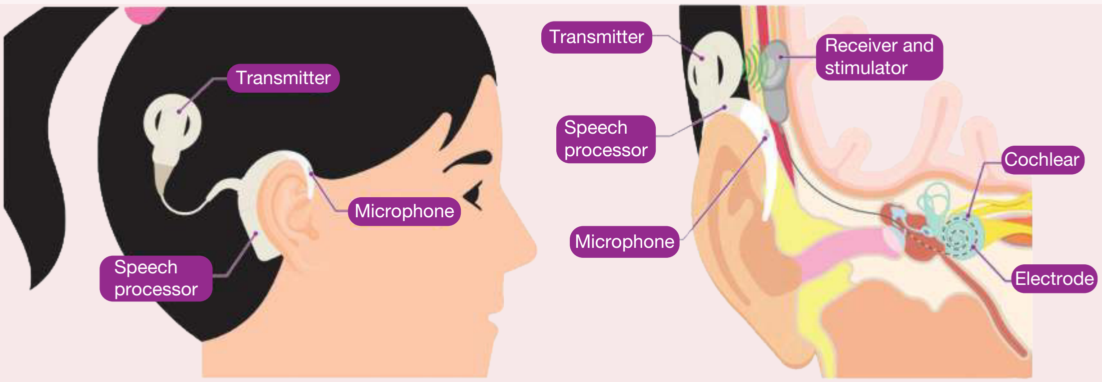
Unlike hearing aids, which amplify sound, cochlear implants convert sound into electrical signals, which are sent to the auditory nerve and interpreted by the brain as sound.

FIGURE 3.32 Professor Graeme Clark

Cochlear implants represent a significant leap in the intersection of medicine and technology, paving the way for innovations in neural prostheses. From its Australian origins, the technology has become a standard treatment for profound hearing loss worldwide, enabling people to hear, communicate and engage with society. Scientists are now working to refine cochlear implant technology to improve sound quality and expand its use to patients with varying degrees of hearing loss.

FIGURE 3.33a An individual fitted with a cochlear implant

FIGURE 3.33b Components of a cochlear implant



1. Identify the key differences between a hearing aid and a cochlear implant.
2. Explain how the cochlear implant can bypass the damaged areas of the ear to stimulate the auditory nerve.
3. Explain the challenges individuals might face when adapting to a cochlear implant.
4. Discuss how Professor Graeme Clark's invention influenced the development of other neural prostheses.
5. Suggest why the cochlear implant is considered a milestone in the intersection of medicine and technology.
6. What ethical considerations might arise when developing and implementing medical technologies like the cochlear implant?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

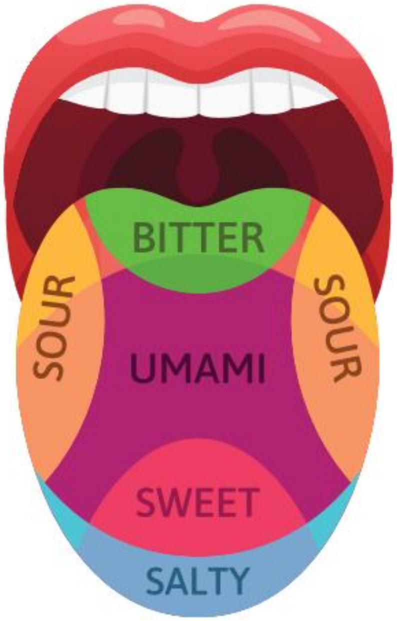
3.4.6 Taste receptors

The tongue is your sense organ for taste. **Tastebuds** located within bumps called **papilla** across your tongue have the ability to sense all flavours. This is because each of these tastebuds (see figure 3.34) contains cells with receptors for each type of flavour. Taste can be classified into five categories: sweet, salty, sour, bitter and umami.

Many people believe that different parts of the tongue are responsible for tasting different flavours — but this is actually a myth (see figure 3.35). Taste buds that can detect sweet, salty, bitter, sour and umami flavours are spread all over the tongue. While some areas such as the tip of the tongue might be slightly more sensitive to certain tastes, all regions of the tongue can detect all five flavours.

FIGURE 3.34 Tastebuds contain chemoreceptors (as shown here), which are sensitive to particular chemicals.

FIGURE 3.35 The idea that different parts of the tongue are responsible for different tastes has been proven wrong.



ACTIVITY: Umami

Historically, we have classified taste into four main types: sweet, salty, bitter and sour. More recent findings suggest a fifth basic taste, known as umami. Find out what umami is and create an infographic or poster outlining the five basic tastes, including common foods in each category.

INVESTIGATION 3.4

Our senses and the stimulus–response model

Aim

To investigate our senses and the stimulus–response model

Background knowledge

Our body has receptors designed to detect stimuli. We then respond to these stimuli. There are five traditional 'senses' — sight, hearing, touch, taste and smell. We can compare our reactions to three of these senses — sight, hearing and touch — with the following experiment.

Materials

- metre ruler
- blindfold (optional)

Method

1. Work in groups of two. Person 1 holds their hand steady (rest it on a desk if this makes it easier) with their thumb and forefinger 2 cm apart.
2. Person 2 holds the ruler with the 0 cm marker between the thumb and forefinger of the person being tested.
3. Person 2 drops the ruler without warning.
4. Person 1 catches the ruler as soon as they see it drop.
5. Record the distance the ruler dropped before being caught.
6. Repeat three times and calculate the average distance dropped.
7. Blindfold person 1 (or have them close their eyes).
8. Repeat steps 1–6, but with person 2 calling out 'now!' as they release the ruler.
9. Repeat steps 1–6, but with person 2 tapping person 1 (still blindfolded) on the forearm as they release the ruler.

Results

1. Record your results in a suitable table.
2. Plot a bar graph of sense versus average drop.

Discussion

1. Compare your reaction times using different senses. Which one was the fastest, and why do you think it worked best?
2. Identify things that could have affected your reaction time during the investigation, such as distractions or how alert you were.
3. Suggest a way to improve the experiment or test a different sense. How could this make your results more accurate?

Conclusion

Summarise the findings for this investigation.

3.4 Activities

learnon

3.4 Quick quiz on	3.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 9	2, 6, 8, 10, 11	3, 5, 7, 12, 13

Remember and understand

1. **State** the purpose of the sense organs.
2. **Identify** the missing words to complete the following table.

Sense organs, stimuli and types of receptors

Sense organs	Stimuli	Types of receptors
		Photoreceptor
Ear		
	Smell	
Tongue		
	Touch	

3. **Identify** which of the receptor locations on the left matches each receptor type on the right.

Receptors and their location

Receptor location	Receptor type
a. Tastebuds in mouth	1. Photoreceptor
b. Hot and cold receptors in skin	2. Mechanoreceptor
c. Rods and cones in the retina	3. Thermoreceptor
d. Hairs in the cochlea of ear	4. Chemoreceptor

4. **Identify** the location and function of the:
   a. optic nerve
   b. olfactory nerve.
5. **Identify** the type of receptor that would respond to the following stimuli.
   a. Light
   b. Sound
   c. Chemicals
   d. Temperature

Apply and analyse

6. **Describe** the difference, relationship and function between:
   a. the pupil and iris in the eye
   b. rods and cones in the eye.
7. **Identify** in which part of the human body an observed image is:
   a. formed
   b. interpreted.
8. If cats have rods but no cones, **explain** what this means in terms of how they see the world.

Evaluate and create

9. SI **Describe** the new model that is used to explain the involvement of our tongues in the sensation of taste. How is this different to the previous model?
10. **Construct** a flowchart or mind map that shows the structures involved in:
    a. smell
    b. vision
    c. sound.
11. **Suggest** why:
    a. the thickest part of your skin is on the soles of your feet
    b. some parts of your skin, such as the back of your hand, are more sensitive to heat than others.
12. **Explain** how movement receptors receive a sensation of movement when they are well below the surface of the skin.
13. SI Olfactory receptor cells are important in our ability to smell things. A human has about 40 million, whereas a rabbit has 100 million and a dog has 1 billion! **Suggest** what effect this difference might have on the chances of survival for these animals.

Answers and sample responses are available in your digital formats.

LESSON 3.5 The nervous system

LEARNING INTENTION

In this lesson you will:
- identify and explain the components of the nervous system
- compare the roles of the somatic and autonomic nervous systems
- describe how messages are transmitted from a stimulus to generate a response
- explain some examples of technological and medical advances in the study of neural diseases and damage.

3.5.1 Components of the nervous system

Your nervous system is composed of the:
- **central nervous system** — contains the brain and spinal cord
- **peripheral nervous system** — contains the **nerves** that connect the central nervous system to the rest of the body.

Messages are sent by:
- **sensory neurons** — take messages to the central nervous system
- **motor neurons** — take messages away from the central nervous system.

The nervous system sends a message as an electrical impulse along a neuron and then as a chemical message (**neurotransmitters**) across the gaps (**synapses**) between neurons. We will discuss this in detail later in this lesson.

FIGURE 3.36 The components of the nervous system

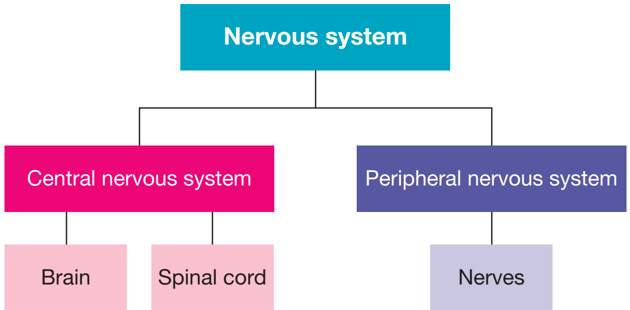
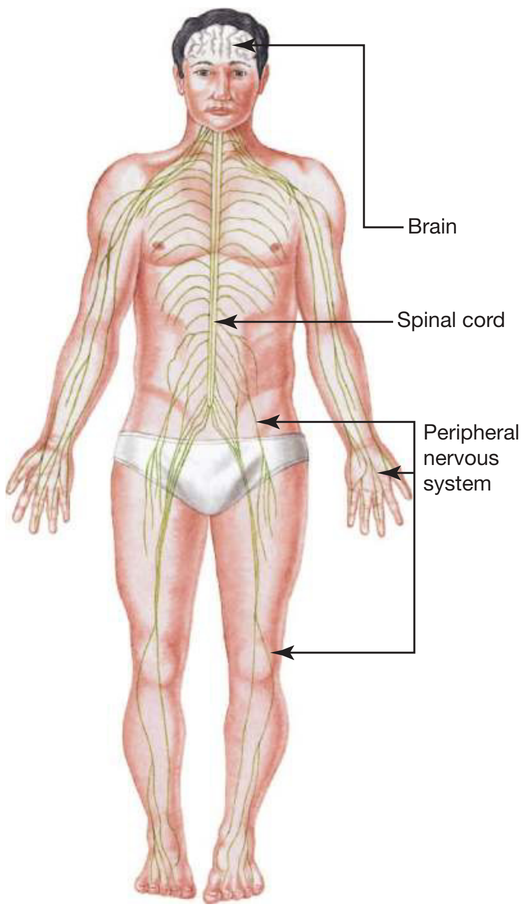


FIGURE 3.37 The human nervous system



3.5.2 The central nervous system

The central nervous system controls how your body responds to changes in the environment. It works by receiving information, processing it and then coordinating a response. The central nervous system is made up of two main parts — the brain and the spinal cord.

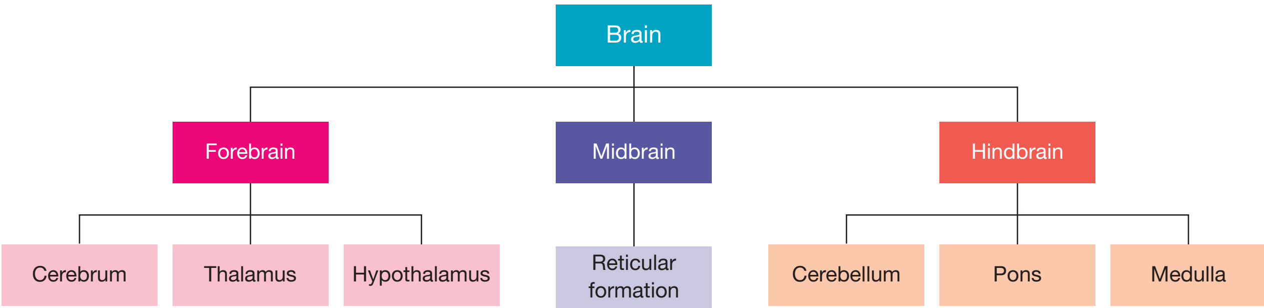
The brain is the control centre of all of your body's functions and is responsible for:
- intelligence
- creativity
- perceptions
- conscious reactions
- emotions and memories.

Your brain cells are organised into different areas within your brain. Although they may have different functions, they communicate and work together to keep you alive.

Components of the brain

- Your **hindbrain** is a continuation of your spinal cord. It develops into the **pons** and **cerebellum**, and the **medulla oblongata** (medulla).
- Extending through your hindbrain and **midbrain** is a network of fibres called the **reticular formation** — a network of neurons that opens and closes to increase or decrease the amount of information that flows into and out of the brain. The reticular formation helps regulate alertness (from being fully awake or deeply asleep), motivation, movement and some of the body's reflexes (such as sneezing and coughing).
- The **forebrain** develops into the **cerebrum**, **cerebral cortex** (outer, deeply folded surface of the cerebrum) and other structures such as the **thalamus**, **hypothalamus** and **hippocampus**.

FIGURE 3.38 Components of the human brain

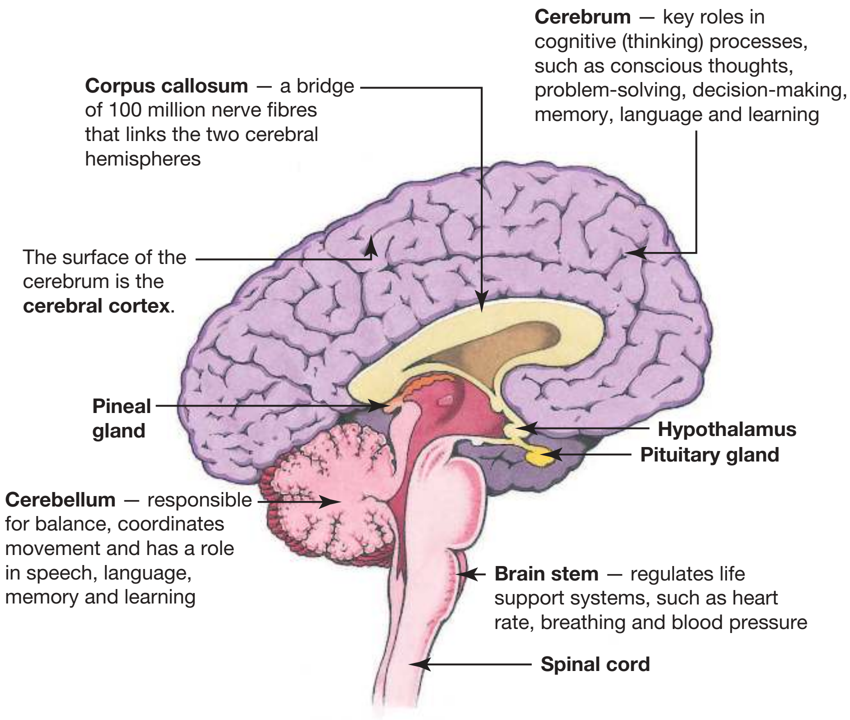


Brain stem (medulla)

Not all actions in your body require conscious thought. These are called involuntary actions and you don't need to think about them for them to occur. Breathing, heartbeat, blood pressure, coughing, vomiting, sneezing and salivating are all examples of involuntary actions controlled by your **brain stem**.

Your brain stem (or medulla) is located between your spinal cord and your cerebrum. If this vital structure is damaged, death may result.

FIGURE 3.39 The human brain



Cerebellum

The cerebellum is found underneath the cerebrum, near the brain stem. Even though it makes up only about 10 per cent of the brain's size, it contains more than half of all the brain's neurons. The cerebellum plays an important role in controlling posture, balance, coordination and movement. Current research also suggests it may help with memory, attention, spatial awareness and language.

The word *cerebellum* comes from Latin and means 'little brain'. It has two halves, or hemispheres, with each side controlling movement and coordination on the opposite side of the body. Each hemisphere of the cerebellum is made up of three lobes, all with a different role. One lobe receives sensory information from your ears to help maintain balance. Another lobe gets messages from your spinal cord, letting your brain know what different parts of the body are doing as they move. The third lobe communicates with the cerebrum — the part of the brain responsible for thinking and decision-making.

Cerebrum

The cerebrum is the largest part of the brain and makes up about 90 per cent of your brain's total volume. The cerebrum is responsible for higher-order thinking (such as problem-solving and making decisions), and controls speech, conscious thought and voluntary actions (actions that you control by thinking about them). The cerebrum is also involved in learning, remembering and personality.

The cerebrum is made up of four lobes. Each of these lobes is associated with particular functions:

- *Frontal lobe*. Responsible for thinking, decision-making, problem-solving, speech, voluntary movements, emotions and personality
- *Parietal lobe*. Processes touch, temperature, pain, spatial awareness, movement coordination, math skills and language comprehension
- *Temporal lobe*. Handles hearing, memory formation, language understanding, facial recognition and emotional responses
- *Occipital lobe*. Focuses on visual processing, recognising colours and shapes, motion, reading and object identification.

Your cerebrum is divided into two **cerebral hemispheres** — the right cerebral hemisphere (mainly responsible for the left side of your body) and the left cerebral hemisphere (mainly responsible for the right side of your body). While each hemisphere is specialised to handle different tasks, they work together as an integrated whole, communicating with each other through a linking bridge of nerve fibres called the **corpus callosum**.

INVESTIGATION 3.5

Dissection of a mammal's brain

Aim

To investigate the structure of the brain

CAUTION: Handle dissecting instruments with care and ensure they are placed in a sterilising solution after use. Wear safety glasses and disposable gloves throughout the dissection and wash your hands thoroughly at the end.

Materials

- a semi-frozen sheep's brain
- dissecting board
- dissecting instruments (scalpel, forceps, scissors)
- plastic ruler
- paper towel
- disposable gloves

Method

1. Place the brain so that the cerebral hemispheres are at the top of the board and the brain stem is at the bottom.
2. Identify the external features of the brain: the cerebral hemispheres, cerebellum and brain stem.
3. Use your forceps and try to lift the meninges (membranes protecting the brain). You may be able to observe the cerebral fluid between these membranes and the hemispheres.
4. Carefully observe the overall appearance of each structure and, using a plastic ruler, measure its size (length, width and height). Include this information in a table in the results section.
5. Draw a diagram of the sheep's brain, labelling the external features.
6. Using your scalpel, cut the brain in half between the right and left hemispheres, and separate the two cerebral hemispheres.
7. Draw a cross-section of the brain. Be sure to label it!
8. Now make a second cut down through the back of one of the hemispheres to see inside the cerebellum and brain stem.

Results

1. Construct a table with the headings shown and record your observations from the dissection. Remember to include a title for your table.

	Appearance			
Brain structure	**Colour**	**Texture**	**Other features**	**Size**
Cerebrum				
Cerebellum				
Brain stem				

2. Sketch the sheep's brain, labelling the external features. On your diagram, identify and label the part of the brain that controls the sheep's:
   a. heart rate
   b. balance required for walking
   c. ability to locate its lamb.
3. Sketch a cross-section of the sheep's brain.

Discussion

1. a. Name the structures that contained the grey and white matter.
   b. Find out why these structures are different colours.
2. Identify which part of the sheep's brain is the biggest. Is this the same pattern as in human brains?
3. The brain is usually protected by a bony skull. It is also covered with three layers of connective tissue called meninges and surrounded by cerebral fluid. Suggest how the meninges and cerebral fluid help protect the brain.
4. Identify strengths and limitations of your investigation of the brain and suggest improvements.

Conclusion

Summarise your findings for this investigation about the structures in the brain.

3.5.3 The peripheral nervous system

The peripheral nervous system consists of all the nerves located outside the central nervous system. The peripheral nervous system is divided into two parts: the **somatic nervous system** and the **autonomic nervous system**.

The somatic nervous system

The somatic nervous system controls our voluntary actions via the skeletal muscles. This includes movement such as picking up an object or walking. It is composed of the sensory and motor neurons. The sensory neurons detect changes to our environment and send these messages to the central nervous system. Motor neurons relay messages from the central nervous system to the effectors, such as muscles or glands.

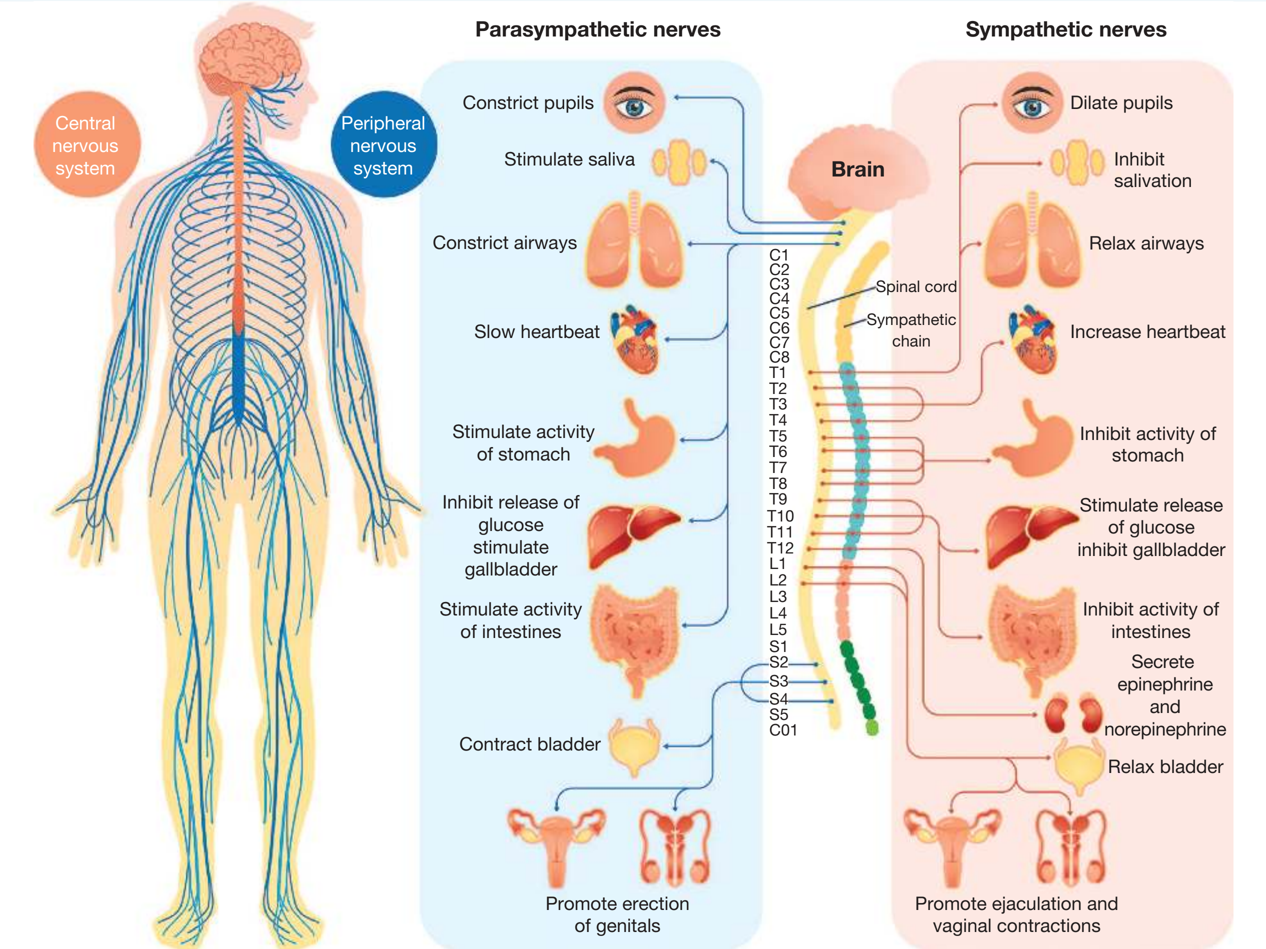
The autonomic nervous system

The autonomic nervous system controls are involuntary actions that control the functioning of our internal organs and functioning systems, including the heart and circulatory system. The autonomic nervous system can be further divided into the sympathetic nervous system and parasympathetic nervous system. The sympathetic and parasympathetic nervous systems have opposite effects on the body; an example is the sympathetic nervous system increasing heart rate and the parasympathetic nervous system decreasing heart rate.

The sympathetic nervous system is responsible for our flight-or-fight response (this is further discussed in lesson 3.6).

Together, these systems maintain homeostasis in the body (figure 3.40).

FIGURE 3.40 The location of the central nervous system and peripheral nervous system, and a comparison of the roles of the sympathetic and parasympathetic nervous systems



3.5.4 Neurons

Whether you are catching a ball, breathing or stopping a fall, your body needs to stay in control. This means being able to detect changes and respond quickly in ways that help keep you safe and alive, which requires control and coordination. Your nervous system assists you in keeping in control, and coordinating other body systems so that they work together and function effectively.

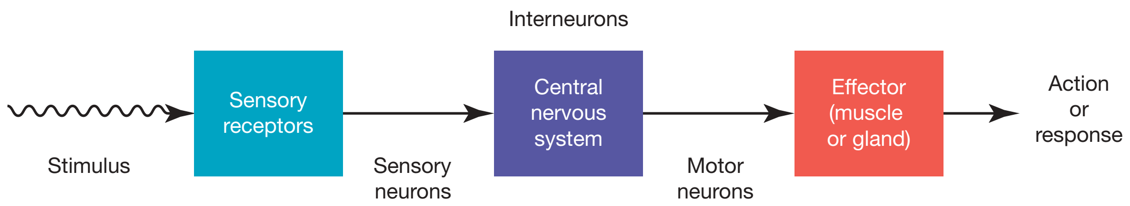
Your nervous system is composed of the central nervous system (brain and spinal cord) and the peripheral nervous system (the nerves that connect the central nervous system to the rest of the body). Both systems are made up of special cells called neurons. The long extensions of these neurons, called axons, are bundled together to form nerves.

Types of neurons

There are three types of neurons:

- Sensory neurons, which carry the impulse generated by the stimulus to the central nervous system
- **Interneurons**, which carry the impulse through the central nervous system
- Motor neurons, which take the impulse to effectors such as muscles or glands

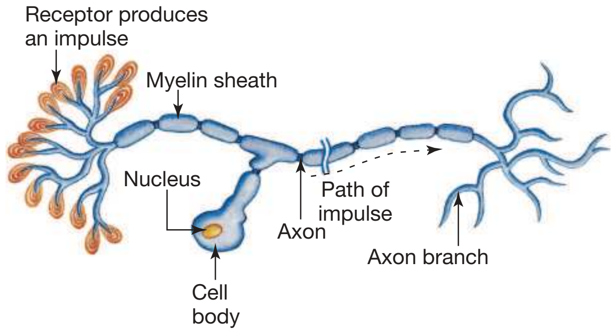
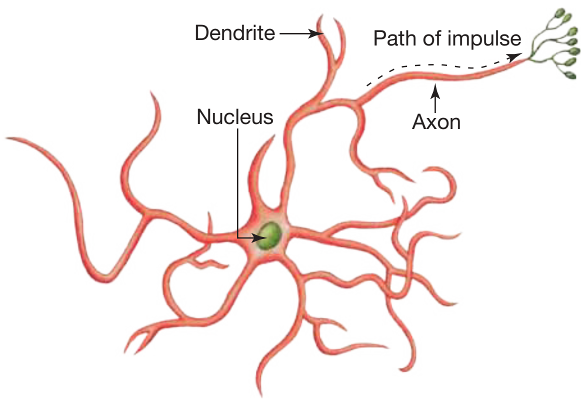
FIGURE 3.41 Relationship between the different neurons in the nervous system

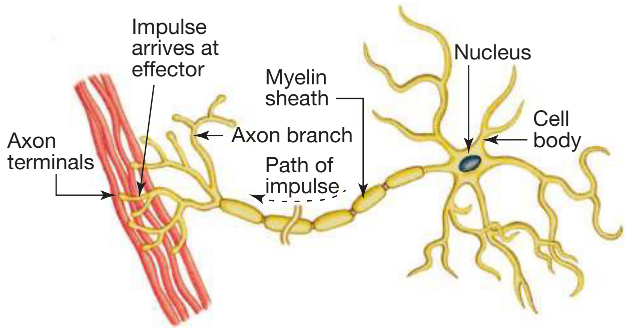


Structure of a neuron

Like all cells, neurons have a **nucleus**, **cytosol**, cell membrane and other **organelles**. However, different types of neurons have specialised structures that make them suited to their specific roles in communication within the nervous system. These structural differences help each type of neuron carry out its job effectively. These differences are shown in table 3.3.

TABLE 3.3 The structures of different types of neurons

<table>
<tr><th>Type of neuron</th><th>Function</th><th>Structure</th></tr>
<tr><td>Sensory neurons</td><td>The sensory neurons in the sense organs detect changes in the environment. Messages about the changes are then relayed as impulses to an interneuron. Sensory neurons are part of the peripheral nervous system.</td><td>
</td></tr>
<tr><td>Interneurons</td><td>The interneurons carry impulses through the spinal cord and brain; therefore, they are part of the central nervous system. Interneurons are sometimes called connector neurons or relay neurons. Impulses are relayed from interneurons to motor neurons.</td><td>
</td></tr>
</table>

Motor neurons	The motor neurons receive impulses from interneurons and cause a response in an effector organ such as a muscle or a gland. Motor neurons are part of the peripheral nervous system.	

Neurons are made up of three main parts as seen in figure 3.42:

- A **cell body** — contains the nucleus of a neuron
- **Dendrites** — highly sensitive branching extensions on the cell membrane of the cell body; these dendrites possess numerous receptors that can receive messages from the other cells
- An **axon** — a long structure of the neuron that carries the electrical message from the dendrite and the cell body. This structure is often covered with a white insulating substance called **myelin**, which helps speed up the conduction of the message through the neuron.

The way an electrical impulse travels through a neuron can be seen in figure 3.43.

FIGURE 3.42 The components of a neuron

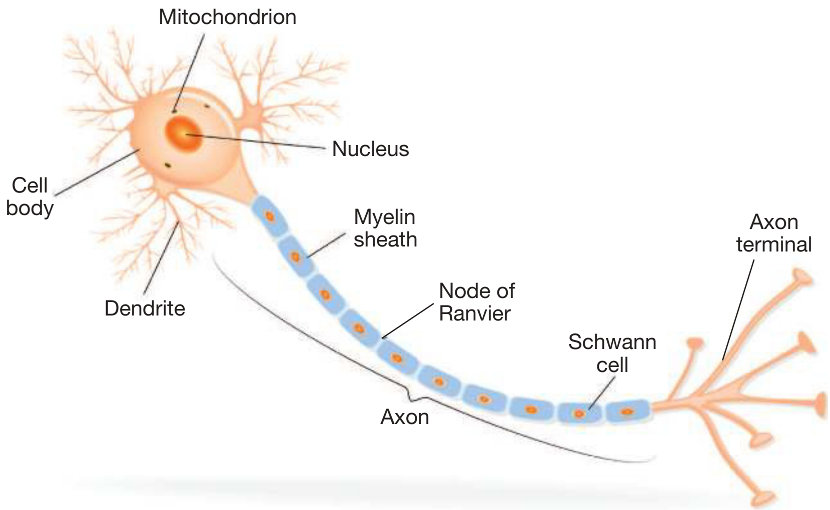
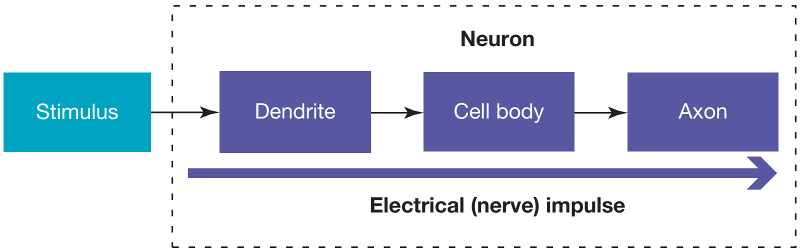


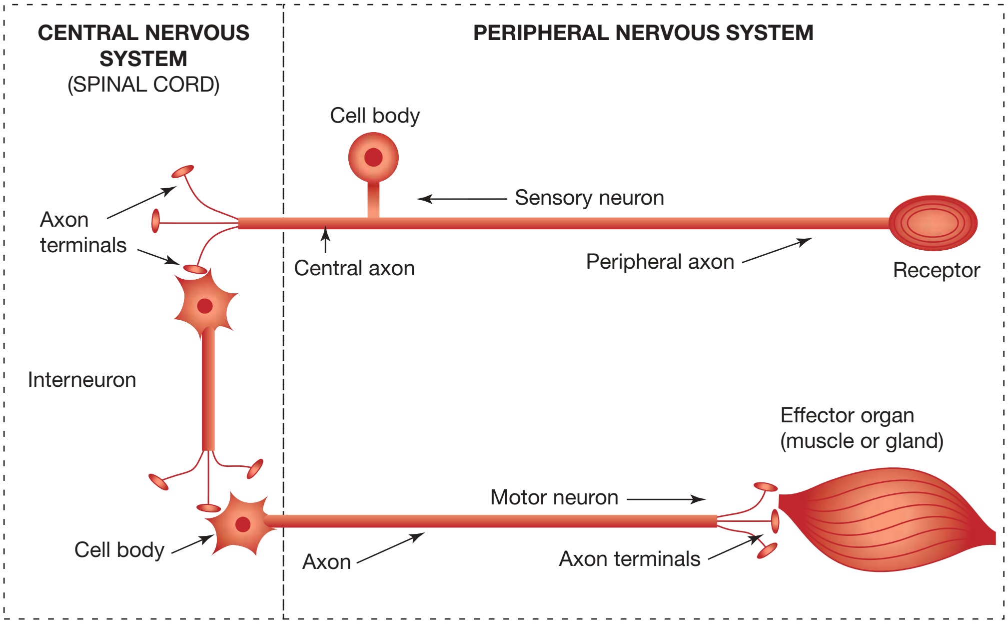
FIGURE 3.43 An electrical impulse moves in only one direction through a neuron.



ACTIVITY: Neuron models

Make models of the different neuron types using balloons, string or cotton, straws and tape. Then try to connect them together using a large outline of the human body.

FIGURE 3.44 Relationship between the different types of neurons

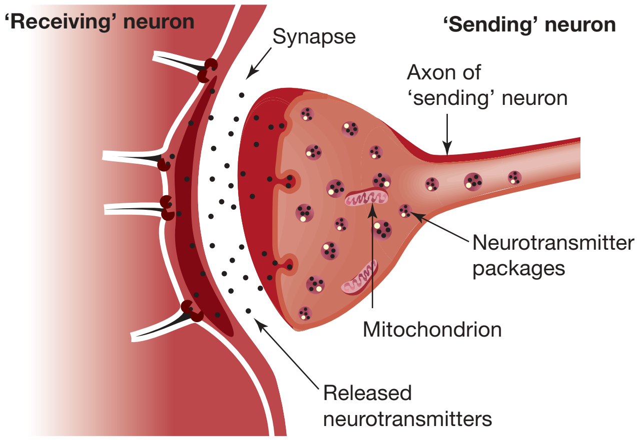


3.5.5 Synapses

The gap between neurons is called a synapse. The nerve impulse cannot jump across the synapse, so when the nervous impulse has reached the axon terminal of a neuron, tiny **vesicles** containing chemicals called neurotransmitters are transported to the cell membrane of the neuron. These chemicals are then released into the synapse, as seen in figure 3.45.

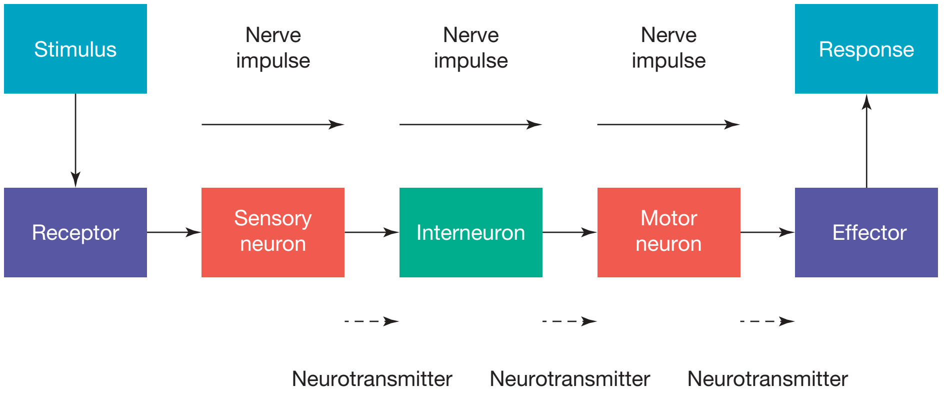
1. The neurotransmitters move across the synapse and bind to receptors on the membrane of the dendrites of the next neuron.
2. This may result in triggering the receiving neuron to convert the message into a nervous impulse and conduct it along its axon.
3. When it reaches the axon terminal, neurotransmitters are released into the synapse to be received by the dendrites of the next neuron.
4. This continues until the message reaches a motor neuron, which then communicates the message to an effector, such as a muscle or gland. The effector may then respond to the message; for example, a muscle cell may contract, or a gland may secrete a chemical.

FIGURE 3.45 Neurotransmitters passing along the synapse to the next neuron



Your nervous system involves the use of both electrical signals (nerve impulses) and chemical signals (neurotransmitters) in order to detect a change in stimulus and initiate a response.

FIGURE 3.46 Your nervous system involves the use of both electrical signals (nerve impulses) and chemical signals (neurotransmitters).



EXTENSION: Neurotransmitters and your mood

Empathy

What happens when you feel upset, or feel upset for someone else? **Mirror neurons** are a group of neurons that activate when you perform an action and when you see or hear others performing the same action. Research is suggesting that these neurons are important in being able to feel **empathy** towards other people. If this theory is further supported, how could this connection increase the chances of the survival of our species?

Mood chemistry

Neurotransmitters are chemicals involved in passing messages between your nerve cells. Within your brain, there are many neurotransmitters that influence how you feel and react: **serotonin**, **noradrenaline** (also known as norepinephrine) and **dopamine** are three examples. Imbalances of these neurotransmitters can contribute to a variety of mental illnesses.

- Serotonin acts like the brakes on your emotions. It can produce a calming effect and is important for maintaining a good mood and feelings of contentment. It also plays a role in regulating memory, appetite and body temperature. Low levels of serotonin can produce insomnia, depression and aggressive behaviour, and are also associated with obsessive-compulsive and eating disorders.
- Noradrenaline can act like an accelerator. It can promote alertness, better focus and concentration. Your brain also needs this chemical to form new memories and to transfer them to your long-term storage.
- Dopamine is important for healthy assertiveness and autonomic nervous system function. Dopamine levels can be depleted by stress or poor sleep. Too much alcohol, caffeine and sugar may also lead to reduced dopamine activity in your brain. People with Parkinson's disease have a diminished ability to synthesise dopamine.

3.5.6 Reflex actions

Sometimes your body needs you to consciously think before acting, like deciding to pick up a pencil. Other times, actions happen automatically without you even thinking about them, like blinking.

Have you ever had sand blown into your eyes or touched something too hot? Or had a 'knee-jerk' reaction when a doctor sharply taps your knee? In situations like these, there is no time to stop and think about how to respond. Your body needs to react instantly — sometimes to protect you from harm. These fast, automatic responses are called reflex actions.

FIGURE 3.47 You do not need to think what to do when you touch something hot.

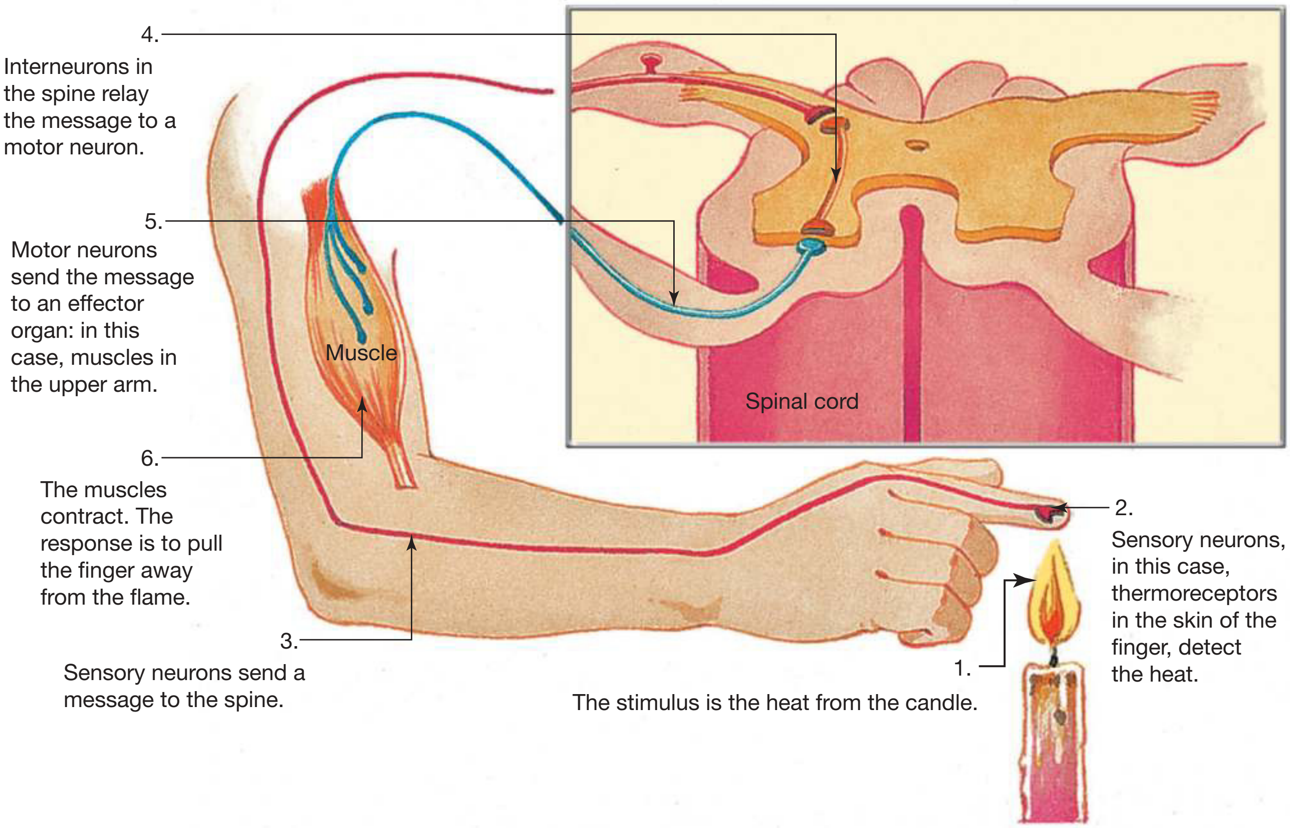
Reflex actions do not just help you respond to changes outside your body; they also help you respond to changes inside it. Breathing is an example of this. Chemoreceptors in your body detect changes in carbon dioxide levels in your blood and automatically adjust your breathing rate. It is a good thing this happens without you having to think about it — imagine what could happen if you forgot to breathe!

Reflex actions may involve only a few neurons and require no conscious thought. Their pathway travels only to and from the spinal cord, and is called a **reflex arc**. An example of this process is outlined in figure 3.48.

1. A stimulus is encountered (in either the internal or external environment).
2. The stimulus is detected by a receptor.
3. The message is sent via the sensory neuron to the interneuron in the spinal cord.
4. Interneurons in the spine send the message to the motor neuron.
5. Motor neurons send the message to the effector to bring about a response.
6. The response occurs.

One of the key features of a reflex arc is that it allows your body to respond without the message needing to travel all the way to the brain. Instead of stopping to think 'That is hot, I should move my hand', the response happens automatically. This faster reaction time helps protect your body by reducing the chance of injury or damage.

FIGURE 3.48 The reflex arc pathway does not go via the brain.



INVESTIGATION 3.6

Observing reflex actions

Aim

To investigate some automatic responses

Materials

- ruler

Method

Work in pairs for this investigation to complete all the activities.

Reflex 1: Blinking

Blinking is a reflex response to protect our eyes from damage.

1. Sit facing your partner.
2. Move your hand suddenly and quickly towards their face. (Do not hit them!)
3. Did they blink?

Reflex 2: Dilation and contraction of the pupil

Our pupils allow light into our eyes. In dim light, they need to be wider to allow more light in, while in bright light they contract to reduce the amount of light entering the eye.

1. Face your partner and look at their eyes.
2. Note the size of their pupils.
3. Have your partner close or cover their eyes for around 30 seconds.
4. Watch their pupils closely when they open their eyes.
5. Describe the size of their pupils immediately after they opened their eyes and what then happened to them.

Reflex 3: Knee-jerk reflex

The knee-jerk reflex straightens the leg and helps you to avoid falling when you trip.

1. Sit on a surface high enough that your feet can hang down without reaching the ground. (If this requires sitting on a Science bench, ensure the surface has been thoroughly wiped clean first.)
2. Making your legs as relaxed as possible, gently tap just below your knee cap with the narrow edge of a ruler.
3. What did your leg/foot do?

Results

Record your observations.

Discussion

Talk about what happened during each activity with the different reflexes.

Conclusion

Summarise the findings for this investigation.

SCIENCE AS A HUMAN ENDEAVOUR: Chemical weapons

Nerve agents are a group of chemicals that disrupt the normal functioning of the nervous system and are among the most toxic substances known to humanity. Originally developed for agricultural purposes, they have since been weaponised for chemical warfare, with devastating effects.

FIGURE 3.49 Scientists and experts working with dangerous chemicals that target the nervous system must use protective suits.

How nerve agents work

Nerve agents target the nervous system by interfering with the function of neurotransmitters, the chemicals responsible for transmitting signals between nerve cells (neurons). At the synapse (the gap between neurons), a neurotransmitter called acetylcholine is released to stimulate muscles. Normally, an enzyme called acetylcholinesterase breaks down acetylcholine after the signal is sent, allowing the muscle to relax.

Nerve agents block the activity of acetylcholinesterase, causing acetylcholine to accumulate in the synapse. This leads to overstimulation of the muscles, resulting in severe symptoms such as:

- continuous muscle contractions, including the diaphragm, which controls breathing
- convulsions and seizures
- paralysis, respiratory failure and, ultimately, death.

Historical development

Tabun was the first nerve agent, developed in Germany during the 1930s while scientists were researching insecticides.

Sarin and VX are more potent nerve agents that were developed later. Sarin is a volatile liquid that easily turns into gas, while VX is an oily substance with long-lasting effects. Both are classified as weapons of mass destruction.

The use of nerve agents is prohibited under the Chemical Weapons Convention (CWC), an international treaty that bans the development, production and stockpiling of chemical weapons. However, their potential misuse remains a global concern.

Medical research

Understanding how nerve agents affect the nervous system has led to advancements in treatments for poisoning. For example, antidotes like atropine and pralidoxime can block or reverse the effects of nerve agents if administered promptly.

1. Explain how nerve agents disrupt the normal functioning of the nervous system.
2. Explain why the inhibition of acetylcholinesterase is so dangerous for the human body.
3. Contrast the differences between nerve agents like sarin and VX in terms of their effects and use.
4. What international measures exist to regulate and prevent the use of chemical weapons?
5. Discuss how the study of nerve agents has contributed to advancements in medical science.

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

DISCUSSION

Is the use of chemical warfare ever justifiable? Discuss this with your class, recording all the various opinions and views.

3.5.7 Damage to the nervous system

Damage to the spinal cord of the nervous system may be the result of a disease or an accident, or it may be congenital (already present at birth). Whatever the cause, this type of damage can be devastating and debilitating.

Although there is currently no cure for spinal injury, teams of scientists around the world are involved in research that is aimed at improving the quality of life for those with this injury.

Paralysis and spinal injury

All the nerves in your peripheral nervous system connect back to your spinal cord, linking the rest of your body to the central nervous system. Damage to this cord can prevent communication of messages between your brain and your body. This loss of communication can lead to **paralysis** (loss of movement).

Damage to different parts of the spinal cord can lead to different types of paralysis. For example, if you were in an accident in which the lower back section of your spine was completely crushed, messages would not be able to travel between your legs and feet and your brain. This loss of communication would mean that you would not be able to sense pain, heat, cold or touch in these parts of your body. You would also be unable to stand or walk as you would not be able to control the muscles in your legs and feet.

FIGURE 3.50 Actor Christopher Reeve raised awareness for spinal injury research.

Christopher Reeve (figure 3.50), an actor who played Superman in the 1970s and 80s, damaged his spinal cord in the neck region in a sporting accident. The consequence was that he was paralysed below the neck and required the use of a machine to breathe air into and out of his lungs as he was unable to breathe for himself. In the years following his accident, he raised awareness of spinal injuries, and increased public and political interest in related research. He died in 2004 as a result of complications from his paralysis.

Paralysis and disease

A number of diseases can also result in paralysis. One such condition is **motor neuron disease** (MND). Although the cause of this disease is still unknown, its effects are devastating. While the brain and the senses are usually unaffected, the person with the disease becomes increasingly paralysed.

FIGURE 3.51 Stephen Hawking suffered from motor neuron disease.

MND targets and gradually destroys motor neurons, but leaves sensory neurons untouched. This means someone with MND can see and hear a mosquito, feel it bite and itch — but be unable to move or speak to ask for help. They can still sense their environment, but their ability to respond fades over time. Eventually, all muscles are affected. Sadly, MND is fatal.

Stephen Hawking (figure 3.51) was an English theoretical physicist and cosmologist. He was diagnosed at the age of 21 with MND. Although the disease affected his body, it never claimed his brilliant mind. Over 55 years, he achieved extraordinary successes in the study of the physical nature of the universe, especially the theory of special relativity and quantum physics. He died in 2018.

Former AFL player and coach Neale Daniher (figure 3.52) is one of Australia's most well-known figures living with MND. He has played a leading role in raising awareness and funds for research into treatments and a possible cure. Daniher helped create the 'Big Freeze at the 'G' to support Fight MND, a charity dedicated to funding research for the disease.

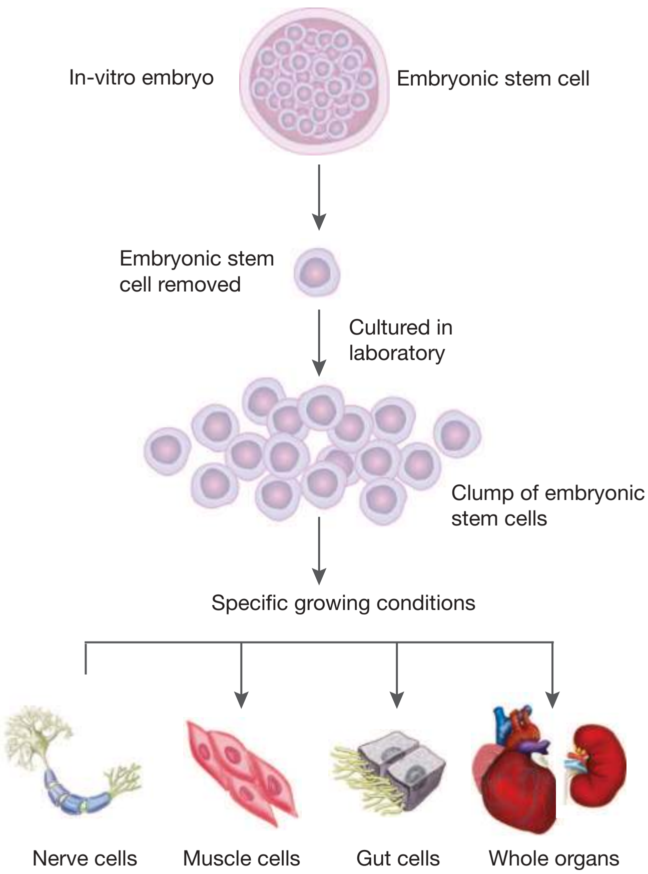
FIGURE 3.52 The 'Big Freeze at the 'G' was started by Neale Daniher (right) in 2015.

Stem cells — a possible treatment?

Embryonic stem cells have many properties that scientists find exciting. They can produce new cells for longer than other cells, and under the right conditions they can be made to differentiate into particular cell types. Some current research is investigating the injection of nerve cells produced from embryonic stem cells into the sites of spinal injury. Although it is early days for this research, it is hoped that it may lead to the recovery of muscle function in some cases.

Although the possible applications of this research are exciting, technologies involving the use of human embryonic stem cells must undertake strict bioethical procedures. The human embryos used in this research are obtained from the surplus embryos of couples undergoing IVF treatment.

FIGURE 3.53 The use of stem cells to treat (and possibly even cure) a variety of diseases is being investigated.



Brain–computer interface technology

Brain–computer interface (BCI) technology is emerging in everyday games and toys. These devices use computer software, often built into headsets, to detect brainwave patterns and facial movements. This information is then used to control objects or actions — for example, moving something just by thinking about it.

Broader applications of this technology, such as implanted electrodes and **neural prostheses**, are being researched and developed in order to provide assistance to people with a variety of disabilities. There have already been cases in which paralysed people have been able to move their wheelchairs by just thinking about the movement, or those who are unable to talk have been able to use their brain to result in their thoughts being spoken aloud. Cochlear implants are also examples of neural prostheses used to stimulate the auditory nerve in individuals with hearing loss.

FIGURE 3.54 Brain–computer interface technology has many possible applications.

SCIENCE INQUIRY: Investigating the potential and challenges of brain–computer interface technology

Brain–computer interface (BCI) technology is a revolutionary advancement that enables communication between the brain and external devices by decoding neural signals. This technology has profound implications for assistive devices, allowing individuals with disabilities to control prosthetic limbs, wheelchairs and computers through thought. Neural prostheses, such as cochlear implants, are examples of BCI applications already in widespread use.

BCI technology relies on detecting and decoding electrical activity in the brain, often through electrodes placed on the scalp or implanted in the brain. This activity, generated by neurons communicating via electrical impulses, is interpreted by software to produce specific responses, such as moving a robotic arm or typing on a screen.

Recent advancements include the following:
- *Improved signal decoding.* This includes algorithms that enhance the accuracy of interpreting neural signals.
- *Bidirectional communication.* Recent prosthetics not only respond to brain signals but also send sensory feedback to the user, creating a more natural experience.
- *Assistive devices*. Individuals with spinal cord injuries or paralysis can use BCI to control wheelchairs or robotic limbs.
- *Neural prostheses.* Cochlear implants restore hearing by stimulating the auditory nerve. Research is underway to develop similar devices for vision and touch.
- *Emerging technologies.* Australian company Synchron developed a brain implant allowing paralysed individuals to control digital devices like smart glasses.

While BCI technology has immense potential, it also presents challenges:
- *Technical challenges.* Noise in neural signals and delays in processing can reduce device reliability.
- *Ethical issues.* Privacy concerns arise when neural data is collected, and equitable access must be ensured for all individuals.
- *Cost and accessibility*. Advanced technologies can be expensive, limiting their availability to a wider population.

1. Explain how neural prostheses like cochlear implants demonstrate the principle of bidirectional communication in BCI.
2. Describe the improvements in neural signal decoding that might make BCI technology more effective for everyday use.
3. Explain how feedback loops in BCI systems could improve the user experience of prosthetic limbs.

4. Explain why it is important to address privacy concerns when developing devices that collect neural data.
5. Suggest some potential future applications of BCI technology beyond medical uses.

Information and processed data can be analysed and compared to identify and explain qualitative and quantitative patterns, trends, relationships and anomalies (VC2S10I05)

DISCUSSION

How else might brain–computer interface technology be used? What other senses could be assisted using this technology? Could it be used to enable us to experience senses that humans do not currently possess?

3.5 Activities

learnon

3.5 Quick quiz on	3.5 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 6, 7, 9, 11, 13, 15	2, 4, 10, 14, 16, 19, 21	5, 8, 12, 17, 18, 20, 22, 23, 24

Remember and understand

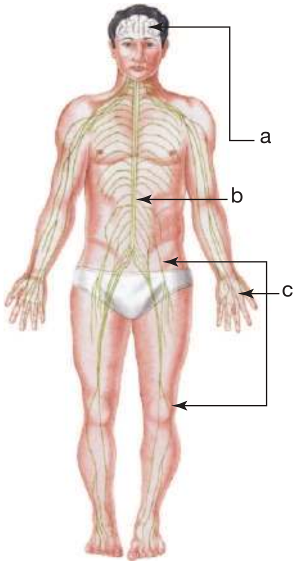
1. **Identify** the missing words to complete the sentence, using the word bank provided.
   brain, central, nerves, peripheral

   The human nervous system is composed of the ___________ nervous system (___________ and spinal cord) and the ___________ nervous system (the ___________ that connect the central nervous system to the rest of the body).
2. **Identify** which of the terms on the left matches each of the definitions on the right.

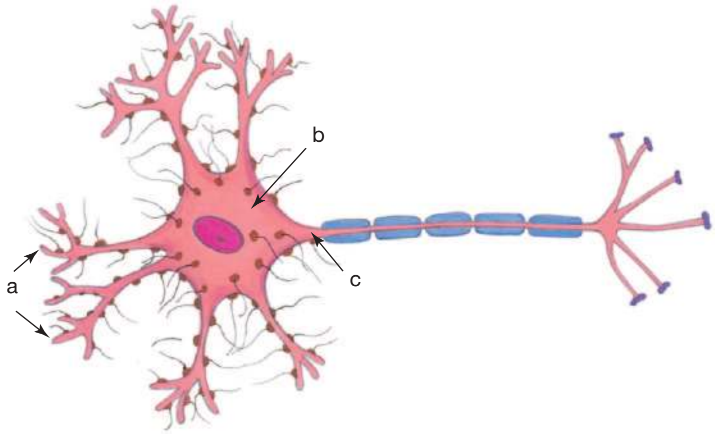
Components of the nervous system

Term	Definition
a. Central nervous system	1. Gap between neurons
b. Motor neuron	2. Made up of neurons
c. Nerves	3. Nerves that connect the central nervous system to the rest of the body
d. Neuron	4. Takes messages to the central nervous system
e. Neurotransmitter	5. Made up of a cell body, dendrites and axon
f. Peripheral nervous system	6. Brain and spinal cord
g. Sensory neuron	7. Chemical messenger that carries messages from one neuron to another across a synapse
h. Synapse	8. Takes messages away from the central nervous system

3. **Identify** the labelled components of the nervous system in the figure shown and **describe** their function.



4. **Identify** and label the cell body, dendrites and axon on the motor neuron, and show the direction in which the impulse travels.



5. **Distinguish** between:
   a. a receptor and an effector
   b. a sensory neuron, an interneuron and a motor neuron
   c. a neuron and a nerve
   d. a reflex action and a conscious reaction.
6. **Name** the organ that has been described as the control centre of your body.
7. **Identify** the part of your brain that does each of the following.
   a. Takes up the greatest volume
   b. Regulates heartbeat, breathing and blood pressure
   c. Generates the most complex thoughts
   d. Coordinates movement
   e. Manages communication between the left and right hemispheres
8. **Distinguish** between:
   a. the cerebrum and cerebellum
   b. the left and right cerebral hemispheres
   c. the cerebrum and cerebral cortex.
9. **Define** the term 'paralysis'.
10. **Outline** the properties that make stem cells interesting to researchers.
11. **Outline** the cause and symptoms of motor neuron disease.

Apply and analyse

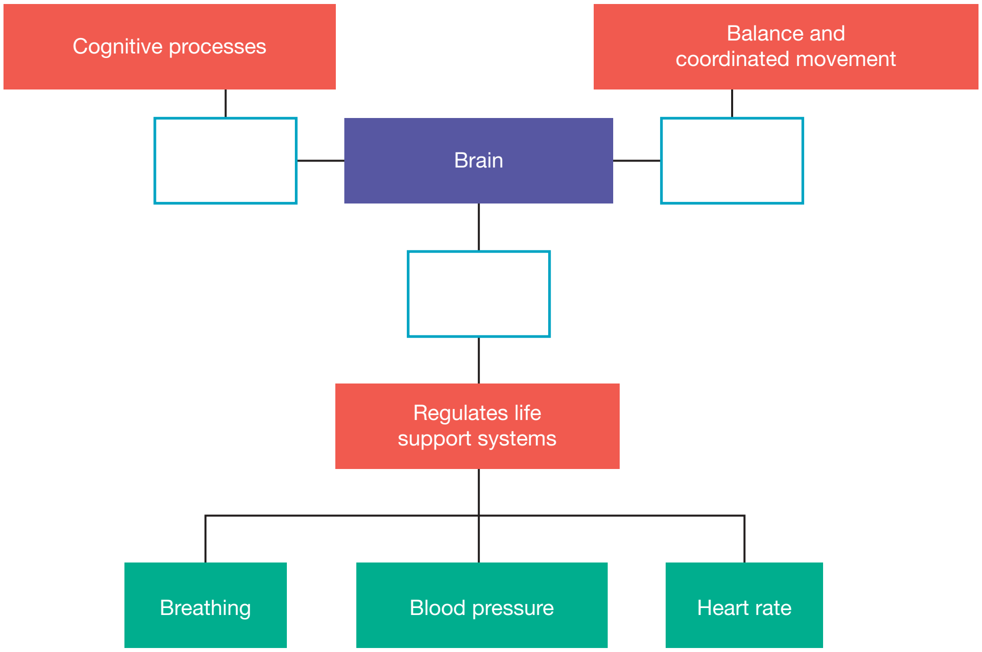
12. **Suggest** how the structure of the different types of neurons suits their function.
13. **Describe** the advantage of the presence of myelin on the axon of a neuron.
14. With reference to chemical and electrical signalling in nerve cells, **describe** one way in which paralysis can occur in animals.
15. a. Place a tick in the correct box in each row of the table to **identify** the responses that are reflex actions and those that are conscious responses.

Reflex action or conscious response?

Action	Reflex action	Conscious response
Sneezing		
Blinking		
Scratching your head		
Knee-jerk reaction		
Clapping		
Breathing		

b. **Explain** how you decided whether each action was a reflex action or conscious response.

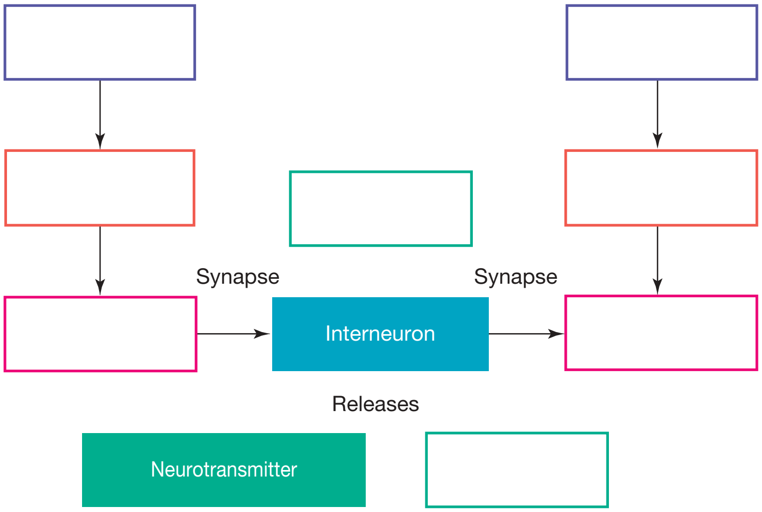
16. Complete the following cluster map by inserting ‘cerebrum’, ‘cerebellum’ and ‘brain stem’ into their appropriate locations.



17. a. **Explain** the difference between the cerebral hemispheres.
b. **Outline** how these hemispheres are able to work together.
18. **Describe** evidence that suggests that stem cells may one day be used to restore some mobility after a spinal injury.

Evaluate and create

19. **Suggest** how you could link the nervous system terms provided using the following flowchart.
    - Electrical impulse
    - Motor neuron
    - Sensory neuron
    - Response
    - Receptor
    - Neurotransmitter
    - Stimulus
    - Effector



20. a. SI **Suggest** a reason why the pupil of your eye increases in size in dim light.
    b. **Outline** some triggers that may cause the size of your pupil to change in size.
21. **Explain** how blocking the production and action of neurotransmitters causes paralysis. Include a diagram to show this.
22. SI Imagine that you are a scientist involved in researching the nervous system. Propose a relevant question or suggest a hypothesis for a scientific investigation and **outline** how you would design your investigation.
23. SI There is a danger of chemical and biological weapons being used in acts of terrorism. **Suggest** what sorts of strategies we could have in Australia to cope with threats of chemical warfare.
24. SI 'Brains react to music like a drug.' This was a claim made in the media in 2011. It was based on a scientific study that used PET (positron emission tomography) and fMRI brain scans to record brain activity of volunteers while they listened to their favourite piece of music. The PET scan detected a release of dopamine (a neurotransmitter responsible for feeling a sense of reward and pleasure) in the volunteers' brains and the fMRI scan showed increased blood flow to the emotional response areas.
    For this investigation, **suggest**:
    a. a hypothesis
    b. the dependent variable(s) and independent variable
    c. an appropriate control group
    d. controlled variables.

Answers and sample responses are available in your digital formats.

LESSON 3.6 The endocrine system

LEARNING INTENTION

In this lesson you will:

- explain how the endocrine system controls body functions through hormones released by various glands
- use the stimulus–response model and negative feedback loops to explain the role of the endocrine system in the regulation of body temperature and blood glucose by homeostatic mechanisms.

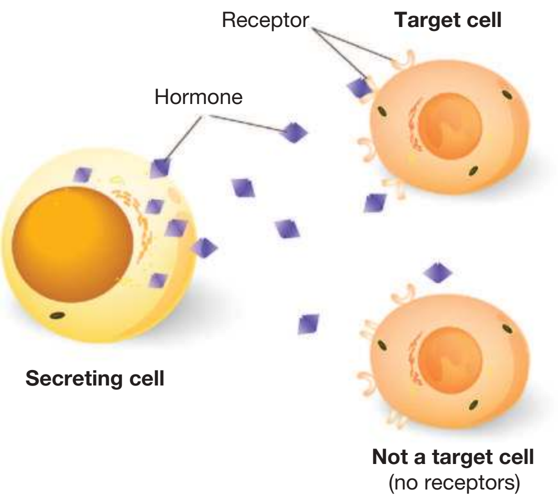
3.6.1 Hormones — chemical messengers

Thirsty? Too hot or too cold? Feeling different or noticing changes in how you look or act? Chemicals in your blood not only help to keep you balanced, but are also very important in controlling and coordinating your growth and development.

The nervous system is not the only means of controlling and coordinating activities in your body. The endocrine system uses chemical messengers called hormones. Cell communication is critical in maintaining homeostasis. As cells detect changes in our environment, it is important these cells can pass on the message to other cells in order to elicit a response. To communicate with one another, cells use signalling molecules, which can bind to other cells and initiate a response.

An important group of signalling molecules in our body are hormones. They are produced in **endocrine glands** and released into the bloodstream. Although hormones travel via the bloodstream to all parts of the body, they only act on specific cells called **target cells**. Target cells contain receptors on their surface that are complementary to a hormone (figure 3.55). Therefore, cell communication via hormones is highly specific in response.

FIGURE 3.55 Hormones are released by secretory cells, located in endocrine glands. Hormones then bind to complementary receptors on the surface of target cells.

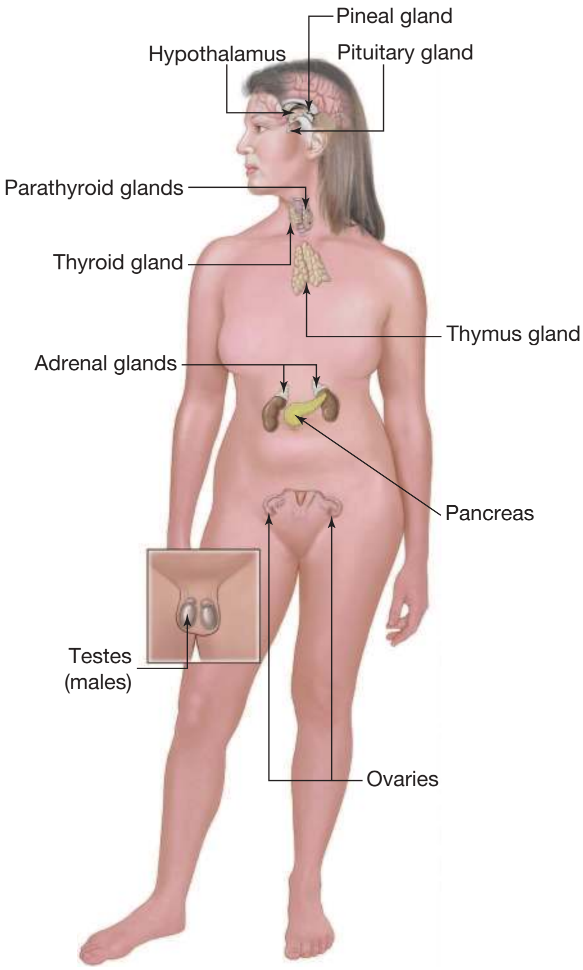


The endocrine system is made of many glands located around our body. Each gland is responsible for producing and secreting hormones into the bloodstream (table 3.4). Endocrine glands include the adrenal glands, pancreas and the ovaries and testes (figure 3.56).

TABLE 3.4 Examples of endocrine glands and their hormones

Endocrine gland	Example of hormone released	Response
Thyroid	Thyroxine	Raises basal metabolic rate
Adrenal	Adrenaline	Increases heart rate and blood pressure in times of stress
Pancreas	Insulin	Lowers blood glucose levels
Pituitary	Anti-diuretic hormone (ADH)	Reabsorption of water in kidneys
Ovaries	Progesterone	Controls menstrual cycle and pregnancy
Thymus	Thymosin	Stimulates the production of white blood cells to fight infection

FIGURE 3.56 The human endocrine system



Hormones control and regulate functions such as metabolism, growth, development and sexual reproduction. Like the nervous system, the endocrine system detects a change in a variable, and often acts using a negative feedback mechanism to counteract the initial change. The endocrine system also works with the nervous system to regulate your body's responses to stress. The effects of the endocrine system are usually slower and generally longer-lasting than those of the nervous system.

3.6.2 Endocrine glands in your brain

Endocrine glands are located in various parts of your body, with three major glands located in the brain.

1. **Pituitary gland**: Often referred to as your 'master gland' because it controls many other endocrine glands, stimulating them to release their own hormones. For example, your thyroid gland, ovaries and testes are all controlled by hormones released by this endocrine gland. Hormones released by the pituitary gland can control water balance, growth, development and reproduction-related processes.
2. Hypothalamus: Sends hormones to the pituitary gland to control its release of hormones to other endocrine glands. It also releases hormones that control body temperature, growth, sex drive, thirst, hunger and sensations of pleasure and pain. The hypothalamus links your nervous system to your endocrine system and is used in reflex actions such as those involved in the beating of your heart and breathing.
3. **Pineal gland**: Produces the hormone melatonin, which controls body rhythms such as waking and sleeping.

EXTENSION: Fight-or-flight response

Feeling angry? Is your heart racing, are your hands cold or do you have a sick feeling in your stomach? Anger can be one of our most primitive emotions. It is certainly a powerful one. Uncontrolled anger can lead to physical fights, arguments and self-harm. However, controlled anger can be a very useful emotion that can help motivate you to make positive changes.

When you feel angry, your hypothalamus responds by sending messages to your pituitary gland to instruct your **adrenal glands** to release **adrenaline** (also known as epinephrine). This hormone acts to:

- increase your heart rate
- dilate your pupils
- constrict skin blood vessels
- shut down digestion.

This helps you to see any threats better and provides your muscles with more glucose and oxygen, just in case you need to face the danger and *fight*, or take *flight* and escape it by running away (or you could *freeze* because you don't know what to do).

3.6.3 Thermoregulation

Thermoregulation is the process of controlling body temperature. For most people, the normal body temperature is around 37 °C. This is the temperature at which the chemical reactions in our cells — and the enzymes that control them — work best. Even small changes in body temperature can make us feel unwell. If body temperature drops below 35 °C, a person may develop **hypothermia**, which becomes severe and life-threatening around 32 °C. On the other hand, if body temperature rises above normal, it is called **hyperthermia**. Heat stroke and possible death can occur if the body reaches 40 °C or higher.

The homeostatic, negative feedback control of our body temperature involves quite a complex combination of the nervous and endocrine systems working together.

We have thermoreceptors in our skin monitoring our skin temperature, and in our hypothalamus monitoring our core temperature. Information from these is processed by the hypothalamus, which then coordinates the response to a rise or fall in temperature.

In response to a temperature drop, we typically:

- shiver — rapid muscular movements generate heat
- get goosebumps — our hair stands up in an effort to trap a layer of insulating air next to our skin
- look pale — blood vessels in our skin narrow (**vasoconstriction**) to reduce blood flow to our surface and retain it in our core to reduce heat loss
- change our behaviour — we will often pull our arms tight around our body to try to keep heat in and jump up and down, or pace, to increase muscle use to generate heat
- release the hormones thyroxine and adrenaline — these increase our metabolic rate, which produces heat.

In response to a temperature rise, we typically:

- sweat — the evaporation of sweat from our skin carries heat away
- look red in the face — blood vessels in the skin open wider (**vasodilation**) to move heat from our core to our surface so it can escape to the surroundings
- change our behaviour — we will often seek shade and reduce activity in an effort to cool down
- breathe more deeply, often through the mouth — this increases heat loss from the lungs.

It is important to recognise and treat hypothermia in its early stages as once our body temperature drops below 32 °C, we stop shivering, become increasingly confused, begin to feel too warm and actually start removing clothes in an effort to cool down! This can lead to a very rapid decline into severe hypothermia and possibly death.

FIGURE 3.57 Negative feedback loop of thermoregulation

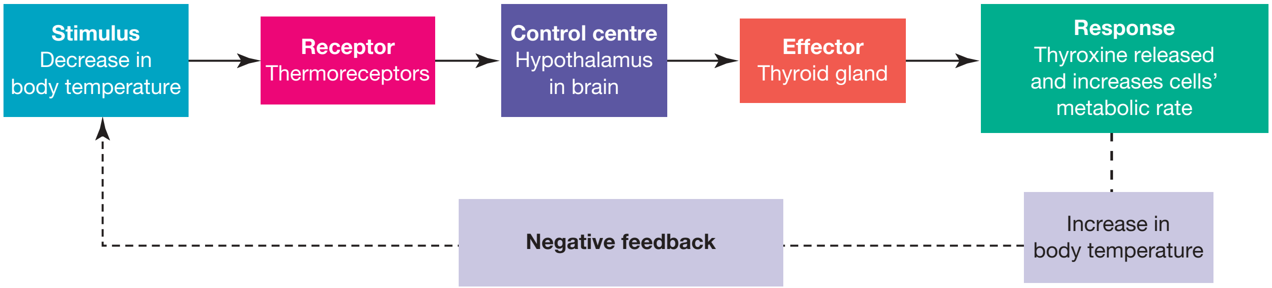
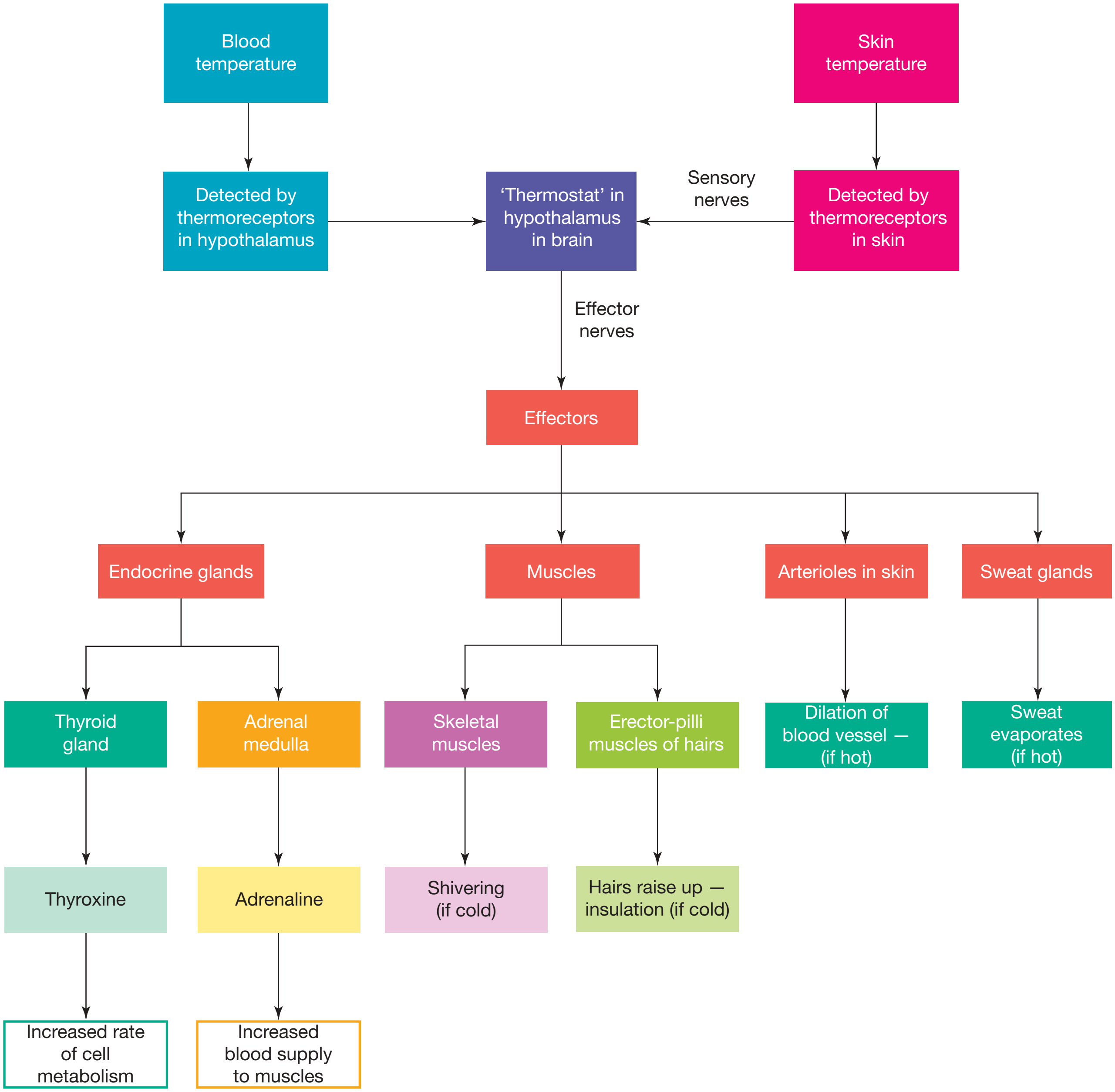


FIGURE 3.58 Temperature regulation is an example in which the nervous system and the endocrine system work together to maintain your body temperature within a range that is healthy for your cells.



3.6.4 Blood glucose regulation

Glucose is one of the human body's primary sources of energy. During cellular respiration, glucose is converted into energy (ATP), the primary energy carrier in the body. Thus, it is critical that glucose levels are closely regulated. Homeostasis of blood glucose levels is maintained by two hormones produced by the pancreas: **insulin** and **glucagon** (table 3.5).

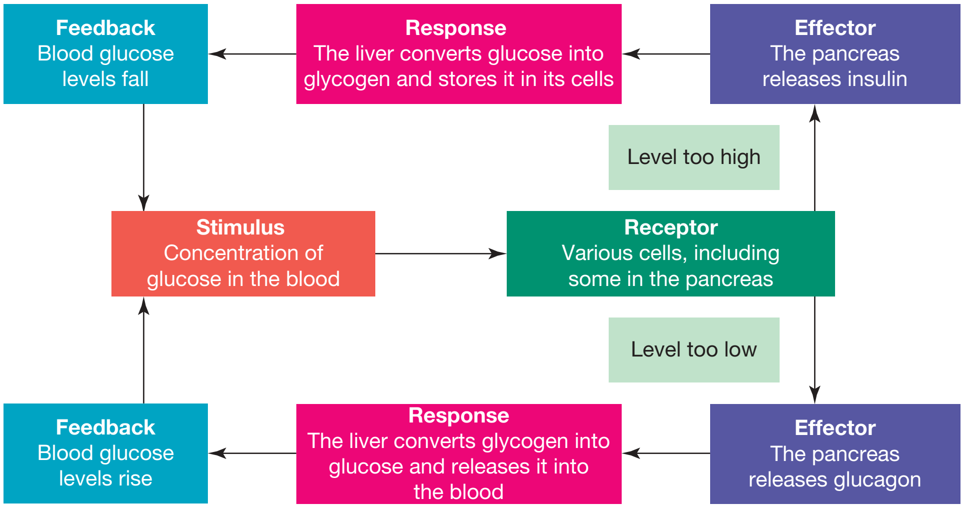
TABLE 3.5 Actions of insulin and glucagon

	Insulin	Glucagon
Stimulus	Increase in blood glucose levels	Decrease in blood glucose levels
Effector	Produced by the pancreas	Produced by the pancreas
Target cells	Liver and skeletal muscles	Liver
Response	Acts on the liver and skeletal muscles to increase the uptake of glucose from the bloodstream and storage as glycogen	Acts on the liver to promote the breakdown of glycogen into glucose. Glucose is then released back into the bloodstream.
Outcome	Decrease in blood glucose levels to within normal range	Increase in blood glucose levels to within normal range

As seen in figure 3.59, if an increase in blood glucose levels has been detected by receptors, the pancreas responds by secreting insulin, which may trigger an increased uptake of glucose by liver and muscle cells and the conversion of glucose into glycogen for storage. This decreases the blood glucose levels back to 'normal' levels.

If a decrease in blood glucose levels has been detected by receptors, the pancreas responds by secreting glucagon. Glucagon travels in the blood to the liver and muscle cells, stimulating the breakdown of glycogen into glucose. This increases the blood glucose levels back to 'normal' levels.

FIGURE 3.59 If your blood glucose levels are too high or low, your body will release hormones to bring it back to ideal levels.



Increase in blood glucose levels

Figure 3.59 is an example of how the endocrine system regulates blood glucose levels via negative feedback.

Responding to an increase in blood glucose levels

1. After you have eaten a lot of sugary food, your blood glucose levels increase.
2. This rise is detected by cells in your pancreas, which then secretes the hormone insulin.
3. Insulin travels in the bloodstream, and specific target cells in your liver and muscles respond by increasing the uptake of glucose into the cells and the conversion of glucose into glycogen, which is then stored.
4. The result is that blood glucose levels are reduced back to their 'normal' levels.

Responding to a decrease in blood glucose levels

1. If you have not eaten for some time, your blood glucose levels decrease.
2. This decrease is detected by cells in your pancreas, which then secretes the hormone glucagon.
3. Glucagon travels in the bloodstream, and specific target cells in your liver and muscles respond by breaking down glycogen into glucose, which is released into the blood.
4. The result is that glucose levels are increased back to their 'normal' levels.

3.6.5 Reproductive hormones

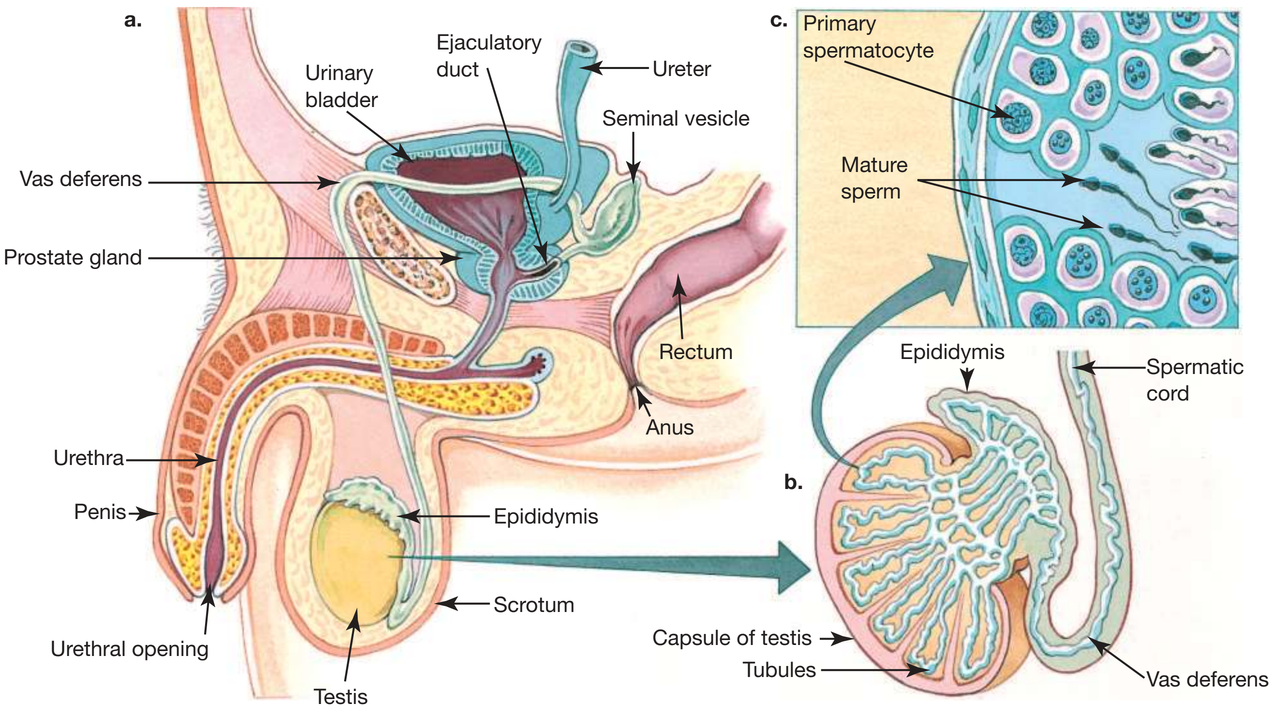
The endocrine system also plays a key role in controlling and coordinating human reproduction and development.

Male reproductive hormone levels

When a male reaches puberty, the endocrine system releases several hormones.

1. The male's pituitary gland secretes **luteinising hormone** (LH).
2. LH acts on his testes to produce another hormone called **testosterone**. An increase in testosterone levels causes sex organs to grow and testes to begin to produce sperm. Secondary sex characteristics are increased muscle development, and changes in voice, muscle and hair growth.

FIGURE 3.60 a. The male reproductive system **b.** The internal structure of the testes **c.** An increase in the level of testosterone during puberty triggers the testes to produce sperm cells.

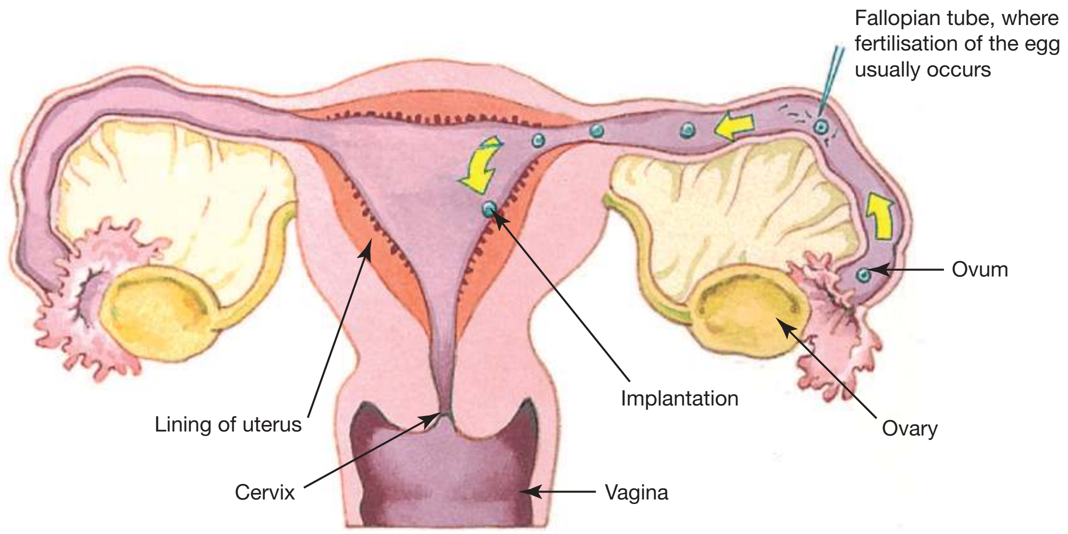


Female reproductive hormone levels

When a female reaches puberty, the endocrine system releases different hormones.

1. The female pituitary gland secretes **follicle-stimulating hormone (FSH)**.
2. FSH acts on ovaries to stimulate the **follicles** (structure in which the egg develops) to grow.
3. A hormone called **oestrogen** is secreted from the ovaries (and the placenta during pregnancy), which causes the thickening of the lining of the **uterus** to prepare it for a potential fertilised egg.
4. Increased levels of oestrogen also stimulate the hypothalamus to produce more FSH and LH.
5. Increasing levels of LH cause the follicle to swell. The mature follicle bulges on the surface of the ovary, ruptures, and the **ovum** (unfertilised egg cell) is released from the ovary into the fallopian tube. This process is called **ovulation**.
6. Following ovulation, the empty follicle from which the egg was released becomes a **corpus luteum**. This structure secretes another hormone called **progesterone**.
7. Progesterone continues to prepare the uterine lining for pregnancy.
8. If **fertilisation** does not occur, both the ovum and corpus luteum break down. This causes the progesterone levels to drop and hence the lining of the uterus (endometrium) to break down. Blood and uterine lining are discharged through the vagina in a process called **menstruation**.
9. When progesterone levels drop, the pituitary gland produces FSH and the cycle begins again. These cyclic changes in the ovaries and lining of the uterus as a result of changing hormone levels in the blood are called the menstrual cycle.

FIGURE 3.61 The female reproductive system showing the release of an ovum



SCIENCE AS A HUMAN ENDEAVOUR: Using hormones to control reproduction

Hormones play a crucial role in regulating many processes in the human body, including reproduction. Scientists have learned how to use hormones to influence fertility, which has led to the development of contraceptives (birth control). These contraceptives work by interacting with the body's natural hormonal systems to either increase or decrease fertility.

Hormonal contraceptives

Hormonal contraceptives are designed to control the levels of key reproductive hormones, such as estrogen and progesterone, to prevent pregnancy. They affect the body's natural processes in the following ways:

- *Preventing ovulation.* Normally, rising levels of luteinising hormone (LH) trigger the release of an egg from the ovary (ovulation). Contraceptives keep hormone levels steady, preventing the surge of LH and stopping ovulation from occurring.

- *Thickening cervical mucus.* Hormones like progestin cause the mucus in the cervix to thicken. This makes it harder for sperm to swim through and reach the egg.
- *Thinning the uterine lining.* Hormonal contraceptives thin the endometrium (the lining of the uterus), making it less likely that a fertilised egg can implant and grow.

FIGURE 3.62 Contraceptive pills contain different levels of hormones.

Emergency contraception

Emergency contraceptive pills, like the 'morning-after pill', work differently. They contain high doses of hormones that temporarily stop ovulation or alter the environment of the reproductive tract, making it harder for sperm to fertilise an egg.

Male contraceptives and hormones

Research into male hormonal contraceptives focuses on altering levels of testosterone and other hormones to reduce sperm production. These contraceptives often combine testosterone with progestins to stop the testes from making sperm. However, the challenge is finding the right balance to avoid side effects like mood changes or a drop in libido.

Mechanisms of hormonal contraception

- *Negative feedback loops.* The hypothalamus and pituitary gland use negative feedback to control hormone levels. Contraceptives 'trick' the body into thinking hormone levels are stable, preventing the usual rise and fall of reproductive hormones.
- *Regulating hormone balance.* By providing consistent levels of hormones, contraceptives suppress the body's natural hormone production. This prevents processes like ovulation and thickening of the uterine lining from happening.

Advances in hormonal contraception

Modern contraceptives are becoming more targeted, focusing on specific hormone receptors rather than broadly altering hormone levels. For example:

- some contraceptives aim to block sperm from fertilising an egg by 'tricking' the egg into thinking it is already fertilised
- some contraceptives prevent the fertilised egg from implanting in the uterus by modifying hormone interactions.

1. Explain how hormonal contraceptives prevent ovulation by affecting the body's hormone feedback systems.
2. Describe the role that negative feedback plays in the way hormonal contraceptives work.
3. Discuss how emergency contraception differs from regular contraceptives in the way it interacts with hormones.
4. Discuss why male contraceptives need to balance testosterone and progestin levels to avoid side effects.
5. List the advantages of newer contraceptives that target hormone receptors instead of altering hormone levels broadly.

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

DISCUSSION

How might hormone replacement therapy help reduce the effects of menopause in women?

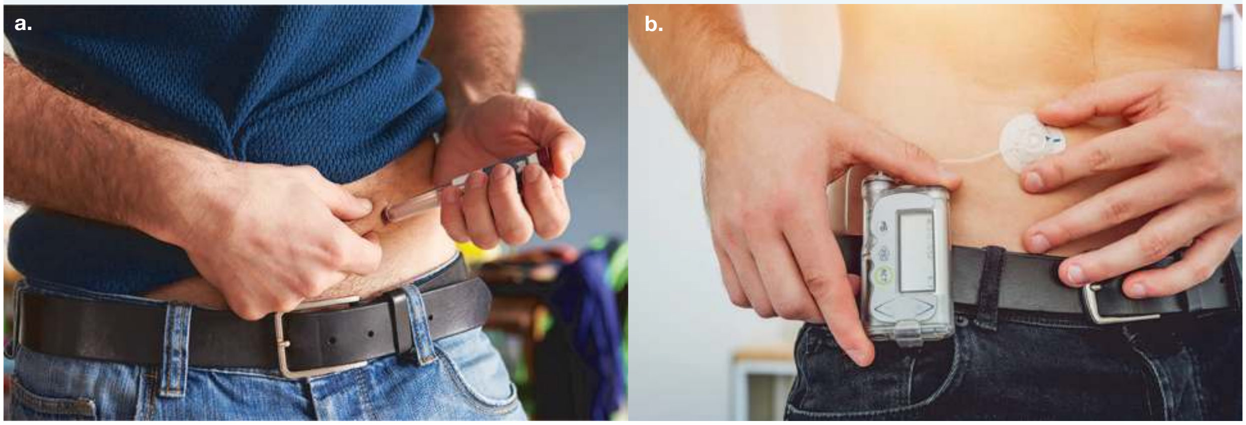
3.6.6 Malfunctions in the endocrine system — diabetes

Type 1 diabetes

One of the most common disorders of the endocrine system is type 1 diabetes. This is an autoimmune disease that causes the body's immune system to mistakenly attack and destroy the insulin-producing cells in the pancreas. Without insulin, the body cannot properly control blood sugar levels. Type 1 diabetes usually develops in people under the age of 30. While the exact cause is still unknown, research suggests that genetics may play a role in increasing a person's risk of developing this condition.

As there is no cure, people with type 1 diabetes must carefully monitor their blood glucose levels (up to six times a day) and undergo insulin replacement therapy. Insulin replacement uses artificially made insulin and is administered via injections or an insulin pump (figure 3.63). An insulin pump is a small device that stores insulin. Individuals wear the pump 24 hours a day. After a meal, insulin is injected into their body via a small needle inserted under the skin. If not carefully monitored, diabetes could lead to the development of **hyperglycaemia** or **hypoglycaemia**.

FIGURE 3.63 a. A diabetic person injects themselves with insulin. **b.** A diabetic person with an insulin pump connected via the abdomen.



Type 2 diabetes

Type 2 diabetes is the most common form of diabetes, making up about 85–90 per cent of all cases. Unlike type 1 diabetes, which is an autoimmune disease and cannot be prevented, type 2 diabetes is linked to both genetics and lifestyle factors, such as being overweight, smoking or having an unhealthy diet. It usually develops later in life and is caused by insulin resistance, which means the body's cells stop responding properly to insulin. In response, the pancreas produces more insulin to try to control blood glucose levels. Over time, this extra demand can damage the insulin-producing cells in the pancreas. As a result, people with type 2 diabetes have high blood sugar levels (hyperglycaemia) because their body does not produce enough effective insulin.

Effects of prolonged hyperglycaemia can include:
- kidney damage
- lack of circulation, leading to numbness in feet and/or hands
- heart disease
- vision loss/blindness
- development of wounds that are difficult to heal.

Type 2 diabetes can be managed with regular exercise and by maintaining a healthy diet and lifestyle. In severe cases where blood glucose levels remain high, medication and insulin therapy may be required.

SCIENCE AS A HUMAN ENDEAVOUR: Diabetes-induced blindness

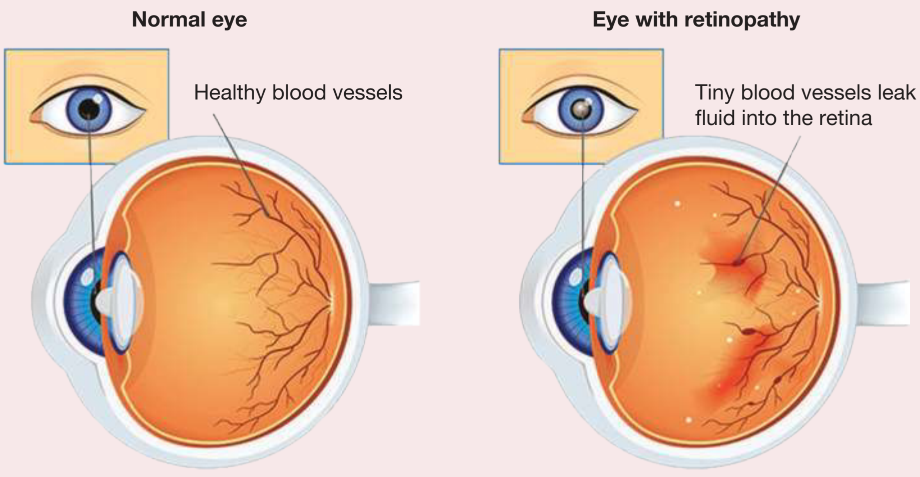
Diabetic retinopathy is a serious complication of diabetes and a leading cause of preventable blindness worldwide, including in Australia. This condition damages the retina, which is the part of the eye responsible for detecting light and colour. The retina contains photoreceptors known as rods and cones, which convert light into signals sent to the brain for visual interpretation.

When blood sugar levels remain elevated over a long period, small blood vessels in the retina (capillaries) can become blocked, reducing blood supply to the area. In response, the body attempts to grow new blood vessels (a process called neovascularisation) to restore blood flow. However, these new vessels:
- are fragile and prone to leaking blood into the vitreous humour (the gel-like substance in the eye)
- can lead to scar tissue formation, increasing pressure in the eye
- may cause retinal detachment, where the retina separates from the back of the eye, resulting in permanent vision loss if untreated.

Symptoms of diabetic retinopathy can include:
- blurred or distorted vision
- double vision
- eye strain and frequent headaches
- dark spots or floaters in the field of vision.

These symptoms often develop gradually, so regular monitoring is essential for early detection and management.

FIGURE 3.64 a. Blood vessels in a normal eye **b.** Damaged, leaky blood vessels as a result of diabetic retinopathy



In Australia, diabetic retinopathy is a leading cause of preventable blindness, affecting an estimated 25–35 per cent of Australians with diabetes. Early diagnosis and management are critical to preventing vision loss. Key strategies include:

- *blood sugar management.* Keeping blood glucose levels within target ranges reduces the risk of damage to retinal blood vessels.
- *regular eye exams.* Annual eye screenings for people with diabetes allow for early detection of retinal changes.
- *advanced treatments.* Laser therapy, injections of anti-VEGF drugs (vascular endothelial growth factor inhibitors) and surgery can help manage the progression of severe cases.

Advancements in retinal imaging technologies, such as optical coherence tomography (OCT), provide detailed 3D images of the retina, enabling earlier and more accurate diagnosis. Emerging therapies, including gene-based treatments and regenerative medicine, aim to repair damaged retinal tissue and restore vision.

1. Explain what happens to the retinal blood vessels in diabetic retinopathy and why this leads to vision loss.
2. Describe how neovascularisation in diabetic retinopathy differs from normal blood vessel formation.
3. Explain why controlling blood sugar levels is important in preventing complications like diabetic retinopathy.
4. What role do advanced technologies, such as optical coherence tomography, play in diagnosing and treating diabetic retinopathy?
5. How might new treatments, such as gene therapy, improve outcomes for individuals with diabetic retinopathy?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

3.6 Activities

learnon

3.6 Quick quiz on	3.6 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 5, 6, 8, 12	3, 7, 11, 13, 14, 15, 16	4, 9, 10, 17

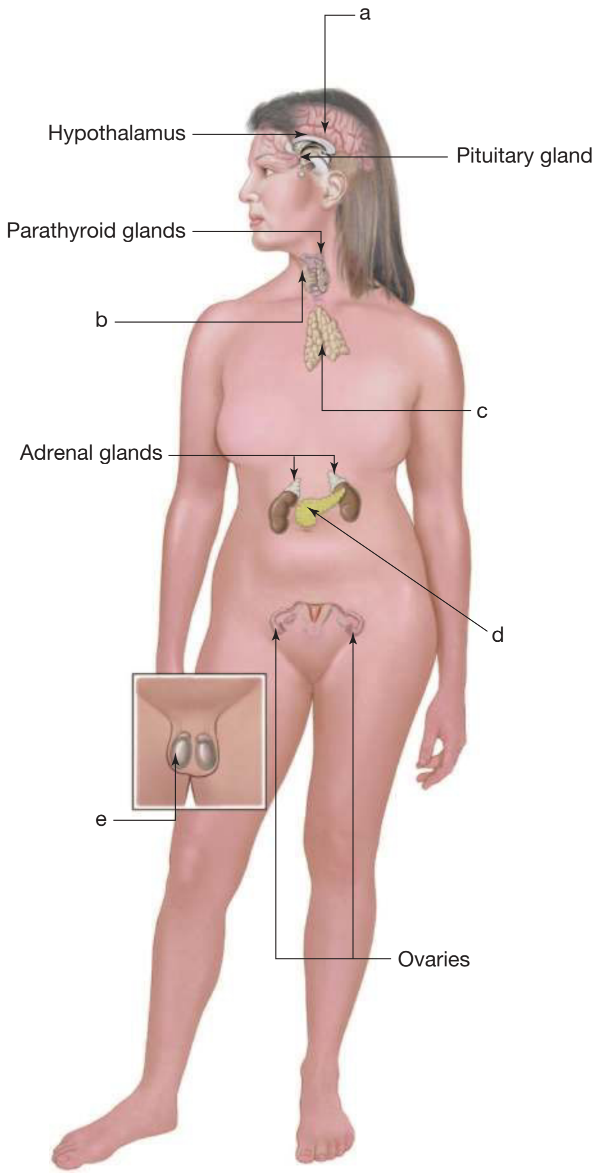
Remember and understand

1. **Identify** which of the terms on the left matches each of the definitions on the right.

Components of the endocrine system

Term	Definition
a. Anti-diuretic hormone (ADH)	1. Increases blood glucose levels
b. Glucagon	2. Lowers blood glucose levels
c. Insulin	3. Increases metabolic rate of cells
d. Oestrogen	4. Causes testes to produce sperm
e. Progesterone	5. Controls menstrual cycle and pregnancy
f. Testosterone	6. Causes thickening of the uterine lining
g. Thyroxine	7. Causes reabsorption of water in kidneys

2. **Identify** and **describe** the three endocrine glands located in your brain.
3. **Explain** what hormones are, where they are produced and how they are transported through the body.
4. **Explain** whether all parts of the body are affected by a particular hormone.
5. **Identify** the components of the endocrine system labelled a to e in the figure provided.



6. **Identify** two ways in which the actions of the endocrine system differ from the nervous system.
7. **Describe** an example of negative feedback that includes the involvement of a hormone.

Apply and analyse

8. **Distinguish** between:
   a. hormones and endocrine glands
   b. menstruation and ovulation
   c. endometrium and uterus
   d. testes and sperm.

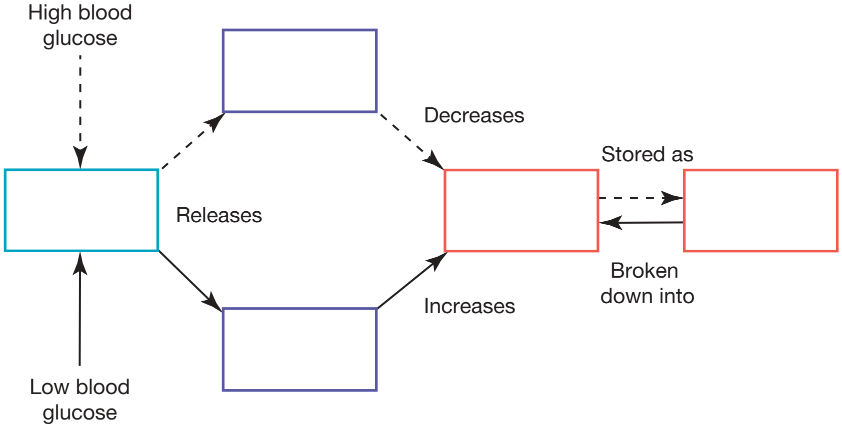
9. **Describe** the relationship between the:
   a. pancreas, liver, glucose, glucagon, glycogen and insulin
   b. pituitary gland, LH, testes, testosterone and sperm
   c. pituitary gland, FSH, ovary, oestrogen, follicles, uterine lining, hypothalamus, LH, ovum, fallopian tube and ovulation
   d. corpus luteum, uterine lining, progesterone and menstruation.
10. a. Other than pills, **name** the forms in which hormone-based female contraceptives can be used.
    b. **Outline** how these hormones can be used to prevent fertility.
11. a. **Name** the two hormones that may be used in a male contraceptive pill.
    b. **Outline** how these hormones can be used to prevent fertility.
12. The nervous and endocrine systems both play a vital role in the maintenance of homeostasis in the body. **Compare** the speed and duration of response produced by the nervous and endocrine systems.
13. **Compare** and **contrast** the types of messages sent by the endocrine and nervous systems.

Evaluate and create

14. **Identify** which of the following terms are part of the nervous system and which are part of the endocrine system.

Central nervous system	Electrical impulse
Endocrine gland	Glucagon
Insulin	Homeostasis
Hormone	Motor neuron
Neurotransmitter	Pancreas
Peripheral nervous system	Sensory neuron
Stimulus–response model	Negative feedback

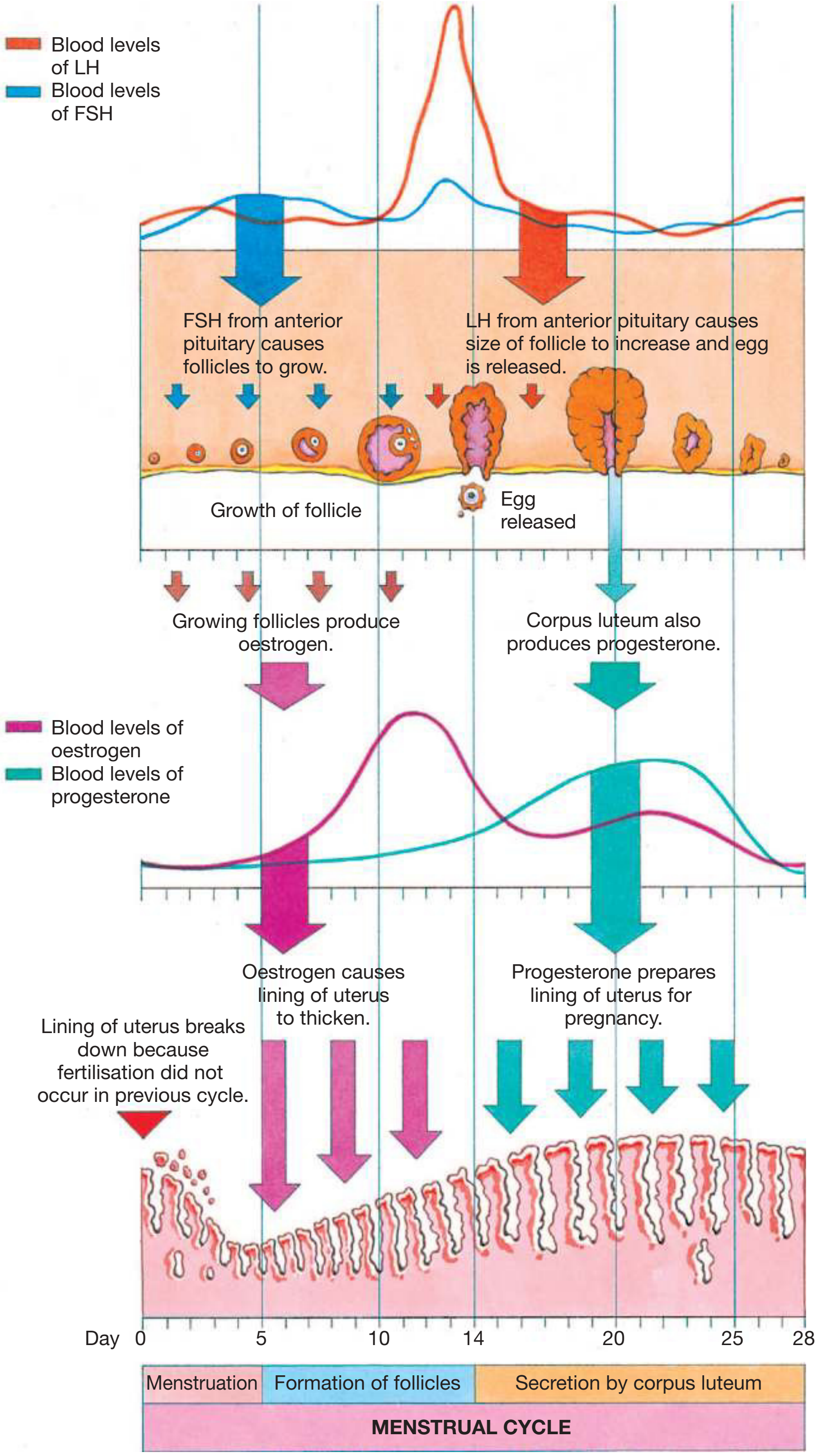
15. Complete the flowchart to link the following terms.
    - Glucagon
    - Insulin
    - Pancreas
    - Glycogen
    - Glucose



16. Male and female fertility patterns are different. **Explain** what you think the key differences are and comment on how they may affect the development and use of effective hormone-based contraceptives.

17. SI Ovulation occurs when the mature follicle ruptures on the surface of the ovary and the ovum is released. Use the diagram provided to answer the following questions.

a. **Identify** which hormone in the diagram is at the highest level just prior to ovulation.
b. **Identify** when ovulation is likely to occur.
c. **Identify** when progesterone is at its highest level.
d. **Identify** the stage in the cycle that the endometrium is at its thickest.
e. **Describe** the changes in the concentrations of each of the hormones throughout the menstrual cycle.



Answers and sample responses are available in your digital formats.

LESSON 3.7 Review

3.7 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
3.2	I can understand how the respiratory and circulatory systems work together to supply oxygen to your cells and remove carbon dioxide from them.			
3.3	I can recall the five key features of a stimulus–response model.			
	I can define homeostasis.			
	I can explain the difference between negative and positive feedback mechanisms.			
3.4	I can describe the links and differences between the senses and different types of receptors in the human body.			
3.5	I can identify and explain the components of the nervous system.			
	I can compare the roles of the somatic and autonomic nervous systems.			
	I can describe how messages are transmitted from a stimulus to generate a response.			
	I can explain some examples of technological and medical advances in the study of neural diseases and damage.			
3.6	I can explain how the endocrine system controls body functions through hormones released by various glands.			
	I can use the stimulus–response model and negative feedback loops to explain the role of the endocrine system in the regulation of body temperature and blood glucose by homeostatic mechanisms.			

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Post-test	Topic 3 Post-test
eWorkbook	Topic 3 eWorkbook
Digital document	Key terms glossary

3.7 Activities

learnon

3.7 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4, 6, 8, 10, 16, 17, 18, 20	3, 7, 9, 11, 14, 15, 19, 21	5, 12, 13, 22, 23

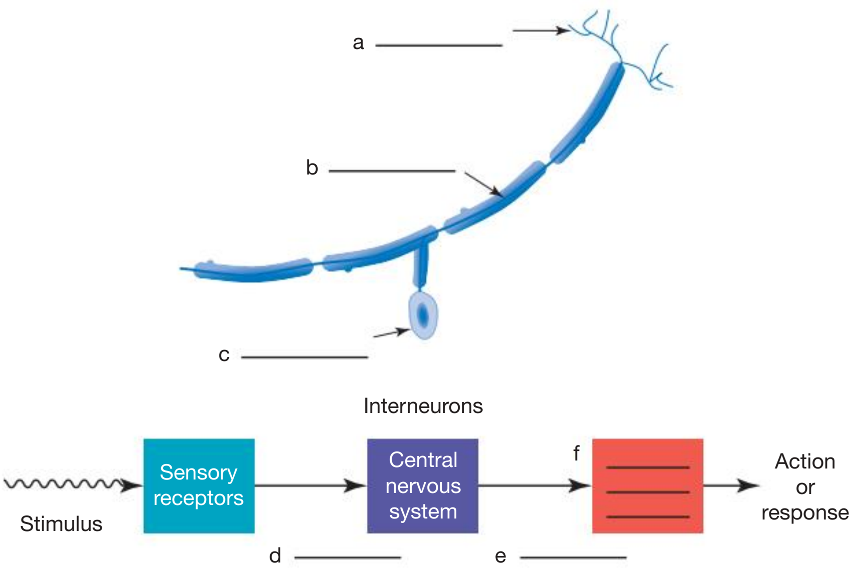
Remember and understand

1. **Construct** a flowchart to show the stimulus–response model.
2. MC **Identify** the name given to the connections between neurons where a message is passed from one neuron to the next.
   A. Axon
   B. Dendrite
   C. Myelin
   D. Synapse
3. **Identify** the missing terms to complete the following table.

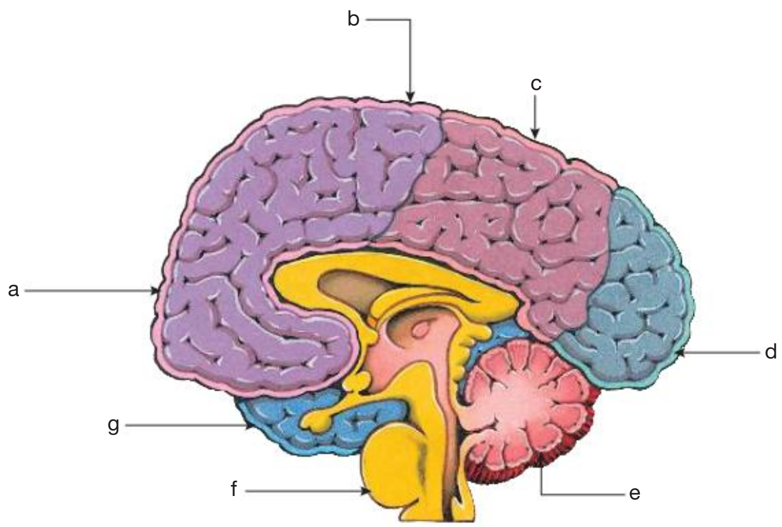
Stimuli, receptors and sense organs

Stimulus	Receptor	Sense organ
		Eye
	Chemoreceptor	
Vibrations, pressure		
	Thermoreceptor	

4. **Name** the parts of the diagram using the terms provided.
   - Dendrite
   - Sensory neurons
   - Cell body
   - Effector
   - Axon
   - Motor neurons



5. **Identify** the parts of the brain on the figure provided and **state** one of the functions of each.



6. **Identify** which of the hormones on the left matches each of the functions on the right.

Functions of different hormones

Hormone	Function
a. Anti-diuretic hormone (ADH)	1. Causes reabsorption of water in kidneys
b. Glucagon	2. Causes testes to produce sperm
c. Insulin	3. Causes thickening of the uterine lining
d. Oestrogen	4. Controls menstruation cycle and pregnancy
e. Progesterone	5. Increases blood glucose levels
f. Testosterone	6. Increases metabolic rate of cells
g. Thyroxine	7. Lowers blood glucose levels

7. **Identify** which of the terms on the left matches each of the definitions on the right.

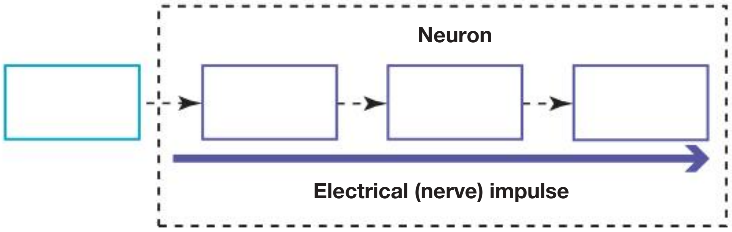
Components of the nervous system

Term	Definition
a. Central nervous system	1. Made up of a cell body, dendrites and axon
b. Motor neuron	2. Takes messages away from the central nervous system
c. Nerves	3. Takes messages to the central nervous system
d. Neuron	4. Brain and spinal cord
e. Neurotransmitter	5. Chemical messenger that carries messages from one neuron to another across a synapse
f. Peripheral nervous system	6. Nerves that connect the central nervous system to the rest of the body
g. Sensory neuron	7. Gap between neurons
h. Synapse	8. Made up of neurons

8. **Identify** the missing words to complete the sentence.
Myelin _________ the speed at which the ____________ can move through the neuron and hence the speed at which the message is communicated.
9. **Describe** the relationship between the pituitary gland, the adrenal glands and adrenaline.
10. **Explain** how the release of adrenaline can increase your chances of survival.
11. a. **Identify** three neurotransmitters in your brain that can influence how you feel and react.
    b. **Describe** the effects that each of these neurotransmitters can have on your behaviour.

Apply and analyse

12. a. **Identify** and underline the incorrect term in each sentence and replace it with the correct term.
        i. The neuron carries hormones to target cells.
        ii. The master gland of the endocrine system is the adrenal gland.
        iii. The brain and spinal cord make up the peripheral nervous system.
        iv. Each molecule has tissues that carry out particular functions.
    b. **State** definitions for the incorrect words you replaced.
13. **Outline** the differences between each pair of terms.
    a. Positive feedback and negative feedback
    b. Thermoreceptor and chemoreceptor
    c. Axon and dendrite
    d. Hormone and neurotransmitter
    e. Central nervous system and peripheral nervous system
    f. Thalamus and hypothalamus
14. Place the following terms in their appropriate positions in the flowchart shown:
    - cell body
    - axon
    - dendrite
    - stimulus

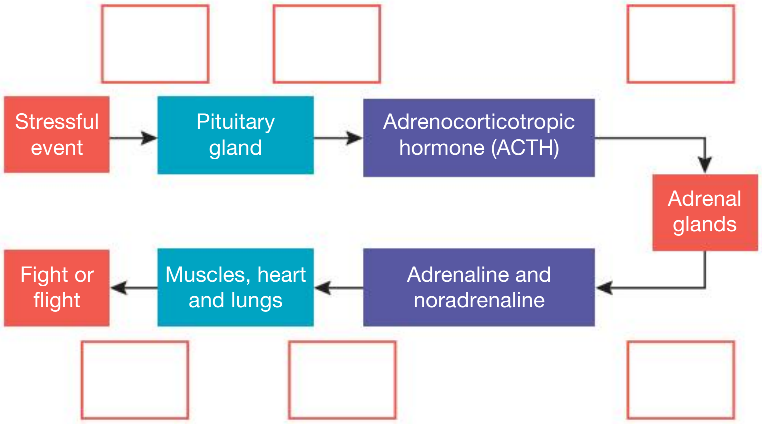


15. **Describe** the relationship between adrenaline, pituitary, adrenal cortex, heart rate and stress.
16. **Recall** three endocrine glands and the hormones they produce. **Describe** a function of each of the hormones.
17. **Provide** an example of a negative feedback mechanism. **Explain** why it is important.
18. **Compare** type 1 and type 2 diabetes.
19. **Explain** how type 2 diabetes can lead to diabetic retinopathy.

Evaluate and create

20. **Construct** a table to summarise the differences between the nervous and endocrine systems. Make sure you include the name of the information each system produces, how that information is carried throughout the body, and the speed and length of each system's response.
21. **Construct** a flowchart that outlines what happens when you sit on a chair that has a sharp object on it. Include both nervous and endocrine responses.

22. **Explain** the role of the nervous and endocrine systems in regulating body temperature, and **outline** both voluntary and involuntary processes involved in thermoregulation.
23. The following flowchart shows a series of events that may occur when you encounter a stressful event. **Suggest** descriptions or labels for each of the links (shown as blank boxes).



Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

4 Disease

CONTENT DESCRIPTION

Infectious and non-infectious diseases are caused by different organisms and agents; measures to control the transmission of infectious diseases include personal hygiene, quarantine protocols, medical treatment and public education programs (VC2S10U03)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 4.1 Overview

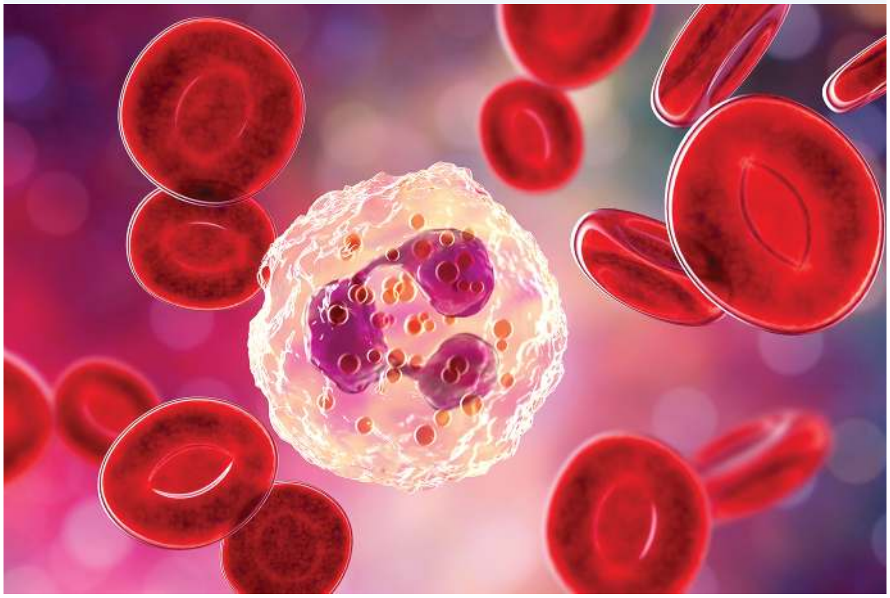
4.1.1 Introduction

Lines of defence, specialised cells and chemical weapons all form a part of the amazing array of strategies used by our bodies to keep us healthy.

Figure 4.1 shows a neutrophil, which has a hidden advantage: projections. These arm-like extensions reach out from the cell membrane, helping to pull the yeast cell closer and guide it towards the centre of the cell, where it can be engulfed and broken down.

In this topic, we will explore how infectious diseases have shaped the world and the medical breakthroughs that have been developed in response to these challenges. At the heart of these medical breakthroughs is the improved understanding of how our bodies respond to disease.

FIGURE 4.1 Your body has many ways to defend itself, including using specialised cells such as this neutrophil white blood cell, which has engulfed a yeast cell (purple).



DISCUSSION

1. Define an infectious disease.
2. Compare the differences between viruses and bacteria.
3. Describe what a parasite is and explain how it interacts with its host.
4. Explain what the Black Death is and describe how it spreads.
5. Evaluate whether immunisation is necessary and justify your response.
6. Identify the parasite that can grow up to 10 metres long and live inside the human body, and explain its effects on human health.
7. Explain the connection between H5N1 and birds, including the virus' impact on their health and its significance to humans.
8. Explain how COVID-19 developed into a global pandemic and identify the factors contributing to its widespread transmission.
9. Determine whether diabetes is contagious and explain the reasoning behind your answer.
10. Why are anthrax, cholera, botulism and smallpox drawn to harmful attention?

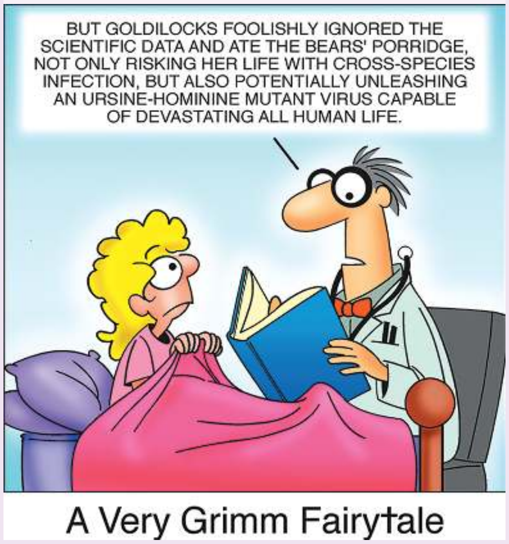
SCIENCE INQUIRY: Using stories and rituals to pass on knowledge about food safety

Throughout history, stories and rituals have been used to pass knowledge about food and nutrition from one generation to the next.

Goldilocks and the Three Bears

1. Imagine that Goldilocks got sick after eating the porridge. Suggest some reasons why this may have happened.
2. The three bears did not cover their porridge while they went for their walk. Was this a good idea or not? Give reasons for your answer.
3. How long can porridge stay uncovered at room temperature before it is dangerous to eat? Find out the spoiling time of four other foods.
4. Create your own fairytale to teach young children about poisonous or spoiled food. Present your story as a slide show presentation, storybook, pantomime or puppet play.

FIGURE 4.2 Why might it have been dangerous for Goldilocks to eat the bears' porridge?

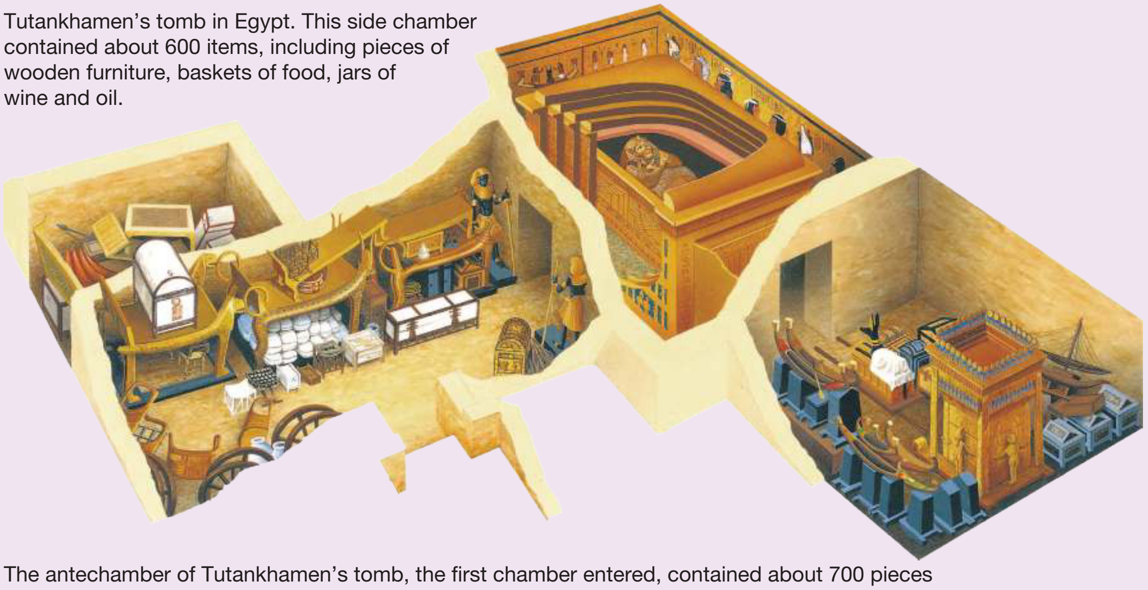


Tutankhamen

Baskets of food, along with jars of wine and oil, were found in Tutankhamen's tomb in Egypt in 1922 (see figure 4.3). Other Egyptian tombs contained honey that was in a well-preserved state; when opened, it retained some of its aroma. Today, most foods have a use-by or best-before date on the packaging.

FIGURE 4.3 Inside the tomb of Tutankhamen

Tutankhamen's tomb in Egypt. This side chamber contained about 600 items, including pieces of wooden furniture, baskets of food, jars of wine and oil.



The antechamber of Tutankhamen's tomb, the first chamber entered, contained about 700 pieces of furniture, a chariot (in bits) and two black and gold life-size statues either side of the entrance. There were also jars of oil, lamps, vases, musical instruments, board games and clothing.

5. For three different foods, find out what might happen, and why, if you used them well after their use-by date.
6. Sometimes canned food is unsafe to eat. Find out why.
7. Find out what strategies humans have to survive eating lots of different foods, some of which may cause food poisoning.

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

learnON

Pre-test	Topic 4 Pre-test
eWorkbook	Topic 4 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 4 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 4.2 Infectious diseases

LEARNING INTENTION

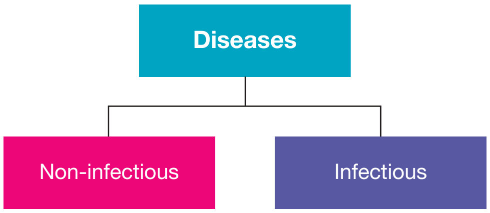
In this lesson you will:

- compare and describe the differences between non-infectious and infectious diseases
- understand how infectious diseases are spread and the range of strategies that can prevent or contain their spread.

4.2.1 Classifying diseases

A human **disease** can be defined as being any change that impairs the function of an individual in some way; it causes harm to the individual. Diseases can be classified as being infectious or non-infectious.

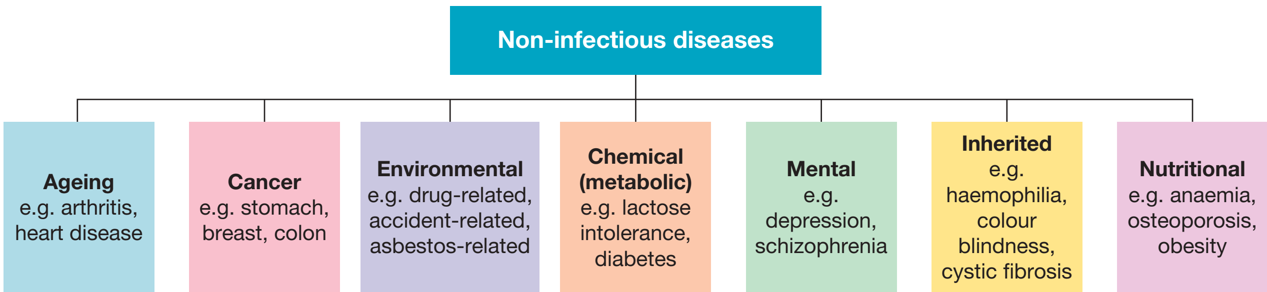
FIGURE 4.4 Diseases can be infectious or non-infectious.



Non-infectious diseases

Non-infectious diseases cannot be spread from one person to another; they are not contagious (transferred from one organism to another). Obesity, rickets and scurvy are examples of non-infectious diseases that may be related to unbalanced diets or nutritional deficiencies. Inherited diseases such as haemophilia and cystic fibrosis, and diseases related to exposure to particular poisons or drugs, are also non-infectious. Although **viruses** have been implicated in some cancers (e.g. cancer of the cervix), most cancers are considered to be non-infectious diseases.

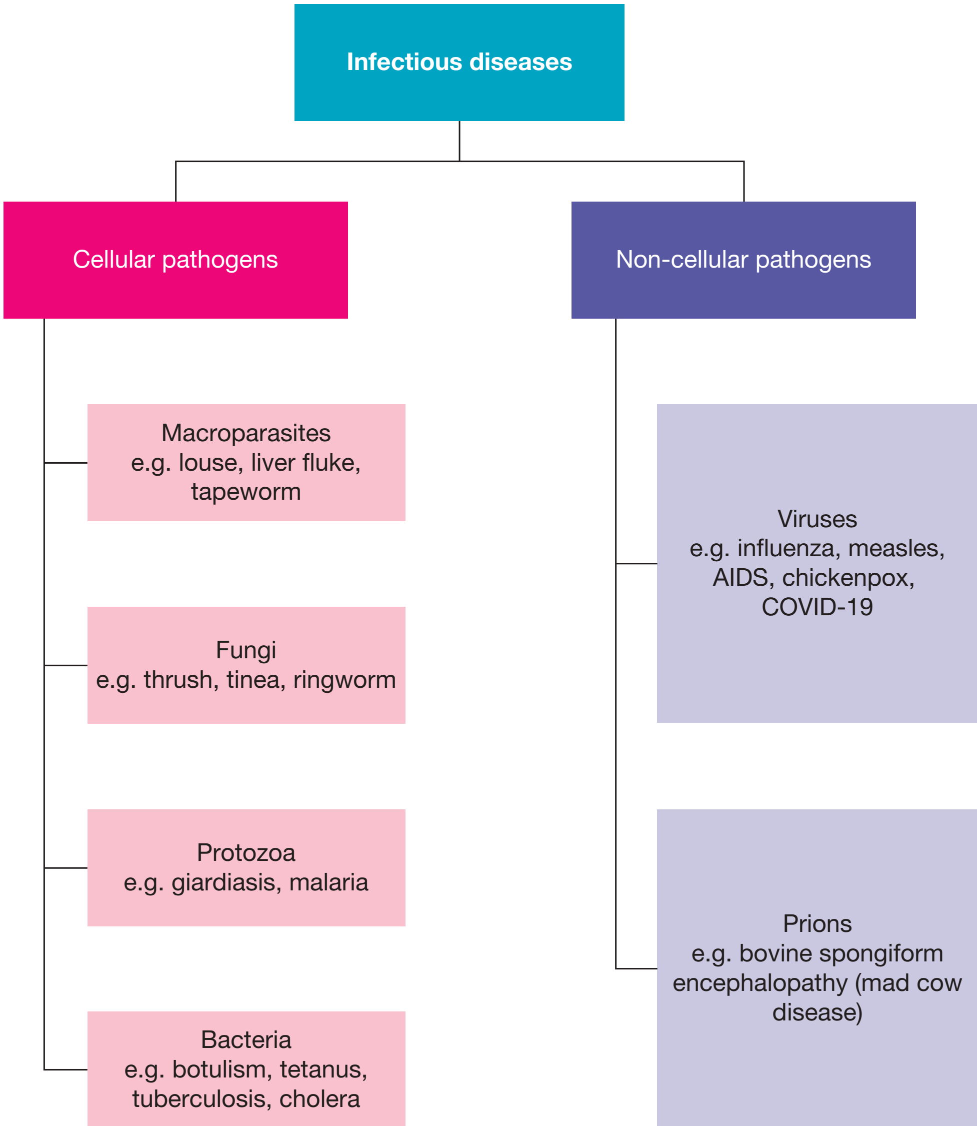
FIGURE 4.5 Non-infectious diseases include diabetes, heart disease and cancer.



Infectious diseases

Infectious diseases are diseases that are contagious and are caused by a **pathogen**. Tapeworms, head lice, liver flukes, fungi, protozoans and bacteria are examples of pathogens that are made up of cells and can be referred to as **cellular pathogens**. Some other pathogens, such as viruses, are not made up of cells and for this reason are sometimes referred to as **non-cellular pathogens**.

FIGURE 4.6 Infectious diseases in humans



4.2.2 Causes of infectious diseases

When bacteria, fungi or some other type of pathogen cause an infection, they are referred to as **parasites**. They live in or on the body of the sick person (the **host**) and cause harm. For instance, some bacteria produce toxins.

There are six main groups of pathogens: viruses, bacteria, fungi, protozoa, macroparasites (parasites that can be seen without a microscope) and **prions**. Bacteria, fungi, protozoa and macroparasites are cellular organisms and consist of one or more cells. Viruses and prions are non-cellular.

4.2.3 Causes of non-infectious diseases

Some of the causes of non-infectious diseases include:

- poor nutrition, including eating an unbalanced diet
- other lifestyle factors, including lack of exercise and exposure to prolonged periods of stress
- ageing, which results in the gradual breakdown of the body
- environmental factors, such as exposure to tobacco smoke, UV radiation, poisons, asbestos or drugs
- heredity — refers to when disease is caused by a genetic defect passed on from an individual's parents.

Non-infectious diseases often have multiple causes. For instance, genetics can raise your risk of heart disease, but a healthy diet and regular exercise can lower it. Most cancers don't have a single cause either. A specific gene can increase the risk of breast cancer, but lifestyle factors also play a role. Mental health conditions can be caused by genetics, chemical imbalances and stress or trauma. Additional information on causes of infectious and non-infectious diseases is discussed later in this topic.

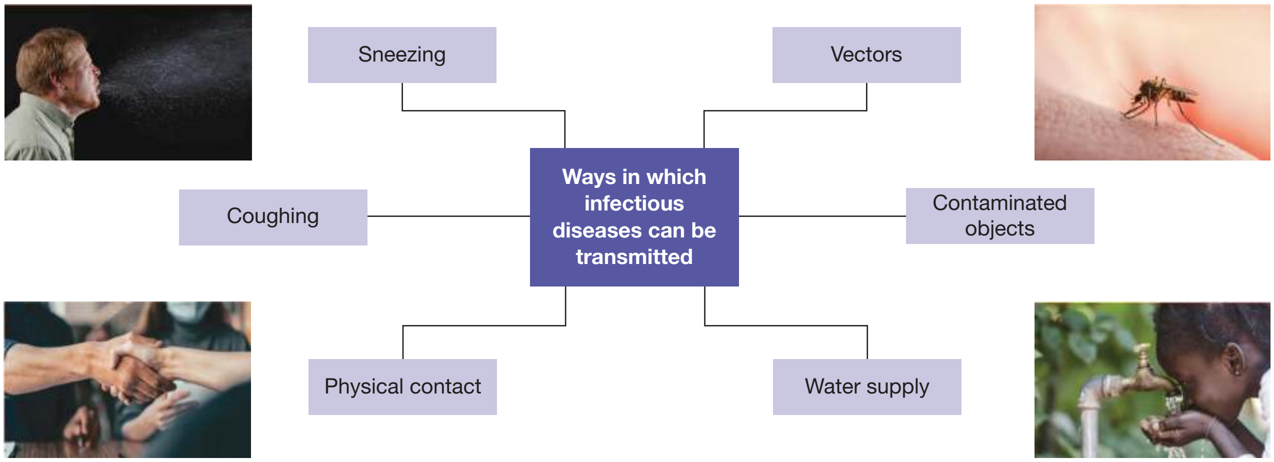
KEY IDEAS

- Infectious diseases can be passed on from one person to another. They are caused by pathogens.
- Pathogens are disease-causing agents and include some bacteria, viruses and fungi. They can be transmitted from one person to another.

4.2.4 Modes of transmission

The knowledge of how infectious diseases are transmitted is important if ways to control their spread are to be found. Some key ways in which pathogens may be transmitted include direct contact, vectors, contaminated objects or contaminated water supplies (figure 4.7).

FIGURE 4.7 Different ways in which infectious diseases can be transmitted



Direct contact

Some diseases are spread by direct contact. Touching others or being touched is one way in which pathogens can be directly transferred from one person to another. Another way is via airborne droplets that are produced when you cough, sneeze or talk. These droplets may contain pathogenic bacteria or viruses and may land on objects or people around you, which can result in disease.

Vectors

Some diseases are spread by vectors. **Vectors** are organisms that carry the disease-causing pathogen between organisms — without being affected by the disease themselves. Mosquitoes, houseflies, rats and mice are examples of organisms that can act as vectors to spread disease.

FIGURE 4.8 Mosquitoes are the vectors for many infectious diseases.

Contaminated objects

While fungal diseases such as tinea and ringworm can be spread by direct physical contact, they may also be transmitted by towels or surfaces that have been contaminated with skin cells of an infected person.

Food poisoning is often caused by contamination of food (or food utensils) with particular types of pathogenic bacteria called *Salmonella*. This can cause diarrhoea and vomiting, usually within 2–24 hours after ingestion. This is why washing your hands is so important after going to the toilet and before touching food or being involved in food preparation.

Contaminated water

Many pathogenic organisms live in water and are carried about in it. Our domestic water supply is usually chemically treated to kill disease-causing microorganisms within it. However, this may not be the case with water drunk directly from water tanks, rivers or creeks. This water may need to be boiled before it is drunk.

During the summer months, the Environment Protection Authority (EPA) measures the levels of *Escherichia coli* (*E. coli*) bacteria in water in coastal beaches. The level of *E. coli* in the water is used as an indicator of levels of potentially pathogenic bacteria, as it is found in faeces.

DISCUSSION

As a class, discuss the following.

1. Why are vectors, such as mosquitoes and rats, able to spread diseases without being affected by the pathogens they carry?
2. How can contaminated objects, like towels or utensils, contribute to the spread of diseases, and what strategies can be used to prevent this?
3. Why is it important to treat or boil water before drinking it, especially from natural sources, and how does monitoring *E. coli* levels help protect public health?

4.2.5 Preventing transmission of infectious disease

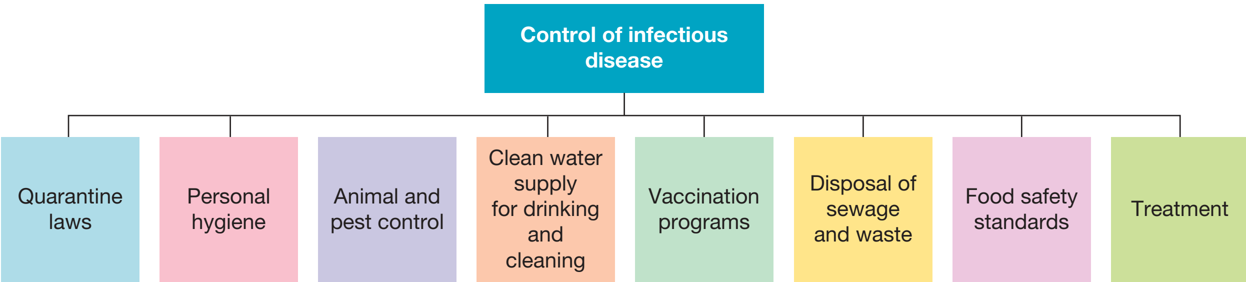
Preventing the spread of infectious diseases has been a challenge throughout history. The ancient Hebrews isolated those with disease by keeping them away from others or by sending them beyond the boundaries of the towns. In the Middle Ages, Mediterranean people refused to allow ships to dock for 40 days if they carried sick people. The separation of sick people from healthy people to avoid infection was the beginning of **quarantine**. Unfortunately, these methods were not enough to stop large outbreaks of disease.

KEY IDEA

The word ‘quarantine’ is derived from the Latin word *quadrāgintā*, meaning ‘forty’. In the Middle Ages, sick people were strictly isolated for a period of 40 days in order to prevent the spread of disease.

There are a number of ways in which the spread of disease may be controlled.

FIGURE 4.9 Preventing the transmission of infectious disease



SCIENCE INQUIRY: Investigating the spread and prevention of infectious diseases

In this investigation, you will compare the spread of infectious diseases under different conditions and evaluate preventative strategies to reduce transmission. You will also develop hypotheses about how factors like hygiene, physical barriers and **vaccinations** affect disease transmission, and test these using models or simulations.

Formulate investigable questions

Examples:

- How do physical barriers, such as masks and gloves, affect the spread of airborne particles that simulate infectious diseases?
- What role does handwashing play in reducing the spread of germs and diseases?
- How does vaccination help contain the spread of infectious diseases in a population?

Develop hypotheses

Examples:

- Washing hands with soap significantly reduces the spread of infectious particles compared to rinsing with water alone.
- Vaccinated populations will show lower rates of infection compared to unvaccinated populations in simulated models.

Plan and conduct investigations

- Use glitter or fluorescent powder to simulate germs and track their spread through touch or airborne transmission during interactions.
- Test the effectiveness of handwashing methods by comparing residue left under UV light.
- Model herd immunity using digital simulations to demonstrate how vaccinations reduce infection rates in populations.

Organise and analyse data

- Record infection rates with and without preventative strategies like masks, handwashing and vaccinations.
- Create graphs or tables to identify patterns and relationships.

Draw conclusions

- Evaluate which strategies were most effective in reducing transmission.
- Discuss limitations and real-world applications of the findings.

1. What patterns did you observe about the effectiveness of different preventative strategies in stopping the spread of diseases?
2. How do vaccines protect individuals and populations from infectious diseases?
3. Why is it important to model and test different strategies before applying them to real-life health policies?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

SCIENCE AS A HUMAN ENDEAVOUR: How science advances disease control and prevention

The study of infectious diseases has advanced significantly due to improvements in technology and scientific research, enabling scientists to develop strategies for prevention, containment and treatment.

The invention of the microscope in the 1600s allowed scientists like Louis Pasteur to discover microorganisms as the cause of diseases. This led to the development of germ theory, which formed the foundation for modern medicine. Technologies like PCR (polymerase chain reaction) now allow scientists to rapidly identify pathogens and trace the origins of disease outbreaks.

FIGURE 4.10 Wearing masks is one way to help prevent the spread of infectious diseases.

Scientific research has also led to the development of vaccines, which have eliminated or reduced diseases like smallpox and polio. The creation of antibiotics has further improved survival rates from bacterial infections.

Modern technologies, such as genetic engineering and mRNA vaccines, have enabled scientists to respond quickly to more recent disease outbreaks, including COVID-19. Contact tracing apps, data modelling and global communication networks now allow health authorities to track the spread of diseases and implement effective containment strategies.

These advances highlight how science and technology work together to protect public health and address global challenges; but they also raise ethical concerns, such as vaccine accessibility and data privacy.

1. How have advances in technology, such as microscopes and genetic sequencing, improved our understanding and treatment of infectious diseases?
2. What role do vaccines and antibiotics play in controlling the spread of infectious diseases?
3. What ethical challenges might arise when using technology to track and prevent the spread of diseases?
4. Why is it important for scientists to work quickly during global pandemics, and what risks might they need to manage?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

4.2 Activities

learnon

4.2 Quick quiz on	4.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 5, 6	2, 3, 7, 8, 11	4, 9, 10, 12

Remember and understand

1. **Define** the following terms and **state** one example for each of them.
   a. Disease
   b. Non-infectious disease
   c. Infectious disease
   d. Pathogen
   e. Contagious
   f. Vector

2. **Identify** three differences between non-infectious and infectious diseases.
3. **Explain** the difference between a pathogen and a disease.
4. Bacteria causes tuberculosis, a virus causes Ebola and a parasite causes malaria. **Explain** why all three are considered infectious diseases. **Discuss** what these infectious agents have in common in their structures and functions.
5. **Identify** which of the pathogens on the left causes each of the infectious diseases on the right.

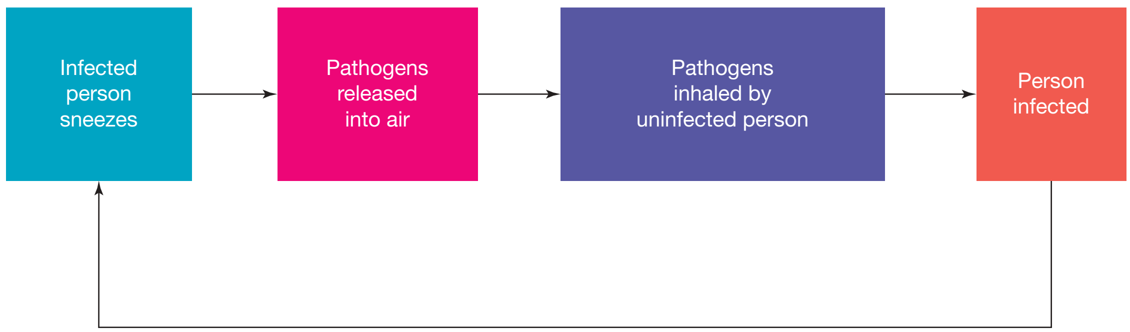
Pathogens and the diseases they cause

Type of pathogen	Infectious disease
a. Macroparasites	1. Giardiasis
b. Bacteria	2. Tinea
c. Fungi	3. Tapeworm
d. Protozoans	4. Cholera
e. Viruses	5. Influenza

Apply and analyse

6. a. Media campaigns can be effective in improving our health by changing social behaviours. **Explain** how the social media campaign involving the 'dab', which gained popularity as a dance move, impacted coughing etiquette and the spread of the common cold and influenza.
   b. **List** another five ways of preventing the spread of colds and flu.
7. The flowchart provided describes how diseases can be spread by sneezing. **Construct** similar flowcharts to show three other ways in which diseases can be spread.

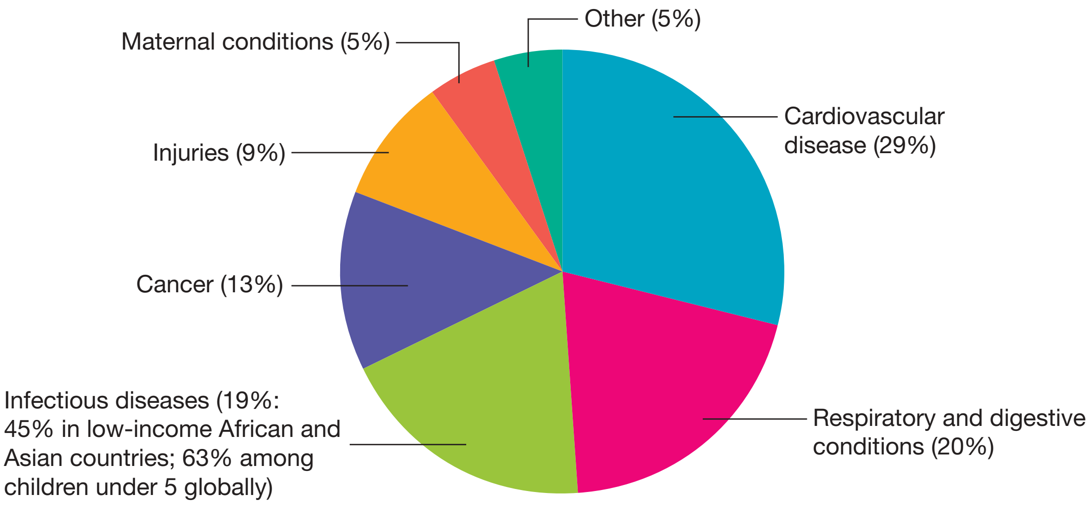
Some infectious diseases can be spread from one person to another via a sneeze.



Evaluate and create

8. SI Study the pie chart provided. It is an historical illustration that shows the main causes of death worldwide in 2002.
   a. **State** the percentage of people who died from infectious diseases:
      i. worldwide
      ii. in low-income African and Asian countries.
   b. **Suggest** why there is such a large difference in the percentage of people who died from infectious disease between wealthier countries and poor countries.
   c. **State** the percentage of children who died before the age of five of infectious diseases. **Suggest** why this figure is so high. (*Hint*: Think about the other main causes of death and who they are likely to affect.)
   d. **Construct** a column graph to represent the data shown in the pie chart.
   e. If the same data was collected in 2025 and a similar graph was drawn, **describe** how you think the two graphs would differ. **Justify** your answer.

Main causes of death worldwide in 2002



9. a. **State** which pathogen is the most common cause of food poisoning due to consumption of undercooked chicken.
   b. **Describe** the symptoms that are observed.
   c. **State** how many hours after consumption it takes for the onset of symptoms.
10. SI **Predict** social or ethical issues that might arise in designing policies for disease prevention.
11. **Describe** the most common illness suffered by overseas travellers.
12. **Suggest** practical methods for avoiding traveller's diarrhoea. Consider as many influences — such as drinking water, and the impact of water on food production and food preparation — as you can.

Answers and sample responses are available in your digital formats.

LESSON 4.3 Types of pathogens

LEARNING INTENTION

In this lesson you will:
- understand that not all microorganisms cause disease
- distinguish between cellular and non-cellular pathogens
- provide examples of different types of pathogens
- explain how pathogens can cause diseases in a host.

4.3.1 Microbiome — good bacteria

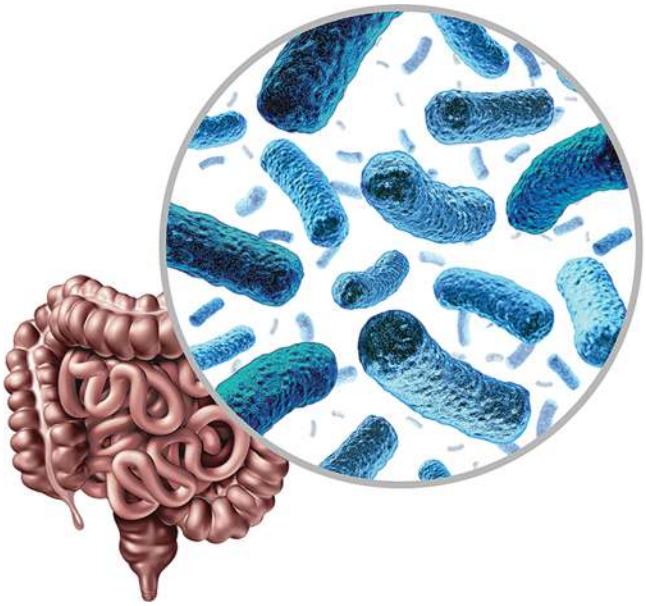
We do not live alone! There are trillions of microorganisms that live on us and in us — our **microbiome**. There are more of them than our own cells. We need them and they need us to survive. They even play a role in defending us from attack from outside invaders. Our microbiome is continually changing and no two people have the same microbiome. Development of our microbiome begins at birth, with the bacteria that colonises our intestines, and these are considered the normal **gut flora**. This gut flora varies depending upon whether the birth was a vaginal birth or a caesarean section, and is continued to be influenced by whether the baby is breast- or bottle-fed. We depend on our gut bacteria to obtain vitamins K and B.

Other factors that change our gut flora include:

- antibiotics — using antibiotics destroys both pathological and beneficial microbes, which can promote the growth of other pathogens
- the environment in which we live (rural, city, developing countries)
- diet — vegetarian diets are associated with healthy diverse gut microbiota. Diets high in sugar can slow the production of proteins, which inhibits the growth of beneficial gut microbes. Many people now choose to boost their gut flora by consuming probiotics, which are living organisms. Prebiotics can also be beneficial. These promote the activity or structure of the current gut microbiota.

Bacteria do not live only in our gut, but all over our bodies. The skin under your armpits contains more than 2 million bacteria per square centimetre. The unpleasant smell is caused not by the bacteria themselves, but is the result of the bacteria breaking down the proteins in your sweat. The bacteria in your armpits can prevent pathogenic bacteria from colonising, and so keep you healthy.

FIGURE 4.11 Probiotic bacteria in the small intestine and digestive microflora in the bowel work together to support digestion, nutrient absorption and maintaining a healthy gut environment.

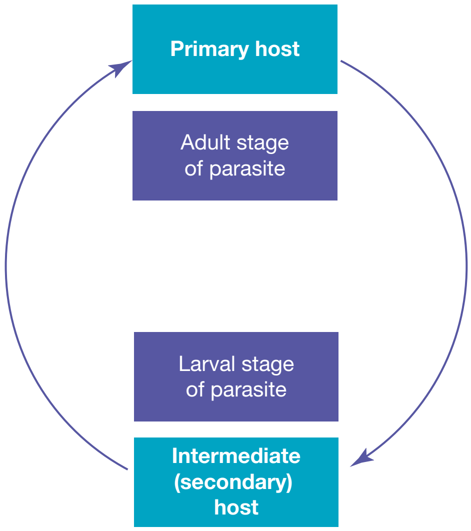


4.3.2 Parasites

Some relationships between organisms may provide one with resources and cause harm to the other. An example of this relationship is that of a parasite and its host.

The organism that a parasite lives in or on is referred to as its host. The life cycle of parasites can involve one or more hosts. The **primary host** is the organism used for the adult stage and the **intermediate host** (or secondary host) is used for the larval stage (figure 4.12).

FIGURE 4.12 The organism in which the parasite completes some part of its life cycle is referred to as its host.



Parasites can be classified according to the part of your body in which they live:

- **Endoparasites** — parasites that live inside your body
- **Ectoparasites** — parasites that live outside your body

Some parasites can harm their hosts and cause disease; these parasites are also considered to be pathogens. However, not all parasites kill their hosts. It's probably a very good idea if they don't, because they rely on their host for resources. Both animals and plants carry parasites; for example, fleas are a parasite that can be found living within the hair of a dog.

FIGURE 4.13 Flea living in dog hair

4.3.3 Non-cellular pathogens

Infectious diseases are caused by pathogens. Pathogens may be cellular (made up of cells) or non-cellular.

- Cellular pathogens include disease-causing bacteria, protists, fungi and macroparasites.
- Non-cellular pathogens include prions, viruses and **viroids**.

Non-cellular pathogens are considered to be non-living, as they are unable to undergo independent replication. In order to replicate, they must gain entry into a host cell.

Prions

Prions are non-cellular pathogens. The word prion is derived from the terms protein and infection. They are abnormal and infectious proteins that can convert your normal protein into prion protein. When cells containing prions burst, more of these infectious proteins are released to infect other cells. The bursting of these cells can also result in damage to the tissues of which they are a part.

Prions are thought to be responsible for degenerative neurological diseases. These diseases are also called **transmissible spongiform encephalopathies (TSE)**. The term spongiform is included because of the tiny holes that result from the bursting of infected cells, giving the brain a spongy appearance. Examples of these diseases include kuru, Creutzfeldt-Jakob disease (CJD) and bovine spongiform encephalopathy (BSE).

FIGURE 4.14 Comparison between a normal prion protein and the disease-causing abnormal prion protein

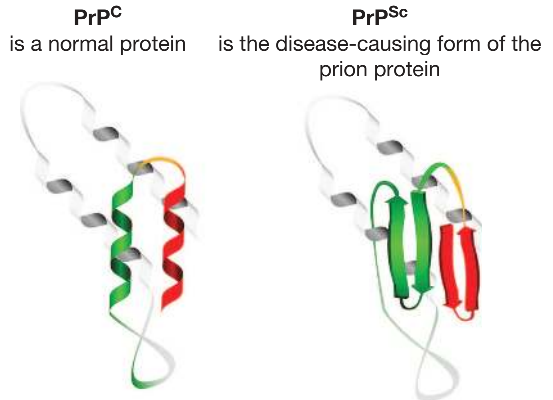
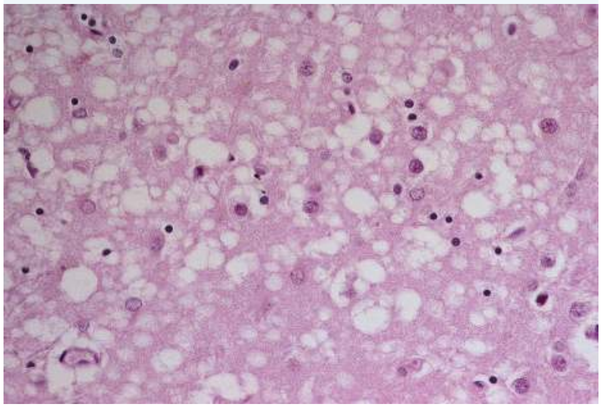


FIGURE 4.15 Brain tissue infected with Creutzfeldt-Jakob disease has a 'spongy' appearance, showing large holes due to cell damage.



BSE is commonly known as 'mad cow disease' because of the nervous or aggressive behaviour observed in infected cows. Mad cow disease was first discovered in the United Kingdom in 1986. Hundreds of thousands of cattle were destroyed when it was discovered that humans could become infected with this disease (giving them CJD) by eating meat from infected cows.

Viruses

Viruses are another example of non-cellular pathogens. Viruses are so small that they can only be seen with very powerful electron microscopes. Viruses come in many shapes and sizes (figure 4.16); however, all viruses contain the following features (figure 4.17):

- Genetic material (**DNA (deoxyribonucleic acid)** or **RNA (ribonucleic acid)**)
- Protein coat (capsid)

Scientists debate whether viruses should be called living things, as they are **obligate intracellular parasites**. This means that they need to infect a host cell before they can reproduce; they cannot do it on their own (figure 4.18). As viruses cause damage to their host cell in the process, they are also classified as pathogens. Examples of infectious diseases caused by viruses include warts, rubella, mumps, poliomyelitis, influenza, AIDS, SARS-CoV-2 (the virus that causes COVID-19) and the common cold.

FIGURE 4.16 Viruses come in many shapes and sizes.

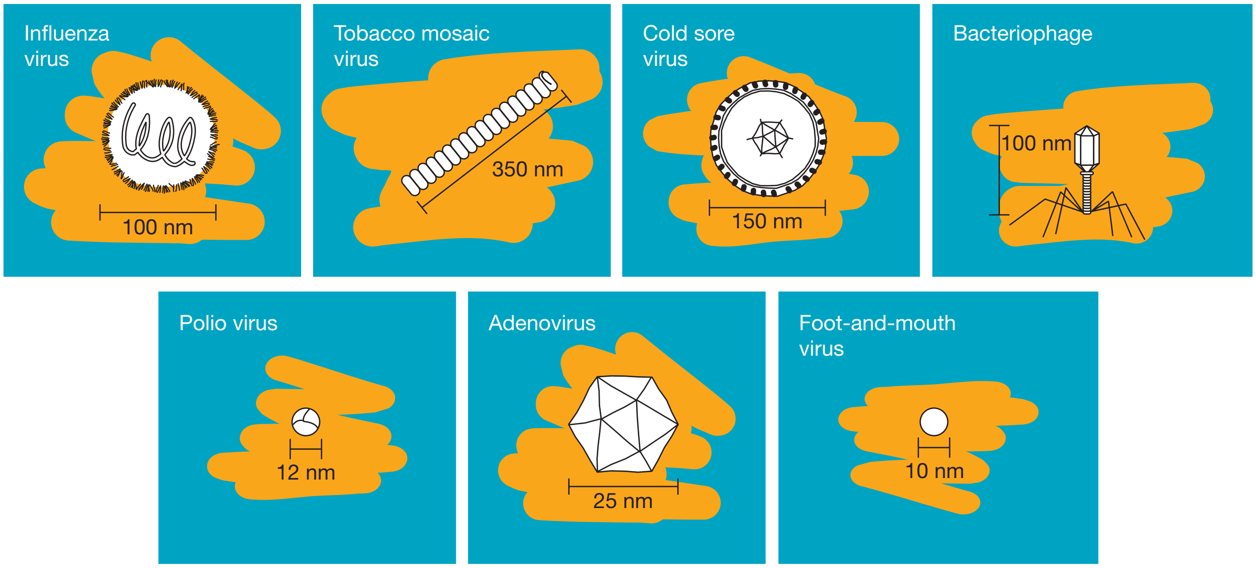


FIGURE 4.17 The influenza virus consists of RNA surrounded by protein and lipid layers. It is not cellular.

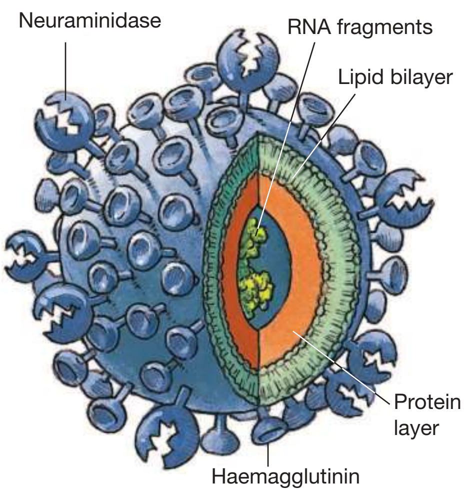
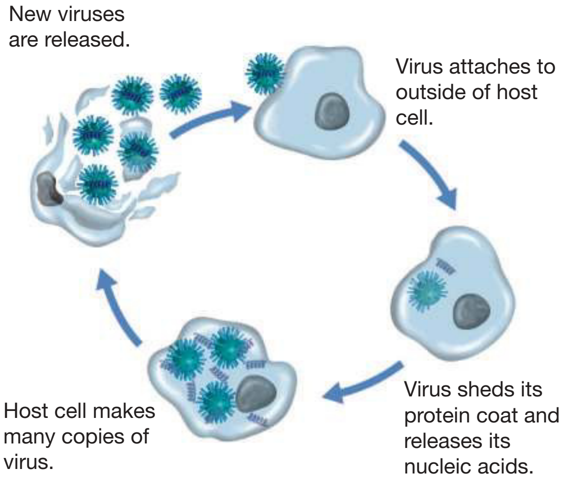


FIGURE 4.18 This cycle depicts how a virus is spread.



4.3.4 Cellular pathogens

Bacteria

Disease-causing bacteria are cellular pathogens that consist of a single cell. They can be classified on the basis of their cell shape, the organisation of colonies of bacteria and the presence or absence of structures (such as a flagellum) or particular chemicals in their cell wall. Some examples include:

- coccus — a spherical bacterium (e.g. *Staphylococcus*)
- bacillus — a rod-shaped bacterium (e.g. *Bacillus anthracis*)
- spirochaete — a thin, tightly-coiled bacterium (e.g. *Vibrio*).

Diseases caused by bacteria include tetanus, pneumonia, food poisoning, gastroenteritis, cholera, gonorrhoea, leprosy, tetanus, scarlet fever, whooping cough, meningitis and typhoid.

FIGURE 4.19 Some types of disease-causing bacteria

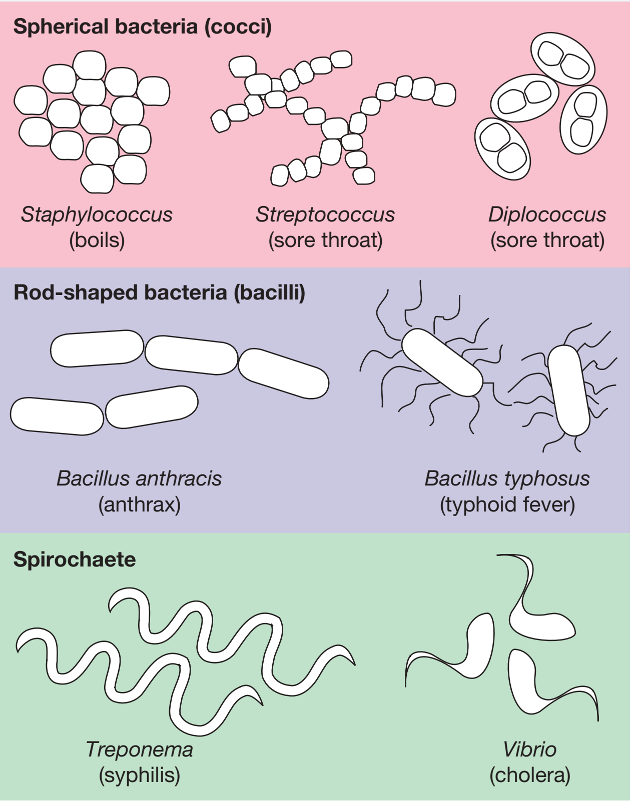
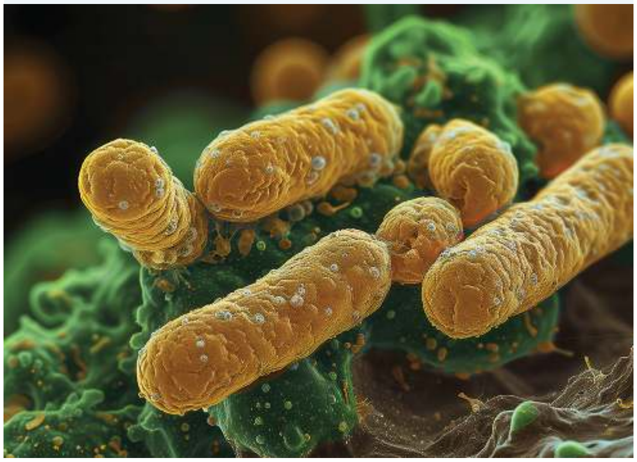


FIGURE 4.20 *Bacillus anthracis* bacteria



CASE STUDY: Leprosy

Leprosy, also known as Hansen's disease, is rare in Australia. It is caused by *Mycobacterium leprae*, a rod-shaped bacterium, and is a contagious disease that affects the skin, mucous membranes and nerves, causing discolouration and lumps on the skin and, in severe cases, disfigurement and deformities. Leprosy is now mainly confined to tropical Africa and Asia. This disease is transmitted through droplets expelled by sneezes and coughs or by coming in contact with nasal fluids on surfaces.

Leprosy is curable with multidrug therapy, which involves treatment with two or more antibiotics over a period of around 6 months. In the past 20 years, 16 million people worldwide have been cured of leprosy.

FIGURE 4.21 Leprosy may cause disfigurement or deformities in severe cases.

SCIENCE AS A HUMAN ENDEAVOUR: Pasteurisation

In 1864, Louis Pasteur developed the process of pasteurisation, which has since become a vital technology for ensuring food safety. Pasteurisation works by heating milk to 71.7 °C for at least 15 seconds and then rapidly cooling it to below 3 °C. This process kills harmful bacteria while preserving the milk's nutritional value and extending its shelf life.

Before pasteurisation, diseases such as tuberculosis, diphtheria and brucellosis were commonly spread through contaminated milk. Pasteur's discovery revolutionised public health, reducing foodborne illnesses and making milk safer for consumption.

Today, pasteurisation is used worldwide not only for dairy products, but also for juices, canned goods and egg products. Modern technologies have improved this process, making it faster, more efficient and more accessible to ensure food safety for growing populations.

While pasteurisation has been a scientific breakthrough, debates occasionally arise about raw milk consumption. Supporters of raw milk argue it retains more natural enzymes and nutrients, but scientists emphasise the health risks posed by harmful bacteria in untreated milk. Strict food safety laws in Australia ban the sale of raw milk to protect public health, reflecting how scientific knowledge informs policies and regulations.

Ongoing research continues to refine food processing technologies, balancing safety, nutrition and sustainability to meet modern challenges.

1. How did Louis Pasteur's discovery of pasteurisation improve public health and food safety?
2. Why is raw milk considered unsafe for human consumption, and how does pasteurisation reduce these risks?
3. What role does scientific research play in developing food safety technologies, and how might future advancements improve food processing methods?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

Protozoans

Parasitic protozoans are single-celled organisms that are usually found within their host's body. Infectious diseases caused by protozoans are common in tropical regions. Examples of diseases caused by protozoans include malaria — which is caused by *Plasmodium falciparum* (see the case study) — amoebic dysentery and African sleeping sickness.

Fungi

Fungi belong to one of the biggest groups of organisms. They include some that are large, such as toadstools, and others that are microscopic, such as the **moulds** that grow on bread. Many fungi are parasites, feeding on living plants and animals, including humans. This often results in disease.

Common human diseases caused by fungi are tinea or athlete's foot, thrush and ringworm. Some fungi live in the mouth, the vagina and the digestive system at all times, without causing harm. However, if resistance to disease is low, the fungi in these places can become active and cause problems such as thrush.

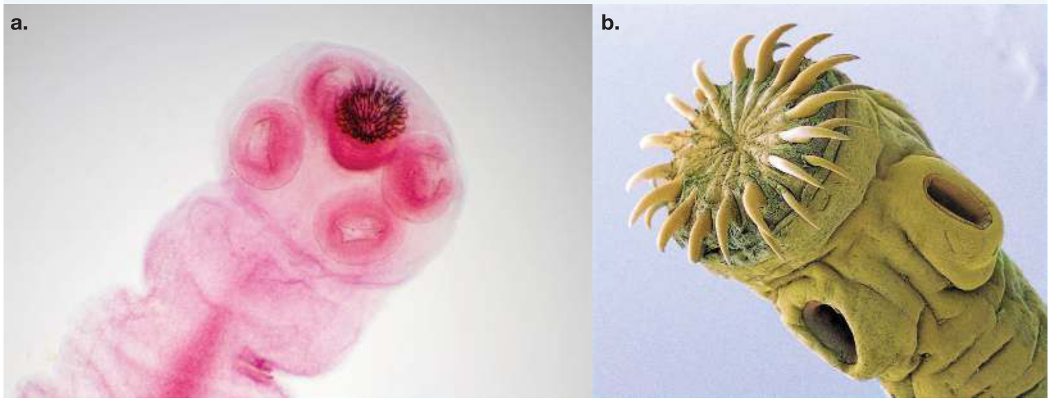
FIGURE 4.22 Two forms of fungi: **a.** mould (growing on an orange) **b.** athlete's foot (tinea)

Worms and arthropods

Larger parasites include endoparasites such as tapeworms, roundworms and liver flukes, and ectoparasites such as ticks, fleas and lice.

Tapeworms (figure 4.23) are the largest of the parasites that feed on the human body and can be up to 10 metres long! They have hooks and suckers to keep a firm hold on your intestine. Tapeworms don't have to worry about finding a mate. When they are reproductively mature, their end segment, which is full of eggs, along with their host's faeces, moves on to its next host.

FIGURE 4.23 a. The head of a tapeworm showing its hooks and suckers **b.** A pork tapeworm with hooks that cling to the digestive track of the host



Did you get an itchy bottom at night when you were little? You probably had a roundworm infection such as threadworm or pinworm. Although these worms usually live in the large intestine, when ready to lay her eggs the female worm moves down to lay them on the moist, warm skin of your anus. The sticky material they are covered with irritates your skin so that you scratch it, picking up some eggs in your nails. Better remember to wash your hands before you eat!

TABLE 4.1 Some common parasites that are also pathogens

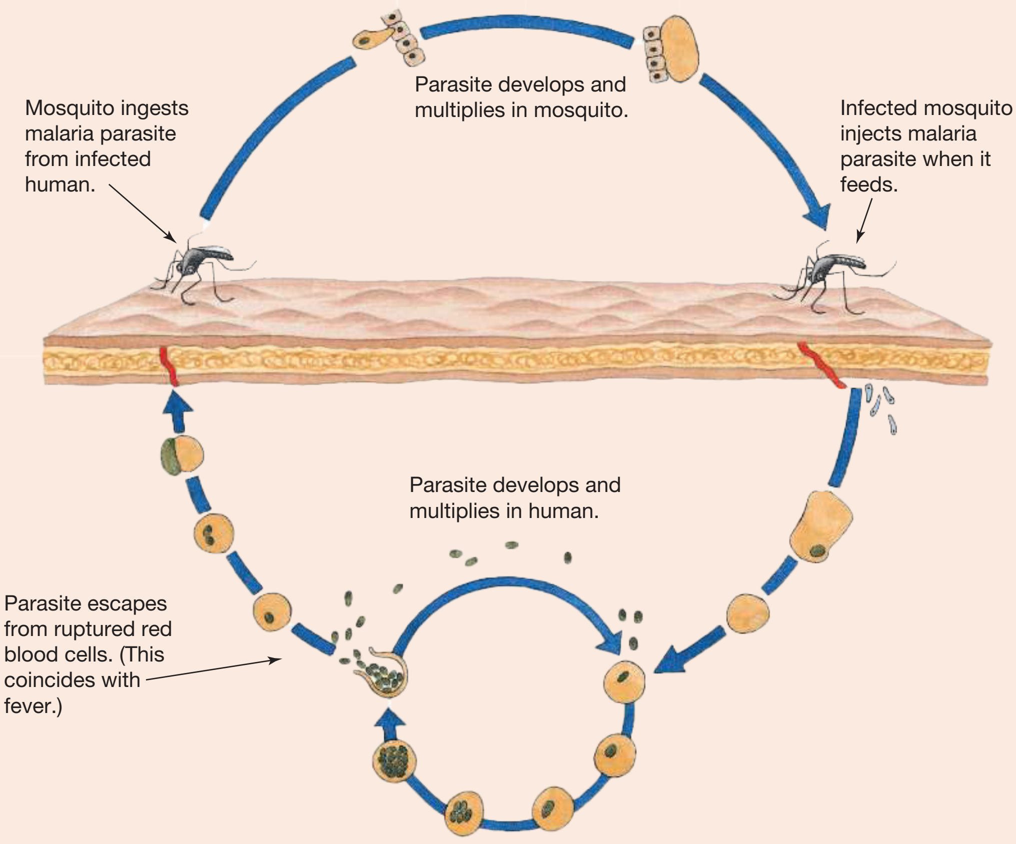
Parasite	Condition caused	Source of infection
Amoeba	Amoebic dysentery	Contaminated food and drink
Malarial parasite	Malaria	Bite from infected mosquito
Tapeworm	Tapeworm	Raw or poorly cooked meats
Blood fluke	Schistosomiasis	Contaminated water
Tick	Skin infestation	Tick-infested areas
Louse	Pediculosis	Contact with human carrier, bedding, clothing
Flea	Skin irritation	Animal and human carriers

CASE STUDY: Malaria

How do you catch malaria?

You catch malaria by being bitten by a female *Anopheles* mosquito that has been infected by the *Plasmodium* parasite. The parasite moves into the salivary glands of the mosquito and is passed into your bloodstream when it bites you.

FIGURE 4.24 Malaria transmission cycle



How dangerous is malaria?

In 2023, the World Health Organization (WHO) estimated that malaria caused 597 000 deaths worldwide. It is one of the most serious public health problems worldwide. It is a leading cause of death and disease in many developing countries, where pregnant women and young children are most affected. An infected mother can transmit the malaria parasite to her unborn child through the placenta.

How do you know if you have malaria?

Most people have high fevers, aches, pains, shivering and night sweats. Fatigue, low blood-cell counts and yellowing of the skin and whites of the eyes (caused by jaundice) may also result. Severe complications include cerebral malaria, anaemia and kidney failure, and can often result in death.

What causes malarial night sweats?

Once inside your body, malaria parasites grow and multiply first in your liver cells and then in your red blood cells. Successive broods of malaria parasites grow inside your cells until your red blood cells burst open and are destroyed. The new malaria parasites (or merozoites) seek other cells to infect and destroy. This causes night sweats.

What's new in malaria research?

In Australia, teams led by Professor Alan Cowman at the Walter and Eliza Hall Institute of Medical Research have studied how the malaria parasite uses genetic trickery to evade our **immune systems**. The scientists have developed a novel class of compounds that target multiple stages of the parasite's life cycle, and may overcome existing drug resistance. In October 2023, WHO recommended the safe and effective malaria vaccine, R21/Matrix-M. Vaccines are now being rolled out in routine childhood immunisation programs across Africa. Malaria vaccines in Africa are expected to save tens of thousands of young lives every year. The highest impact will be achieved, however, when the vaccines are introduced alongside a mix of other WHO-recommended malaria interventions, such as bed nets and chemoprophylaxis.

INVESTIGATION 4.1

Microbes

Aim

To explore and identify the types of microbes present in the air within the laboratory environment

Materials

- prepared agar plate
- marking pen
- sticky tape

Background

Agar is a jelly-like material made from seaweed. It provides a source of nutrients for microbes.

CAUTION: Do not open the tape seals after incubation. Wash your hands thoroughly after making your observations.

Method

1. Take the lid off the agar plate to expose the agar to the air in your laboratory for about 5 minutes.
2. Seal the lid on the agar plate carefully, using the sticky tape.
3. Give the plate to your teacher to incubate at about 35 °C for two days.
4. After two days, examine your incubated plate and record your observations. *Note:* Do not open the plate seals.
5. Give the unopened plates back to your teacher for proper disposal.

Results

1. Sketch your plate after it has been incubated for two days and record any observable changes.
2. Examine the general appearance, colour, size and shape of the groups or colonies on the agar plate shown in the following figure.

Discussion

1. Conclude what the observations reveal about your science laboratory's air quality and microbial content.
2. Predict whether the air in other parts of your school would differ and justify your reasoning.
3. Discuss the risks that could be associated with the experiment and ways to reduce these risks.
4. Formulate your own question or hypothesis about microbial growth, and design an experiment that could be used to investigate it. Include an explanation of your choice of variables and required specific safety precautions.

Conclusion

What can you conclude about the microbes in your school laboratory?

4.3 Activities

learnon

4.3 Quick quiz on | 4.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 5, 9, 10	3, 6, 8, 11, 13	4, 7, 12

Remember and understand

1. **Distinguish** between:
   a. pathogens, antigens and hosts
   b. prions, viruses and bacteria
   c. parasites, endoparasites and ectoparasites.

2. **MC** **Identify** which of the following statements is correct.
   A. All pathogens are cellular because only cells can cause infections.
   B. Fungi, bacteria and protozoa are cellular; viruses and prions are non-cellular.
   C. Prions and protozoa are both non-cellular and reproduce inside host cells.
   D. Viruses are cellular because they contain genetic material.
3. Our microbiome consists of trillions of microorganisms that live in us and on us. The bacteria that colonised the intestines after birth are important for development and function, and are considered the normal flora of the gut. We depend on our gut bacteria to obtain vitamin K and vitamin B.
   a. **Explain** where we obtain the bacteria that colonise our gut.
   b. **State** whether any two people's gut microbiomes are identical. **Justify** your response.
   c. **Suggest** factors that influence the composition of our gut microbiota over our lifetime.
4. **Describe** how our human microbiome protects us from pathogen attack.
5. **Identify** whether the following are features of *bacterial* or *viral* reproduction.
   - Invade host cell to reproduce
   - Reproduction results in new cells
   - Contain DNA or RNA
   - Can only reproduce inside host cell using host cell machinery
6. a. **State** the cause of leprosy and describe how it is transmitted.
   b. **State** whether leprosy is curable today. **Justify** your response.
7. a. **Explain** why many biologists consider viruses to be non-living.
   b. **Explain** why the cell that is invaded by a virus is called a host cell.

Apply and analyse

8. **Construct** a cycle map to show how prions replicate.
9. **Explain** why most milk is pasteurised rather than sterilised.
10. **Describe** the relationship between mosquitoes and malaria. Is there a vaccine to protect against contracting malarial disease?
11. After taking medication, antibiotics or being ill, people are often advised to eat yoghurt or other probiotics. **Explain** why yoghurt can be beneficial. **Suggest** some other foods that might be recommended and **justify** why.
12. The skin under your armpits contains more than 2 million bacteria per square centimetre.
    a. **Explain** why these bacteria do not cause disease more often.
    b. **Explain** what would happen if the same bacteria entered your bloodstream through a cut.

Evaluate and create

13. Design a pamphlet for someone travelling to tropical climates that advises them to read up on protozoans. What key information should they gather, and how could it help them avoid health risks?

Answers and sample responses are available in your digital formats.

LESSON 4.4 Lines of defence

LEARNING INTENTION

In this lesson you will:
- identify the chemical and physical barriers that form the body's first line of defence
- explain the processes of inflammation and phagocytosis as part of the second line of defence
- describe the roles of B and T lymphocytes and the lymphatic system in the third line of defence.

4.4.1 Cell reproduction

Understanding how cells work and, in particular, how they reproduce has led to a number of innovations that improve the quality of life of other organisms, particularly humans.

Bacteria are very good at reproducing by creating exact replicas of the parent cell very quickly. This can make them particularly nasty pathogens as they can affect a number of the cells of the body rapidly, and because they are so small, they are easily transferred from one person to another.

FIGURE 4.25 Bacteria growing on an agar plate

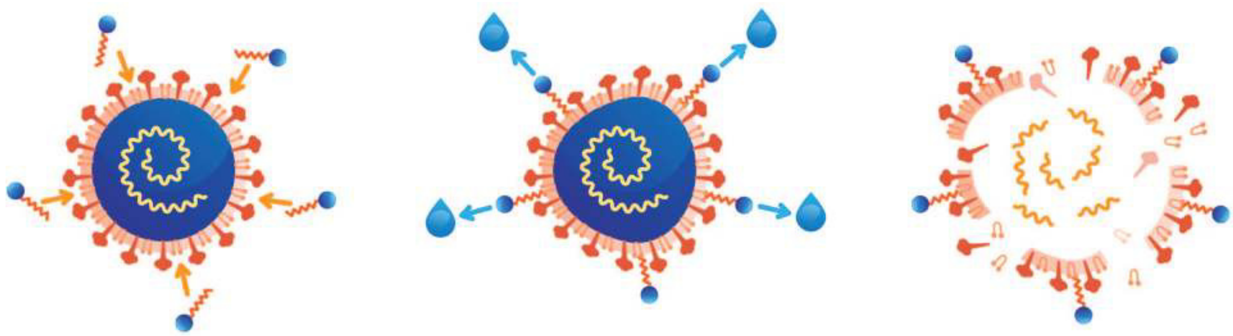
Preventing and treating disease

Scientists use their knowledge of cell division of disease-causing organisms to control or kill them. **Antibiotics** can be used to kill bacteria inside your body. **Disinfectants** can be used to kill bacteria on surfaces of non-living objects. Disinfectants should not be used on your skin as they can damage your cells. **Antiseptics** can be used on your skin. Antiseptics that kill bacteria are referred to as **bactericidal**, and those that stop bacteria from growing or dividing (but do not kill them) are called **bacteriostatic**.

Soap

Have you ever wondered why soap is so effective against disease? It is because soap can break apart the cell membrane of the bacteria or virus (if there are enough soap molecules) as seen in figure 4.26. It also helps separate the cell from your skin so it can be washed away. Since all cells have a cell membrane, targeting this area makes it very effective. However, our skin cells are not harmed when we use soap.

FIGURE 4.26 Soap is a cheap and effective way to stop the spread of bacteria and viruses.



Soap bonds to the membrane of the bacteria or virus.

The soap molecules bond to water.

The cell membrane breaks apart if there are enough soap molecules.

Using bacteria to make human proteins

The rapid reproduction of these simple cells has also led scientists to use bacteria to make human hormones, which are then produced very quickly in large quantities. By inserting a gene into the bacterial DNA, we have been able to get bacteria to create human insulin, a hormone used to keep blood sugar levels under control in diabetics.

Treating burns

In order for a person to grow and repair damaged cells, body cells must replicate. They do this in much the same way as bacteria, by producing genetic replicas of each cell type. This information was used to design 'spray-on skin', which was created by Dr Fiona Wood (Australian of the Year 2005) to treat burns. Skin cells harvested from the patient are grown in a culture (replicated in a test tube) and then sprayed onto the patient's skin at the burn site to reduce scarring.

Treating cancer

Cancer is a disease that is caused when replication of cells is out of control — in other words, when too many cells are produced. Understanding the mechanism through which cells replicate has allowed treatments for cancer to be designed that target specific cells.

INVESTIGATION 4.2

Where are those germs?

Aim

To observe a variety of microorganisms from your local environment

Materials

- sterile cotton buds
- sticky tape
- nutrient agar plates in Petri dishes (3 per group)
- sterile Pasteur pipette
- marker pen

CAUTION: Agar plates should not be opened after incubation.

Method

1. Swipe a sterile cotton bud across a surface of your choice (such as a canteen counter, computer keyboard, phone mouthpiece or bin lid).
2. Swipe the cotton bud across the surface of the agar. Be careful not to push down too hard. The cotton bud should not leave a mark on the agar.
3. Use sticky tape to seal the plate around the edge.
4. Use a marker pen to write your group's name and where you collected the sample from.
5. Use a different cotton bud to swipe a part of your body (such as the inside of your nose, your teeth, inside your ear or your scalp).
6. Swipe the cotton bud on the surface of the second agar plate, then seal and label it as before.
7. Use the sterile Pasteur pipette to collect about 1 mL of water from a location of your choice (such as a fish tank, puddle, local creek, school swimming pool or drain pipe).
8. Pour the sample of water over the surface of the agar and swish it around. Seal and label the agar as before.
9. Incubate the three plates upside down at 30 °C for 48 hours. Remove the plates from the incubator and observe the colonies of bacteria through the lid of the Petri dishes. (Do not open the Petri dishes.)

Results

Draw a diagram of each Petri dish showing the location and size of the colonies.

Discussion

1. Colonies of bacteria tend to be smooth, whereas colonies of fungi appear furry and are often larger. Do you have colonies of bacteria or fungi or both on your plates?
2. Look at the other groups' plates.
   a. Which of the surfaces tested by your class had the most microbes? How can you tell?
   b. Which body part tested had the most microbes?
   c. Which of the water samples tested contained the most microbes?
3. Explain why it would be dangerous to unseal the agar plates and lift the lid to look at the colonies of microbes.
4. Design an experiment to test whether antibacterial surface spray really does kill bacteria.

Conclusion

Summarise the findings for this investigation.

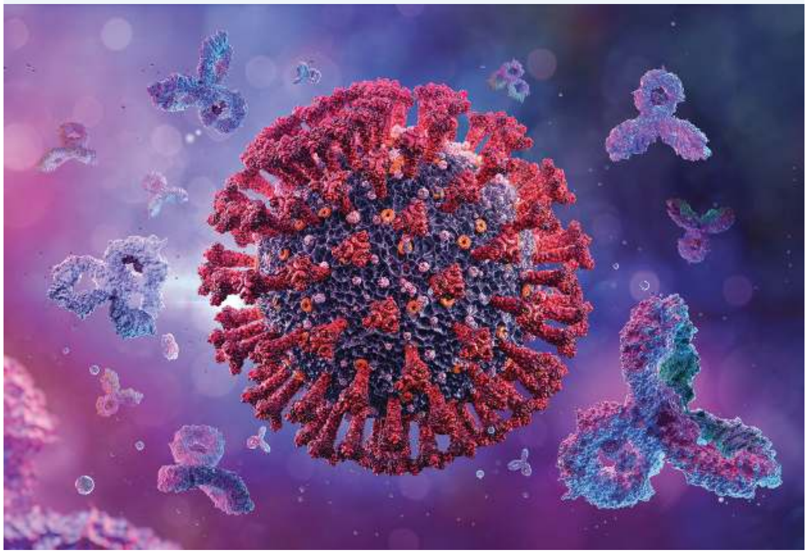
ACTIVITIES: Investigating bacteria

- Design an experiment to test whether antibacterial surface spray really does kill bacteria. Justify your strategy.
- Research examples of genetic engineering in which bacteria have foreign DNA inserted into them so that they produce human proteins. Communicate your findings as a newspaper article. What beliefs and values do you hold about this type of engineering? How is this different to what others think?

4.4.2 Antigens

All cells from organisms contain molecules on their surface called **antigens**. Each antigen is unique, which allows our body to recognise antigens as being self or non-self (foreign) to your body. Non-self antigens trigger an immune response.

FIGURE 4.27 Antigens (seen in red) on the surface of a virus



4.4.3 First line of defence

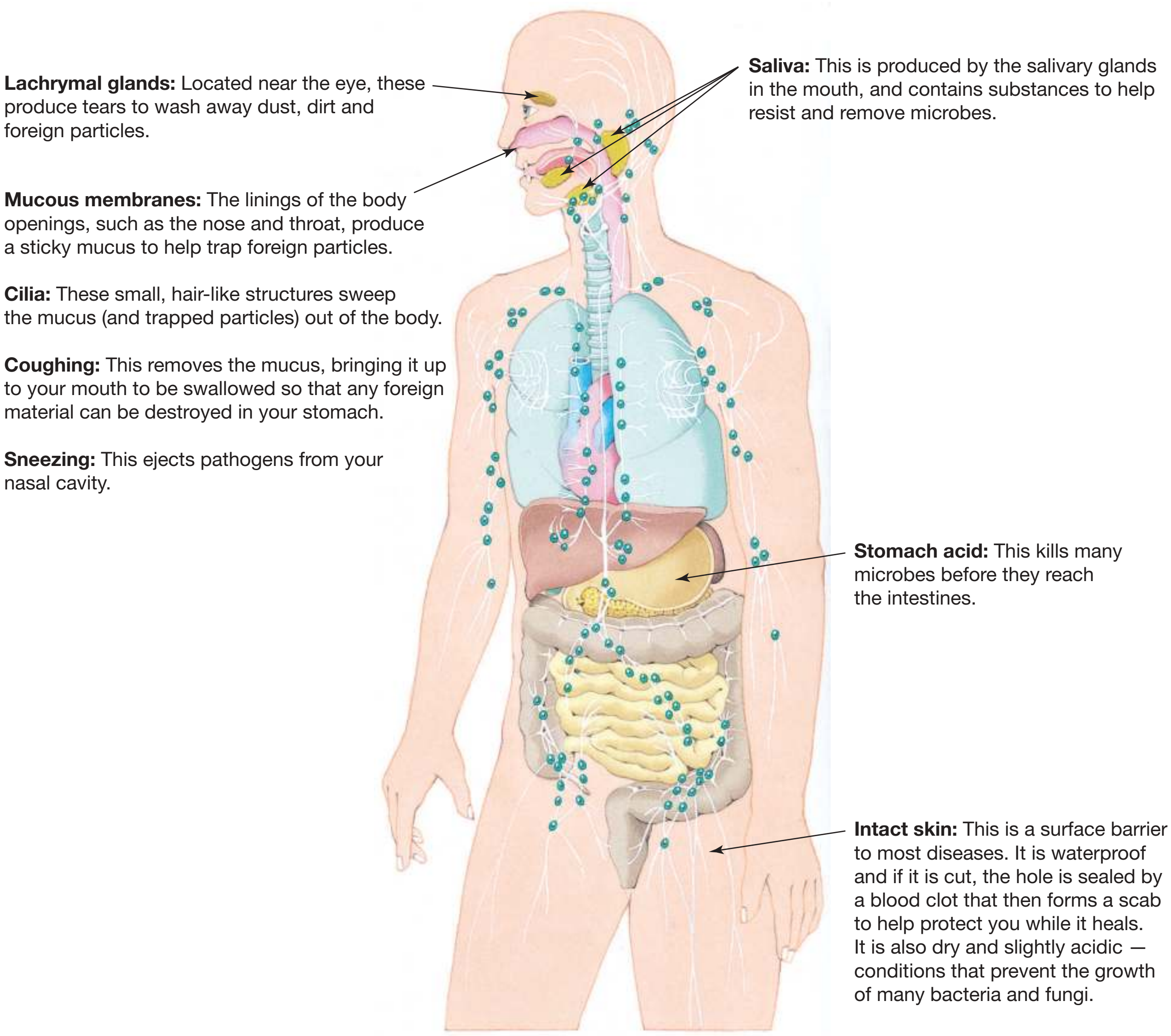
Pathogens can cause disease, preventing or stopping your body from working well. A healthy body helps you to defend yourself against infectious disease by setting up natural barriers, or lines of defence. The first and second lines of defence are described as being non-specific (also referred to as innate immune response). They fight the same way for all infections, regardless of whether they have encountered them before. The third line of defence is specific (also referred to as the adaptive immune response). It fights differently for different types of invaders and may react differently if it has been exposed to them before.

Your body's first line of defence is designed to prevent the entry of invading pathogens.

These defences (see figure 4.28) can be:

- physical barriers such as intact skin, cilia and nasal hairs
- chemical barriers — body fluids such as saliva, tears, stomach acid and acidic vaginal mucus.

FIGURE 4.28 The body's first line of defence against disease



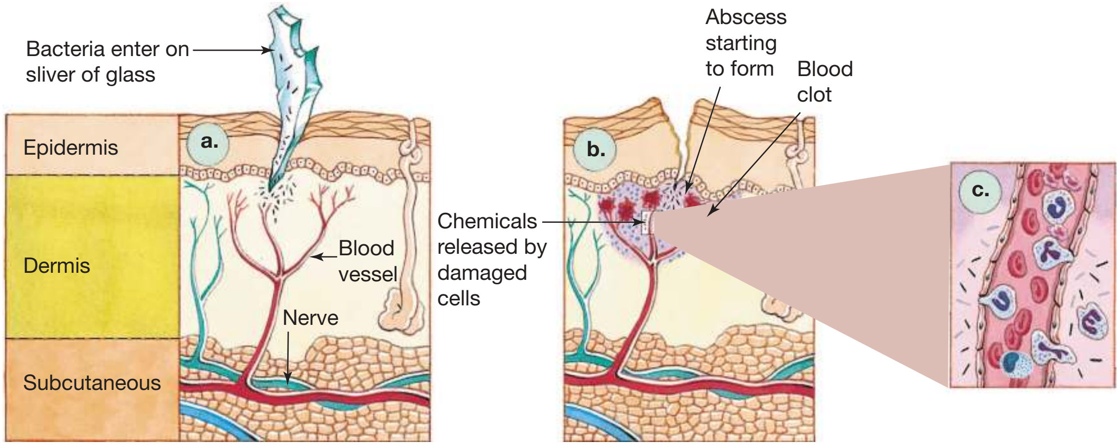
4.4.4 Second line of defence

If pathogens manage to get through your first line of defence, the second line of defence comes into play. The second line of defence is a non-specific immune response, meaning it will respond the same way with each exposure to a pathogen. This is because it has no 'memory' of the prior exposures.

Inflammation

If you have had a cut that became infected you may have noticed that the area became red, warm and swollen (inflamed). The redness, caused by the increased blood flow to the area (vasodilation), and **inflammation** are signs that your second line of defence has been triggered (figure 4.29). The increase in blood flow is due to specialised cells located within the dermis of the skin, which when damaged release a chemical known as histamine. Histamine causes an increase in blood flow and **white blood cells** to the site of infection.

FIGURE 4.29 If a pathogen has breached your first line of defence — your skin — your second line of defence is then activated.



Phagocytosis

Special types of white blood cells, **phagocytes**, that engulf and destroy pathogens and other foreign material move to the site of the infection. This action of engulfing and destroying materials is called **phagocytosis** (figure 4.30). Phagocytes have membrane-bound organelles called lysosomes, which contain a digestive enzyme, lysozyme. Lysozyme can break down foreign material (figure 4.31).

FIGURE 4.30 Phagocytes (such as some types of white blood cells) engulf and destroy materials. This action is called phagocytosis.

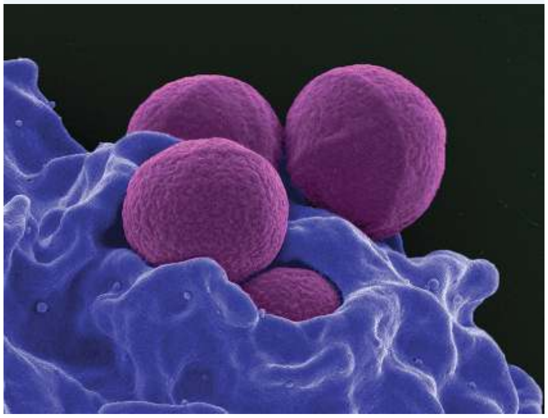
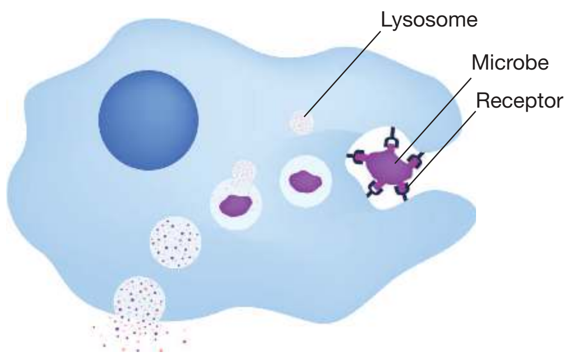


FIGURE 4.31 The process of phagocytosis: a phagocyte engulfs a pathogen, where it will fuse with a lysosome and undergo degradation

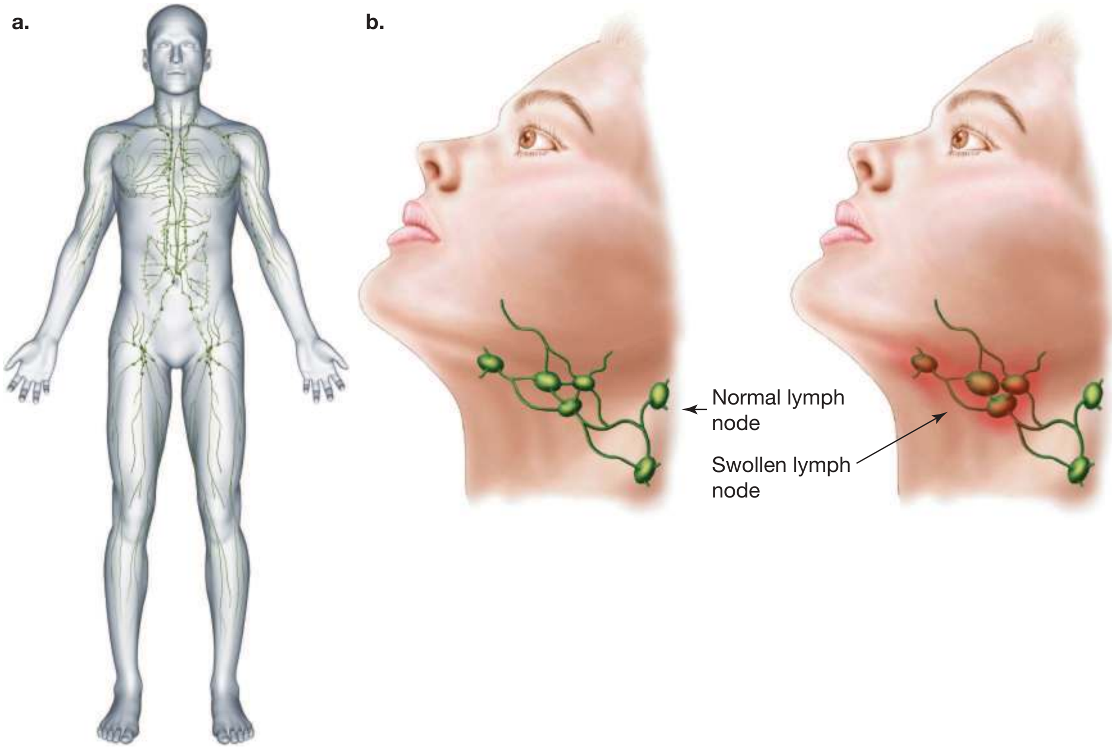


4.4.5 Third line of defence

The lymphatic system

Have you ever felt swollen glands in your neck when you had an infection? These glands are part of a network of fine tubes running throughout your body called your **lymphatic system** (figure 4.32). Your lymphatic system contains lymph vessels, lymph nodes, lymph and white blood cells. Some of these white blood cells are **lymphocytes**. Two important types of white blood cells are the B and T lymphocytes. Both cells originate in the bone marrow, but play very different roles in the third line of defence. Unlike the second line of defence, the third line of defence is highly specific and forms the ability to remember pathogens.

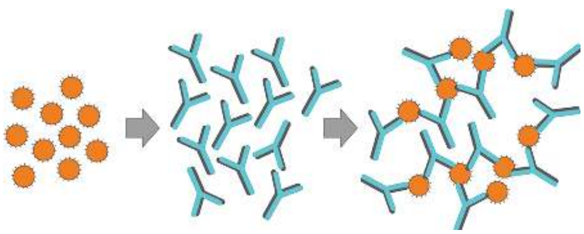
FIGURE 4.32 a. The lymphatic system containing lymphatic vessels and lymph nodes **b.** Swollen lymph nodes in the neck



B lymphocytes (humoral immunity)

B lymphocytes (or B cells) divide into **plasma cells**. Plasma cells produce chemicals called **antibodies** that are specific to the invader's antigens. These antibodies assist in the destruction of the invading pathogen. Antibodies (produced by B lymphocytes) can bind to antigens, causing pathogens to clump together (agglutination), as shown in figure 4.33. This clumping makes it easier for the phagocytes to engulf them.

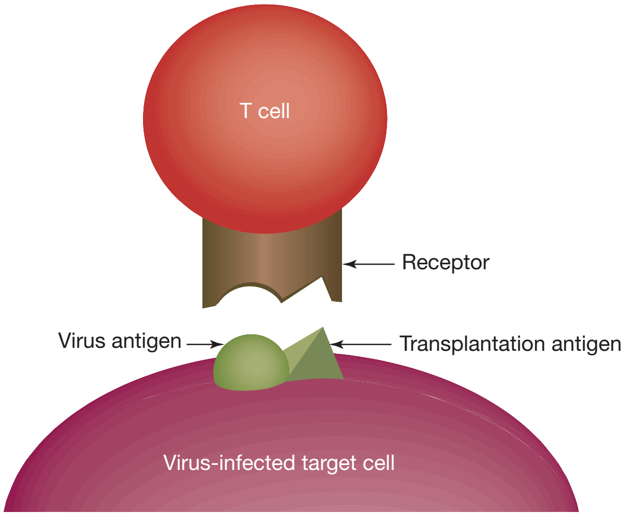
FIGURE 4.33 Humoral immune response: antibodies (green) binding to the surface of the pathogen (orange), causing agglutination



T lymphocytes (cell-mediated immunity)

T lymphocytes (or T cells) fight at a cellular level and are one of the main components of the adaptive immune system (see figure 4.34). These cells not only attack foreign invading cells, but may also attack your own cells that have been invaded. By destroying these infected cells, they also destroy the cause of infection and reduce the chance that it will be spread to other cells. There are four main types of T lymphocytes, which include T helper lymphocytes and natural killer T lymphocytes. Once T lymphocytes are activated, they secrete cytokines to directly attack infected or cancerous cells, and stimulate the growth of more T lymphocytes. The actions of lymphocytes can assist phagocytes in their duties. For example, some T lymphocytes produce substances that can attract or activate phagocytes.

FIGURE 4.34 Cellular immune response: a natural killer T lymphocyte must identify both the virus antigen and the cells of the organism it is trying to protect. It makes a matched fit at the place where the antigen is attached to the host.



Your immune system can be so effective that you can be infected with a pathogen but not develop any symptoms. Lymphocytes can form **memory cells**, so that next time you encounter the same type of invader your immune response can be faster and stronger. Sometimes it is so fast and strong that, even though you may be infected with the pathogen, you may not show any symptoms of the disease that it could cause.

4.4.6 Systems working together

Defence against disease is another example of how your systems work together. Your respiratory system's lining of mucus and ciliated tubes, and your digestive system's enzymes and stomach acids, help your fight against invaders. White blood cells produced in your bone marrow include those that will become phagocytes and lymphocytes. These defending cells will be circulated throughout your body in your circulatory system and lymphatic system to areas of infection, where they perform their task of destroying invaders. The remnants of these invaders are then excreted from your body via your excretory system.

EXTENSION: HIV attack on T cells

A type of T lymphocyte called the helper T lymphocyte (helper T cell) can be infected by the human immunodeficiency virus (HIV). This is the virus that causes AIDS (acquired immune deficiency syndrome). HIV destroys the helper T lymphocytes, and in doing so gradually damages the immune system of the infected person; this is why people with AIDS often die from diseases that a healthy immune system could normally defend itself from. HIV can be transmitted through body fluids such as blood, semen, vaginal fluid and breast milk. While there is currently no known cure, treatment for HIV is called antiretroviral therapy. This therapy aims to reduce the person's viral load to a level where HIV in the blood is too low to be detected by a viral load test. The viral load is reduced by HIV medicines, which prevent HIV from multiplying. By reducing the amount of HIV in the body, the immune system has a chance to recover and produce more T lymphocyte cells.

FIGURE 4.35 HIV (orange) attacking a T lymphocyte

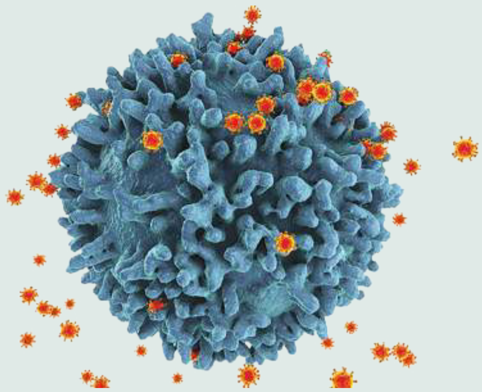
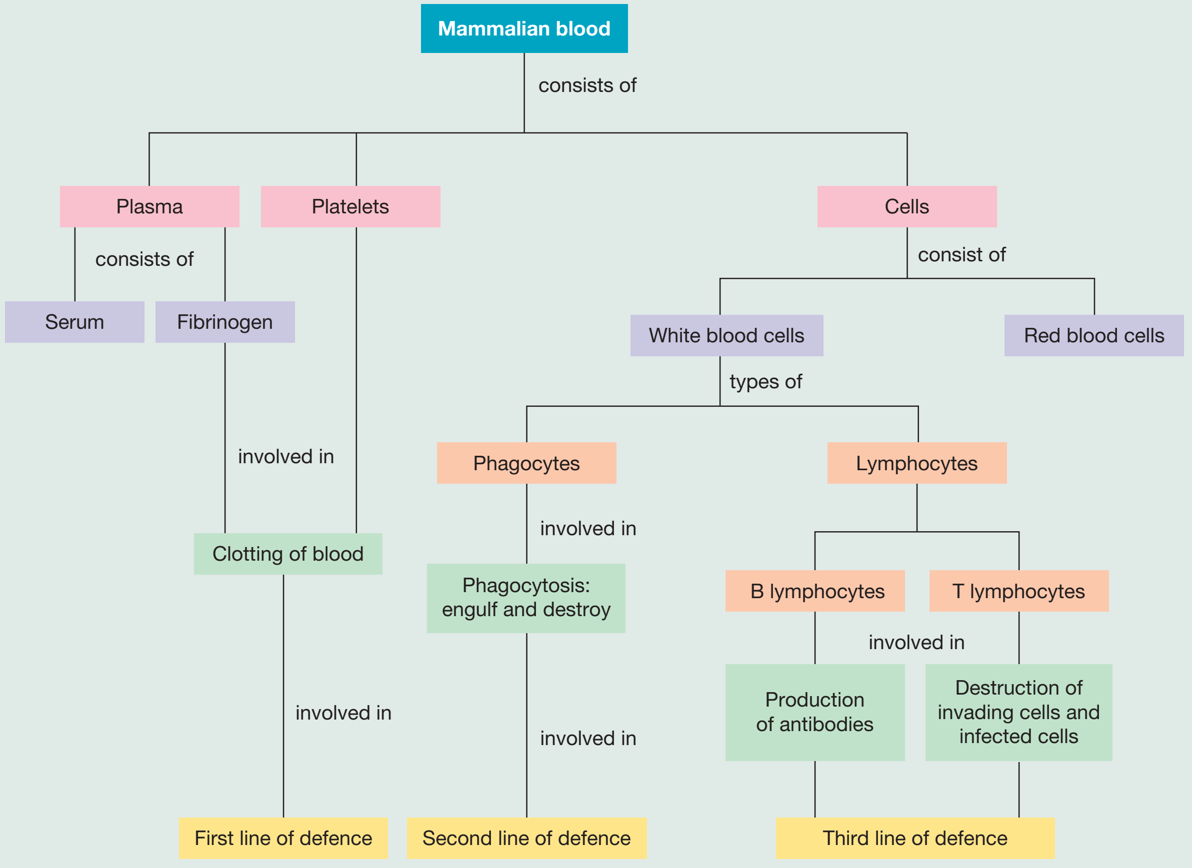


FIGURE 4.36 Your blood is involved in your body's defence against disease.



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4.4 Quick quiz on	4.4 Exercise

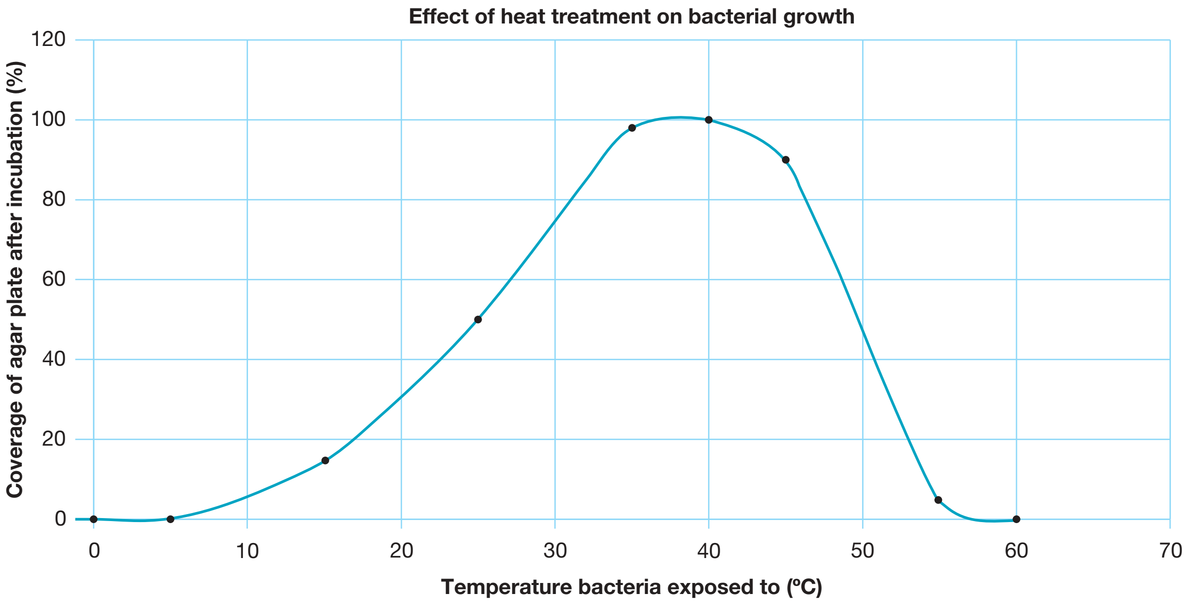
LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 6, 7, 10	2, 5, 8, 11	3, 9, 12

Remember and understand

1. **Explain** how cilia, mucus, coughing and stomach acids can work together to help defend you against pathogens.
2. **State** three lines of defence that protect your body against pathogens and **describe** one key difference between each of them.
3. a. **Explain** why many species of bacteria and fungi find it difficult to grow on skin.
   b. **Describe** some of the microorganisms that typically reside on human skin (normal skin microbiota).
   c. **Explain** why they are of benefit to us and how they contribute to our first line of defence against pathogens.
4. **State** two examples of physical barriers and two examples of chemical barriers involved in the first line of defence.

Apply and analyse

5. Before mitosis begins, the DNA in the cell is replicated. **Suggest** why this replication step needs to occur.
6. **Suggest** three ways in which foreign particles might be able to enter your body.
7. **Explain** how you can be infected with a pathogen but not show any symptoms.
8. **Explain** how T lymphocytes:
   a. protect us from disease
   b. recognise that a body cell has been infected by a virus.
9. **Outline** how your blood is involved in each line of defence against disease.
10. The following graph shows the amount of bacteria grown after being heat treated and then left to incubate on a Petri dish for 24 hours.



   a. **Identify** the best temperature for bacterial growth.
   b. **Suggest** a reason food is cooked to reduce the likelihood of being affected by this bacterium.

Evaluate and create

11. **Analyse** how the body's first line of defence, including chemical and physical barriers, helps prevent infections. **Discuss** the role of the skin, mucus membranes and other barriers in protecting the body from pathogens. **Describe** examples of how these barriers work together to keep harmful microorganisms out.
12. **Explain** the processes of inflammation and phagocytosis as part of the body's second line of defence. Additionally, **evaluate** the roles of B and T lymphocytes and the lymphatic system in the third line of defence, and how they contribute to the body's overall immune response.

Answers and sample responses are available in your digital formats.

LESSON 4.5 Immunity and immunisation

LEARNING INTENTION

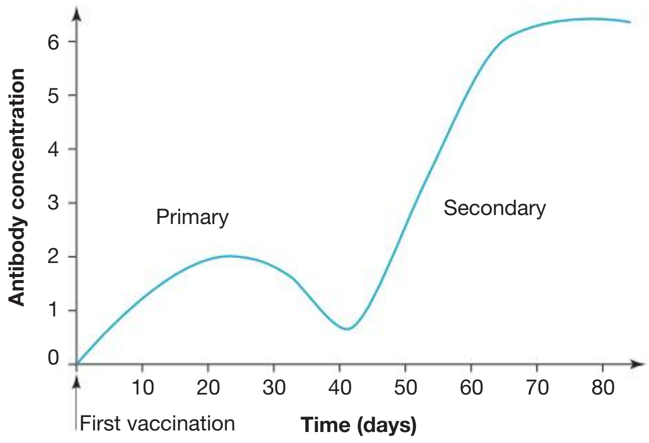
In this lesson you will:
- explain what immunity is
- compare the differences between active and passive immunity
- understand how immunity can be acquired naturally or artificially
- understand how the development of vaccines has positively affected the world in the fight against smallpox, polio and HPV.

4.5.1 Immunity and immunisation

Immunity is resistance to a particular disease-causing pathogen. A person who is immune has a reduced chance of obtaining and developing the disease.

If a person is exposed to the antigen of a particular pathogen, or non-self material, their immune system will develop specific antibodies against it. The next time they encounter that antigen, their response may be so fast and effective that they can resist infection, and the individual is unaware they have come in contact with the antigen (figure 4.37).

FIGURE 4.37 On the second exposure to an antigen, the immune system is able to start producing antibodies more rapidly and in greater amounts.



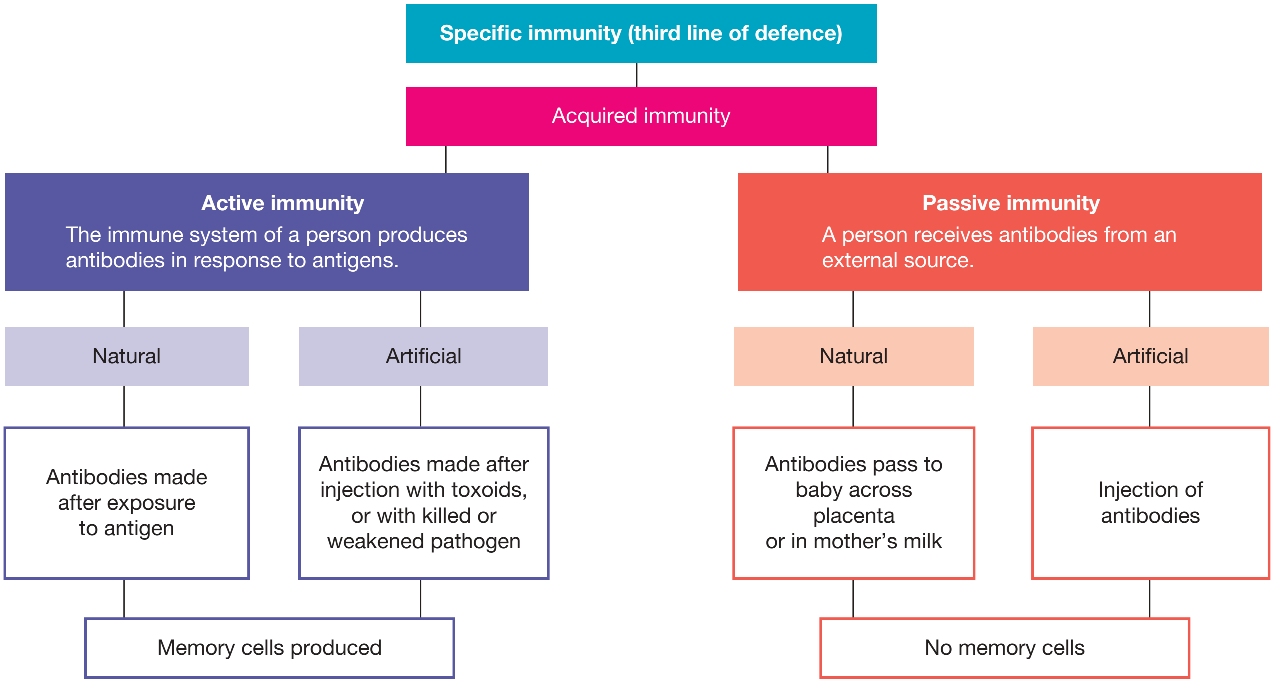
Active and passive immunity

If your body makes antibodies to a specific antigen, this is described as **active immunity**. Your body has memory cells that remember the antigen and you can make more identical antibodies very quickly. You could also gain artificial (or induced) active immunity by producing antibodies after being injected with a toxoid or a killed or treated pathogen that contains the antigen.

If you receive antibodies from an outside source, this is called **passive immunity**. In this case, you don't have memory cells for this infection so, if you were exposed to it again, your body would react as it did the first time. You can get passive immunity from your mother's milk, across the placenta or through an injection of antibodies.

The development of one type of immunity involves the use of a vaccine. Vaccination or **immunisation** is the giving of a vaccine to produce a type of immunity called artificial immunity. Vaccination trains the immune response to fight a pathogen without being exposed to the dangers of the pathogen itself. Vaccination generates antibody responses against an immunological memory of the pathogen, mimicking the primary infection without being infected.

FIGURE 4.38 Immunity can be active or passive, and acquired naturally or artificially.



Tetanus vaccination

In the case of tetanus, a safe part of the tetanus toxin produced by *Clostridium tetani* — called tetanus toxoid — is used as the antigen to generate a protective immune response (generation of antibodies) against the deadly toxin. When someone who has been vaccinated against tetanus is exposed to it, these pre-existing antibodies bind rapidly to the tetanus toxin and prevent it from binding to and affecting the nerves and muscles. This prevents paralysis and death. Memory cells respond quickly (within a few days), rapidly removing the bacteria and producing higher levels of antibodies against the toxin (see the example in figure 4.37). An unvaccinated person has no pre-existing antibodies to bind to the toxin, which could kill the person in 1–2 days. The antibody response would take weeks to occur without prior vaccination (primary response).

Herd immunity

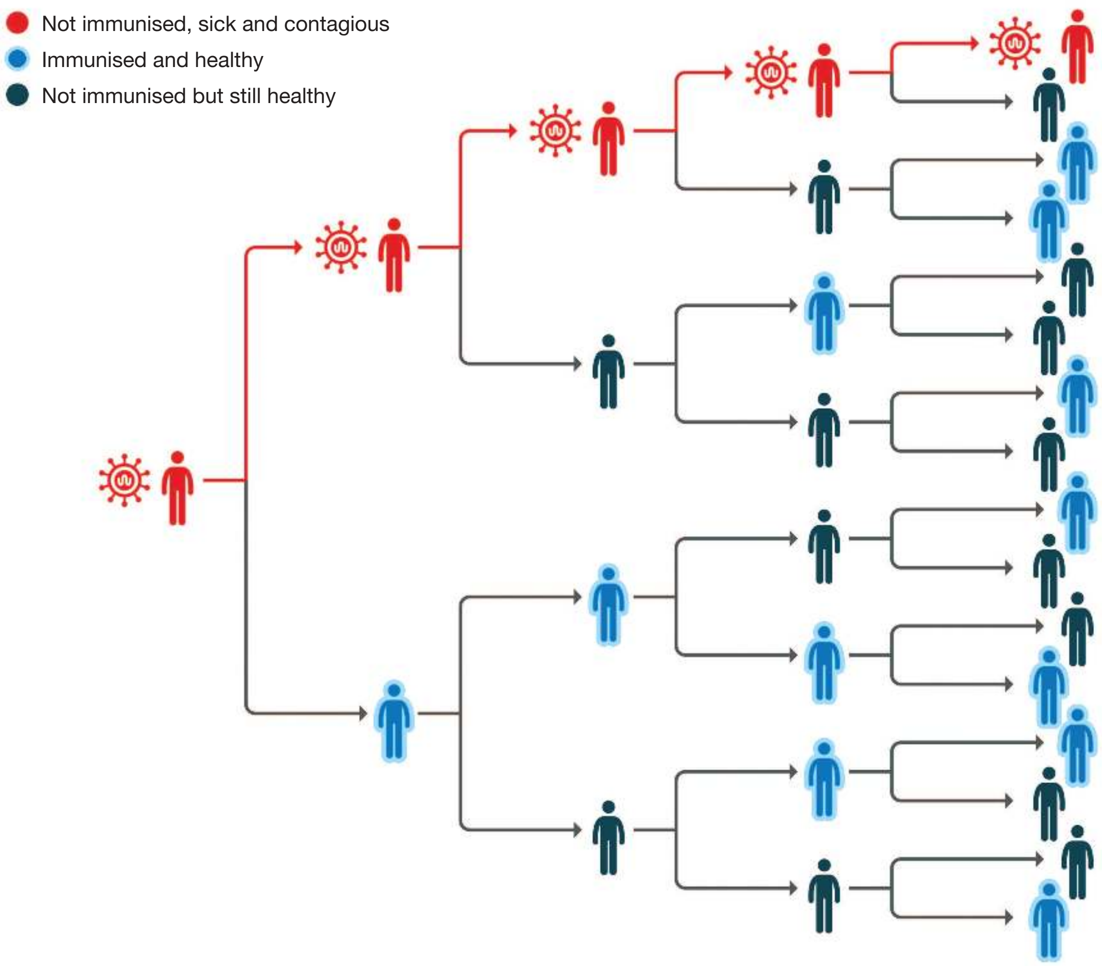
Herd immunity is the protection that exists when a high proportion of the population has been immunised against a disease. Herd immunity is vital to limit the spread of a disease and protect vulnerable individuals within the community. As vaccinations are not 100 per cent effective it is important that vaccination rates are high among the population for a program to be successful. Herd immunity allows the protection of individuals who are unable to be vaccinated, such as babies, the elderly and those with weakened, suppressed or immunocompromised immune systems.

The higher the proportion of the population that is immune, the lower the chance that an unimmunised individual will encounter an infected individual. Over time, the pathogen will have a decreased chance of finding a suitable host and eventually the disease will not be able to spread.

Vaccination programs have led to herd immunity for many infectious diseases, successfully reducing transmission. In some cases, herd immunity has resulted in the worldwide elimination of some diseases, such as smallpox and rinderpest. Several other diseases, such as polio, are close to worldwide elimination but still have local outbreaks.

Recently, scientists focused on COVID-19 and the vaccination rates required to achieve herd immunity Herd immunity is achieved when 94 per cent of the population are vaccinated. At the time of writing, scientists are still unsure how long immunity would last after infection with COVID-19 or a vaccination, and booster vaccinations are required to provide longer-lasting immunity. At the beginning of the pandemic in 2020, herd immunity was the desired outcome; however, since then many new variants of COVID-19 emerged.

FIGURE 4.39 Herd immunity reducing the spread of a disease



SCIENCE AS A HUMAN ENDEAVOUR: The development of vaccines

Smallpox

Throughout history, people noticed that, once infected, a survivor of a disease often did not catch that disease again. A long time before vaccination had been created in England, the Chinese used this observation as a basis for a process called **variolation**.

FIGURE 4.40 Smallpox leaves the sufferer with scarred skin.

In the case of smallpox, variolation involved transferring material from the lesions of those infected with smallpox to healthy individuals. The transference was achieved by inserting infected material under the skin or inhaling an infected powder. The relative success of this process in reducing mortality and morbidity rates resulted in its spread to other countries.

It was an English aristocrat and writer, Lady Mary Wortley Montagu (1689–1762), who was responsible for bringing variolation to England from Turkey around 1721. She had been scarred by smallpox herself and had also lost close relatives to it. Although variolation was used by some of the aristocracy (including the royal family), it was not until 1797 that Edward Jenner (1749–1823) refined this method. Jenner noticed that people who had contracted cowpox, a much less serious disease, did not seem to ever develop smallpox. Jenner took some pus from an infected cow and deliberately gave a person cowpox. Some time later he exposed this person to smallpox, but the person never showed signs of the illness. Jenner had successfully produced an immunity to smallpox. He called the method 'vaccination', from the Latin word for cow, *vacca*. Jenner's vaccination method was able to be used by wider populations, and occasionally its use was enforced. By 1980, because of the use of vaccination, the World Health Organization (WHO) was able to announce the elimination of smallpox from our planet.

Cervical cancer

Human papillomavirus (HPV) is the cause of greater than 90 per cent of cervical cancers. Cervical cancer was once responsible for the deaths of more than 300 Australian women each year. A vaccine against the human papillomavirus was developed by Professor Ian Frazer from the University of Queensland's Centre for Immunology and Cancer Research. He was recognised as Australian of the Year in 2006 for his involvement in this development. Vaccination against HPV began in 2007 for girls aged 12–13 years and has resulted in a significant decrease in the cervical cancer rate of women who have been vaccinated. This vaccine may assist in the prevention and eventual eradication of cervical cancer, which currently affects more than half a million women worldwide each year.

In the past, women required a Pap test every two years, which was used to detect pre-cancerous and cancerous cells in the cervix. In Australia, this has been replaced by the cervical screening test in women aged 25–75. This test detects the presence of HPV before the cells have become cancerous. Predictive modelling indicates that if screening and vaccination rates remain at current levels, cervical cancer could be eliminated as a public health issue in Australia by 2035.

Polio

Poliomyelitis (polio) is a disease caused by the *Picornaviridae* virus. This disease is highly infectious and consequences can include complete recovery, limb and chest muscle paralysis, or death. It is not contagious, but spreads by consuming contaminated water or food.

A vaccine for polio was developed by Jonas Salk in 1955 using a dead virus. However, this vaccine required a booster shot about every 3 years, and occasionally a live virus contaminated the vaccine. One batch in 1955 infected 44 children with polio; this resulted in some fear within the population about its use. In 1956, Polish-American doctor Albert Sabin announced that his oral live-virus polio vaccine was ready for mass testing. Public mistrust in the safety of a vaccine using a live virus resulted in Sabin using Soviet (Russian) school children in his large population tests. His tests indicated that this vaccine was not only safer, but also more effective, providing lifelong immunity — and it was cherry-flavoured and could be taken by mouth!

By 1961, Sabin's oral polio vaccine was adopted as the standard in the United States of America. In 1966, Australia also introduced this oral vaccine, and the entire western Pacific region (including Australia) has been declared polio-free since 2000. One case was reported in 2007, in a traveller who acquired polio overseas. Given the extent of travel around the world, polio vaccination remains an important part of Australia's immunisation schedule.

FIGURE 4.41 People suffering with polio may become paralysed.

1. How did technological and scientific advancements allow Edward Jenner, Jonas Salk and Ian Frazer to develop vaccines that have prevented or reduced diseases like smallpox, polio and cervical cancer?
2. Why is it important to continue vaccination programs, even for diseases like polio that have been eliminated in many countries?
3. What ethical and safety challenges did scientists face when developing vaccines, and how did they address public concerns about their use?

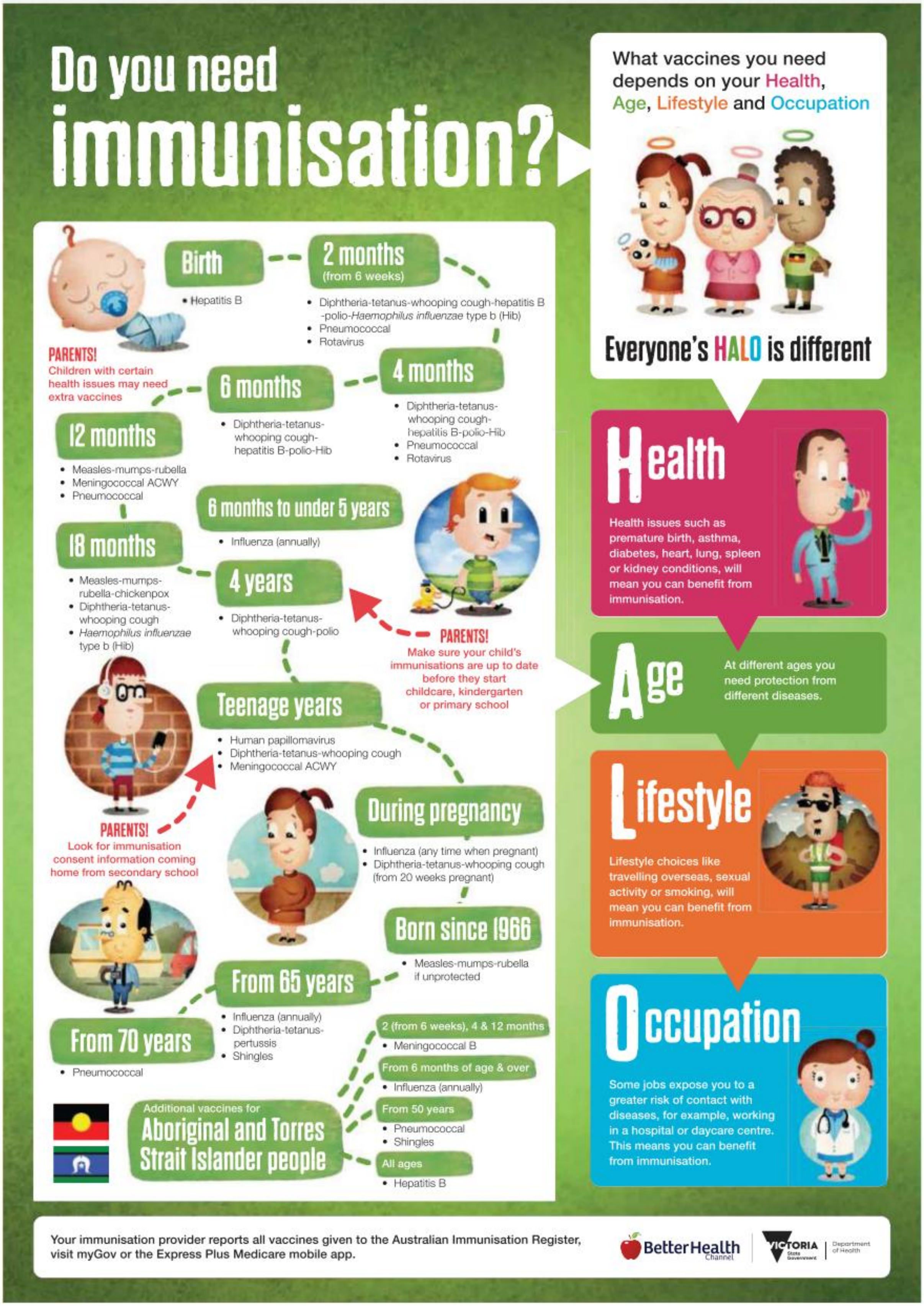
Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

4.5.2 Vaccination in Australia

Vaccinations have been developed by scientists against many diseases and are available to the majority of Australians. Community health programs ensure that children are vaccinated to protect them against infectious diseases such as tetanus, rubella, mumps, diphtheria, poliomyelitis and whooping cough. Many of these diseases have now been controlled so are rarely seen in Australia.

However, there is an increasingly low child immunisation rate in some areas in Australia. This has resulted in the Australian government taking steps to boost the numbers of children immunised.

FIGURE 4.42 A vaccine program schedule as recommended by the Victorian Department of Health



Travel vaccinations

If you are planning an overseas trip, it is recommended that you research the conditions in your holiday destination carefully. Otherwise you may bring back more than you expect!

Although many travellers are aware that immunisations to travel to certain countries are recommended, the most common illness suffered by overseas travellers is diarrhoea. While this may cause a little discomfort in the short term, it may be lethal if it continues for a long time. It is responsible for the deaths of almost 5 million children in tropical regions each year. There are no vaccines to protect you against it, but you can reduce your risk of getting diarrhoea by following a few simple precautions. These include avoiding uncooked foods that may have been washed with contaminated water or handled unhygienically. Only bottled or boiled water may be safe to drink.

FIGURE 4.43 Proof of vaccination against yellow fever

Vaccines are currently available for some strains of hepatitis, typhoid, yellow fever, Japanese encephalitis, cholera, influenza, rabies and bacterial meningitis.

If you are travelling to a region where malaria is a problem, you are advised to begin a course of antimalarial tablets before leaving. This preventative action should be continued for at least a month after your return. Some countries require proof of a vaccination against yellow fever before you are allowed to enter the country.

EXTENSION: No more needles? Vaccine delivery via patch

Since 1853, the syringe has been the main delivery system for vaccines. Professor Mark Kendall and his team of researchers at the University of Queensland have developed a game changer for vaccine delivery — a painless, tiny skin patch that does not require trained doctors and nurses to deliver it, and does not need refrigeration. Find out more about the Vaxxas nanopatch, then consider the following points.

- How does the nanopatch deliver the vaccine antigens? Which cells are targeted in the person being vaccinated?
- How will the nanopatch benefit African countries? Compare and contrast with the benefits for Australia.
- What is the first vaccine being trialled in conjunction with the World Health Organization using this new technology?

4.5 Activities

learnon

4.5 Quick quiz on	4.5 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3	2, 4, 5	6, 7

Remember and understand

1. **Describe** a way in which each of the following people contributed to the fight against disease.
   a. Lady Montagu
   b. Edward Jenner
   c. Jonas Salk
   d. Albert Sabin

2. **Distinguish** between the following.
   a. Immunity and immunisation
   b. Antigen and antibody
   c. Active immunity and passive immunity
   d. Natural passive immunity and artificial passive immunity
   e. Natural active immunity and artificial active immunity

Apply and analyse

3. SI Whooping cough, caused by *Bordetella pertussis*, is a very serious infection of the respiratory system. It can cause violent coughing fits. The cough has a distinctive whooping sound, which led to the disease's name. Whooping cough is most harmful for young babies and can be deadly.
   a. Look at the vaccination schedule in figure 4.42. Pertussis (whooping cough) is vaccinated against using the DTP (diphtheria, tetanus and pertussis) vaccine. **Identify** when children are vaccinated against whooping cough.
   b. **Explain** how unborn babies and newborn babies can be protected against whooping cough before they are old enough for their first vaccination.
   c. **State** whether people visiting babies in hospitals and homes, including grandparents, should be required to be vaccinated. **Justify** your answer.
4. 'No Jab, No Play' is the name of the legislation that requires all children to be fully vaccinated, unless they have a medical exemption, in order to be enrolled in childcare or kindergarten in Victoria. **State** who else is vulnerable to harm and potential death from disease in our community.
5. a. **Describe** herd immunity.
   b. **Explain** why the World Health Organization states that 94 per cent of the population needs to be vaccinated against a pathogen to maintain herd immunity.

Evaluate and create

6. SI The following table shows statistics for the number of people infected with vaccine-preventable diseases in Victoria from January 2019 to January 2020.

Infections of preventable diseases in Victoria, 2019

Vaccine-preventable diseases	128 (current)
Diphtheria	0
Haemophilus influenzae type B infection	0
Influenza	63
Measles	1
Meningococcal infection	0
Mumps	0
Pertussis (whooping cough)	54
Invasive pneumococcal disease (IPD)	10
Rotavirus infection	0
Rubella	0
Tetanus	0
Varicella zoster infection (chickenpox)	0
Varicella zoster infection (shingles)	0

   a. Use the table to **identify** how many whooping cough infections there were from January 2019 to January 2020. **Suggest** why there were so many whooping cough infections when cases of other vaccine-preventable diseases were not occurring in the same 12-month period.
   b. **State** whether you think we will ever be able to eradicate whooping cough from the planet, as was done with smallpox. **Justify** your response.
7. SI a. **Explain** the effect of *Clostridium tetani* infection on the human body systems. Include the time it would take for a person to die from tetanus if unvaccinated.
   b. **Explain** why a person who has been vaccinated against tetanus does not die when they are infected with *Clostridium tetani*. Refer to figure 4.37.

Answers and sample responses are available in your digital formats.

LESSON 4.6 Outbreaks

LEARNING INTENTION

In this lesson you will understand how epidemics and pandemics have shaped human history and why the world's population is more vulnerable to infections than in earlier times.

4.6.1 Epidemics and pandemics

Disease has shaped our human history. It could be argued that we are who we are because of and in spite of disease.

Throughout history there have been records of **plagues** — contagious diseases that have spread rapidly through a population and resulted in high death rates. There are also other terms used to describe the spread of disease. **Epidemics** occur when many people in a particular area have the disease in a relatively short time, and **pandemics** are diseases that occur worldwide.

The Black Death — bubonic plague

The Plague of Justinian in the sixth century was one of the first recorded pandemics. It is thought to have been the result of **bubonic plague**. Of all of the plagues throughout history, the bubonic plague (known as the **Black Death** in Europe) has been the most widespread and feared. Its name is due to the presence of black sores on the skins of victims. The cause of the disease is the bacteria *Yersinia pestis*. These bacteria were transmitted by fleas that had bitten an infected rat and then bitten a human, infecting the human with the disease.

FIGURE 4.44 Plague doctors wore protective clothing that included a long beak filled with antiseptic substances.

Bubonic plague was first recorded in the north-eastern Chinese province of Hopei in 1334, where it is thought to have been responsible for the death of about 90 per cent of the people there. By 1348, bubonic plague had reached Europe. Within five years, an outbreak of this disease had resulted in the death of almost one-third of Europe's population. After this time, plague visited England another six times before the end of the century.

Nearly all those infected died within three days of their first symptoms appearing. Lack of medical knowledge and great fear resulted in the development of a diverse range of methods being used to fight the condition. Some people tried special diets or were cut or bled in the hope that the disease would leave their bodies along with their bodily fluids. Others (flagellants) whipped themselves to show their love for their god, hoping to be forgiven for their sins and spared the disease. Most importantly, bodily wastes and the bodies and clothes of those infected with the disease were burned in deep pits. In some areas, improved public sanitation resulted from these outbreaks.

The last recorded epidemic of the Black Death was around 1670. A victim of its own success, it had killed so many so quickly that those remaining had either immunity or genetic resistance. While it could still infect, its hosts were able to fight back and destroy it. Its demise paved the way for another disease, smallpox, to take over as the number one infectious disease.

4.6.2 Crossing boundaries

Recent years have seen not only the discovery of new infectious agents, but also the emergence of some of our old infectious enemies. Some of these new diseases are crossing the species barrier and are now infecting species that they previously did not affect. Increasing resistance of many pathogens to antibiotics or vaccines has also raised concerns about the potential for sudden outbreaks of infectious diseases around the world.

FIGURE 4.45 The bacteria causing the Black Death was transmitted by fleas.

Some of the new diseases and pathogens that have been identified as having crossed the species barrier over the past few decades include Lyme disease, rabies, henipavirus, bovine spongiform encephalopathy (mad cow disease), Legionnaire's disease, HIV, Marburg virus, hantavirus, SARS, H5N1, Ebola virus and SARS-CoV-2 (the virus that causes COVID-19).

Increased travel between continents brought new knowledge and discoveries. It also brought death. At the turn of the sixteenth century, around the year 1500, expeditions by Columbus and other explorers brought venereal diseases, smallpox and influenza to areas that had no history of them. This resulted in the deaths of millions of native people, who had no prior exposure to enable them to develop immunity. In some areas, up to 95 per cent of the native population died. This drop in population from introduced diseases was so significant it can be seen in a global fall in carbon dioxide levels around the globe (as preserved in Antarctic ice core records). Carbon dioxide levels fell so significantly because farming across the American continent nearly stopped entirely, which resulted in re-growth of forests, which in turn consumed more carbon dioxide. This event is recognised globally and has been suggested to mark the start of a new geological era known as the Anthropocene — the age of humans.

4.6.3 Viral diseases

Why are viruses so effective at infecting large populations? Let's consider some of the major viruses that have affected the world in modern times.

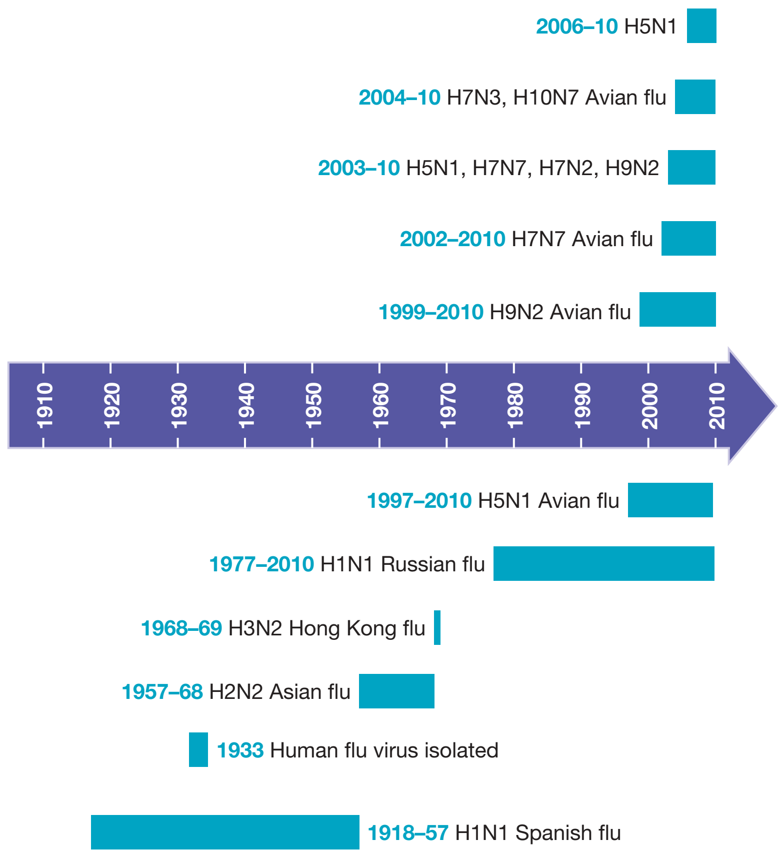
Influenza

Throughout history, there have been numerous outbreaks of influenza. The influenza virus constantly evolves, and pandemics happen every few decades when the flu virus gets new **surface proteins** that people have little immunity to, generally because they come from an animal strain.

By the end of 1918, more than 25 million people had died from a virulent strain of **Spanish influenza** (H1N1). In 1919, the League of Nations Health Organization was established, with the aim of preventing and controlling disease around the world.

The **Asian influenza** (H2N2) pandemic emerged in 1957, followed by a series of others over the next decades. **Avian influenza** (H5N1) made its debut in 1997 in a form that was highly contagious among birds and also infected humans. Since that time, it has devastated East Asian poultry industries. By 2006, a particular strain of H5N1 had been transmitted to humans and had caused a number of fatalities. H5N1 was dangerous because its H5 surface protein was totally new to humans — this is why it has killed more than half of the people who have been infected with it.

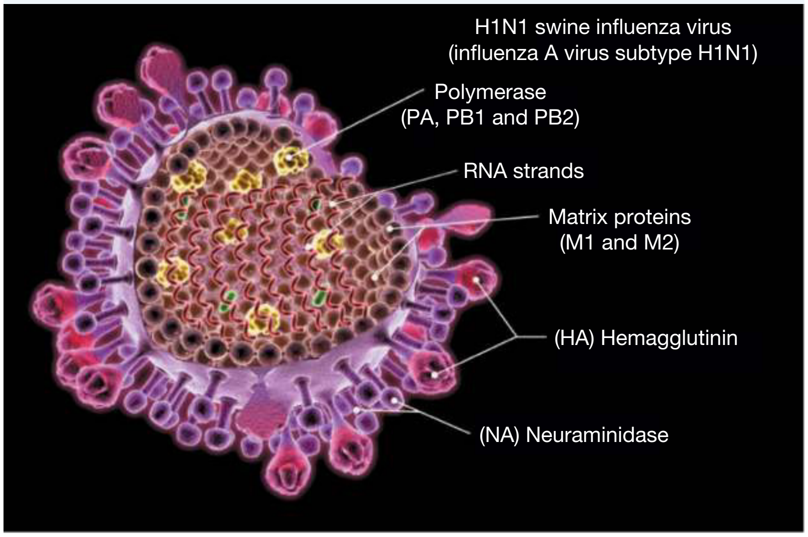
FIGURE 4.46 A timeline of influenza outbreaks



Swine flu

In 2009 there was a **swine flu** (H1N1) pandemic, which killed several thousand people. This strain of influenza contained a mixture of genes from the swine flu, human flu and avian flu viruses. It was of particular concern because it was thought that this new strain might have surface proteins that the human immune system may not recognise.

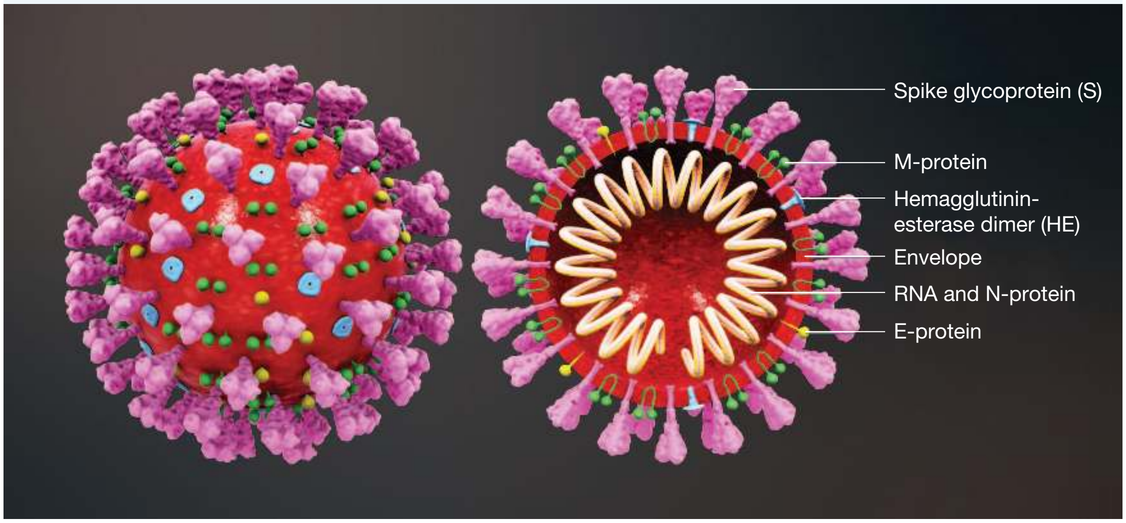
FIGURE 4.47 The swine flu (H1N1) virus contains a mixture of genes from the swine flu virus, human flu virus and avian flu virus.



Coronaviruses

Coronaviruses are named for the 'corona' or crown of spikes on their viral envelope, which gives them their characteristic shape. These spikes bind to specific receptors on the host cell. Coronaviruses have a strand of RNA surrounded by the viral envelope with spike proteins. In humans and some other animals, coronaviruses cause respiratory tract infections. They were first discovered in the 1930s in a respiratory tract infection in domesticated chickens.

FIGURE 4.48 Morphology of a coronavirus



There have been three coronaviruses that have produced severe symptoms in humans.

SARS-CoV: Severe acute respiratory syndrome coronavirus

During 2002–2004 this virus infected around 8000 people, with a mortality rate of approximately 10 per cent. In 2017, scientists traced the cause of the virus from a population of horseshoe bats in China, which passed the virus through the intermediary species of civets (a small, nocturnal mammal native to Asia and Africa), and then on to humans. No cases have been recorded since 2004.

MERS-CoV: Middle East respiratory syndrome-related coronavirus

This is another virus thought to have originated in bats; humans are typically infected through contact with camels or camel products. Spread between humans is not common, and requires close contact. Between its discovery in 2012 and 2024, there were approximately 2620 cases, but it has a mortality rate of 35 per cent. There is currently no vaccine.

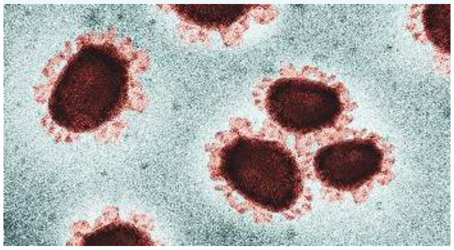
SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2

This is the virus that causes COVID-19. It was recognised as a global pandemic, and the World Health Organization (WHO) designated it a Public Health Emergency of International Concern. Initial scientific investigations suggest it has an animal origin due to its genetic similarity to bat coronaviruses, and may have passed through pangolins as an intermediate species in its spread to humans. China was the first country to report the disease to the WHO in late December 2019, and it is currently thought to have originated in Wuhan, China, in people working in a market. By 2022, there were more than 500 million confirmed cases of COVID-19 around the world, and the mortality rate is thought to be less than 5 per cent. While it is thought to cause less severe illness in the majority of cases compared to SARS-CoV, it appears to be much more infectious.

The shape of SARS-CoV-2 is much like other coronaviruses, and it is approximately 50–200 nanometres in diameter. It has four structural proteins as shown in figure 4.48. The spike protein is what allows it to attach to the cell membrane of the host cell. The virus is thought to infect a patient in the following way:

- An infected person expels droplets with the virus and they are absorbed through the mucus membranes (inhaled, or perhaps even through touching the eyes or mouth).
- Cells in the nose have a cell-surface receptor called ACE2, which the virus attaches to and then enters the cell, and starts making many copies of itself. Although they are infectious, patients may not even have symptoms at this point, or they may develop a fever, dry cough, sore throat or a loss of smell and taste.
- If the body does not fight off the invading virus at this point, the virus moves down the windpipe and enters the lungs. The tiny air sacs in the lungs (the alveoli) are lined with a single layer of cells that are also rich in ACE2 receptors. The virus populates the alveoli and the patient can struggle to breathe.
- White blood cells try to fight off the virus, and encourage more immune cells to grow, killing the virus but leaving fluid and dead cells (pus) in the lungs, which can fill the lungs and leave patients struggling to breathe.
- In severe cases the immune system overreacts to the virus, causing a 'cytokine storm', and the immune system starts to attack healthy cells. Blood pressure drops, blood vessels leak and blood clots form, which can lead to severe damage to — and even failure of — other organs, such as the heart, liver, kidneys and intestines.

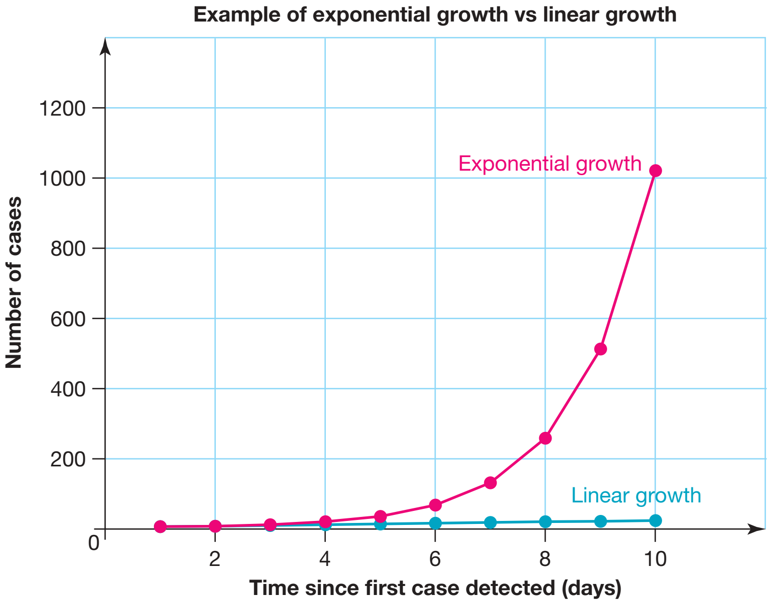
FIGURE 4.49 A scanning electron microscope image of SARS-CoV-2



These severe symptoms require high levels of care in hospitals, and that is why the world's population was placed under instructions to minimise physical contact, so as to ensure hospitals were not overwhelmed by severe cases of COVID-19. This public health strategy became known as 'flattening the curve' of new infections. Due to the infectiousness of this virus, the curve of new infections could be defined by a mathematical phenomenon known as exponential growth, where infections were doubling every three days.

Exponential growth is difficult to visualise. The graph in figure 4.50 compares linear and exponential growth.

FIGURE 4.50 A comparison of exponential and linear growth



The World Health Organization (WHO) has identified a likely series of steps that allow viruses to spread across the world:

- An influenza virus in birds or animals develops the ability to infect humans and cause serious disease. Humans need close contact with animals for this to occur.
- The virus mutates (changes its genetic make-up), which allows it to pass from human to human.
- The virus is able to transmit readily between humans because of its short incubation period and how easily it can be spread (e.g. through contact with body fluids, coughing and sneezing). As we saw with COVID-19, rapid global spread occurs through international travel.

Since the emergence of the virus, scientists around the world have been working in collaboration to understand COVID-19.

FIGURE 4.51 Scientists wearing protective clothing while studying samples of COVID-19

FIGURE 4.52 There are many ways to help stop the spread of contagious diseases.

ACTIVITY: Indigenous rangers

Biosecurity measures are important when people and products enter Australia as it stops diseases and pests from damaging Australia's primary industries.

The Indigenous Rangers Program (IRP) assists in managing Country according to Traditional Owners' objectives. It supports the use of traditional knowledge and cultural practices, combined with Western science, to manage land, river and sea Country, and deliver environmental, cultural, social and economic development outcomes.

Indigenous rangers play a crucial role as they combine traditional knowledge with conservation training.

1. Research the role of Indigenous rangers and the jobs they undertake. Explain how they prevent the transfer of certain diseases and pests.
2. How do they use their traditional knowledge to protect and manage their land, sea and culture?

4.6 Activities

learnon

4.6 Quick quiz on	4.6 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 8	4, 5, 9, 10	6, 7, 11, 12

Remember and understand

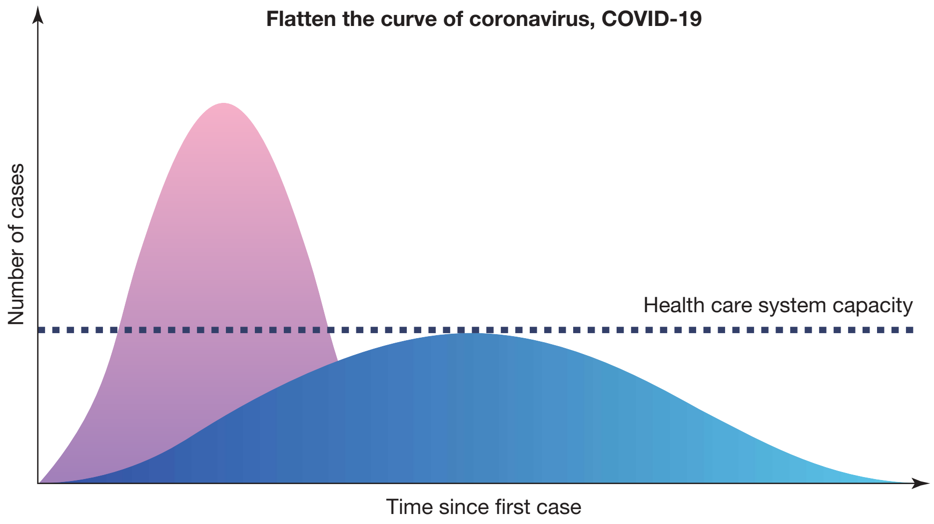
1. **Define** the term *plague* and **state** one example.
2. **State** two differences between an epidemic and a pandemic. **State** one example for each of them.
3. **Suggest** why bubonic plague is often referred to as the Black Death.
4. **Suggest** why the last recorded epidemic of bubonic plague was around 1670.
5. **State** three examples of new infectious diseases that have been identified over the last few decades.

Apply and analyse

6. **Explain** the relationship between the bubonic plague pathogen, fleas and rats.
7. The names of human diseases can change over time for various reasons. Hendra virus was originally called equine morbillivirus, but after further investigation was found not to be a morbillivirus. It was re-named after the Brisbane suburb where the first outbreak occurred. The 1918 'Spanish flu' did not originate from Spain. The swine flu outbreak had a significant impact on the meat and pork trade, and the virus is now referred to as influenza A H1N1.
   In 2015 the WHO identified a best practice for naming new human diseases. Diseases are no longer named after geographical locations, animals, individuals or groups of people. **Explain** why you think this change was made.
8. **Explain** the relationship between international travel and pandemics.
9. **Explain** why you think COVID-19 spread so rapidly around the world.
10. **Suggest** three actions that can help control the spread of a virus.

Evaluate and create

11. SI The following graph shows the relationship between the number of cases of COVID-19 and the time since the first case was identified.



   a. **Describe** the shape of the two curves with reference to health care system capacity.
   b. **Explain** why it is important to 'flatten the curve' of infections.
12. **Suggest** how COVID-19 is different from SARS.

Answers and sample responses are available in your digital formats.

LESSON 4.7 Our noble Nobels and other notables

LEARNING INTENTION

In this lesson you will provide examples of some of the contributions that our Australian Nobel Prize winners have made to scientific knowledge and understanding.

4.7.1 Australian Nobel Prize winners

Australian scientists have made significant contributions to disease control and to the quality of life that we enjoy today. Sir Howard Florey, Sir Frank Macfarlane Burnet, Professor Peter Doherty, Barry Marshall and Robin Warren have each won a Nobel Prize in Medicine. Others such as Fiona Stanley, Fiona Wood, Ian Frazer, Georgina Long and Richard Scolyer have also made notable impacts in the field.

One hundred years ago, many children died from both infectious diseases and bacterial infections. A small scratch was sometimes enough to allow deadly bacteria to enter the body and cause swelling, the formation of pus and severe pain. Children born today can avoid the harsh consequences of most bacterial infections.

Understanding and finding cures for infectious diseases has been a long process involving the efforts of many scientists around the world. Some of the key researchers in the discovery and development of **penicillin**, and their ideas and breakthroughs, are listed in tables 4.2 and 4.3. If it were not for their contributions, we may not have the antibiotic medicines that we take for granted today.

TABLE 4.2 Australian Nobel Prize-winning scientists

Year of Nobel Prize	Scientist	Contribution to our understanding of disease
1945	Howard Florey (1898–1968)	Isolation and manufacture of penicillin, and discovery of its curative effect in various infectious diseases
1960	Frank Macfarlane Burnet (1899–1985)	Discovery of acquired immunological tolerance
1996	Peter Doherty (1940–)	Discoveries about the specificity of the cell-mediated immune defence
2005	Barry Marshall (1951–) and Robin Warren (1937–)	Discovery of the involvement of the *Helicobacter pylori* bacterium in stomach ulcers and gastritis

TABLE 4.3 Other notable Nobel Prize-winning scientists

Scientist	Field	Contribution to our understanding of disease
Katalin Karikó (1955–) and Drew Weissman (1959–)	Biochemist and immunologist	Their work contributed to the mRNA vaccines against COVID-19.
Alexander Fleming (1881–1955)	Bacteriologist	In 1928, while studying the influenza virus, Fleming went on holiday and left several discarded Petri dishes on his bench. He had been using them to grow bacteria in nutrient jelly. When he returned, he noticed that where some of the mould had fallen, the bacteria had been killed. He called this substance penicillin but was unable to extract it and did not pursue it further.

4.7.2 Howard Florey

Howard Florey was born in Adelaide in South Australia in 1898. He was a keen student who loved sport and chemistry. He studied medicine at the University of Adelaide, where he won a Rhodes scholarship to Oxford University, England. While in England he led the team who finally extracted penicillin in 1940. In 1945 he shared his Nobel Prize with Alexander Fleming and Ernst Chain. In speaking of his discovery, he modestly stated, ‘All we did was to do some experiments and have the luck to hit on a substance with astonishing properties.’

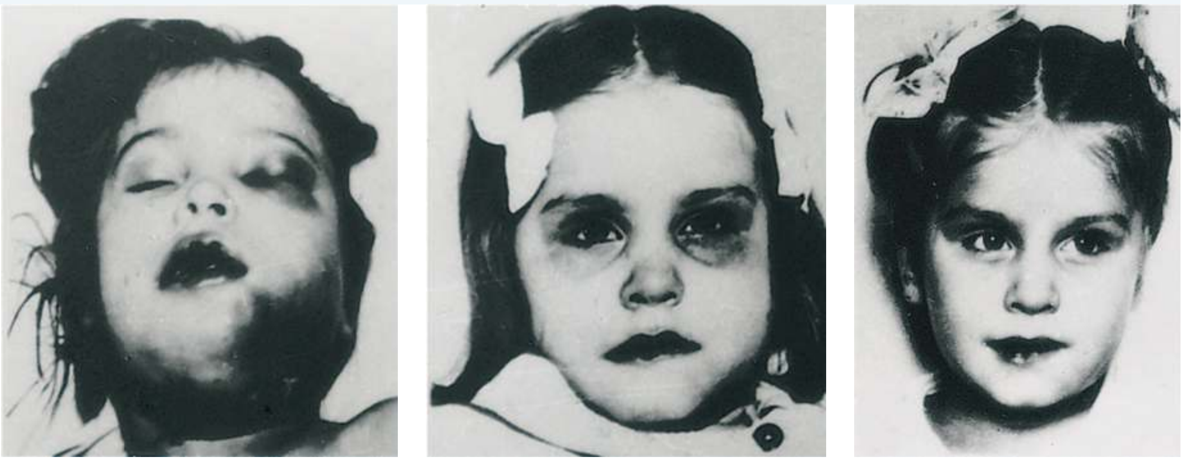
FIGURE 4.53 Sir Howard Florey

Penicillin was so successful in saving lives that population control became an issue for medical researchers. Florey later worked on contraception research. In honour of his contribution to medicine, he was knighted in 1944. His likeness appeared on an Australian $50 banknote and a suburb of Canberra was named after him.

Penicillin is an antibiotic and is a chemical made by the mould (fungus) *Penicillium*. If you leave oranges for too long in the fruit bowl, you will sometimes find them growing a greenish mould. This is *Penicillium*.

Antibiotics destroy bacteria, and so they are widely used to treat diseases caused by bacteria. In the human bloodstream, penicillin works by stopping bacteria from forming cell walls as they try to divide. Natural penicillin must be given by injection as otherwise it is destroyed by stomach acid. Some people are allergic to penicillin, but luckily there are now several different antibiotics to choose from. There are few people in the community who have not taken antibiotics at some time in their lives.

FIGURE 4.54 These photographs from 1942 show how serious a bacterial infection can be. After being treated with penicillin, the patient's condition improved and she recovered fully.



While penicillin has saved millions of lives, there are now strains of bacteria that are becoming resistant to penicillin. These include *Staphylococcus aureus* ('golden staph' or MRSA) and *Neisseria gonorrhoeae* (the cause of gonorrhoea). This resistance develops due to mutations (or changes) to the bacteria that result in the bacteria being able to affect the penicillin before it has a chance to work. This resistance is thought to be due to overuse of antibiotics, which allows the bacteria to mutate. These mutations in the bacteria affect penicillin in different ways:

- The breaking down of the antibiotic by the bacteria through degradation by enzymes
- Changes to the bacterial proteins that are the targets for the antibiotic
- Changes in membrane permeability of the bacteria to antibiotics

4.7.3 Frank Macfarlane Burnet

Sir Frank Macfarlane Burnet, known as 'Mac', was born in Traralgon, Victoria, in 1899 and died in 1985. As a boy, he loved science and spent hours exploring the bush near his home searching for beetles. Charles Darwin was his hero. After graduating from the University of Melbourne as a medical researcher, he started work at the Walter and Eliza Hall Institute (WEHI) in Melbourne. He then worked in England for many years, returning to Australia in 1944 to become director of the WEHI. He was knighted in 1951 and received his Nobel Prize in 1960. In 1961 he was named Australian of the Year, and four years later he was elected President of the Australian Academy of Science.

FIGURE 4.55 Mac demonstrates his method of growing viruses, by injecting them into eggs, to a class of US postgraduate students.

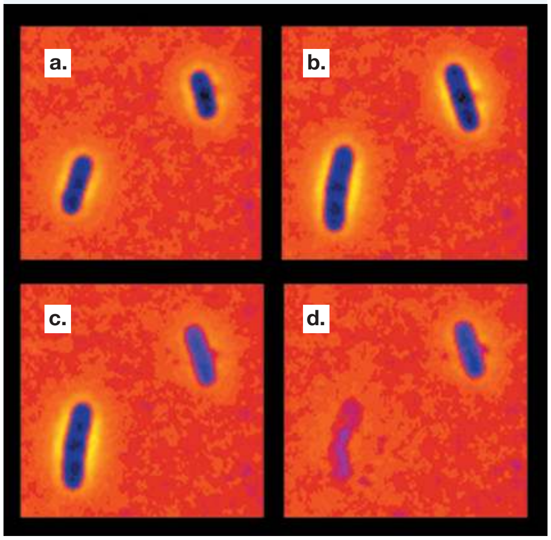
Immunology, the science that deals with protection from diseases, was Mac's speciality and he spent most of his career studying viruses. His doctorate thesis was on the **phage**, a type of virus that infects and kills bacteria. Scientists of the time thought there was only one species of phage. Mac showed that there are, in fact, several species.

In 1928, there was public hysteria against vaccination when 12 children died after receiving their diphtheria injections. Mac was part of a team that investigated this tragedy. His experiments showed that contamination of the vaccine caused the deaths, rather than the vaccine itself. This no doubt saved many further lives as people regained their confidence in vaccination.

Influenza strains

While in England, Mac worked on the human influenza (flu) virus and developed a successful method of growing high concentrations of the virus using fertilised chickens' eggs. This work led to the development of an influenza vaccine. Mac determined that there were several strains of influenza. This meant a new vaccine had to be developed each year once the particular strain of influenza had been identified. His work laid the foundation for the discovery by Dr Peter Coleman from CSIRO that all influenza viruses had a common part. Researchers then focused on ways to attack this common part and were able to produce drugs that can kill all strains of influenza virus. Now, people in high-risk categories are encouraged to be vaccinated each autumn to avoid contracting the disease.

FIGURE 4.56 These photographs show bacteria that were grown in penicillin for 30 minutes. The bacteria grow longer as shown in image **b**, but eventually rupture as shown in image **d**, unable to divide due to the influence of the penicillin.



Mac was so dedicated to his work that he was willing to risk his life to show others what he knew. In the early 1950s, CSIRO released the myxomatosis virus so it would infect and reduce the rabbit population in Australia. At the same time, there was an outbreak of encephalitis that made hundreds of people sick. The public started to blame myxomatosis. Mac knew how the myxoma virus worked and that it could not affect humans. He set up an experiment where he and two colleagues, Professor Frank Fenner and Dr Ian Clunies Ross, injected themselves with live myxoma virus. When it was shown that their health was not affected, the panic died down.

4.7.4 Peter Doherty

Professor Peter Doherty was born in Brisbane in 1940. He received a veterinary science degree from the University of Queensland and a graduate medical degree from the University of Edinburgh. He shared his Nobel Prize in 1996 with Rolf Zinkernagel when they described the way the immune system recognises virus-infected cells. In 1997 Peter Doherty was named Australian of the Year. Doherty and Zinkernagel worked at the John Curtin School of Medical Research in Canberra from 1973 to 1975.

FIGURE 4.57 Laureate Professor Peter Doherty

The immune system uses special white blood cells called T lymphocytes, or T cells, to protect an organism from infection by eliminating invading microbes. T lymphocytes have to be smart enough to avoid damaging their own organism. They need a recognition system so that they can identify the parts they must destroy and those they must protect. The body also needs to know when to activate them.

Doherty and Zinkernagel studied mice to learn how their immune systems (particularly their T lymphocytes) protect them against the virus that causes meningitis. They discovered that mice can make killer T lymphocytes that protect them. However, when these T lymphocytes were placed in a test tube with infected cells from another mouse, they did not work. Doherty and Zinkernagel developed a model to explain why this happened. They said that each T lymphocyte carries a marker that allows it to recognise the cell of the organism it is protecting, as well as the antigen of the invading microbe. At the spot where the antigen attaches itself to the host, the T lymphocyte can make a matched fit and destroy the antigen. It works like two interlocking pieces of a jigsaw puzzle.

When your body is exposed to a microbe, it develops T lymphocytes that give it immunity. If there are enough of the right type of T lymphocytes, these can eliminate the microbes faster than they can reproduce, and you remain well. Your body keeps some of these T lymphocytes as immunity against future attacks from the same microbe.

This work has had a major impact on our understanding of organ transplantation and vaccines. Scientists now realise they must try to match both tissue and immune system types for a successful transplantation. Laureate Professor Peter Doherty is now the patron and namesake of the Peter Doherty Institute for Infection and Immunity, which is a research facility between the University of Melbourne and the Royal Melbourne Hospital. He is still active in Science, and has also written a number of popular Science books, including *The Beginners Guide to Winning the Nobel Prize*.

4.7.5 Barry Marshall and Robin Warren

Before the 1990s, it was widely believed that painful stomach ulcers were caused by stress. In 1982, Barry Marshall and Robin Warren showed that bacteria called *Helicobacter pylori* cause stomach ulcers and that it was possible to treat ulcers successfully with antibiotics. To prove that these bacteria cause ulcers, Barry Marshall swallowed the bacteria and soon developed symptoms associated with the formation of a stomach ulcer.

Their groundbreaking discovery revolutionised the understanding and treatment of stomach ulcers. Both scientists were awarded a Nobel Prize in 2005 for their work.

FIGURE 4.58 Robin Warren and Barry Marshall were awarded a Nobel Prize for their work on the cause and treatment of stomach ulcers.

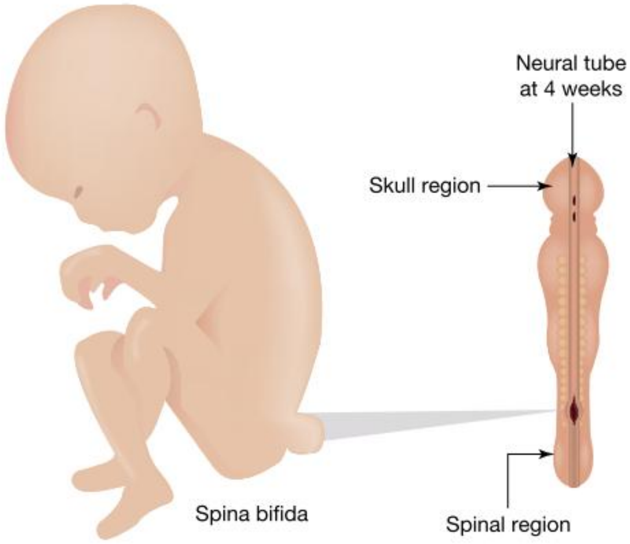
4.7.6 Fiona Stanley

Many breakfast cereals, bread and other foods have folate added because it is crucial for women of child-bearing age. Low folate levels early in pregnancy can cause neural tube defects, like spina bifida, where the spinal cord isn't properly protected, potentially leading to paralysis.

Dr Fiona Stanley, an Australian scientist, linked folate deficiency to neural tube defects. In the late 1980s, she led research that collected health data from mothers and babies, identifying patterns. Her work led to adding folate to staple foods to prevent these birth defects.

FIGURE 4.59 Dr Fiona Stanley

FIGURE 4.60 Neural tube defects occur when the neural tube does not close up properly early in pregnancy. Spina bifida is a neural tube defect affecting the lower area of the spine.



4.7.7 Fiona Wood

Dr Fiona Wood pioneered the development of 'spray-on skin' to treat burns patients, including victims of the Bali bombing in 2002. She started a company that makes the spray-on skin using the patient's own skin cells. It can be applied to burnt areas of the body or to scars. It is also used in cosmetic surgery. The main advantage of spray-on skin is that it reduces scarring. Wood was named Australian of the Year in 2005.

FIGURE 4.61 Dr Fiona Wood, pioneer of 'spray-on skin'

FIGURE 4.62 'Spray-on skin' in action

4.7.8 Ian Frazer

Ian Frazer, an Australian scientist, developed Gardasil, a vaccine that prevents cervical cancer. He worked alongside Chinese virologist Dr Jian Zhou to create virus-like particles that trigger an immune response without causing infection. Their breakthrough formed the basis of the first HPV (human papillomavirus) vaccine and has been recognised globally as a major medical achievement. In recognition of this life-saving contribution, Ian Frazer was named Australian of the Year in 2006.

FIGURE 4.63 Australian immunologist Professor Ian Frazer developed Gardasil, a cervical cancer vaccine.

Cervical cancer affects the cervix, the passage between the vagina and uterus. HPV increases the risk of cervical cancer. Most women with HPV show no symptoms, and cancer may develop years later. Late-stage cervical cancer may require removal of reproductive organs and can spread, causing death. Early detection improves recovery chances.

HPV spreads through sexual contact. Men can carry and transmit HPV, although they do not get cervical cancer. Gardasil, introduced in 2006, has reduced cervical cancer rates. It is best to vaccinate before potential HPV exposure.

4.7.9 Georgina Long and Richard Scolyer

Georgina Long and Richard Scolyer were named Australians of the Year in 2024 for their melanoma treatment research. Immunotherapy, which uses the patient's immune system to fight cancer, can be combined with surgery. Their research showed that immunotherapy is more effective when used before surgery, rather than after.

In 2023, Richard Scolyer was diagnosed with aggressive brain cancer and given eight months to live. He applied their technique to his own treatment and documented his progress. He remained cancer-free for more than 18 months after undergoing the revolutionary treatment; however, in February 2025, scans showed the cancer had returned and he underwent further surgery.

FIGURE 4.64 Georgina Long and Richard Scolyer were named Australians of the Year in 2024.

4.7 Activities

learnon

4.7 Quick quiz on	4.7 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2	3, 4	5, 6

Remember and understand

1. **Identify** the scientist who discovered that infectious diseases are spread by bacteria.
2. Sir Howard Florey, Sir Frank Macfarlane Burnet and Professor Peter Doherty are Australians who have received a Nobel Prize for their contributions to medical research.
   a. **State** which Nobel Prize each scientist won and in what year.
   b. **State** which area of science each of the scientists specialised in.
3. Are there are any strains of bacteria that are resistant to penicillin? **Explain** your answer.

Apply and analyse

4. **Explain** what would have happened to you if you had a bacterial infection in the time before penicillin was discovered.
5. **Explain** how antibiotic resistance develops.

Evaluate and create

6. SI Sir Howard Florey infected eight mice with *Streptococcus*. Four of the mice that were given a penicillin injection survived the infection and those that did not receive penicillin died from the infection.
   a. **Explain** why the mice given the penicillin injection survived the infection. **Explain** how penicillin works.

   Following the success of penicillin in treating infection in mice, Florey and his team of scientists produced cultures of *Penicillium notatum* as a source of penicillin in the 'fungus juice' to try to slow or counteract bacterial infections in humans. In 1940, Oxford Police Constable, Albert Alexander, was hospitalised following infection with *Streptococcus* and *Staphylococcus*, resulting from a rose bush's scratch to his face. Howard Florey's wife, Ethel, a pharmacologist, brought Albert's plight to Florey's attention, as other treatments were failing and Albert's face was covered in abscesses. Albert lost his eye to the infection. Within 24 hours of injection with penicillin, Albert was showing signs of recovery, but after five days of treatment the penicillin ran out. They had even been extracting penicillin from Albert's urine to prolong his treatment. Albert unfortunately died without this continued treatment.

   b. **Suggest** why the penicillin treatment was successful in mice but was unable to save Albert.
   c. **Suggest** reasons why someone with a serious infection can fully recover after treatment with penicillin.

Answers and sample responses are available in your digital formats.

LESSON 4.8 Review

4.8 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria			
4.2	I can compare and describe the differences between non-infectious and infectious diseases.			
	I can understand how infectious diseases are spread and the range of strategies that can prevent or contain their spread.			
4.3	I can understand that not all microorganisms cause disease.			
	I can distinguish between cellular and non-cellular pathogens.			
	I can provide examples of different types of pathogens.			
	I can explain how pathogens can cause diseases in a host.			
4.4	I can identify the chemical and physical barriers that form the body's first line of defence.			
	I can explain the processes of inflammation and phagocytosis as part of the second line of defence.			
	I can describe the roles of B and T lymphocytes and the lymphatic system in the third line of defence.			
4.5	I can explain what immunity is.			
	I can compare the differences between active and passive immunity.			
	I can understand how immunity can be acquired naturally or artificially.			
	I can understand how the development of vaccines has positively affected the world in the fight against smallpox, polio and HPV.			
4.6	I can understand how epidemics and pandemics have shaped human history and why the world's population is more vulnerable to infections than in earlier times.			
4.7	I can provide examples of some of the contributions that our Australian Nobel Prize winners have made to scientific knowledge and understanding.			

learnon

Post-test	Topic 4 Post-test
eWorkbook	Topic 4 eWorkbook
Digital document	Key terms glossary

4.8 Activities

learnon

4.9 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 9, 10, 15	4, 5, 6, 11, 14, 16, 17, 21	7, 8, 12, 13, 18, 19, 20, 22

Remember and understand

1. **Identify** which type of diseases can be transmitted from one person to another.
2. MC **Identify** the term used for the cause of an infectious disease.
   A. Accident
   B. Ageing
   C. Nutritional deficiency
   D. Pathogen
3. MC **Identify** the term used for any foreign particles that stimulate an immune response.
   A. Antibodies
   B. Antigens
   C. Lymphocytes
   D. Vaccination
4. MC **Identify** chemical barriers involved in the first line of defence against disease.
   A. Inflammation and fever
   B. Lymphocytes and antibodies
   C. Saliva and stomach acid
   D. Skin, cilia and nasal hairs
5. MC **Identify** the type of specific proteins that are produced rapidly and in great amounts during the secondary exposure response.
   A. Antibodies
   B. Antigens
   C. Lymphocytes
   D. Vaccination
6. MC **Identify** a way of tricking your immune system into acting as though it has met a pathogen before.
   A. Antibodies
   B. Antigens
   C. Lymphocytes
   D. Vaccination
7. MC **Identify** the type of acquired immunity in which a person makes their own antibodies after exposure to an antigen.
   A. Active artificial immunity
   B. Active natural immunity
   C. Passive artificial immunity
   D. Passive natural immunity
8. MC **Identify** the type of acquired immunity in which antibodies are injected into a person.
   A. Active artificial immunity
   B. Active natural immunity
   C. Passive artificial immunity
   D. Passive natural immunity
9. a. **State** whether all parasites are pathogens.
   b. **Justify** your response.
10. **Identify** which of the pathogens on the left causes each of the infectious diseases on the right.

Pathogens and the diseases they cause

Type of pathogen	Infectious disease
a. Bacteria	1. Malaria
b. Fungi	2. Measles
c. Protozoans	3. Ringworm
d. Viruses	4. Scarlet fever

11. **Identify** the types of cells that can divide into plasma cells and produce antibodies.
12. **Describe** what helper T lymphocytes signal B lymphocytes to do.
13. **Identify** which blood component on the left is part of each of the lines of defence on the right.

Components of the body's three lines of defence

Blood component	Line of defence
a. Lymphocyte	1. First line of defence
b. Phagocyte	2. Second line of defence
c. Platelet	3. Third line of defence

Apply and analyse

14. **List** the following cyclic events in order of occurrence, beginning with the infected person sneezing: person infected, pathogens inhaled by uninfected person, infected person sneezes, pathogens released into air.
15. **Describe** the host type in the life cycle of a parasite.
16. **Explain** the cycle of how a virus is spread.
17. **Describe** the malaria transmission cycle.
18. **Explain** how vaccines work.

Evaluate and create

19. **Explain** why viruses such as HIV, cold and flu are so difficult to cure.
20. **Construct** your own summary mind maps or concept maps on the following topics, using the terms suggested (as well as any others that may be relevant).
    a. Infectious disease: contagious, infected, pathogen, cellular pathogens, non-cellular pathogens, quarantine, direct contact, vectors, contaminated objects, contaminated water, sneezing, coughing, physical contact, antibiotics, personal hygiene, tapeworms, head lice, fungi, protozoans, bacteria, viruses, prions
    b. Pathogens and parasites: parasite, host, primary host, intermediate host, endoparasite, ectoparasite, pathogen, non-cellular pathogen, cellular pathogen, prions, kuru, mad cow disease, viruses, obligate intracellular parasites, mumps, AIDS, warts, influenza, bacteria, coccus, bacillus, *Streptococcus*, cholera, pneumonia, typhoid, whooping cough, Gram stain, protozoans, malaria, amoebic dysentery, fungi, tinea, ringworm, thrush, worms and arthropods, tapeworm, liver fluke
21. **Construct** your own summary mind maps or concept maps on the following topics, using the terms suggested (as well as any others that may be relevant).
    a. Putting up defences: lines of defence, first line of defence, second line of defence, third line of defence, antigen, non-self, specific, non-specific, physical barriers, chemical barriers, inflammation, phagocytosis, phagocytes, white blood cells, inflammation, cilia, skin, acid, enzymes, nasal hairs, sneezing, coughing, lymphocytes, B lymphocytes, plasma cells, antibodies, T lymphocytes, lymphatic system, lymph, lymph vessels, memory cells
    b. Immunity: vaccine, vaccination, immunisation, active immunity, passive immunity, artificial immunity, natural immunity, antibodies, active natural immunity, active artificial immunity, passive natural immunity, passive artificial immunity
22. SI **Propose** an experiment that would show which disinfectants and antiseptics are most effective against the growth of bacteria in your kitchen.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

5 Inside the atom

CONTENT DESCRIPTION

The model of the atom changed following the discovery of electrons, protons and neutrons; natural radioactive decay results in a change from unstable to stable atoms (VC2S10U06)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 5.1 Overview

5.1.1 Introduction

What does a cake have to do with chemistry? This model depicts an early idea for the structure of an atom. It was called the 'plum pudding model' and was devised by English chemist J.J. Thomson. It showed negatively charged electrons embedded in a positively charged sphere. We now have a much better understanding of atoms and know that this model is incorrect.

Atoms are the smallest component of matter and cannot be easily observed under the microscope. Over time, scientific research has resulted in the development of new scientific models of the atom in an attempt to explain what we observe, which is how scientists have come to the current accepted theory for the structure of the atom.

FIGURE 5.1 The atom was once thought to have a structure similar to this cake, which has raisins randomly mixed throughout its structure.

Models and theories are developed by scientists who research and study the prior knowledge and information of a topic, perform and observe experiments, and analyse the results. They also repeat experiments many times, with slight differences to the original experiment. By analysing all of the data obtained, scientists then fit all the data together into a model that makes sense. Models are very useful as they can be used to make predictions and to explain why something behaves the way it does. Most importantly, new discoveries can be used to improve models over time, so they are more useful and can better explain our observations.

The use of models is one example of how the scientific process keeps improving our understanding of the universe.

DISCUSSION

1. How did a plum pudding help scientists gain an understanding of atoms?
2. How did Lord Ernest Rutherford use gold foil to find out that atoms are mostly empty space?
3. What causes radioactivity?
4. Is radioactivity always dangerous?
5. Are bananas radioactive?
6. What's the connection between radioactivity and fossils?
7. How is radioactivity used in the treatment of cancer?

SCIENCE INQUIRY: What is all matter made of?

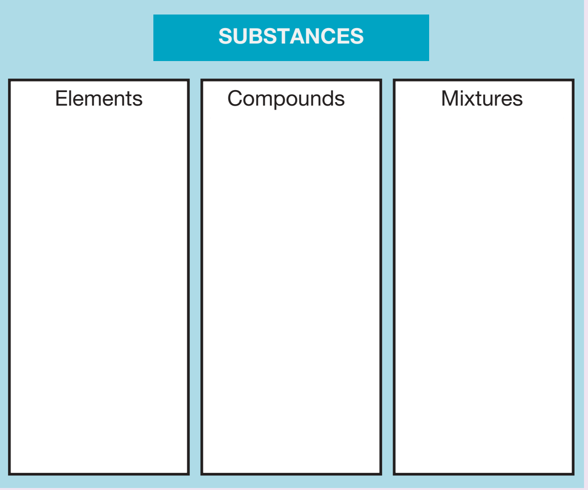
You probably already know quite a lot about the different types of particles that make up substances. This knowledge is the first step in your quest to find out why substances behave the way they do.

Answer the following questions to find out how much you already know about the inside story on substances.

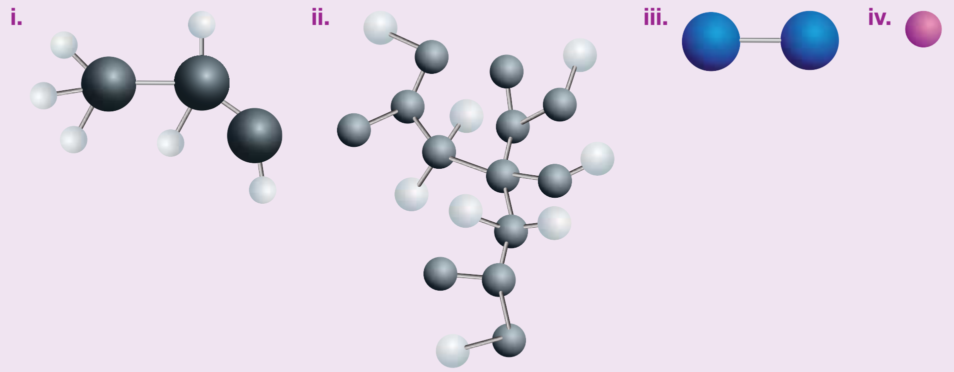
1. The substances around you and inside you can be placed into three groups — elements, compounds and mixtures.
   a. Which one of these groups contains substances that are made up of only one type of atom?
   b. What is the difference between a compound and a mixture?

c. Arrange each of the terms listed on the left into the three groups of substances to complete the affinity diagram.

gold
carbon dioxide
blood
diamond
air
sea water
iron
chocolate thick shake
copper
table salt
ammonia
soil
concentrated hydrochloric acid
pure water
brass
calcium
sodium hydroxide
oxygen



2. Elements, compounds and mixtures are made up of tiny particles called atoms and molecules.
   a. How is a molecule different from an atom?
   b. Give an example of an element that is found as a molecule in its natural state.
   c. List two compounds that are made up of molecules.
   d. Name one compound that is not made up of molecules.
3. Which of the diagrams shown represents:
   a. an atom of an element
   b. a molecule of an element
   c. a molecule of a compound?



4. Name three different particles found inside an atom.

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

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Pre-test	Topic 5 Pre-test
eWorkbook	Topic 5 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 5 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 5.2 Chemical building blocks

LEARNING INTENTION

In this lesson you will:
- describe the masses and charges of protons, neutrons and electrons
- explain how the discovery of these particles resulted from experimental evidence
- answer questions related to properties and behaviours of atoms.

5.2.1 The structure of atoms

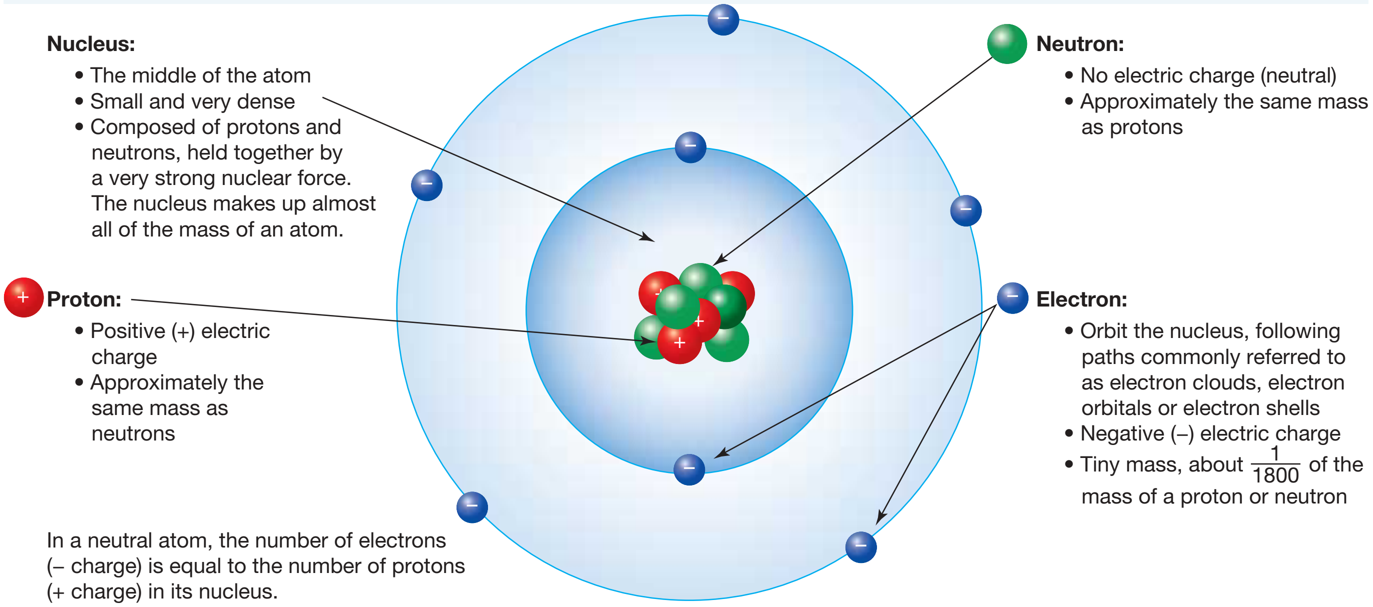
The current model of the atom accepted today consists of a tiny, dense **nucleus**, made up of the **subatomic particles protons** and **neutrons**, which is surrounded by **electrons**. Table 5.1 and figure 5.2 summarise the properties of these particles.

Atoms are tiny.
- Even the largest atoms are less than one billionth of a metre across. That's a millionth of a millimetre and about $\frac{1}{20\,000}$ of the diameter of the finest of human hairs.
- The nucleus is $\frac{1}{100\,000}$ of the diameter of an atom. If an atom were the size of the Melbourne Cricket Ground, the nucleus would be the diameter of a grain of rice.
- Atoms are mostly empty space. For example, a hydrogen atom is about 99.999 999 999 999 6 per cent empty space.

TABLE 5.1 Subatomic particles and their properties

Subatomic particle	Charge		Relative mass	Location
Proton	Positive	+1	1	Nucleus
Neutron	Neutral	0	1	Nucleus
Electron	Negative	–1	0	Energy shells (orbits; electron cloud)

FIGURE 5.2 The current model of the atom



The amount of negative charge carried by each electron is equal but opposite to the amount of positive charge carried by each proton. In an atom, where the number of protons is equal to the number of electrons, there is no overall electric charge. The electrons are arranged according to energy levels called shells — the lowest energy level (shell) can hold up to two electrons and the next shell can hold up to eight electrons.

KEY IDEA

Atoms contain the subatomic particles protons, neutrons and electrons.

5.2.2 Representing atoms

Atoms are not all the same. To date, chemists have identified 118 different types of atoms.

Elements are substances that contain only one type of atom. For example, pure oxygen contains only oxygen atoms, and pure lead contains only lead atoms. Elements are defined by the number of protons in the nucleus.

KEY IDEA

- Elements are substances that contain only one type of atom.
- An element is defined by the number of protons in the nucleus.

Representing elements

Elements are represented by an element **symbol**, and with the atomic number and the mass number.

Most symbols for elements come from the first letter or two letters of their names; for example, C for carbon and Cd for cadmium. Some atoms have symbols that have originated from a Greek or Latin name; for example, Au is the symbol for gold because gold was known in the past by its Latin name, *aurum*.

Atomic number

- Each of the 118 elements known to chemists has its own **atomic number**.
- The atomic number of an element is defined as the number of protons in the nucleus of an atom of that element.
- When an atom is neutrally charged, the atomic number of the atom corresponds to the number of electrons, because the number of positive charges must be the same as the number of negative charges. For example, oxygen has an atomic number of 8 and, therefore, has eight protons and eight electrons.

Mass number

- The **mass number** is defined as the total number of protons and neutrons in an atom of an element.
- Protons have approximately the same mass as neutrons. The electron's mass is so small that it is negligible compared with protons and neutrons. Therefore, the mass of an atom depends only on the number of particles in the nucleus.

DISCUSSION

- How do we know that the current model of the atom is the correct structure? Atoms are very tiny and we cannot see individual ones.
- How is it therefore possible to describe the structure of atoms? Do you think that there might be other, even smaller particles in atoms?

TABLE 5.2 Symbols, subatomic particles, and atomic and mass numbers for the first 12 elements

Name	Symbol	Protons (atomic number)	Neutrons*	Electrons	Mass number
Hydrogen	H	1	0	1	1
Helium	He	2	2	2	4
Lithium	Li	3	4	3	7
Beryllium	Be	4	5	4	9
Boron	B	5	6	5	11
Carbon	C	6	6	6	12
Nitrogen	N	7	7	7	14
Oxygen	O	8	8	8	16
Fluorine	F	9	10	9	19
Neon	Ne	10	10	10	20
Sodium	Na	11	12	11	23
Magnesium	Mg	12	12	12	24

*The number of neutrons can vary but this is the most common number of neutrons for these elements.

ACTIVITY: PhET simulation

Access the **PhET simulation: Build an atom** interactivity in the Resources panel.

1. Click on 'Atom'.
2. Add seven protons to the atom. What element is it? What is the net charge?
3. Add seven neutrons to the atom. What impact does this have on the net charge?
4. If electrons are added to the atom, how many electrons must be added to have a net charge of zero?
5. What is the relationship between the number of protons and the number of electrons?
6. What is the mass number of this atom?
7. Try adding a proton to the atom. State two things that change.
8. Remove the proton and remove an electron. State two things that remain the same.
9. Draw and label the atom, and record the atomic number and mass number.
10. Build some more atoms, draw and label them.
11. Choose from the games section at the bottom of the page for more fun.

SCIENCE AS A HUMAN ENDEAVOUR: Dark matter

Scientists have been puzzled about something making up about 27 per cent of the universe that they call 'dark matter'. They know dark matter exists because they can see its gravitational effect on stars and how it holds galaxies together, but it is not made of atoms and is invisible. The existence of dark matter was only proposed in the 1930s by astronomers observing the unusually fast movement of galaxies. Super-sensitive detectors have been built and deployed in deep underground mines to perform experiments and take measurements to find out what makes up this mysterious dark matter. The first dark matter laboratory built in the southern hemisphere is 1 km kilometre underground, in the Stawell Gold Mine.

1. Why is technology important in helping scientists investigate dark matter?
2. Why do scientists need underground laboratories, like the one in Stawell, to study dark matter?
3. How does the discovery of dark matter show the connection between science and technology?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

5.2.3 The story of the atom

Most of our knowledge about the 'building blocks' of matter that we call atoms is less than 100 years old. But the idea that matter was made up of atoms was first suggested about 2500 years ago by the great philosopher and teacher Democritus. He did not do experiments, but imagined that if you kept cutting something like a shell in half, you would eventually reach a point where you could not divide it any further. He named the smallest particles *atomos*, the Greek word for 'indivisible'. Since then, various theories and models of the atom have been accepted, rejected and modified using evidence from experiments performed by many famous scientists.

SCIENCE AS A HUMAN ENDEAVOUR: Experimental evidence for the structure of the atom

It was in 1808 that the British scientist John Dalton experimented on a few different elements and found out that they always reacted together in the same ratio to form compounds. He proposed that elements were made of indivisible particles that he called atoms.

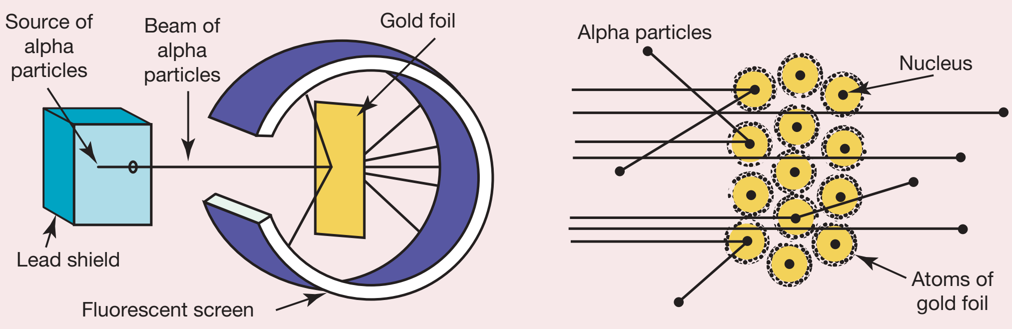
It was not until about 100 years later that J.J. Thomson discovered the electron. He conducted experiments with cathode-ray tubes, passing electric current through gases at low pressure. Electric or magnetic fields could deflect the cathode rays, which showed that they consisted of charged particles. Thomson proposed the existence of a negatively charged particle much smaller than an atom, later called an electron. He described atoms as being like a plum pudding, with negative particles embedded in a positive plum pudding.

The next major discovery was credited to Lord Ernest Rutherford, a New Zealand physicist. His experiment in 1911 involved firing a beam of high-speed helium nuclei through thin sheets of gold. He used gold because he could make it very, very thin. Rutherford was amazed to discover that most of the particles passed through the foil without being diverted; however, a few were slightly or fully deflected.

Rutherford's model of the atom was based on a series of experiments using very thin sheets of gold, called gold foil, and involved the following:

- A source of tiny, positive **alpha particles** was obtained. For safety, the source of alpha particles had a lead shield.
- A beam of alpha particles was fired at the gold foil.
- The pathway of the particles was detected using a fluorescent screen. Rutherford was very clever in his design of the fluorescent screen, as it was circular-shaped. This enabled him to see all pathways that the particles travelled.
- The observed results of this experiment were that many particles travelled straight through the gold foil, some were deflected at various angles and others were deflected right back to the alpha particle source.
- At the time, the bouncing back of the particles was stated as the equivalent to firing a cannon ball and having it come back to you!

FIGURE 5.3 An enlarged view of the gold foil experiment



Niels Bohr worked with Rutherford. In 1913, he used observations of the atomic spectra (light emitted from energised atoms) of different atoms to develop Rutherford's model. He showed, using mathematics, that electrons revolve around the nucleus at distinct energy levels. His calculations, however, did not work for larger atoms. There was still more work to be done!

The neutron was the last subatomic particle to be discovered. Scientists had a problem — they knew that the mass of an atom was much greater than the mass of the protons, but that the mass of electrons was negligible. James Chadwick, in 1932, decided to investigate the possibility of the existence of a neutral particle with a similar mass to the proton. He performed a similar experiment to Rutherford, firing alpha particles at beryllium, and discovered that there were indeed particles of mass as close to that of protons but without a charge. Finally, the neutron was discovered, giving us a more complete view of the atom.

But there's more! A new branch of physics, quantum theory, investigates tiny particles even smaller than atoms. These tiny particles behave quite weirdly. They can act like waves, but we do not know exactly where or how fast they are going. Studying these extremely small particles sometimes requires extremely large equipment. The particle accelerator at CERN (the European Organization for Nuclear Research), for example, is a 27-kilometre circular tunnel under the border of Switzerland and France.

Scientists at CERN explore the tiniest building blocks of the universe and the forces that hold everything together using a huge machine called the **Large Hadron Collider (LHC)**. The LHC smashes particles travelling at close to the speed of light to find out what they are made of. This research helps us learn how the universe began, what it is made of and why things work the way they do. The CERN scientists also investigate mysterious things like antimatter and dark matter. In addition, CERN's work has led to inventions like the World Wide Web, which was created there.

FIGURE 5.4 The Large Hadron Collider

1. Why was Rutherford's gold foil experiment considered groundbreaking at the time?
2. How did Rutherford's experiment demonstrate the importance of observation and experimentation in science?
3. Why is it important for scientific discoveries, like Rutherford's model, to be tested and reviewed by other scientists?

Scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)

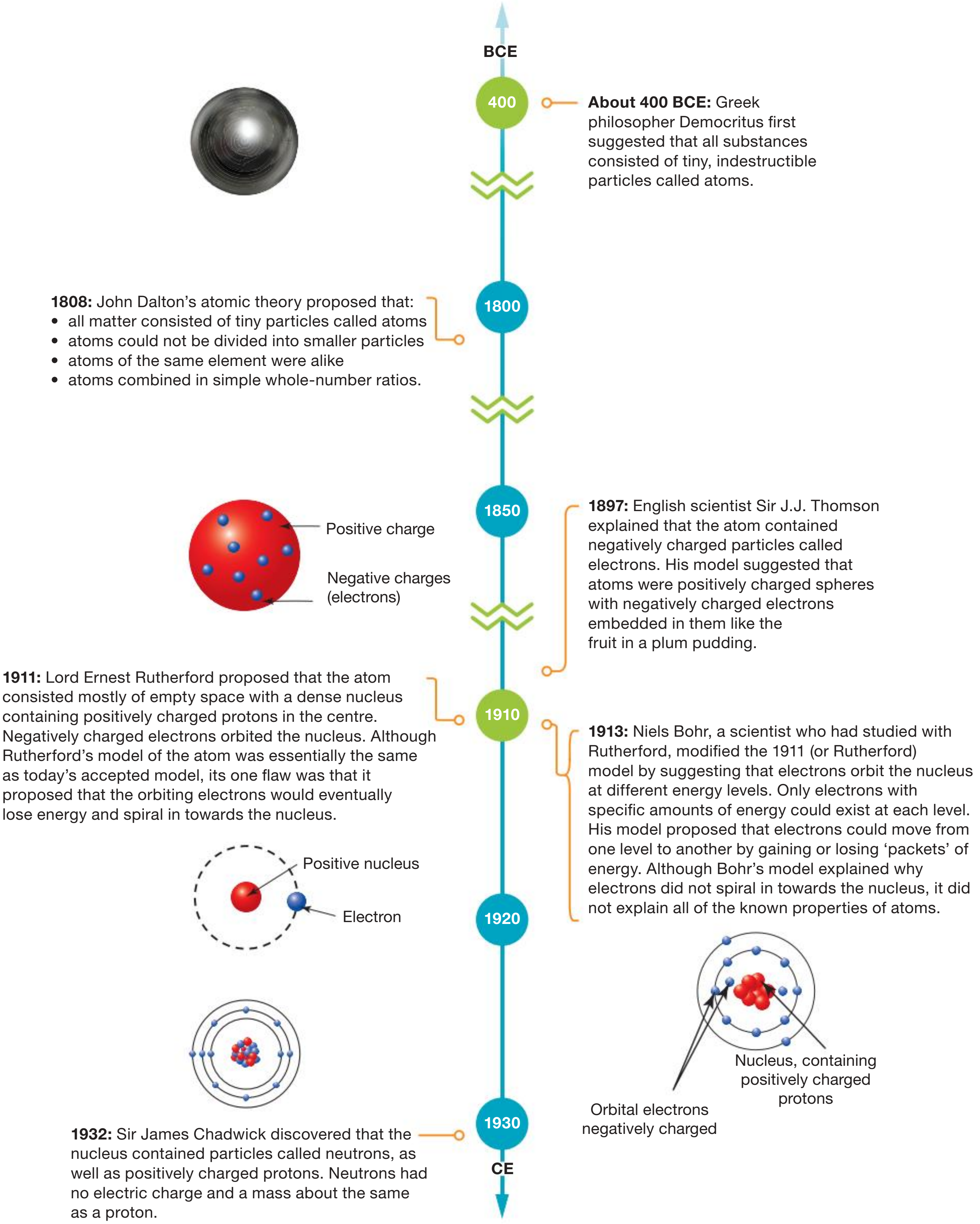
Those discussed previously are a few of many scientists who used the scientific method to develop our knowledge of atomic structure. To obtain valid results, they repeated experiments and tried different techniques to make observations and collect precise results. These experiments were used to test hypotheses and theories to support conclusions. Scientists build on the knowledge obtained by those before them and use their own insights to guide, improve and confirm their investigations.

KEY IDEA

Experiments are a key part of the scientific method, which is a systematic way to explain the world.
The development of scientific discoveries over time relies on repeated observations and measurements.

The timeline in figure 5.5 summarises some of the important developments of the model of the atom over time.

FIGURE 5.5 Timeline of the development of the model of the atom



INVESTIGATION 5.1

Exploring models of the atom

Aim

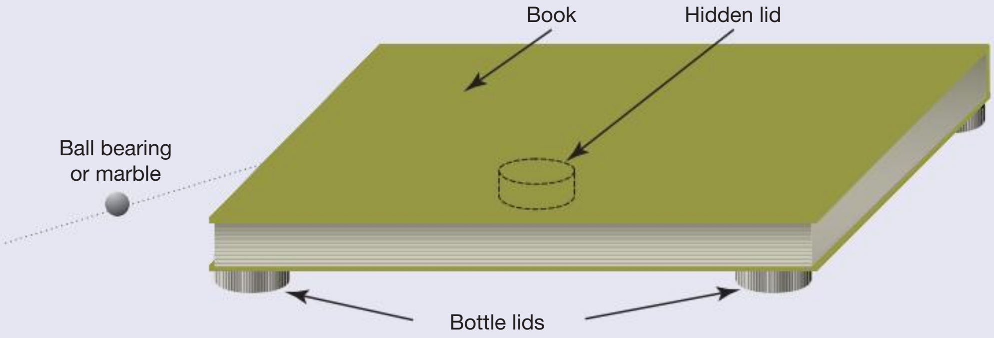
To explore Rutherford's experiment

Materials

- a hardcover book of at least A4 size
- 5 plastic soft drink bottle lids
- a 10 mm diameter ball bearing or 12 mm diameter marble

Method

1. Support the book on a benchtop using a bottle lid under each corner.
2. Have one member of your group lift the book, place the fifth bottle lid somewhere in the area surrounded by the other four lids and replace the book. The fifth lid represents the nucleus of the atom in this model. The other members of the group should look away while the fifth lid is being placed.
3. After the other members of the group turn around, they take turns to roll the ball bearing or marble under the book to find the location of the 'nucleus'.



Results

Record the number of times the ball bearing or marble is rolled before striking the 'nucleus' for the first time.

Discussion

1. Comment on how difficult it is to locate the 'nucleus' in this model.
2. What is represented in this model of Rutherford's experiment by:
   a. the area under the book that is surrounded by the four lids
   b. the ball bearing or marble?
3. a. Recall that the plum pudding model does not contain a nucleus. Write a hypothesis for this experiment according to the plum pudding model.
   b. Based on your observations, justify why this cannot be the plum pudding model of the atom.

Conclusion

Summarise the findings of the investigation in three or four sentences using correct scientific terms.

DISCUSSION

Models of the atom have changed greatly over the past century. Do we now understand the atom completely, or could our models improve further? Learning from the past, how might such improvements be made? What might be discovered at CERN?

5.2 Activities

learnon

5.2 Quick quiz on	5.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 5	2, 4, 7, 9	6, 8, 10

Remember and understand

1. MC **Identify** where most of an atom's mass is located.
   A. Protons
   B. Neutrons
   C. Electrons
   D. Nucleus
2. **Identify** the missing words to complete the sentence.
   According to the plum pudding model, the atom is a _____________ with _____________ embedded in it like the fruit in a plum pudding.
3. **Explain** the main difference between John Dalton's model of the atom and the models of Thomson, Rutherford and Bohr.
4. Complete the following table by **stating** one example for each pair.

Comparison of subatomic particles

	Protons and electrons	Protons and neutrons	Electrons and neutrons
Similarity			
Difference			

Apply and analyse

5. **Explain** why most of Rutherford's alpha particles went through the thin sheets of gold foil.
6. **Describe** the main weakness of the Rutherford model of the atom.
7. SI **Explain** why it was important for Rutherford to fire many alpha particles at the gold atoms.
8. SI **Explain** why it is not surprising that the neutron was discovered quite a long time after the electron and proton.
9. **Construct** a diagram of the modern model of the atom and include the following labels: proton, neutron, electron, positive, negative, neutral, nucleus.

Evaluate and create

10. SI **Evaluate** if the current model of the atom is proven.

Answers and sample responses are available in your digital formats.

LESSON 5.3 Isotopes and radioactivity

LEARNING INTENTION

In this lesson you will:

- explain what isotopes are and that some are unstable
- describe how different unstable isotopes decay to form stable atoms
- define half-life and give examples
- interpret radioactive decay curves.

5.3.1 Neutrons and isotopes

All atoms of a particular element have the same number of protons. For example, every hydrogen atom has only one proton in its nucleus, and every carbon atom has six protons in its nucleus. However, sometimes the number of neutrons in atoms of the same element is different. Such atoms are called **isotopes**. Isotopes have the same atomic numbers but different mass numbers.

KEY IDEAS

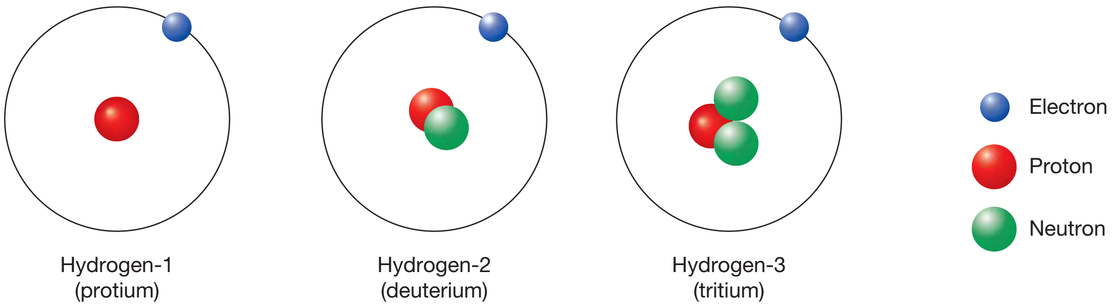
- Atoms of the same element with different mass numbers are called isotopes.
- Isotopes are atoms of the same element that contain different numbers of neutrons.
- Many elements exist as two or more isotopes.

Naming isotopes

Hydrogen has three isotopes. Each isotope has one proton. However, the different isotopes have zero, one or two neutrons, respectively. **Nuclide** notation is used to represent the isotopes of an element, and includes the atomic and mass numbers. For example, the three isotopes of hydrogen can be represented as $^{1}_{1}H$, $^{2}_{1}H$, and $^{3}_{1}H$.

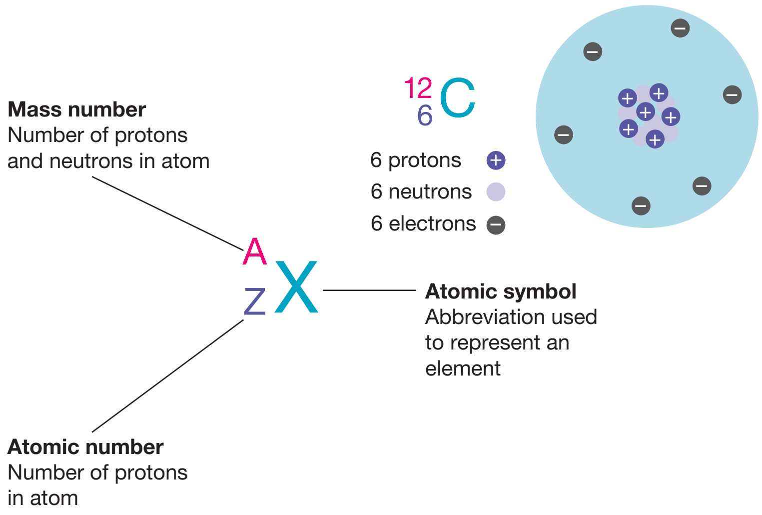
Isotopes are also named with the element name and mass number — for example, hydrogen-1, hydrogen-2 or hydrogen-3, as shown in figure 5.6.

FIGURE 5.6 The three isotopes of hydrogen. Hydrogen-1, hydrogen-2 and hydrogen-3 are also known as protium, deuterium and tritium, respectively.



The nuclide symbol notation of carbon-12 is shown in figure 5.7.

FIGURE 5.7 Nuclide symbol notation



EXTENSION: Why are they called isotopes?

The word 'isotope' is derived from the Greek words *isos*, meaning 'equal', and *topos*, meaning 'place'. It came about because even though each isotope of the same element had different numbers of neutrons and therefore different weights, they occupied the same place on the periodic table of the elements.

Stable or unstable atoms

Within the nucleus, protons and neutrons are usually held together by incredibly strong forces. However, sometimes the difference in the number of neutrons compared to the number of protons in the nucleus results in instability of the atom. The forces between the protons and neutrons are unbalanced.

- In **stable** atoms, the protons and neutrons found in the nucleus are held together very strongly.
- In **unstable** atoms, the neutrons and protons in the nucleus are not held together as strongly.
- Unstable isotopes **decay** to form other elements. These isotopes are said to be radioactive and are called radioactive isotopes, or **radioisotopes**.

For example, consider the three isotopes of carbon — carbon-12, carbon-13 and carbon-14 — which have identical chemical properties. However, the nucleus of carbon-14 is not stable and disintegrates naturally. Carbon-12 is a stable isotope, while carbon-14 is a radioactive isotope. Generally, in small atoms, the number of neutrons is usually about the same as the number of protons. As the size of the atom increases, there tend to be more neutrons than protons in the nucleus. This difference in the number of neutrons compared to protons increases as the atom gets bigger and bigger. As a result, the element tends to become more unstable.

KEY IDEA

Radioactivity is the property of some unstable atoms to spontaneously emit radiation from their nuclei.

TABLE 5.3 Examples of stable and unstable (radioactive) isotopes of carbon and uranium

Element	Symbol	Number of protons	Number of neutrons	Stable or radioactive?
Carbon-12	$^{12}_{6}C$	6	6	Stable
Carbon-13	$^{13}_{6}C$	6	7	Stable
Carbon-14	$^{14}_{6}C$	6	8	Radioactive
Uranium-235	$^{235}_{92}U$	92	143	Radioactive
Uranium-238	$^{238}_{92}U$	92	146	Radioactive

ACTIVITY: PhET simulation

Access the **PhET simulation: Build an atom** interactivity in the Resources panel.

1. Draw a table with the following headings in your workbook or computer with about 20 rows. Part of the first row has been filled out for you.

Protons	Electrons	Neutrons	Mass number	Nucleotide symbol	Stable or unstable?
1	1	0	1	$^{1}_{1}H^{0}$	

2. Click twice on the Li symbol.
3. Tick the Stable/Unstable box.
4. Add a proton and an electron to make a neutral hydrogen atom. Decide if it is stable or unstable, recording your response in the first row of the table.
5. Add another neutron and fill in the next row of the table.
6. Reset the model by clicking the orange button and tick the Stable/Unstable box.
7. Try starting with two protons and add electrons to make a neutral atom. Add a neutron and fill in the table. (*Hint:* The number of protons in the nucleus should equal the number of electrons outside the nucleus.)
8. Add a proton to the atom. Record your observations in the table.
9. Make this atom stable by adding one or more neutrons and/or electrons. Record your observations in the table.
10. Repeat steps 8 and 9 until your table is full.

Discussion

1. What did you notice if you tried to put electrons in the centre of the atom?
2. Were there any patterns in your results?
3. Use the simulation to infer how many isotopes of magnesium Mg (atomic number 12) are stable.
4. State what happened to the atomic number and mass number when a neutron was added.
5. Write a conclusion about what you have learned from this interactivity.

KEY IDEA

An unstable atom will decay to form other elements and is called a radioactive isotope.

EXTENSION: The relationship between mass and energy

You may remember that matter cannot be created nor destroyed — it can only be transferred or transformed into a different form. Einstein's theory of relativity states that mass and energy are the same physical entity, which is captured by the equation $E = mc^2$. In this equation, E represents energy, m represents mass and c is a constant (the speed of light). Therefore, the relationship is $E \propto m$ (E varies by the same factor as m). Einstein concluded that mass and energy can (at least theoretically) be converted into each other.

Nuclear fission is another example of the relationship between mass and energy. Nuclear fission is an explosive reaction in which one atom is split into one or more other atoms. A huge amount of energy is released in this process. As the number of protons in the nucleus has now been changed, new (and smaller) elements are formed. This conversion process in the atomic nuclei also results in a tiny reduction in mass. Power plants use uranium and nuclear fission to produce energy, which is then converted to electricity. You will learn more about this in lesson 5.4.

5.3.2 Radioactivity and radiation

Natural radioactivity

Natural radioactivity is emitted from matter without energy being supplied to atoms. There are about 50 isotopes that emit radioactivity naturally. They exist in the air, in water, in living things and in the ground.

Sources of natural radioactivity include the following:

- *Background radioactivity.* Radioactivity is all around us. Fortunately, it is quite safe. It mostly comes from naturally occurring radioactive elements in Earth's crust and atmosphere, in the form of radon, which is a gas produced during the breakdown of other radioisotopes such as uranium and thorium. A smaller amount comes from outer space in the form of **cosmic radiation** emitted by the Sun and other stars. Earth's atmosphere protects us from the dangers of cosmic radiation, as we will discover in topic 9.
- *Bananas.* Yes, bananas (potassium-40) are radioactive, but so are spinach, potatoes, oranges and Brazil nuts, as well as the air you breathe! There are even small amounts of radioisotopes in the human body, including hydrogen-3 (tritium), carbon-14 and potassium-40. However, the amount of radiation is minute.
- *Kitty litter and granite bench tops.* There is a tiny and harmless amount of radioactivity found in these objects.

FIGURE 5.8 Bananas are a natural source of radioactivity

Artificial radioactivity

Most radioactive isotopes (about 2000 in total) are made radioactive artificially by bombarding their atoms with subatomic particles like protons and neutrons. Examples of artificial isotopes include americium-241, which is used in smoke detectors; the stable isotope cobalt-59, which becomes the radioactive isotope cobalt-60 under neutron bombardment (used in medicine); and iridium-192, which is used in gamma radiography. The uses of radioisotopes are discussed in lesson 5.4.

KEY IDEA

Natural radioactivity occurs spontaneously, while artificial radioactivity occurs when atoms are bombarded with particles such as neutrons.

Radiation

Radiation is energy that is emitted in the form of particles or waves. There are two main types: **non-ionising radiation** and **ionising radiation**. Radiation can be natural; for example, it can be emitted from the Sun or naturally radioactive materials; or it can be artificial, such as x-rays or nuclear energy. While some forms are harmless, others — particularly ionising radiation — can damage living tissues and require careful handling.

Non-ionising radiation does not have sufficient energy to ionise atoms, but it can still affect matter. It includes radio waves, microwaves, infrared, visible light and ultraviolet radiation. Ionising radiation has enough energy to remove electrons from atoms, creating ions. It includes x-rays and **nuclear radiation**.

KEY IDEA

There are two types of radiation: non-ionising and ionising. Nuclear radiation is ionising radiation because it can remove electrons from atoms.

You may have seen the sign shown in figure 5.9; it is the ionising radiation symbol. It has been used since 1946 to warn people that radioactive material is nearby. The circle in the middle represents an atom and the blades around it represent the three types of nuclear radiation coming out from the nucleus of the atom — alpha, beta and gamma. These types of radiation were described by Lord Ernest Rutherford and are explained in table 5.4.

FIGURE 5.9 Ionising radiation symbol

5.3.3 Types of nuclear radiation

There are three types of nuclear radiation: alpha, beta and gamma.

TABLE 5.4 The three types of nuclear radiation

	Alpha particles	Beta particles	Gamma rays
Symbol	α	β	γ
Description	Helium nuclei that contain two protons and two neutrons, so they are positively charged	The same size and mass as electrons, can have a negative or positive electric charge and can travel at speeds as high as 99 per cent of the speed of light	Not particles, but bursts of energy released after alpha or **beta particles** are emitted; travel at the speed of light
Penetration and danger to health	Cannot travel easily through materials and can be stopped by a sheet of paper or human skin. They pose little hazard to the external body but can cause serious damage if breathed in, eaten or injected.	Can penetrate human skin and damage living tissue, but they cannot penetrate thin layers of plastic, wood or aluminium	Highly penetrating; they can cause serious and permanent damage to living tissue and can be stopped only by a thick shield of lead or concrete

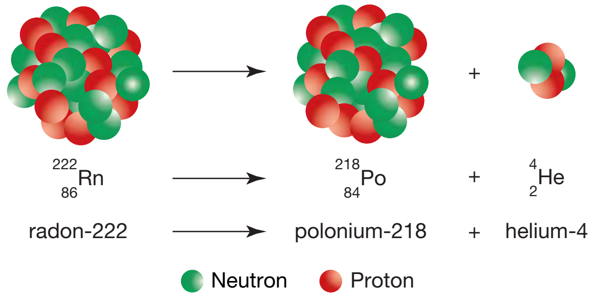
Examples of radioisotope decay

The gas radon was mentioned earlier as a source of natural radiation. It forms in the ground as a result of the radioactive decay of natural uranium, which is present in many rocks. Radon-222 decays, releasing α particles and producing polonium-218, which then decays to lead-214. Rn-222 has a short **half-life** of 3.8 days. The half-life of a radioactive isotope refers to the amount of time it takes for one-half of the isotope to decay. This will be discussed further later in this lesson.

This is an example of a nuclear equation. To write a nuclear equation:

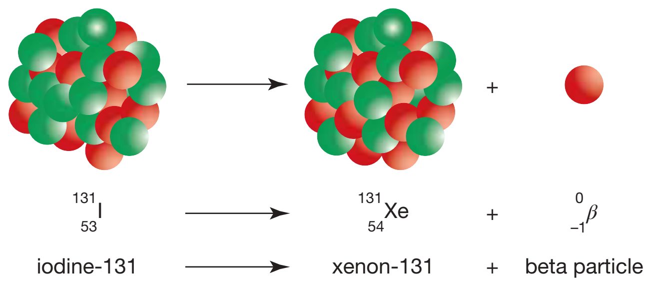
1. Identify the starting isotope (e.g. radon-222).
2. Determine the type of decay (alpha, beta or gamma).
   - Alpha decay – loses two protons and two neutrons (He-4 nucleus)
   - Beta decay – a neutron changes into a proton, releasing an electron
   - Gamma decay – energy is released, but the element stays the same
3. Balance the equation by ensuring the mass and atomic numbers are equal on both sides. In this example:
   - Mass numbers: $222 = 218 + 4$
   - Atomic numbers: $86 = 84 + 2$

FIGURE 5.10 Alpha decay of a radon-222 isotope



Iodine-131 is widely used in medicine to diagnose and treat cancers of the thyroid gland. A small dose of radioactive iodine I-131 is swallowed and taken into the bloodstream. This iodine isotope has a physical half-life of 8.0 days and emits beta-particles. Iodine-131 is artificially produced as a **fission** of the uranium-235 isotope.

FIGURE 5.11 Beta decay of an iodine-131 isotope



The radioisotope cobalt-60 emits high-energy **gamma rays**. It is used medically for radiation therapy in hospitals and in many industrial applications — for example, to detect faults. Some foods are irradiated with Co-60 to destroy insects and bacteria; this does not make food radioactive or change its quality. Cobalt-60 is an artificial radioisotope with a half-life of 5.27 years. Cobalt-60 is produced by bombarding a target material — either cobalt-59 or nickel-60 — with neutrons in a nuclear reactor.

FIGURE 5.12 Gamma decay of a cobalt-60 isotope

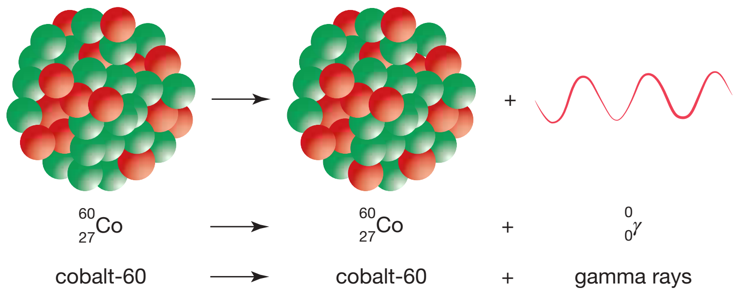
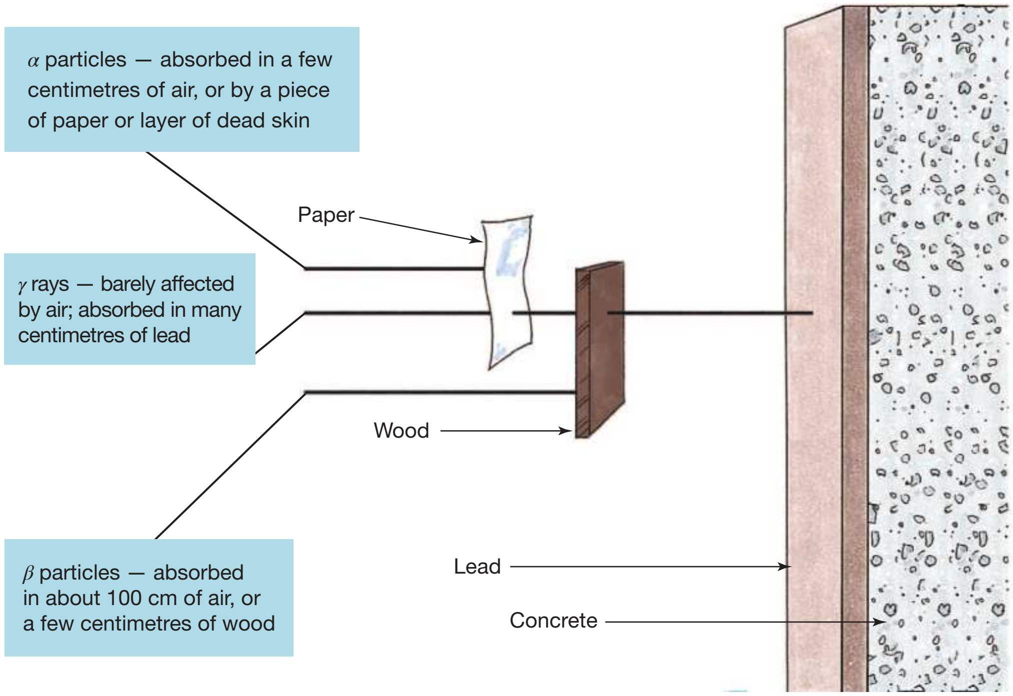


FIGURE 5.13 The different penetrating powers of alpha (α), beta (β) and gamma (γ) radiation

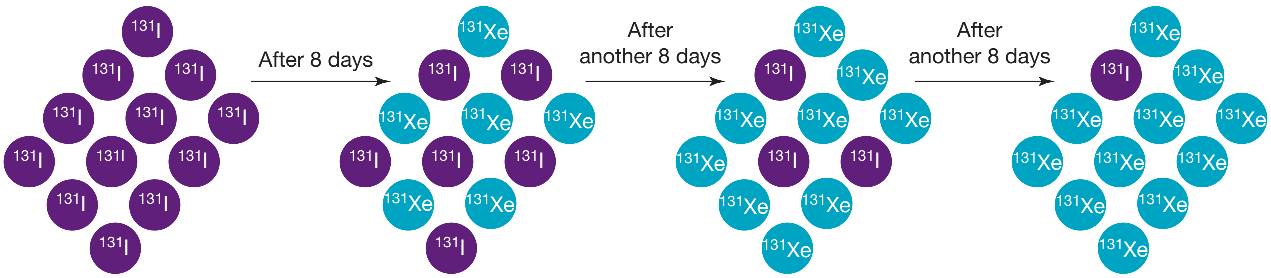


5.3.4 How quickly do atoms decay?

The nuclei of different radioactive substances decay at different rates. Some decay in seconds while others take millions of years. The concept of half-life allows a comparison of rates of decay. As mentioned previously, half-life refers to the amount of time it takes for one-half of a radioactive isotope to decay. Returning to the example of a banana, the half-life of the potassium-40 it contains is 1.3 billion years, so hardly any of its atoms decay each second. You can continue to safely eat this healthy snack.

The half-life of tritium — an isotope of hydrogen, ${}^{3}_{1}H$ — is 12.3 years. So, if we start with 100 g of tritium, then after 12.3 years, half of it will have decayed, leaving 50 g of tritium; and after another 12.3 years, half of the 50 g of tritium will have decayed, leaving 25 g of tritium, and so on.

FIGURE 5.14 The half-life of iodine-131 is about eight days.



KEY IDEAS

- The half-life of a radioisotope is the time taken for half of all the nuclei in a sample of the radioisotope to disintegrate or decay.
- Half-lives can vary from microseconds to billions of years.

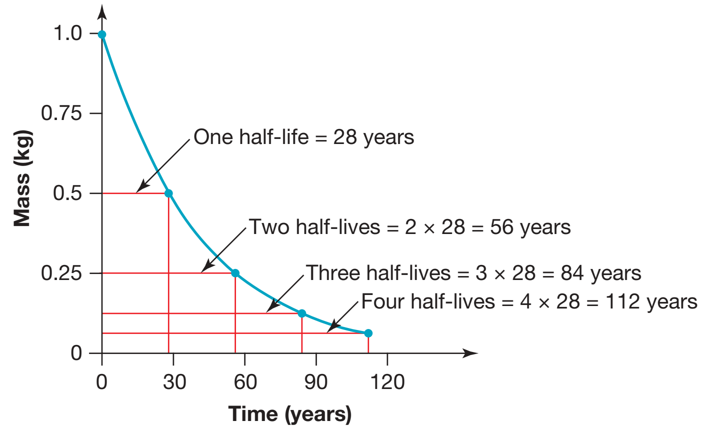
Uranium is probably the best known of the radioisotopes. There are three naturally occurring isotopes of uranium: uranium-238, uranium-235 and uranium-234.

- Each of the isotopes spontaneously disintegrates or decays, producing alpha particles and gamma rays.
- Each isotope has its own half-life; that is, the time taken for the concentration to fall to half its initial value.
- The half-lives of each of the uranium isotopes are more than a billion years.

TABLE 5.5 The half-life of an isotope and the fraction remaining after each half-life

Number of half-lives	Fraction remaining
1	$\frac{1}{2}$
2	$\frac{1}{4}$
3	$\frac{1}{8}$
4	$\frac{1}{16}$

FIGURE 5.15 A graph showing the radioactive decay of strontium-90, which has a half-life of 28 years



DISCUSSION

- Most naturally occurring radioisotopes on Earth were created before the planet was formed. Given Earth is approximately 4 billion years old, what does that tell us about the half-life of these radioisotopes?
- Carbon-14 has a half-life of only 5700 years, yet it makes up 1.1 per cent of all naturally occurring carbon. How can this observation be explained?

INVESTIGATION 5.2

Modelling half-life

Aim

To model the process of radioactive decay using M&Ms and observe how the number of decayed M&Ms decreases over time

Hypothesis

Write a hypothesis.

Materials

- 50 lollies with a letter on them (e.g. M&Ms or Skittles) or small coins
- ziplock bag
- A4 sheet of paper

Method

1. Place the lollies (or coins) into the Ziplock bag.
2. Zip the bag closed.
3. Shake the bag gently for 10 seconds.
4. Open the bag and tip the lollies onto the A4 paper.
5. Completely remove the lollies without a letter visible (or coins that have the 'heads' side showing). These are the 'atoms' that have decayed.
6. Count the remaining 'atoms' and record the number in your results table.
7. Return the undecayed atoms to the Ziplock bag
8. Repeat this process until there are no radioactive 'atoms' left.

Results

1. Copy and complete the table below. Remember to include a title for your table.

Trial	Time (s)	No. of radioactive 'atoms' remaining
At the start	0	50
1	10	
2	20	
3	30	
4	40	
5	50	

2. Plot a graph with 'No. of radioactive 'atoms' remaining' on the vertical axis and 'Time (s)' on the horizontal axis. You may do this in your workbook or on a computer.

Discussion

1. Was your hypothesis correct?
2. How does the total number of radioactive 'atoms' change with each trial?
3. What difference to the outcome would there be if you started with 100 atoms?
4. What does it mean when we say an atom has 'decayed'?
5. How long did it take for three-quarters of the atoms to decay?
6. How does this model help us understand how atoms decay?
7. What is something about the decay of atoms that is not shown in this model?
8. After each half-life, did you find that exactly half of the atoms decayed? Comment on whether you think this is always the case. How could you confirm your answer?
9. How would combining the class data affect the accuracy of the results?

Conclusion

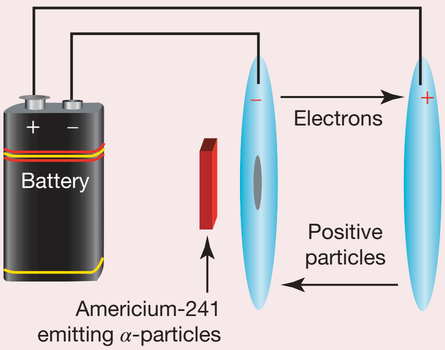
Write a conclusion to this investigation as a response to the aim.

SCIENCE AS A HUMAN ENDEAVOUR: Using radiation to detect smoke

Smoke alarms are an example of radioisotopes used routinely in the home. They contain a tiny amount of americium-241, an alpha-particle-emitting radioisotope. Smoke alarms work by setting up a small electrical circuit in the detector. When that circuit is disrupted by smoke, the alarm sounds.

- Alpha particles from americium-241 knock electrons off molecules in the air, creating positive particles and free electrons.
- These charged particles are attracted to two oppositely charged plates, setting up a small current.
- When the current flows, there is no alarm.

FIGURE 5.16 The electrical circuit of a smoke detector



- However, when smoke particles enter the detector, they attach to the positive particles, making them neutral.
- This disrupts the current, and the siren sounds.
- The half-life of americium-241 (Am-241) in smoke detectors is 432 years.

1. Why is americium-241 suitable for use in smoke detectors?
2. How does the use of radiation in smoke detectors demonstrate the connection between science and technology?
3. What makes alpha particles ideal for creating the electrical current in smoke detectors?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

5.3 Activities

learnon

5.3 Quick quiz on	5.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 5, 7, 9	3, 6, 8, 10	4, 11, 12, 13

Remember and understand

1. **State** what each letter represents in a nuclide symbol, ${}^{A}_{Z}X$.
   a. A **b.** Z **c.** X
2. **Identify** which of the terms on the left matches each of the definitions on the right.

Nuclide terminology

Terms	Definition
a. Atomic number	**1.** Mass number – number of protons
b. Number of neutrons	**2.** Number of protons + number of neutrons
c. Mass number	**3.** Number of protons

3. Complete the following table by **identifying** the missing values.

Nuclide notation of different elements

Nuclide symbol	Atomic number	Mass number	Protons	Neutrons
${}^{14}_{6}C$				
	19	39		
			15	17
		31		16
	92			146

4. **Identify** one similarity and one difference between two particles that are isotopes.
5. Alpha particles are the heaviest type of radiation. Complete the following table by **identifying** the properties of alpha particles.

Properties of alpha particles

Charge	Protons	Mass number	Nuclide symbol

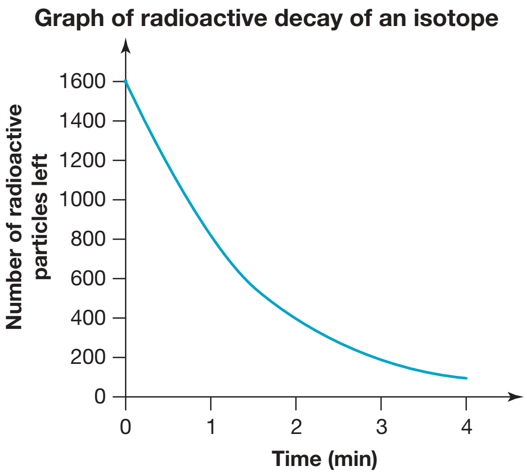
6. **Explain** how we are protected from cosmic radiation from outer space.

Apply and analyse

7. **State** whether the atoms ${}^{230}_{93}X$ and ${}^{239}_{94}X$ are isotopes of the same element. **Justify** your answer.
8. The half-life of an isotope of tritium is 4500 days. **Calculate** the number of days it will take an amount of tritium to fall to a quarter of its initial mass.
9. An atom of uranium-238, ${}^{238}_{92}U$, decays by emitting a single alpha particle. **Identify** the nuclide symbol for the resulting atom. **Explain** how you got your answer.
10. **Explain** why the isotopes of some elements are radioactive.
11. **State** the type of nuclear radiation described by the following statements.
    a. A radioactive particle that has the same size and mass as an electron
    b. A radioactive particle that is made up of two protons and two neutrons
    c. The type of radiation that can penetrate the human body and can be stopped only by a thick shield of lead or concrete
    d. A radioactive particle that can travel almost at the speed of light

Evaluate and create

12. SI The following graph shows the decay of a radioisotope over four minutes.



    a. **State** the half-life of this isotope.
    b. **Calculate** the number of radioactive particles that would be left after five minutes.
    c. When the decay takes place in a sealed container, helium gas is collected. **Identify** one type of radiation produced in the decay.
13. SI A scientist wished to determine the type of radiation emitted by a radioisotope. She had three materials (paper, plastic and lead) and an instrument called a Geiger counter, which detects nuclear radiation. She covered the radioisotope with each of the three materials and measured the radiation that passed through each. The results of her experiment are shown in the following table.

Results of radioactivity experiment

Material	Effect on Geiger counter readings
Paper	No effect on readings
Plastic	Readings fell by two-thirds
Lead	Readings fell by nine-tenths

    a. **Identify** the independent variable in this experiment.
    b. **Identify** the dependent variable in this experiment.
    c. **Identify** a controlled variable in this experiment.

d. Complete the following table to **identify** whether certain variables should be controlled in this experiment.

Experiment variables

Variable	How could this variable affect the dependent variable?	Should this variable be controlled? (Y/N)
The thickness of the material covering the radioisotope		
How far the Geiger counter is placed from the radioisotope		
The scientist wearing her lab coat for only some measurements		

e. **State** the type of nuclear radiation that this radioisotope emits. **Explain** your answer, with reference to the data.

Answers and sample responses are available in your digital formats.

LESSON 5.4 Using radioactivity

LEARNING INTENTION

In this lesson you will:

- describe the timescales of decay of different elements
- explain how radiocarbon and other dating methods have been used to establish that Aboriginal and Torres Strait Islander Peoples have been present on the Australian continent for at least 65 000 years
- describe where applications of radioactivity are used in medicine and industry.

5.4.1 Uses of radioisotopes

Radioisotopes are used for many purposes in industry, research and medicine. They can be used:

- as radioactive 'tracers' to follow the movement of substances through liquids (e.g. sediment movement in rivers and the movement of substances in the blood)
- to treat disease
- to sterilise instruments
- in determining the age of samples from archaeological sites and geological formations
- in checking the quality of materials by measuring the thickness of objects or finding flaws in materials
- in power generation by nuclear reactors
- in smoke detectors
- in soil and pollution analysis
- in agriculture to see how plants absorb nutrients and water
- to preserve food by killing bacteria.

FIGURE 5.17 A home smoke detector containing radioisotopes

These applications of radioisotopes are crucial for advancements in various fields, but care must be taken to maintain safety measures to handle their radiation.

DISCUSSION

In Australia, irradiation can only be used for fresh fruit and vegetables to destroy moulds and bacteria, and to control the spread of insects like fruit flies. Irradiation does not make the food radioactive. How would you feel about eating irradiated food?

FIGURE 5.18 Food can be irradiated to extend shelf life.

SCIENCE AS A HUMAN ENDEAVOUR: Using radioisotopes

Marie Curie and her husband Pierre worked out that the element radium produced lots and lots of energy. However, it took a long time for them to determine what was actually happening — as energy cannot be created or destroyed, how was radium creating energy? During this time, radium was used in everyday consumer products from toothpaste to toys to heating pads. Radium was the new health craze, and any product that contained radium sold immediately. Marie and Pierre Curie eventually discovered that, unfortunately, radium is radioactive and is actually detrimental to our health. All the everyday consumer products containing radium that were being sold at the time were harming people rather than improving their health.

FIGURE 5.19 Marie and Pierre Curie were awarded the Nobel Prize in Physics for their discovery of radium.

Radium decays to lead (and other components), both of which are harmful to living organisms. In 1903, Marie Curie, her husband Pierre and Henri Becquerel were awarded the Nobel Prize in Physics for their discovery of radioactivity and their work on uranium. Little did they know that their discoveries and investigations would change the course of history.

They could not have imagined that their work would lead to the development of nuclear weapons capable of killing millions of people, of nuclear power plants that generate electricity, and of the use of radioactive isotopes to treat cancers and detect life-threatening illnesses.

1. How did the initial use of radium reflect society's values and beliefs at the time?
2. What are some examples of how radium's discovery has been used for both positive and negative purposes?
3. How does Marie and Pierre Curie's discovery highlight the importance of considering ethics in scientific research?
4. How did the public's enthusiasm for radium-containing products compare to modern health and wellness trends?

Scientific knowledge may be interpreted in different ways by individuals and groups in society; the values and needs of society can influence the focus of scientific research (VC2S10H04)

5.4.2 Radiometric dating

Naturally occurring radioisotopes can be used to calculate the age of samples from archaeological sites and in determining the age of geological formations. This technique is called **radiometric dating**.

One of the most useful types of radiometric dating is **radiocarbon dating**. This uses the carbon-14 isotope, which has a half-life of 5700 years. Carbon is a very common element in living organisms, so the amount of carbon-14 left in a fossil or in an archaeological sample can be used to determine how long ago that organism died.

The process, shown in figure 5.20, is as follows:

1. Carbon-14 is produced by cosmic radiation, which is radiocarbon.
2. Carbon dioxide is constantly being taken in by plants, which are eaten by animals, so all living organisms contain some radiocarbon.
3. When living things die, the decaying radiocarbon is no longer being replaced.
4. Since all fossils were once living, their age can be determined by measuring the amount of radiocarbon remaining.

After 5700 years, only half of the usual amount of radiocarbon will be left. A graph can be used to estimate the age of a sample. After about 50 000 years, the amount of radiocarbon becomes too small to measure accurately.

FIGURE 5.20 Carbon-14 generation and decay and its application in radiocarbon dating

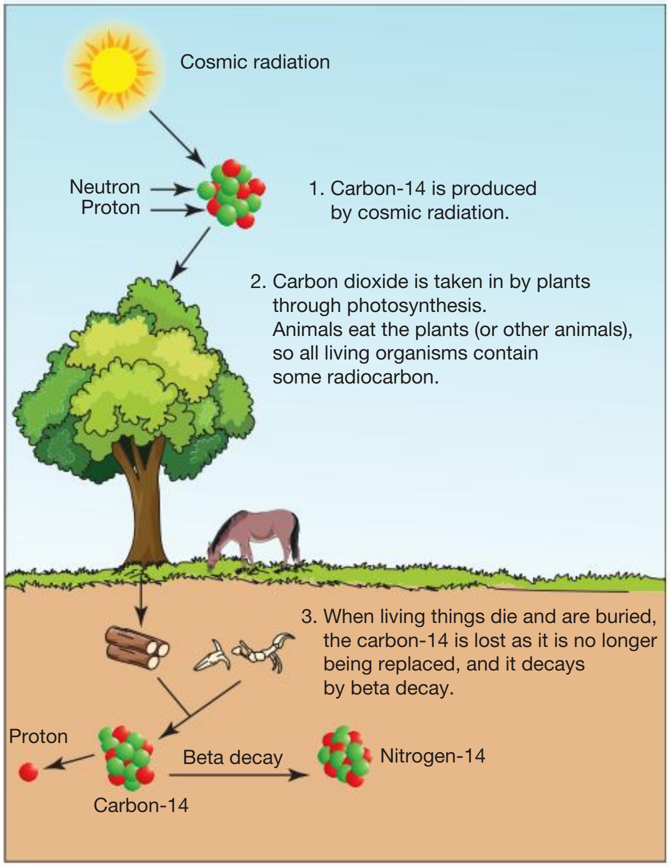
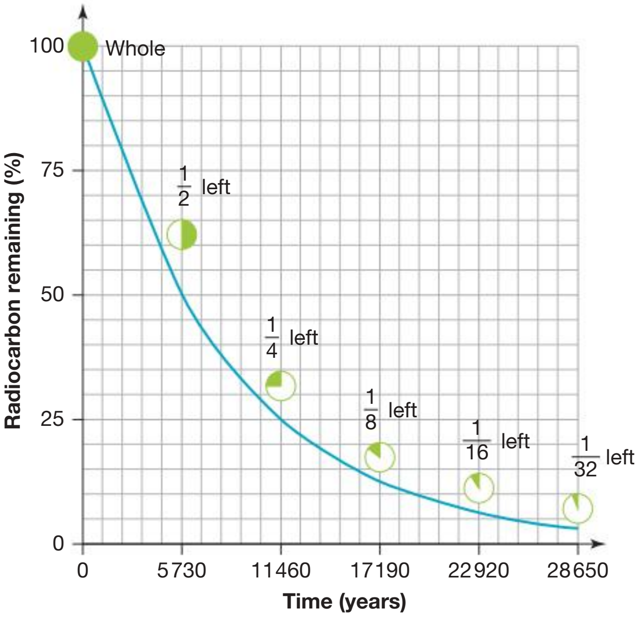


FIGURE 5.21 The decay of a sample of pure radiocarbon



SCIENCE INQUIRY: Determining the age of the universe

All rocks contain small amounts of radioactive elements such as uranium and potassium. Radioactive elements with very long half-lives can be used to determine the age of older rocks and minerals. For example, uranium-238's half-life — about 4.5 billion years — makes it useful for dating ancient materials. When U-238 decays, it goes through a series of steps very, very slowly, eventually turning into a stable element, lead-206. Each step in this chain releases a bit of radiation. By measuring the ratio of U-238 to lead-206 in a rock, scientists can calculate how long the decay process has been happening and, therefore, estimate the age of the rock.

FIGURE 5.22 How old is the universe?

For example:
- If a rock has decayed to half its original U-238, it is approximately 4.5 billion years old.
- If only a quarter remains, the rock is about 9 billion years old.

Scientists have also tested meteorites for U-238 to get a more accurate age, because they are older than our planet. The extended half-life of U-238 is ideal for studying Earth's oldest rocks and meteorites, and helps scientists estimate Earth's age at around 4.5 billion years.

Although U-238 helps date the oldest objects in the solar system, determining the age of the universe is considerably more difficult. The universe is much older than the solar system and even older than the first stars. Scientists study cosmic background radiation from distant stars and galaxies to date the universe; they estimate it is around 13.8 billion years old! Astronomers continue to make observations, gather information, take measurements and perform calculations to discover more about the origin of the universe.

1. How do scientists use radioactive elements, like U-238, to determine the age of rocks?
2. What evidence supports the estimate that the universe is 13.8 billion years old?
3. Why is U-238 better suited for dating older rocks and meteorites than other radioactive elements?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

5.4.3 Dating methods and Aboriginal and Torres Strait Islander Peoples

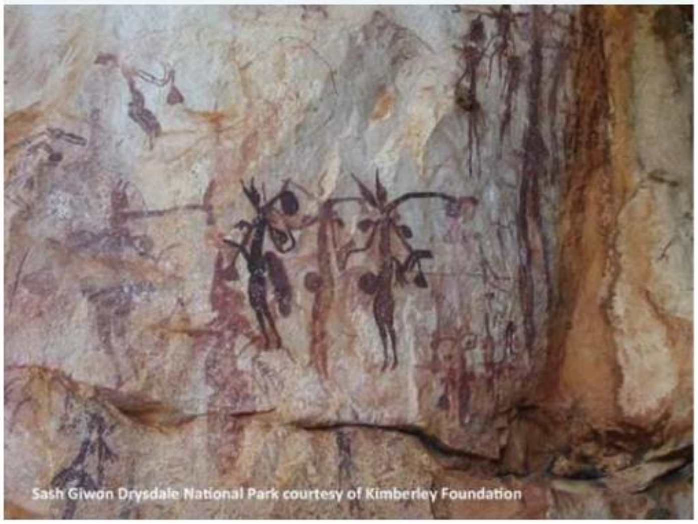
Scientists have used radiocarbon and other dating methods to establish how long Aboriginal and Torres Strait Islander Peoples have been present on the Australian continent. This research has established that people have, in fact, been here for over 65 000 years. Radiocarbon dating can be used to analyse a diverse range of natural materials, such as sedimentary material from lakes, water, tree rings, ice cores, soil and air. It has also been used to establish the age of cultural artefacts and materials from Aboriginal and Torres Strait Islander Peoples. In achieving this, the story of the lives and histories of Aboriginal and Torres Strait Islander Peoples has been captured and recorded for historical purposes, and provides evidence that these communities were among the most advanced in terms of technology at this time.

The Australian Nuclear Science and Technology Organisation (ANSTO) uses nuclear dating methods to analyse the rock art, tools, paints (ochres) and other artefacts used by Aboriginal and Torres Strait Islander Peoples. ANSTO were able to date some rock-art sites as 16 000 years old. Radiocarbon dating requires a certain carbon content in a sample and can only analyse organic materials up to about 50 000 years old. However, **optically stimulated luminescence (OSL)** can analyse minerals, like grains of sand, that are up to about 100 000 years old. This technique has measured thousands of grains of sand individually and produced more accurate ages. OSL dating has played a key role in showing the time that Aboriginal and Torres Strait Islander Peoples have been in Australia.

Optically stimulated luminescence (OSL) dating

Optically stimulated luminescence (OSL) is a technique used by scientists to determine how long ago sand grains, minerals or ceramics were last exposed to sunlight or heat. These methods only work on crystalline materials, meaning they have a regular three-dimensional atomic arrangement.

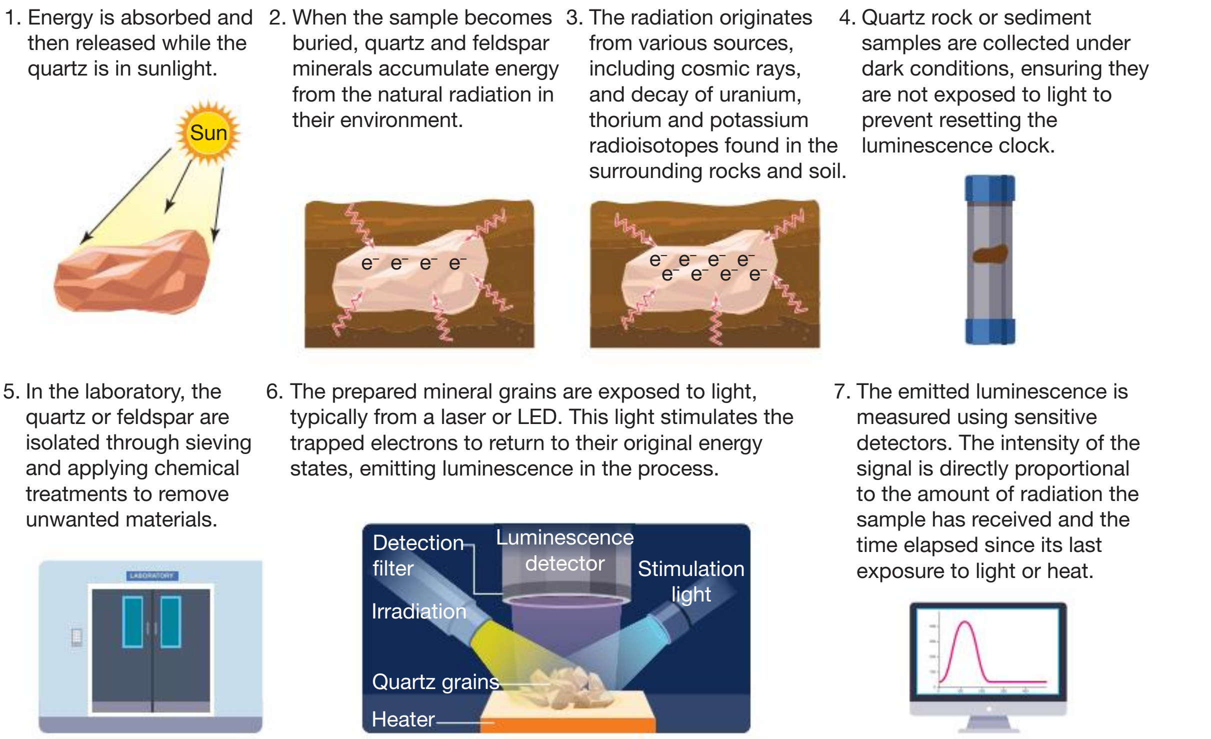
FIGURE 5.23 Sash Gwion figures, Kimberley rock art



The steps involved are as follows:

1. *Minerals are buried.* Quartz grains and minerals have tiny crystals that have been exposed to sunlight and will trap electrons when buried underground.
2. *Timing starts.* Once they are buried under layers of sediment, these crystals start to collect electrons from low-level, natural ground radiation emitted from uranium, thorium and potassium in the soil. These electrons are trapped in imperfections in the mineral crystals. The longer the minerals are buried, the more electrons are trapped.
3. *Samples are analysed.* Samples are dug up in darkness or using a red light to stop sunlight from reaching the samples, and then blue or infrared light is shone on them in the laboratory. This causes the trapped electrons to be released as visible light.
4. *The age of the sample is determined.* Scientists measure the light released (luminescence) and use this to work out how long it has been since the crystals were exposed to sunlight or heat. They can then calculate when they were buried.

FIGURE 5.24 How OSL works



The results from the OSL indicated that the deepest layers that contained stone tools, grindstones, ochre and other artefacts made by early humans were up to 65 000 years old. This produced strong evidence that humans had the knowledge and skills to make complex tools and were living in Australia at this time, much earlier than was previously thought. This proved that Aboriginal and Torres Strait Islander Peoples have been living on the Australian continent for at least 65 000 years, making them the world's oldest continuous culture.

5.4.4 Radioisotopes in medicine

The diagnosis of disease

Radiography is an imaging technique that uses radiation, such as x-rays or gamma rays, to view the internal form of an object. This technique is used in both medical and industrial applications. In medical radiography, x-rays are used to produce images of the inside of the body to diagnose and monitor a wide assortment of medical conditions such as broken bones and diseased organs.

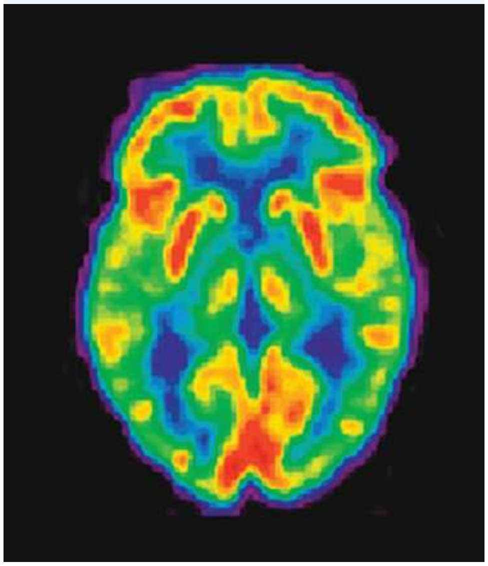
Radioactive substances can also be inserted into the body to detect or identify the cause of disease. The radiation produced by the substance while it is in the part of the body under investigation is measured to diagnose the problem (table 5.6).

TABLE 5.6 Some of the radioisotopes used in the treatment and diagnosis of disease

Radioisotope	Use	Half-life
Barium-137	Diagnosis of digestive illnesses	2.6 minutes
Iodine-123	Monitoring of thyroid and adrenal glands, and assessment of damage caused by strokes	13 hours
Thallium-201	Detection of damaged heart muscles	3 days
Iodine-131	Diagnosis and treatment of thyroid problems	8 days
Phosphorus-32	Treatment of leukaemia	14.3 days
Iron-59	Measurement of blood flow and volume	46 days
Cobalt-60	Used in radiotherapy for treating cancer	5 years

Some radioisotopes can be used to obtain images of parts of the body. The gamma rays emitted by these radioisotopes are used to produce the images. PET (positron emission tomography) scans use cameras surrounding the patient to detect gamma rays coming from radioisotopes injected into the body (figure 5.25).

FIGURE 5.25 A PET image of the human brain



The treatment of cancer

Radiotherapy is the use of radioisotopes or other radiation such as x-rays in medicine. Radioisotopes kill cancer cells or prevent them from multiplying. Cancer cells tend to multiply very quickly. Normal cells are also damaged by the radiation but tend not to be as badly affected. Radiation can be targeted at a small area so that the surrounding tissue is not damaged. Radiotherapy is often used along with other treatments such as surgery, drugs, and harnessing the immune system (immunotherapy) to cure cancer and other diseases.

FIGURE 5.26 A patient receiving external radiotherapy treatment

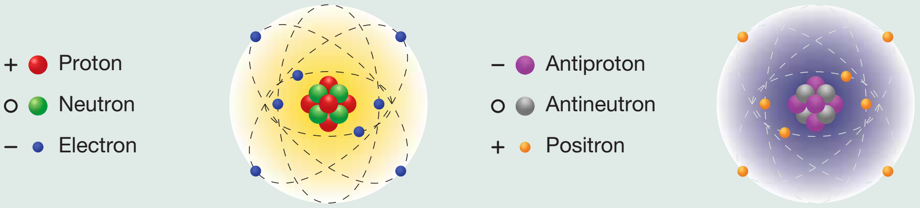
Radiation can be directed at the cancer by a machine like the one in figure 5.26. This method is known as **external radiotherapy**. The other method, known as **internal radiotherapy** or brachytherapy, involves placing radioisotopes inside the body at, or near, the site of the cancer. In some cases, both methods are used. The type of treatment depends on the type of cancer, its size and its location, as well as the general health of the patient.

EXTENSION: Matter and antimatter atoms

As you know, PET detects gamma radiation emitted from radioisotopes that have been inserted into the body. However, the radioisotopes used in PET scans first emit a **positron**, which is like an electron but with a positive charge. This is antimatter, which is like the matter that makes up our universe, but the protons and electrons have the opposite charge; that is, positrons are positively charged electrons and antiprotons are negatively charged protons.

Antimatter is very unstable as it is annihilated when it encounters its opposite matter particle, releasing gamma radiation. It is this gamma radiation that is detected in PET, when an emitted positron encounters an electron.

FIGURE 5.27 Atoms of matter and antimatter



INVESTIGATION 5.3

Radioactive decay

Aim

To investigate the decay of a radioisotope used as a medical treatment

Materials

- graph paper or a graphing program; for example, Microsoft Excel

Method

The half-life of the radioisotope iodine-131 is 8 days.

Calculate the mass of iodine-131 left after 8, 16, 24, 32, 40, 48, 56, 64, 72 and 80 days if 100 g is given to a patient to treat a thyroid problem.

Results

1. Present the results of your calculations in a table.
2. Choose an appropriate graph to show how the radioisotope decays. Represent time on the horizontal axis and the mass of the iodine-131 sample on the vertical axis.

Discussion

1. What fraction of the iodine-131 is left after:
   a. 8 days
   b. 16 days
   c. 24 days
   d. 80 days?
2. Why is it difficult to store radioisotopes with short half-lives?

Conclusion

Write a conclusion to this investigation as a response to the aim.

5.4.5 Radioisotopes in the aircraft and space industries

In industrial radiography, gamma rays are used to inspect the structure and components used in aircraft and spacecraft for defects. These forms of transport must be exceptionally strong to withstand extreme conditions of speed, pressure and temperature changes. To ensure that the materials used in construction are free from weaknesses, engineers use radioisotopes to screen for hidden cracks or faults.

Gamma radiography

Gamma radiography can see through metal parts without cutting them open, similar to when x-rays are taken of your body. When inspecting air or spacecraft, an engineer uses a radioisotope — like cobalt-60 or iridium-192 — that gives off gamma rays, a form of very high-energy radiation more powerful than x-rays. A radiography device containing the radioisotope is placed against one side of the aircraft or spacecraft, and a detector is placed on the other side. Cracks, weaknesses or other faults will affect the rays differently and will be shown on the detector. Engineers carefully study the image to look for any dark lines showing cracks, or for areas showing gaps or weak areas, and then the affected part can be fixed or replaced. Workers must take care to shield the gamma device when it is not in use to be safe from radiation exposure. Some of the benefits of using radioisotopes are they can check even thick parts without damaging them, they can detect invisible cracks and they are accurate. Also, the device is small, so it can fit in tight spaces. Both time and money are saved by finding problems quickly and easily and — importantly — safety is improved.

FIGURE 5.28 View of a linear crack in weld metal with radiograph film

EXTENSION: Consequences of working with radioactivity

Radioactivity was discovered by accident. French physicist Henri Becquerel discovered radioactivity while investigating the fluorescence of uranium salts in 1896. When he developed a photographic plate that had been left in a drawer near his benchtop, he found that it had been fogged up by radiation from the uranium salts.

This effect of radioactivity is now used in a protective device worn by people who work with radioactive materials. The ‘fogging’ of the film in this device measures the amount of radioactivity they have been exposed to.

Becquerel was the first scientist to report the effects of radioactivity on living tissue.

Our modern understanding of radiation has only been developed in about the last 130 years. Based on what you have learned so far, what do you expect were the consequences of working with radioisotopes for the early adopters in the following examples?

- Scientists such as Henri Becquerel who worked closely with uranium salts
- Watchmakers who painted the hands and numbers on watch faces with the luminescent radioisotope radium-226 (workers used to form ‘points’ on their brushes by licking the bristles)

FIGURE 5.29 This watch has been hand-painted in luminescent radium paint.

CASE STUDY: Radioisotopes and nuclear power

The radioactive properties of uranium are used in the generation of electricity in **nuclear reactors**. Australia is one of several countries that have large, high-grade deposits of uranium, which can be used in reactors.

The steps below describe the production of energy in a nuclear reactor.

1. Uranium is converted to uranium dioxide and then sealed in rods, called **fuel rods**.
2. The uranium undergoes a fission reaction in the reactor when neutrons are fired at the radioactive uranium at low speed (figure 5.30).
3. This causes the uranium nuclei to split and form two new elements, releasing neutrons, radiation and heat in the process.
4. This heat energy is used to heat water to produce steam, which is used to turn the turbines that generate the electricity (figure 5.31).

The process of steam-driven turbines to produce electricity is described in detail in topic 10.

FIGURE 5.30 An example of a nuclear fission reaction

Nuclear equation: $^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$

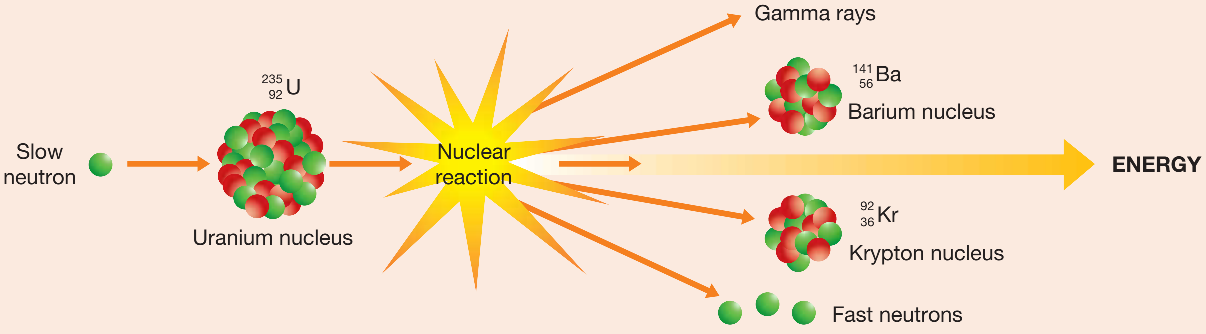
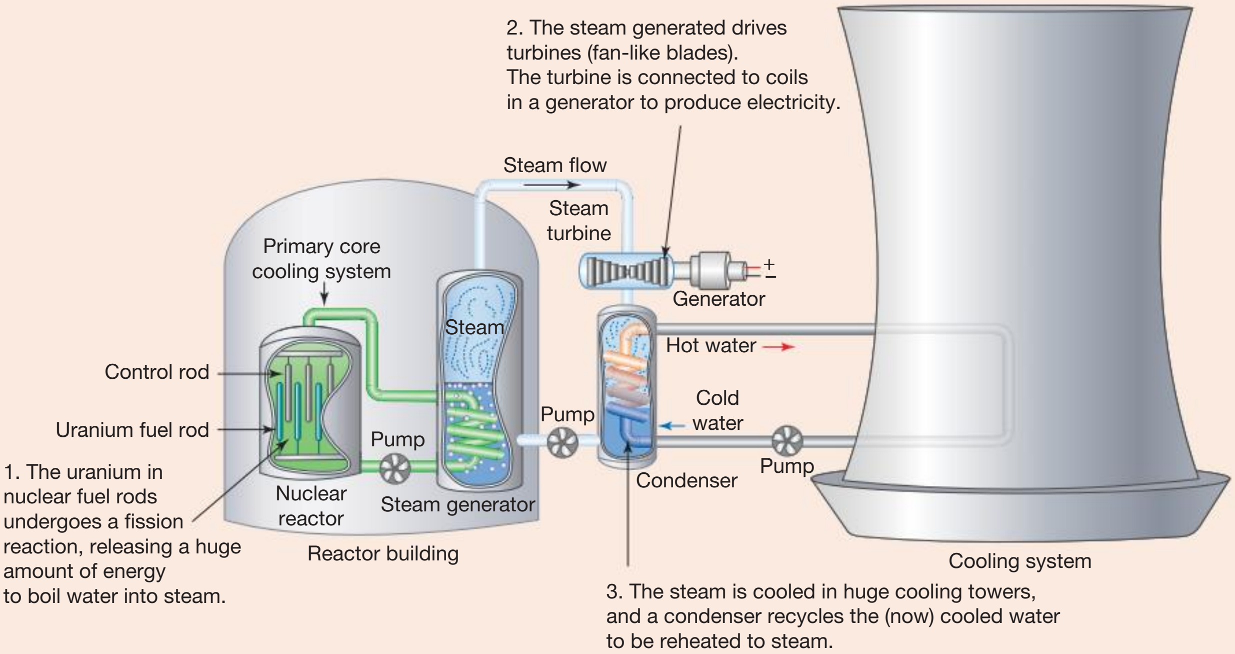


FIGURE 5.31 The heat from nuclear fission reactions boils water to produce steam, which drives a turbine to generate power.



Fast breeders

In some countries, fast breeder reactors use the artificial radioisotope plutonium-239 as a fuel. Plutonium-239 is made by bombarding uranium-238 with fast-moving neutrons (that's why the term 'fast breeder' is used). The plutonium-239 produced can also be used to produce nuclear weapons.

Nuclear waste

A big advantage of nuclear reactors over coal- and gas-fired power plants is that they do not generate large quantities of the greenhouse gas carbon dioxide. However, the used fuel rods in a nuclear reactor are radioactive and contain a mixture of radioisotopes.

Some of the waste radioisotopes have half-lives of only minutes, while others have half-lives of thousands of years. These waste products are currently sealed in steel containers or glass blocks, and stored in power stations or buried deep at sea or underground away from groundwater. However, there is still no permanent solution to the problem of disposing of nuclear waste.

It has been suggested that nuclear waste should be sent by rocket to the Sun or into outer space. However, the risk of a rocket carrying nuclear waste exploding before leaving the Earth's atmosphere makes that solution very risky.

FIGURE 5.32 A worker inspecting output at a nuclear power plant

DISCUSSION

The process of nuclear power generation discussed in the case study is very similar to coal- and gas-fired power plants, although different sources of heat are used to boil water. What are some of the advantages of nuclear reactors over power stations that use fossil fuels? Are you aware of any disadvantages associated with nuclear reactors? Taking both the advantages and disadvantages into consideration, should we replace ageing coal-fired power stations with nuclear reactors?

5.4.6 Advantages and disadvantages of radiation

While nuclear radiation has many uses that are beneficial to society as a whole, there is no doubt that it is very much a double-edged sword.

TABLE 5.7 Advantages and disadvantages of radioisotopes

Advantages of radioisotopes	Disadvantages of radioisotopes
Radiometric dating	Nuclear weapons
Medical treatment	Nuclear disasters at power plants
Medical diagnosis	Nuclear waste from industry and medicine
Power generation	Contamination of ecosystems
Food preservation	Radiation sickness
Smoke detectors	Chronic diseases; for example, cancer
Scientific research	Mutations and birth defects

Disasters at nuclear power plants and the events of World War II are large-scale reminders of the dangers of radioisotopes. While the devastating power of nuclear weapons are obvious, the effects of nuclear radiation on cells can be more insidious. Nuclear radiation damages the components of cells, particularly DNA, leading to many adverse health effects.

- Exposure can have immediate effects including nausea, headaches, vomiting and diarrhoea, collectively termed **radiation sickness**.
- Over longer time frames, exposure can lead to diseases such as cancer and immune system collapse later in life.
- **Mutations** in sperm and eggs can be passed from parents to children, leading to birth defects and other diseases.

Working with radioactive isotopes Safety is crucial to health when working with radioactive materials. Only trained personnel should handle radioactive materials. To prevent harmful effects on the body, workers observe three main precautions:

- Limit the time of exposure.
- Increase the distance from the radioactive source.
- Use shielding like lead barriers or safety screens to reduce radiation.

Remember that alpha particles can be stopped by paper, beta particles by plastic or thin metal, and gamma rays by dense materials like lead or concrete.

Radiation detectors assist in measuring radiation exposure to minimise risk.

EXTENSION: Deaths caused by radiation

Radiation has caused the death of some remarkable people.

- Alexander Litvinenko was a former Russian secret service officer who had fled to the United Kingdom. He unexpectedly fell ill in November 2006 and died in hospital only a few weeks later. It is alleged that he was poisoned with polonium-210 placed in a pot of tea.
- It is a sad irony that Marie Curie (the woman who developed the theory of radioactivity and discovered the radioactive elements radium and polonium) died of leukaemia at the age of 67. Her illness was almost certainly caused by her constant exposure to radioactivity.

FIGURE 5.33 Marie Curie

ACTIVITY: Research other applications of radioactivity in our world and prepare an infographic

Topics could include:

- the use of x-rays for detection of defects in metals and composite materials (e.g. in aeroplanes or other aircraft)
- the use of gamma rays to sterilise medical equipment
- how to preserve food using gamma radiation
- the use of soft x-rays to remove static electricity
- techniques for non-destructive testing of materials (e.g. radiographic testing and neutron radiographic testing).

5.4 Activities

learnon

5.4 Quick quiz on	5.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4	5, 7, 8, 9	10, 11, 12

Remember and understand

1. MC **Identify** the radioisotope of carbon that is used in carbon dating.
   A. Carbon-6
   B. Carbon-7
   C. Carbon-12
   D. Carbon-14
2. **Describe** three uses of radioactive elements.
3. a. **Explain** what radiotherapy is.
   b. **Explain** how it prevents the spread of cancer through the body.

4. **MC** **Identify** how radioisotopes used in food preservation stop food from spoiling.
   A. They increase the microbial-fighting properties of the food.
   B. They create a protective layer on the inside of the can.
   C. Microbes that cause food spoilage are killed by radiation.
   D. None of the above — radiation is dangerous to health
5. **MC** **Identify** what OSL stands for.
   A. Optimally stimulated light
   B. Optically stimulated luminescence
   C. Optimally stimulated luminescence
   D. Optically stimulated light

Apply and analyse

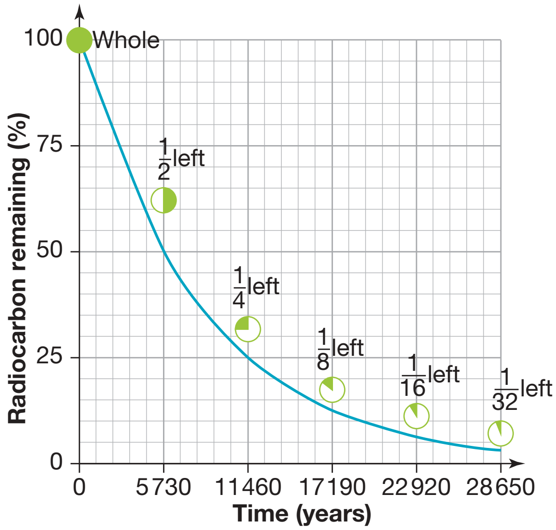
6. **MC** **Identify** what OSL measures.
   A. The age of fossils from more than 50 000 years ago
   B. The half-life of radioisotopes found underground
   C. Radiation absorbed by quartz minerals over time
   D. The time since mineral grains were last exposed to sunlight or heat
7. **Compare** the use of carbon-14 dating with using optically stimulated luminescence dating.
8. **Explain** whether carbon-14 dating can be used for fossils that are millions of years old.

Use table 5.6 to answer questions 9–11.

9. **State** whether iodine-131 is a more stable radioisotope than barium-137. **Justify** your answer.

Evaluate and create

10. The use of barium-137 in the diagnosis of digestive illnesses involves the patient drinking it in a syrup. **State** the property of barium-137 that makes its use quite safe.
11. **Identify** an isotope best suited to use in external radiotherapy. **Justify** your answer.
12. **SI** Use the graph shown to answer the following questions.



   a. Parts of the skeleton of a large animal are found buried in sand dunes. The amount of radioactive carbon-14 in the bones is about one-eighth of that found in the skeletons of living animals. **Identify** how long ago the animal probably died (to the nearest thousand years).
   b. **Identify** the approximate percentage of the original amount of radioactive carbon-14 you would expect to find in:
      i. a spear that is 11 000 years old
      ii. a skull that is 23 000 years old, found in a cave.

Answers and sample responses are available in your digital formats.

LESSON 5.5 Review

5.5 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
5.2	I can describe the masses and charges of protons, neutrons and electrons.			
5.3	I can explain how the discovery of these particles resulted from experimental evidence.			
	I can answer questions related to properties and behaviours of atoms.			
	I can explain what isotopes are and that some are unstable.			
	I can describe how different unstable isotopes decay to form stable atoms			
	I can define half-life and give examples.			
	I can interpret radioactive decay curves.			
5.4	I can describe the timescales of decay of different elements.			
	I can explain how radiocarbon and other dating methods have been used to establish that Aboriginal and Torres Strait Islander Peoples have been present on the Australian continent for at least 65 000 years.			
	I can describe where applications of radioactivity are used in medicine and industry.			

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Post-test Topic 5 Post-test

eWorkbook Topic 5 eWorkbook

Digital document Key terms glossary

5.5 Activities

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5.5 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 5, 6	4, 7, 9, 10, 12	8, 11, 13, 14

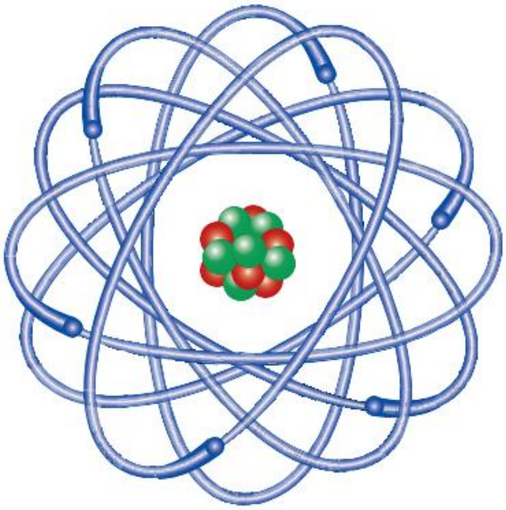
Remember and understand

1. **State** which of the particles in a neutral atom has:
   a. a negative electric charge
   b. a positive electric charge
   c. no electric charge
   d. the smallest mass.

2. **Describe** the contributions of the following scientists to our understanding of the structure of the atom.
   a. J.J. Thomson
   b. Lord Ernest Rutherford
   c. Niels Bohr
3. **State** which type of nuclear radiation travels at the speed of light.
4. The hydrogen atom exists as three different isotopes.
   a. **Describe** how the atoms of each isotope are different from the others.
   b. **Identify** two features of the hydrogen atom that are the same for each of the three isotopes.
5. **State** where most of the natural background radiation that we experience every day comes from.

Apply and analyse

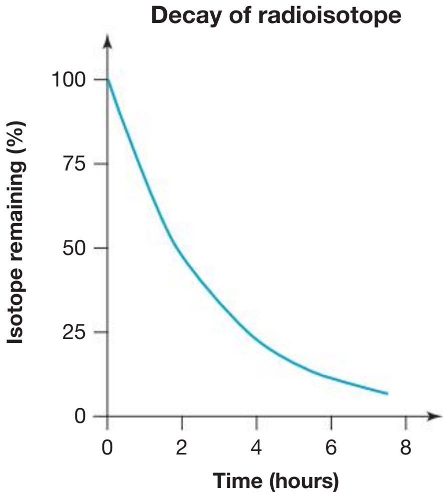
6. The diagram shown represents a model of a neutral atom.



   a. **State** which two particles make up the nucleus of the atom.
   b. **State** which particles are shown orbiting the nucleus in the atom.
   c. **Identify** which element this atom belongs to.
7. Alpha particles are helium nuclei containing two protons and two neutrons.
   a. **Identify** the electric charge of an alpha particle.
   b. **Describe** how the mass of an alpha particle compares with the mass of a beta particle.
   c. **Suggest** why alpha particles are easily stopped by human skin while beta particles are not.
   d. **Identify** the type of radiation from the nucleus that is more penetrating than either alpha or beta particles.
8. Radioisotopes have many uses.
   a. **Identify** the property of radioisotopes that makes them useful.
   b. **Describe** three of the beneficial uses of radioisotopes.
   c. Some radioisotopes are considered highly dangerous even after thousands of years. **Explain** why.
9. **Describe** two ways workers can protect themselves when working with radioactive substances.
10. **Identify** why samples for OSL are not exposed to light.
   a. Light changes the chemical structure of the minerals.
   b. Light can destroy the mineral grains.
   c. Light can reset the radiation signal.
   d. Light can cause the minerals to break down.
11. Two isotopes of the element carbon found naturally on Earth are carbon-12 and carbon-14.
   a. **Explain** how every atom of carbon-14 is different from every atom of carbon-12.
   b. **Identify** the features and properties that carbon-14 and carbon-12 have in common.
   c. **Identify** which of the two carbon isotopes is stable.
12. The half-life of strontium-90 is 28 years. If a 400 g sample of strontium-90 was left to decay, **calculate** how many grams of strontium-90 would be left in the sample after:
   a. 28 years
   b. 56 years
   c. 84 years.

Evaluate and create

13. **Identify** the half-life of the isotope whose decay is shown in the following graph.



14. SI **Explain** how it is possible to use carbon-14 to estimate the age of the remains of a dead plant embedded in a rock.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

6 Modelling chemical reactions

CONTENT DESCRIPTION

Chemical reactions are described by the Law of Conservation of Mass and involve the rearrangement of atoms; they can be modelled using a range of representations, including word and simple balanced equations (VC2S10U08)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 6.1 Overview

6.1.1 Introduction

Every single living thing on Earth depends on chemical reactions — from the largest mammal, the blue whale, right down to the smallest insects and microorganisms. One such reaction is the **respiration** (also called cellular respiration) that occurs in the cells of all plants and animals. Respiration transforms oxygen and the sugars in food into carbon dioxide, water and the energy all living things need to survive. In plants, another critical chemical reaction occurs — **photosynthesis**. This reaction is the reverse of respiration; carbon dioxide and water are converted into oxygen and a sugar called glucose. These are just two of the many thousands of chemical reactions that occur in plants and animals. Other reactions produce proteins, starches and various oils and fats.

FIGURE 6.1 Sometimes it is easy to know if a chemical reaction is taking place.

In this topic, we will investigate chemical reactions. We will learn how to recognise when a chemical reaction has taken place, and how the atoms in the reactants rearrange to form the products of the reaction. We will therefore also learn that matter is neither created nor destroyed during a chemical reaction.

There are many types of chemical reactions, and they are used in all aspects of our lives. We will look at reactions, learning many ways to represent what is happening during these reactions. The periodic table has more than 100 elements, but very few are found naturally. What is special about these, and why is it that the rest are only found in combined forms? While reactions can produce essential or desirable products, sometimes the by-products have side effects and damage the environment. Understanding the chemistry allows for processes to be changed to reduce energy output or develop more environmentally friendly options.

DISCUSSION

1. What happens to atoms in a chemical reaction?
2. What is the difference between an element and a compound?
3. How can you tell what has happened in a reaction?
4. Are all chemical reactions useful?
5. Why are so few elements found in their natural state?
6. How can we reduce the damage to the environment due to some chemicals?
7. Name some places where chemical reactions occur.

SCIENCE INQUIRY: Modelling chemistry

Creating models of chemical reactions helps us to understand what is happening in these reactions. It helps to show that matter is neither created nor destroyed in a reaction. The models help chemists to explain their observations. Answer the following questions to find out what you already know about these reactions.

1. a. What chemicals are used in your house to clean things like surfaces and your clothes, and how should these be stored safely?
   b. Describe a chemical reaction that occurs in the home.
   c. What chemical reactions occur in your body?
2. You may have heard about green chemistry.
   a. Describe a chemical reaction that is hazardous.
   b. How can understanding reactions help us find solutions to environmental problems?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

INVESTIGATION 6.1

Cleaning up with baking soda and vinegar

Aim

To observe the chemical reaction between baking soda and vinegar and to investigate the cleaning properties of the reaction

Materials

- 100 mL white vinegar
- 1 tablespoon of baking soda or baking powder
- rubber gloves
- a small cleaning brush or scourer
- a dirty vessel such as a beaker or cup
- access to a basin or sink

Method

1. Place the dirty vessel in the sink or basin.
2. Add 100 mL of vinegar to the vessel.
3. Carefully add the baking soda or baking powder to the vinegar.
4. Use the brush or scourer to clean the vessel.
5. Rinse the vessel with water.

Results

What did you observe when you added the baking soda (or powder) to the vinegar in the dirty vessel?

Discussion

1. Describe the reaction when the baking soda or powder was added to the vinegar.
2. Suggest what you think caused this reaction.
3. Describe the cleaning effect of the reaction.

Conclusion

What can you conclude about the cleaning properties of the reaction between baking soda and vinegar?

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Pre-test	Topic 6 Pre-test
eWorkbook	Topic 6 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 6 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 6.2 Rearranging atoms and molecules

LEARNING INTENTION

In this lesson you will:
- identify the reactants and products in chemical reactions
- use models and representations to show the rearrangement of atoms in chemical reactions.

6.2.1 Chemical reaction

A cake rising in an oven, a bath bomb fizzing in a full bathtub and an old car getting rusty — what do they have in common? They are all evidence of chemical reactions.

KEY IDEA

Chemical reactions take place when the bonds between atoms are broken and new bonds are formed, creating a new arrangement of atoms and at least one new substance. As the new substance is formed, observable changes take place — a change in temperature or colour, the formation of a visible gas or new solid, or perhaps even just an odour.

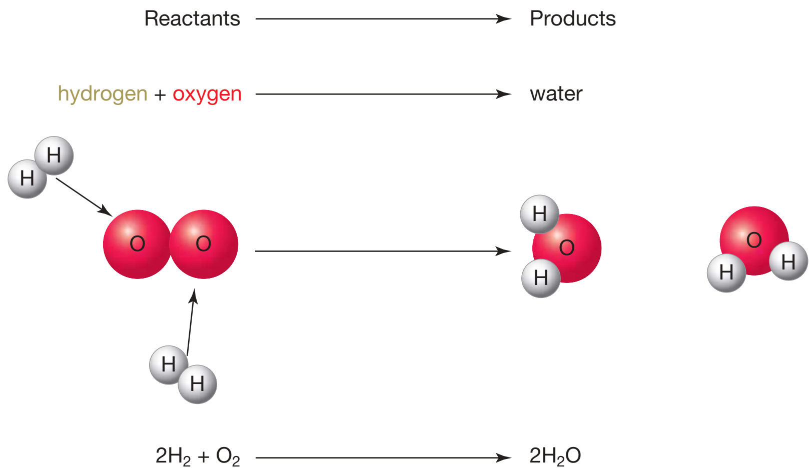
6.2.2 Reactants and products

The new substances that are formed during a chemical reaction are called the **products**. The original substances are called the **reactants**.

For example, when hydrogen gas is added to oxygen gas and ignited, the new substance water is formed. The reactants are hydrogen and oxygen. The product is water. The bonds between the hydrogen atoms and oxygen atoms are broken, and new bonds are formed between oxygen and hydrogen, as shown in figure 6.2.

Notice that the hydrogen and oxygen atoms that were present in the reactants are also present in the product. There is no gain or loss of atoms. They have been rearranged to form new products. Recall that **molecules** can be made up of all the same atoms, as in hydrogen gas and oxygen gas, or as a combination of different atoms, as in water.

FIGURE 6.2 The reaction between the reactants hydrogen and oxygen to create the product water

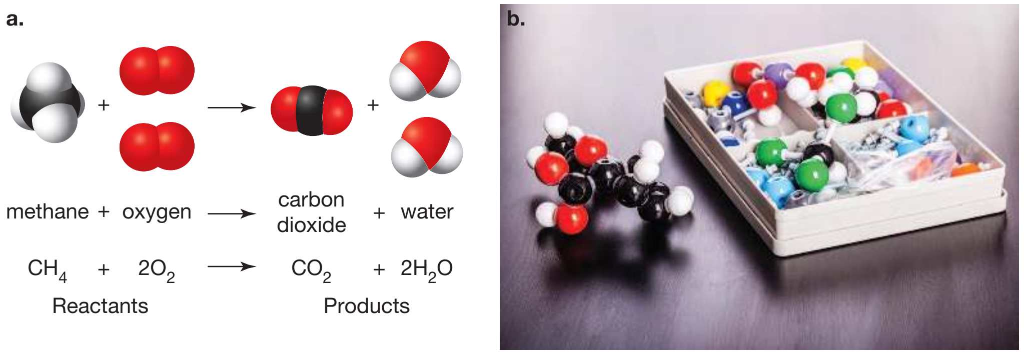


6.2.3 Representing chemical reactions

Creating a model of a chemical reaction helps us understand what happens in the chemical reaction. There are many types of ways to represent chemical **equations** and models. Simple particle models use coloured spheres or circles to show the atoms of the reactants combining or rearranging to form the final product. For instance, in figure 6.3a, carbon atoms are represented as dark grey spheres, oxygen atoms as red spheres and hydrogen atoms as white spheres. This is a common convention, also used with molecular model sets (see figure 6.3b).

Models are helpful to understand the different types of reactions.

FIGURE 6.3 a. A simple representation of a chemical reaction **b.** A molecular model set



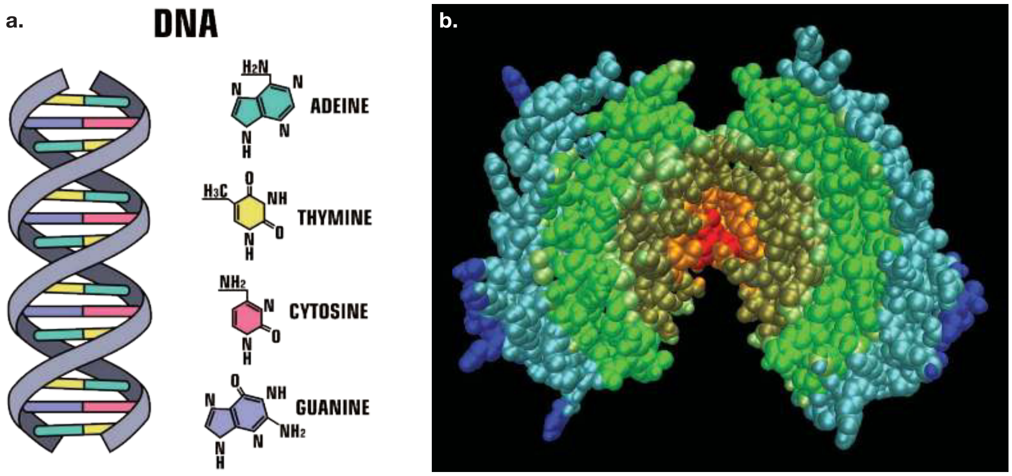
Another common type of model is the 'ball and stick' model. This uses the same colour conventions as shown in figure 6.3a, but the atoms are joined by sticks or straws. The sticks represent the bonds between the atoms. These models are better at showing how atoms are arranged geometrically as well as having other more advanced features. Figure 6.4 shows a ball-and-stick model for methane.

FIGURE 6.4 A ball-and-stick model for methane

Models can help us visualise the reactions by showing how the reactants have changed, to help understand how properties have changed. These models can show the difference between ions, atoms and molecules. One of the most famous chemical models is that of DNA (deoxyribonucleic acid). The understanding of the structure (see figure 6.5a) and function of this molecule is fundamental in fields such as biology, medicine, archaeology and forensics.

Complicated chemical models, such as prions (a type of protein), viruses or drugs (see figure 6.5b) are now produced by computers.

FIGURE 6.5 a. Model of the double helix of a DNA molecule on the left, with the four building blocks that make up the molecule on the right **b.** A digital model of human interferon beta, a drug used to treat multiple sclerosis



ACTIVITY: Making models

Use a molecular modelling kit or some plasticine and toothpicks to make a model of the reaction between hydrogen and oxygen. If you are using a modelling kit, you will need four white atoms to model the hydrogen atoms, and to join them together in two lots of two. You will also need two red oxygen atoms joined together. Now rearrange the atoms to form two molecules of water as in figure 6.2.

SCIENCE INQUIRY: Making use of models

Molecular models can be very useful in modelling molecular shapes in three dimensions. Sometimes there are very subtle differences between molecules that otherwise look identical. These subtle differences are often very important in biology, where they can make a huge difference in how a molecule reacts chemically in an organism.

A very famous example of this is the drug thalidomide.

Research the history of this drug. Use the following questions to guide you.

1. What was thalidomide used for?
2. What unwanted effects did it have?
3. What caused problems with this drug?
4. Is it still used today?

Now try the following to see how subtle these differences can be.

5. Use the same materials as in the previous activity. Construct a shape the same as in figure 6.4. However, use five different colours so that the central atom and the four outside ones are all different colours.
6. Now get a mirror and look at the reflection of the model you have made.
7. Make a second model according to the reflection you see. Once the second model is complete, flip it or spin it. Can you make the two models fit over each other exactly?

What you have made are two molecules that look very alike. However, they are slightly different. Differences such as this are very hard to distinguish without molecular models.

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

KEY IDEA

Models are useful ways of representing chemical reactions. Common models are plastic spheres, ball-and-stick models and computer-generated images.

EXTENSION: Optical isomers — same but different

Optical isomers are molecules that are mirror images of each other. If the central atom has four different atoms attached to it, then its mirror image will be subtly different. This situation was what you saw in the previous science inquiry task.

Where optical isomers exist, only one will usually be able to be processed in the body. The other one will not react at all. This is because nearly all the reactions in the body require catalysts called enzymes. Enzymes usually work with only one optical isomer and not the other.

The side effects of thalidomide explored in the previous task were due to both optical isomers being present in the early forms of the drug. One of these optical isomers was found to be the cause of the serious birth defects, while the other form was harmless.

6.2.4 Word equations

Word equations are also used to represent a chemical reaction. The names of the substances involved are used but the chemical formulas and symbols are not used. In a chemical reaction, the reactants are the substances that react together to form or to produce the products.

$$\text{reactants} \longrightarrow \text{products}$$

The reactants are on the left-hand side of the arrow, while the products are on the right-hand side of the arrow. The + sign separates each reactant or product, and the arrow means 'react to make'.

A word equation describes the reaction. For instance, the chemical reaction in which oxygen and hydrogen react together to form water is described by the following word equation:

$$\text{oxygen} + \text{hydrogen} \longrightarrow \text{water}$$

6.2.5 Chemical formulas and equations

In order to communicate with each other easily about chemical reactions, scientists all over the world need to use the same language. The language used by scientists in chemistry involves chemical symbols, formulas and equations.

Word equations provide a simple way to describe chemical reactions by stating the reactants and products. Chemical equations that use formulas provide more information. They show how the atoms in the reactants combine to form the products.

KEY IDEA

Word equations and chemical equations are useful ways of summarising a chemical reaction. Reactants are always shown to the left of the arrow and products are always on the right.

Writing chemical equations involves some simple mathematics and a knowledge of chemical formulas. Chemical formulas are a quick way to represent the reactants and the products, showing the elements present and how many of each atom are used to make it.

ACTIVITY: PhET simulation

Access the **PhET simulation: Build a molecule** interactivity in the Resources panel to build 3D models of methane (CH_4), ammonia (NH_3) and water (H_2O).

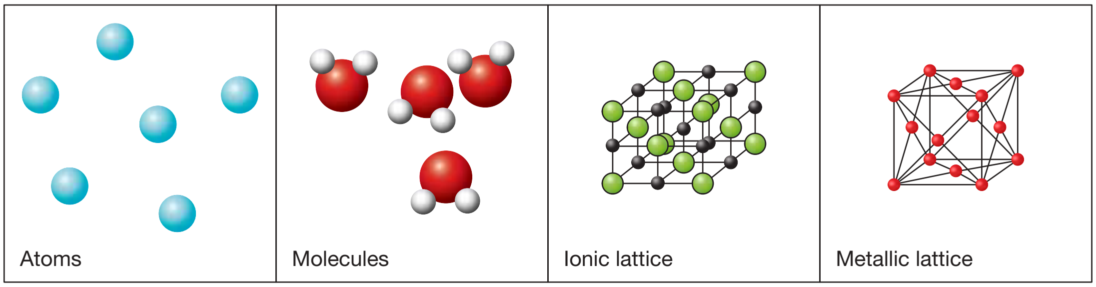
Many non-metal elements, such as carbon (C), hydrogen (H) and oxygen (O), can bond with other non-metals to make molecules. For example, methane has a formula of CH_4, which indicates that the molecule is made of one carbon atom bonded to four hydrogen atoms.

Noble gases are the only elements that exist as single, separate atoms. He, Ne and Ar are examples of these gases. All other elements that exist as gases, such as oxygen or chlorine, exist as **diatomic molecules** and therefore are shown as O_2 or Cl_2 in the chemical reactions, never just O or Cl.

Ionic substances are made of metal and non-metal atoms and form giant lattices rather than separate molecules, so their formula shows the ratio of the different types of atoms. For example, sodium chloride (known as table salt) has a formula of NaCl, which indicates that for every one atom of Na there is one atom of Cl.

Metals also exist in a lattice and are written with only their elemental symbol (e.g. Al, Na, Mg) since they do not form molecules and there is only one type of atom present.

FIGURE 6.6 The various ways that atoms can be organised



Chemical equations are set out in the same way as word equations, with the reactants to the left of the arrow and products to the right. However, they are different from word equations in three ways:

- Chemical formulas are used to represent the chemicals involved.
- The physical states of the chemicals are often included: (g) for gas, (l) for pure liquid, (aq) for an **aqueous solution** and (s) for solid.
- Numbers are written in front of the formulas in order to balance the numbers of atoms on each side of the equation exactly.

When sodium metal reacts with chlorine gas, they form a new substance called sodium chloride. In simple terms, two atoms of solid sodium metal combine with one molecule of chlorine gas to create two units of solid sodium chloride. The chemical formula for this reaction is:

$$2Na(s) + Cl_2(g) \longrightarrow 2NaCl(s)$$

This shows that two sodium (Na) atoms react with one chlorine (Cl_2) molecule to form two sodium chloride (NaCl) units.

Some common formulas for different compounds are listed in tables 6.1 and 6.2.

TABLE 6.1 The formulas of some common ionic compounds

Compound	Formula
Sodium hydroxide	NaOH
Sodium chloride	NaCl
Sodium sulfate	Na_2SO_4
Sodium citrate	$C_6H_5O_7Na_3$
Sodium hydrogen carbonate	$NaHCO_3$
Copper(II) hydroxide	$Cu(OH)_2$
Copper(II) sulfate	$CuSO_4$
Magnesium chloride	$MgCl_2$
Mercury(II) oxide	HgO

TABLE 6.2 The formulas of some common covalent compounds

Compound	Formula
Water	H_2O
Citric acid	$C_6H_8O_7$
Carbon dioxide	CO_2
Oxygen	O_2
Hydrochloric acid	HCl
Carbon monoxide	CO
Hydrogen	H_2
Methane	CH_4
Ammonia	NH_3

6.2 Activities

learnon

6.2 Quick quiz on | **6.2 Exercise**

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 6	4, 7	3, 5, 8

Remember and understand

1. **Identify** the missing words to complete the sentence.
   In a chemical reaction the chemicals that react are called ____________ and the chemicals that are formed are called ____________.
2. MC Consider the following four statements about word equations.
   I. Reactants are shown on the left of the arrow.
   II. Products are shown on the left of the arrow.
   III. Reactants are shown on the right of the arrow.
   IV. Products are shown on the right of the arrow.
   Identify which pair of statements are correct.
   A. I and IV
   B. II and III
   C. I and III
   D. II and IV
3. MC The formula of a substance can often be written in an alternative way. For example, an alcohol called propanol is often written as CH_3CH_2OH.
   Identify which of the following would also be a correct formula.
   A. CHO
   B. C_3H_6O
   C. $C_3H_6O_2$
   D. C_2H_3O

Apply and analyse

4. Is the following statement true or false? **Justify** your response.
Atoms in substances are rearranged after chemical reactions.

5. A student was modelling a chemical reaction using plastic balls of different colours. He found that nine balls in total were required to model the reactants. **Explain** how many balls would be required to model the products.

6. **Identify** which of the metals on the left matches each of the chemical symbols on the right.

Different metals and their chemical symbols

Metal	Symbol
a. Sodium	**1.** Cu
b. Mercury	**2.** Na
c. Magnesium	**3.** Mg
d. Copper	**4.** Hg

Evaluate and create

7. Write a word equation for the reaction that occurs when you eat a sherbet lolly. These sweets commonly contain citric acid, $C_6H_8O_7(aq)$, and sodium hydrogen carbonate, $NaHCO_3(aq)$. In the mouth, these chemicals dissolve in your saliva and react together to form sodium citrate solution, carbon dioxide gas and water.

8. Write a word equation, and show the rearrangement of atoms by drawing a simple model with spheres, for each of the following.
- **a.** When carbon monoxide gas and oxygen gas react to form carbon dioxide gas
- **b.** When sodium hydroxide solution and hydrochloric acid solution react to form sodium chloride solution and water

Answers and sample responses are available in your digital formats.

LESSON 6.3 The Law of Conservation of Mass

LEARNING INTENTION

In this lesson you will:
- describe the Law of Conservation of Mass
- relate data obtained from open and closed systems to the Law of Conservation of Mass.

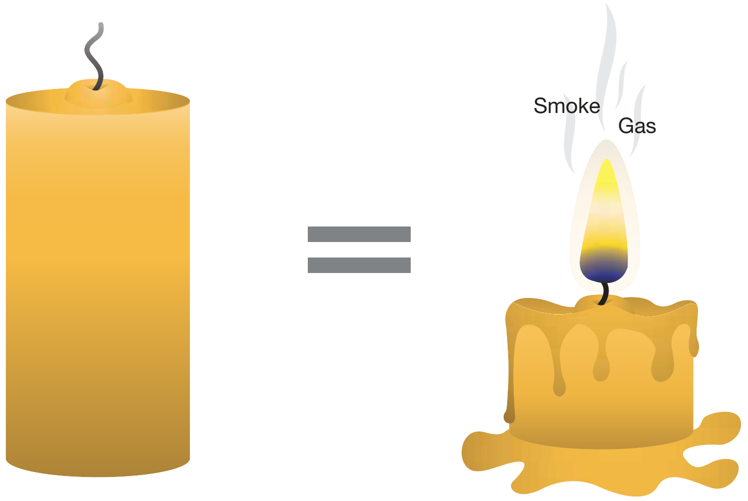
The idea of atoms rearranging themselves may seem obvious now, but two hundred years ago it was not. It was thought, for example, that when a candle burned, the wax simply vanished. In other words, it was thought that matter could disappear.

6.3.1 Conservation of mass

In the eighteenth century, French nobleman Antoine-Laurent de Lavoisier showed that although a candle seems to disappear as it burns, there is as much mass present after it has completely burned as there was before. The apparent loss of mass is caused by gases escaping into the atmosphere.

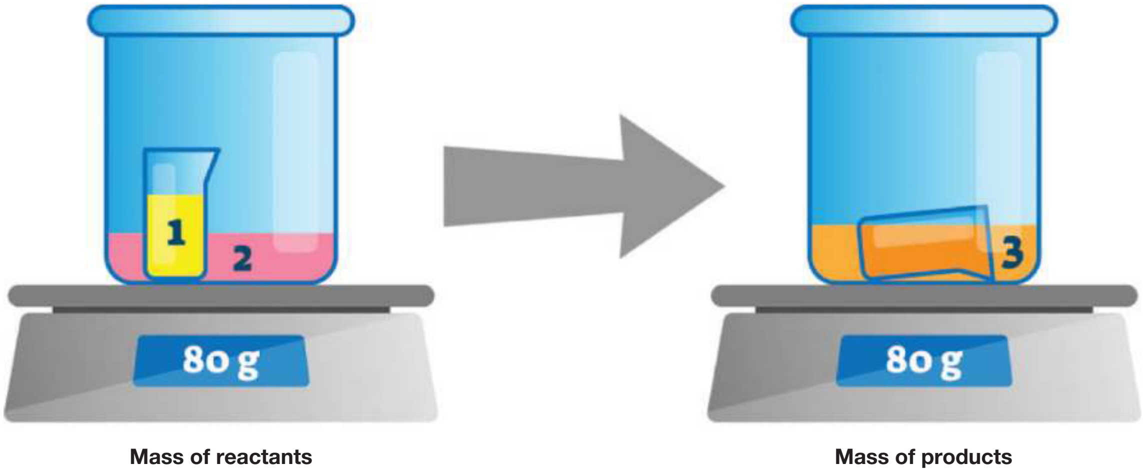
Lavoisier's ideas led to the development of the **Law of Conservation of Mass**, which states that matter can be neither created nor destroyed during a chemical reaction. Figures 6.7 and 6.8 are simple representations of this law.

FIGURE 6.7 The conservation of mass



During ordinary chemical reactions or physical changes:
- the mass of the products equals the mass of the reactants
- no matter is lost or gained.

FIGURE 6.8 The mass of the reactants is the same as the mass of the products.



EXTENSION: The Law of Constant Proportions

Lavoisier also provided evidence for the Law of Constant Proportions, which states that a compound, no matter how it is formed, always contains the same relative amounts of each element. For example, carbon dioxide (CO_2) always contains the same relative amounts of carbon and oxygen (about 27 per cent of the mass is made up of carbon). It does not matter whether the carbon dioxide forms from the reaction of sherbet in your mouth or from the reaction in the engine of a car — this proportion is fixed because every molecule of CO_2 is formed by the bonding of one carbon atom with two oxygen atoms. This law helped to shape our understanding of the way atoms bond together. In fact, after his unfortunate execution during the French Revolution, Lavoisier became known as the Father of Modern Chemistry.

SAMPLE PROBLEM 1 Determining the mass

A student performed a chemical reaction in which 6 g of hydrogen and 48 g of oxygen reacted to form water. What mass of product was formed?

THINK	WRITE
1. The Law of Conservation of Mass states that the total mass of reactants must equal the total mass of products.	
2. Calculate the total mass of reactants.	Reactants = 6 + 48 = 54 g
3. The mass of products must be the same.	Mass of products = 54 g

PRACTICE PROBLEM 1

A student combined 6 g of carbon and 16 g of oxygen to produce carbon dioxide. What mass of product was formed?

6.3.2 Open and closed systems

In chemistry, a *system* can be thought of as the reaction that is under study. Everything else outside this is called the surroundings or the environment. Such systems are commonly classified in one of two ways:

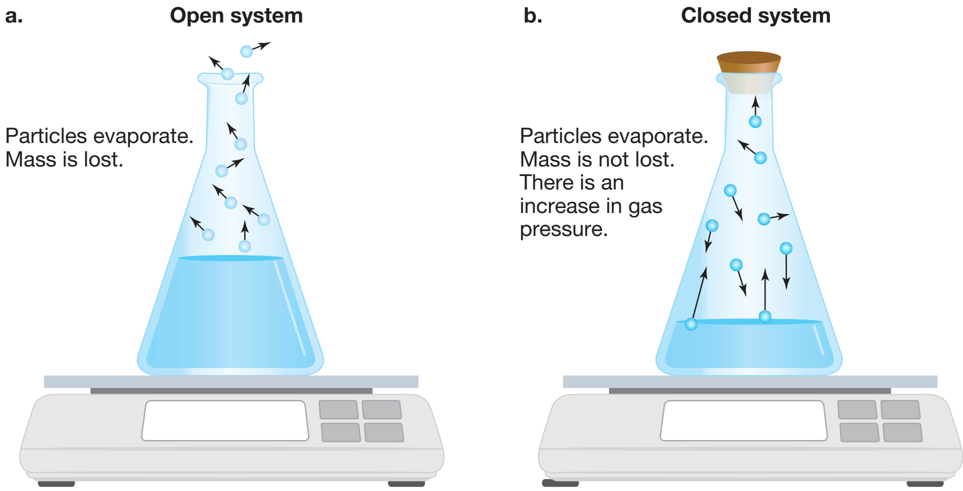
- A **closed system**, which does not allow the transfer of matter, to or from its surroundings
- An **open system**, which allows matter to transfer to or from its surroundings

Whether a system is open or closed can influence the *apparent* loss of mass in some reactions, including some that are familiar from everyday life. The evaporation of liquids is a good example of this.

Evaporation is a result of some molecules having enough kinetic energy to 'break free' from the liquid and escape into the gas phase above the surface. Such molecules can then move away and leave the flask as there is nothing to constrain them. This is an example of an open system, where the Law of Conservation of Mass *seems* to not hold true.

If a stopper is placed in the flask, a different result occurs. This time there is no loss in mass as the molecules cannot escape the flask, even if they rise above the surface in a gaseous state. This is an example of a closed system, where the Law of Conservation of Mass can be observed.

FIGURE 6.9 The resulting mass may be affected by whether it is an **a.** open system or a **b.** closed system.



KEY IDEAS

- An open system allows matter to be transferred between itself and its surroundings.
- A closed system does not allow the transfer of mass between itself and its surroundings.

INVESTIGATION 6.2

Conserving mass

Aim

To compare the mass of the products of a chemical reaction with the mass of its reactants

CAUTION: Wear safety glasses.

Materials

- safety glasses
- 250 mL conical flask
- 4 antacid tablets
- 1 balloon
- matches
- an electronic balance
- 100 mL measuring cylinder
- water

Method

Part A

1. Place the conical flask on the balance and pour in 100 mL of water.
2. Place two antacid tablets alongside the conical flask and record the total mass.
3. Remove the flask from the balance and drop the tablets into the water.
4. When the reaction is complete, weigh the flask and record the mass.

Part B

5. Rinse out the flask thoroughly and again add 100 mL of water.
6. Place two antacid tablets inside the balloon. You may need to break the tablets into pieces to do this.
7. Stretch the neck of the balloon over the conical flask, being careful not to drop the tablets into the water. The balloon should be flopped over, resting against the side of the flask.
8. Place the conical flask and balloon onto the balance and record the total mass.
9. Lift up the top of the balloon and drop the tablets into the water in the conical flask.
10. When the reaction is complete, weigh the flask and record the mass. Do not remove the balloon.
11. After you have recorded the mass, remove the balloon. Light a match and test the gas in the conical flask. Record your observations

Results

1. Copy and complete the tables shown. Remember to include titles for your tables.

Part A

Items weighed	Mass (g)
Mass of conical flask and 100 mL water	
Mass of conical flask, 100 mL water and two antacid tablets before reaction	
Mass of conical flask, 100 mL water and two antacid tablets after reaction	

Part B

Items weighed	Mass (g)
Mass of conical flask, 100 mL water, balloon and two antacid tablets before reaction	
Mass of conical flask, 100 mL water, balloon and two antacid tablets after reaction	

2. Describe what you observed in the gas test with the lit match.

Discussion

1. Which gas do you think filled the balloon and the conical flask?
2. Comment on your results of the total mass before and after each reaction. Explain your answer.
3. Antacid tablets can be taken to relieve indigestion. Why do we sometimes burp after taking antacid tablets?
4. Suggest why it took a long time for the Law of Conservation of Mass to be developed.
5. What improvements would you propose to this experiment?

Conclusion

Write a conclusion outlining your findings when you compared the mass of the products with the mass of the reactants in the reaction.

6.3.3 Examples of open and closed systems

Whether or not a system is open or closed depends on how you define and look at it. In science, the same system might be looked at in different ways — it could be an open system in one context but a closed one in another. In many situations, however, the answer is obvious.

Examples of closed systems that you might be familiar with include the following:

- *Batteries.* A battery produces electricity through its special design and the chemical reactions taking place inside it. Reactants are converted into products, but no matter enters or leaves once it is sealed during manufacture. A flat battery will weigh the same as a fresh battery.
- *Glow sticks.* Glow sticks are thin, plastic tubes containing sealed chemicals that are kept apart until required (see figure 6.10). When the stick is bent, the seals are broken and the chemicals mix, causing the stick to glow. Once again, there is no change in mass as the reaction proceeds.
- *Instant ice packs.* Within these packs are a plastic bag containing ammonium nitrate or ammonium chloride crystals and an inner bag of water. When the pack is squeezed, the inner bag breaks and the crystals dissolve in the water, producing the cooling effect.

FIGURE 6.10 Glow sticks are an example of a closed system.

Each of these examples illustrates the Law of Conservation of Mass. The mass of the system before reaction (consisting of reactants) will be the same as the mass of the system after reaction (consisting of products).

Open systems are more common. Our bodies are good examples of this. We take in food and oxygen, and many chemical reactions take place. While we retain many of the products of these reactions, we produce carbon dioxide and other waste materials that we need to get rid of.

Every industrial process operates as an open system. Raw materials are the inputs (or reactants) and the products are removed.

EXTENSION: Earth — a giant closed system (nearly)

FIGURE 6.11 Earth as seen from the Moon. Earth is very close to being a closed system.

Our planet is very close to being a large closed system. Apart from the odd meteorite, some moon rocks and cosmic dust, nothing is added to it. In the same way, virtually nothing is removed from it. This means that out of the trillions of chemical reactions that are taking place, the products are being kept within the system. An exception to this is helium, most of which is trapped underground. However, once it reaches the surface, it readily escapes into space.

Most of these reactions that occur on Earth are considered individually as open systems, but on a global scale they are part of a closed system. A good example of this is the carbon cycle. There is just as much carbon on Earth as there ever was. The big difference is that a lot of it used to be locked away in fossil fuels beneath the ground. A significant portion of this carbon has now been added to the atmosphere (as carbon dioxide). The problem of climate change is therefore not a matter of too much carbon — it is a problem of its distribution.

Can you think of any examples where matter has been added to the Earth system? Can you think of any examples where matter has been removed from the Earth system?

6.3 Activities

learnon

6.3 Quick quiz on	6.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 7	3, 5, 8	4, 6, 9

Remember and understand

1. **Identify** the second product produced by the following chemical reaction.

   sodium sulfate + barium chloride ⟶ barium sulfate + ____________

2. **Identify** what the Law of Conservation of Mass states.
3. **Identify** the missing word to complete the sentence.
   The Law of Constant Proportions states that a compound, no matter how it forms, always contains the ____________ amounts of each element; atoms in compounds always combine in whole-number ratios.

Apply and analyse

4. SI A piece of paper is weighed on an accurate balance and then burned, leaving a pile of ashes. The ashes are collected and weighed on the same balance.
   a. **State** whether you would expect the mass of the ashes to be the same as the mass of the paper before it was burned.
   b. **Justify** your answer to part **a** in terms of the products produced.
5. SI **Explain** why, when a piece of steel wool burns, the mass of the blackened material is greater than the original mass of the steel wool.

6. A student performed four experiments in four separate test tubes. For each experiment, she first measured the mass of each reactant, then the mass left in each test tube after the reaction was completed. Her results are shown in the following table.

Experimental results

Test tube number	Mass of each reactant (g)	Mass of product left in test tube (g)
1	12,3, 14.2	26.5
2	35.9	22.3
3	17.6, 8.2	29.1
4	19.8, 13.1, 10.5	43.4

Identify which test tubes were open systems and which ones were closed systems.

Evaluate and create

7. SI Read through Investigation 6.2 (you may have already conducted this investigation). **Predict** the results of the experiment when the balloon is left off the conical flask in Part A of the experiment.
8. The water cycle on Earth is an example of a closed system. Recently installed technology on the International Space Station (ISS) has now resulted in a 98 per cent water recovery rate, making the ISS's water cycle very close to being a closed one as well. **Explain** how you think water is recycled on the ISS, including why you think it is important for the ISS's water cycle to be as close to a closed system as possible.
9. Think about the work of Antoine-Laurent de Lavoisier. **Discuss** why you think his contributions to science were important, and what might have led to his execution during the French Revolution.

Answers and sample responses are available in your digital formats.

LESSON 6.4 Balancing chemical equations

LEARNING INTENTION

In this lesson you will:
- balance symbol equations
- explain the rationale for balancing chemical equations with reference to the Law of Conservation of Mass.

6.4.1 Balancing the scales

The reaction represented in figure 6.3a is the combustion of methane. This is also shown on the left of figure 6.12, in which methane reacts with oxygen to form water and carbon dioxide. Notice that one molecule of methane, CH_4, consists of one carbon atom joined to four hydrogen atoms, and oxygen is a diatomic molecule containing two atoms of oxygen. The product carbon dioxide has one carbon atom and two oxygen atoms. The other product is water, which has one oxygen atom and two hydrogen atoms.

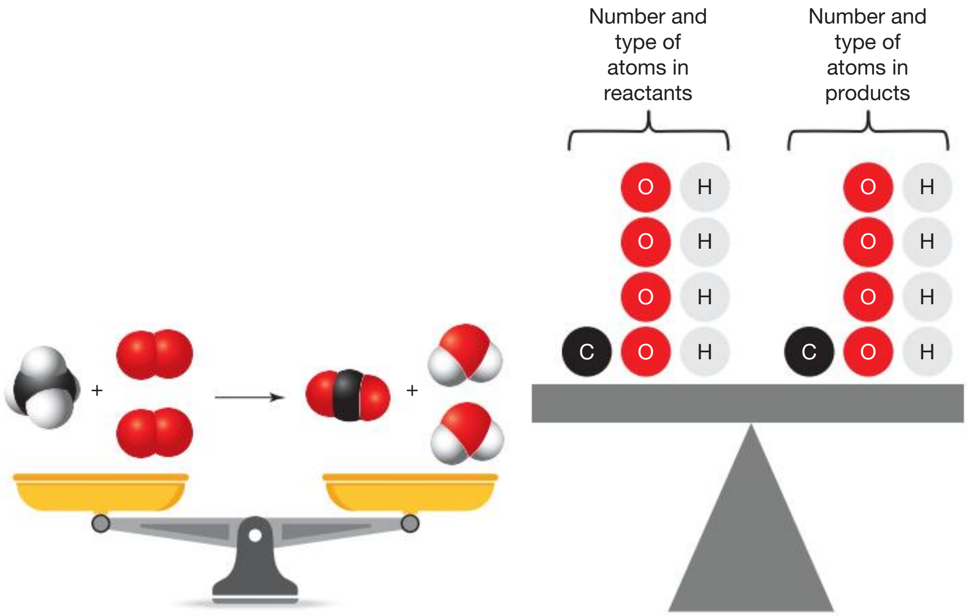
If we remember that a chemical reaction just involves the rearranging of atoms that are present, this reaction can be understood as follows:

- One methane molecule (CH_4) supplies the carbon atom needed to make one molecule of CO_2. One oxygen molecule (O_2) supplies the two oxygen atoms that are also required.
- There are now four 'leftover' hydrogen atoms from the methane. If another oxygen molecule is supplied, there will now be enough atoms (four of hydrogen and two of oxygen) to make two molecules of water (H_2O).

By counting the number of each type of atom in the reactants and in the products, you can see that nothing is created or destroyed.

Conservation of mass is shown in equations when they are balanced. Balancing the equations means ensuring that the same number of atoms for each element in the reactants is the same as the number of similar atoms present in the products, as illustrated in figure 6.12. No matter has been created or destroyed.

FIGURE 6.12 Illustration of the conservation of mass with the combustion of methane



Note that the chemical formula of a molecule shows the number of atoms of each element as subscript just after the symbol for the element, but when two or more molecules are needed to balance the scales, the coefficient (number in front) of the formula is changed.

For instance, water has the formula H_2O, which means that there are two hydrogen atoms for every oxygen atom in one molecule. When the equation has a coefficient 2 in front of the H_2O there are two water molecules, which means a total of four hydrogen atoms and two oxygen atoms. You cannot just change the formula of the reactants or products (you cannot write H_4O_2, for example); however, you can adjust how many of these are present in order to balance an equation.

In the case of the combustion of methane:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

We can therefore see that a chemical equation has the following advantages over a word equation:

- It is quicker to write.
- It shows the relative *proportions* of reactants and products involved in the reaction.

For example, the equation for the combustion of methane tells us that one molecule of methane reacts with two molecules of oxygen to form one molecule of carbon dioxide and two molecules of water.

It also tells us that 100 molecules of methane would react with 200 molecules of oxygen to form 100 molecules of carbon dioxide and 200 molecules of water, and so on.

ACTIVITY: PhET simulation

Access the **PhET simulation: Reactants, products and leftovers** interactivity in the Resources panel to explore the limiting reactant in a chemical reaction, and to identify and predict the amounts of reactants, products and leftovers of a chemical reaction.

6.4.2 Steps to balance a chemical equation

The steps used in balancing equations are described below.

Balancing equations

Step 1: Determine the reactants and products, and write a word equation

The products of a reaction must be known from either observation or reliable sources (such as chemists). For example, it is well known that the product of the reaction between hydrogen gas and oxygen gas is water vapour (gas). Use the knowledge of the reactants and products to write a word equation.

$$\text{hydrogen} + \text{oxygen} \longrightarrow \text{water}$$

Step 2: Chemical formulas

You need to know the formulas of all the reactants and products. For example:

- the formula of hydrogen gas is H_2
- the formula of oxygen gas is O_2
- the formula of water vapour is H_2O.

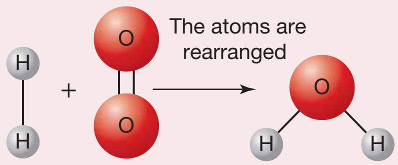
Remember! Because each substance has only one correct chemical formula, it *cannot* be changed by altering the subscript numbers.

Step 3: Write the equation

The formulas must be written according to the word equation, with reactants on the left-hand side of the arrow and products on the right-hand side.

$$H_2 + O_2 \longrightarrow H_2O$$

FIGURE 6.13 Reactants and products



Step 4: Balance the number of atoms

First, make a list of the elements present in the formulas under the heading 'Element', as shown in the following table. Then count up how many atoms of each element are represented by the formulas under the headings 'Reactants' and 'Products'.

Element	Reactants	Products
H	2	2
O	2	1

The Law of Conservation of Mass states that in a chemical reaction, mass is neither created nor destroyed; thus, there must be the same number and type of atom on each side of the equation.

You can see that there are not enough oxygen atoms on the product side. The only way this can be adjusted is by writing numbers in front of the chemical formulas.

When we write a number *in front* of a formula, it *multiplies all the atoms* in that formula. Let's increase the number of oxygen atoms on the product side by placing a 2 in front of the formula for water.

$$H_2 + O_2 \longrightarrow 2H_2O$$

Recounting the atoms we find:

Element	Reactants	Products
H	2	4
O	2	2

The oxygen atoms is now balanced, but the hydrogen atoms are not. Let's try writing a 2 in front of hydrogen's formula on the reactant side to increase the number of hydrogen atoms.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Counting the atoms again we find:

Element	Reactants	Products
H	4	4
O	2	2

The numbers of each of the elements are the same on both sides of the equation. The equation is balanced!

Step 5: Include the states

To indicate the physical state of each chemical involved in the reaction, the following symbols are used:

- Solid (s)
- Liquid (l)
- Aqueous (aq)
- Gas (g)

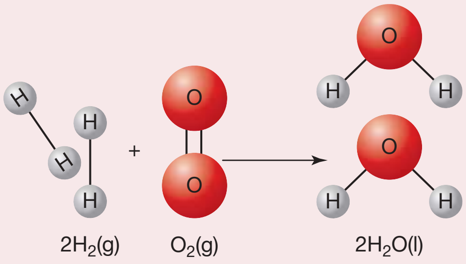
Note that if a word equation for a reaction in water uses the words dissolved, dilute or solution, the symbol of state for the equation is (aq).

Write the correct symbol representing the physical state of each reactant and product.

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$$

The chemical equation is complete.

FIGURE 6.14 Checking reactants and products balance



CASE STUDY: Another example of balancing a chemical equation

Ammonia (NH_3) is a very useful chemical and is made on a large scale industrially using the Haber process. This combines nitrogen gas (N_2) and hydrogen gas (H_2) to form ammonia gas.

Step 1: Determine the reactants and products, and write a word equation

The reactants are nitrogen and hydrogen, and the product is ammonia.

As a word equation, this is:

$$\text{nitrogen} + \text{hydrogen} \longrightarrow \text{ammonia}$$

Step 2: Chemical formulas

Determine the formula for each reactant and product:

Nitrogen gas = N_2

Hydrogen gas = H_2

Ammonia = NH_3

Step 3: Write the equation

Replace the words in the word equation with the formulas:

$$N_2 + H_2 \longrightarrow NH_3$$

Step 4: Balance the number of atoms

Count the number of atoms of each element for the reactants and products.

Element	Reactants	Products
N	2	1
H	2	3

If the number of atoms of each element is the same on both sides of the equation, the equation is already balanced. If not, numbers need to be placed in front of one or more of the formulas to balance the equation. These numbers are called coefficients, and they multiply all the atoms in the formula.

To balance the nitrogen atoms, put a 2 in front of NH_3.

The number of nitrogen atoms are now balanced, but the hydrogen atoms are not.

Element	Reactants	Products
N	2	2
H	2	6

The hydrogen atoms can be balanced by putting a 3 in front of the H_2 on the left:

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

The equation is now balanced. It can be checked by counting the number of atoms of each element on both sides of the new equation.

Element	Reactants	Products
N	2	2
H	6	6

Step 5: Include the states

$$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$$

ACTIVITY: PhET simulation

Access the **PhET simulation: Balancing chemical equations** interactivity in the Resources panel.

1. Select 'Intro'.
2. From the 'Tools' menu, select the scales icon to help with your balancing.
3. The first example equation is making ammonia (NH_3) from nitrogen gas (N_2) and hydrogen gas (H_2). Using the scales to help you, adjust the numbers in each box until you get the smiley face to show that you have a correctly balanced equation.

   What do you notice about the hydrogen and oxygen atoms on each set of scales?
4. The second example is separating water. Select this (near the bottom of the screen) and repeat the steps above until you get the smiley face again.

   What do you notice about the hydrogen and oxygen atoms on each set of scales?
5. The last example is combusting methane. Select this and repeat the above steps.

   Once again, what do you notice about the carbon, hydrogen and oxygen atoms once you get the smiley face?
6. Once you have completed these three examples, click on 'Game' (at the bottom of the screen) and see how you go with some harder examples.

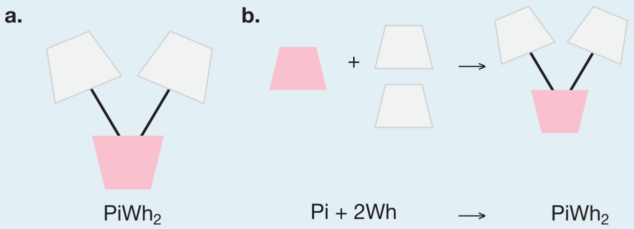
KEY IDEA

A balanced chemical equation illustrates the Law of Conservation of Mass. It contains the same number of each type of atom on each side. Because of this, it not only indicates the substances involved but also shows the relative amounts with which they react.

ACTIVITY: Modelling equations

1. Using up to three pink (Pi) and up to three white (Wh) marshmallows as your building blocks, make as many models of different compounds as you can and write the formula for each compound you have created — such as Pi_2, Pi_3 and $PiWh_2$, as illustrated in figure 6.15a.
2. Select three different compounds from step 1 and, for each, write out a reaction to produce the compound from the initial marshmallows — for example, $Pi + 2Wh \longrightarrow PiWh_2$, as illustrated in figure 6.15b.

FIGURE 6.15 Modelling **a.** a molecule and **b.** a reaction with marshmallows



6.4 Activities

learnon

6.4 Quick quiz on	6.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 7	2, 5, 8	3, 6, 9

Remember and understand

1. MC **Identify** how word equations are different from equations in which chemical formulas are used.
   A. Word equations do not include the formulas of the chemicals involved.
   B. Word equations always include the states of the reactants and products.
   C. Numbers are used in word equations, so it is possible to know the numbers of atoms involved.
   D. All of the above
2. MC **Identify** how states (solid, liquid and gas) are indicated in a chemical equation.
   A. The states are not indicated in a chemical equation.
   B. The symbols (s) for solid, (l) for liquid and (g) for gas are placed after each reactant and product.
   C. The symbols (1) for solid, (2) for liquid and (3) for gas are placed before each reactant and product.
   D. The symbols (s) for solid, (l) for liquid and (g) for gas are placed before each reactant and product.
3. MC **Identify** which of the following describes an aqueous solution.
   A. A substance that has melted and formed a liquid
   B. A substance that has been dissolved in hydrochloric acid
   C. A substance that has been dissolved in water
   D. A substance in the form of a gas

Apply and analyse

4. The unbalanced equation for the combustion of pentane is as follows:

$$C_5H_{12} + O_2 \longrightarrow CO_2 + H_2O$$

Identify and insert the necessary coefficients from the list below to balance this equation.

1 2 4 5 6 8

5. **Explain** why it is necessary to balance chemical equations.

6. Write a balanced chemical equation with states for the following.

a. Mercury metal (Hg) and oxygen gas (O_2) react to form solid mercury(II) oxide (HgO).

b. Magnesium metal (Mg) and hydrochloric acid solution (HCl) react to form hydrogen gas (H_2) and magnesium chloride solution ($MgCl_2$).

c. Sodium metal (Na) and water (H_2O) react to form hydrogen gas (H_2) and sodium hydroxide solution (NaOH).

d. Copper(II) sulfate solution ($CuSO_4$) and sodium hydroxide solution (NaOH) react to form solid copper(II) hydroxide ($Cu(OH)_2$) and sodium sulfate solution (Na_2SO_4).

e. Iron metal (Fe) reacts with oxygen gas (O_2) to produce solid iron(II) oxide (FeO).

Evaluate and create

7. Nitromethane is used as a fuel in one of the classes of drag car racing. The unbalanced equation for its combustion is shown below.

$$CH_3NO_2 + O_2 \longrightarrow CO_2 + H_2O + NO_2$$

Identify and insert the necessary coefficients from the list below to balance this equation.

2 4 5 6 7

8. **Construct** an instructional flowchart explaining how to balance a chemical equation. Use an example that has not already been covered in this lesson to show this process.

9. Hydrocarbons are compounds that contain only carbon and hydrogen. Hydrocarbons burn in air to produce carbon dioxide and water. Below are some balanced and unbalanced equations for this process. **Identify** which of the equations on the left matches each of the statements on the right.

Balancing equations for hydrocarbons

Equation	Statement
a. $2CH_4 + 4O_2 \longrightarrow 2CO_2 + 4H_2O$	1. The are too many hydrogen atoms on the right-hand side of the arrow.
b. $C_2H_4 + 2O_2 \longrightarrow 2CO_2 + H_2O$	2. The are too few oxygen atoms on the left-hand side of the arrow.
c. $C_2H_6 + 4O_2 \longrightarrow 2CO_2 + 4H_2O$	3. This equation is balanced.
d. $C_3H_8 + 6O_2 \longrightarrow 4CO_2 + 4H_2O$	4. There are too many hydrogen atoms on the left-hand side of the arrow and too many oxygen atoms on the right-hand side.
e. $C_4H_{10} + 6O_2 \longrightarrow 4CO_2 + 5H_2O$	5. There are too few carbon atoms on the left-hand side of the arrow.

Answers and sample responses are available in your digital formats.

LESSON 6.5 Chemical reactions in everyday life

LEARNING INTENTION

In this lesson you will describe how acid–base and redox reactions are important in our everyday life.

6.5.1 Reactions between acids and bases

Acids are **corrosive** substances. This means they react with solid substances, 'eating' them away. Acids have a sour taste, and some — such as the sulfuric acid used in car batteries — are dangerously corrosive. The acids in ant stings and bee stings cause pain. Others, such as the acids in fruits and vinegar, are safe — even pleasant — to taste.

Acids can be strong or weak. Strong acids are able to react to their full extent with other substances, while weak acids do not.

- Strong acids include hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and nitric acid (HNO_3).
- Weak acids include ethanoic acid (also called acetic acid, CH_3COOH), carbonic acid (H_2CO_3) and citric acid ($C_6H_8O_7$).

KEY IDEA

The word *acid* comes from the Latin word *acidus*, meaning 'sour'.

Bases have a bitter taste and feel slippery or soapy to touch. Some bases are very corrosive, especially caustic soda (sodium hydroxide). Caustic soda will break down fat, hair and vegetable matter, and is the main ingredient in drain cleaners. Other bases are used in soap, shampoo, toothpaste, dishwashing liquid and cloudy ammonia as cleaning agents. Bases that can be dissolved in water are called **alkalis**.

TABLE 6.3 Common acids and bases, and their uses

Acid	Uses
Hydrochloric acid (HCl)	• To clean the surface of iron during its manufacture • Food processing • The manufacture of other chemicals • Oil recovery
Nitric acid (HNO_3)	• The manufacture of fertilisers, dyes, drugs and explosives
Sulfuric acid (H_2SO_4)	• The manufacture of fertilisers, plastics, paints, drugs, detergents and paper • Petroleum refining and metallurgy
Citric acid ($C_6H_8O_7$)	• Present in citrus fruits such as oranges and lemons • Used in the food industry and the manufacture of some pharmaceuticals
Carbonic acid (H_2CO_3)	• Formed when carbon dioxide gas dissolves in water; present in fizzy drinks
Ethanoic acid (CH_3COOH)	• Found in vinegar • The production of other chemicals, including aspirin
Base	**Uses**
Sodium hydroxide (NaOH) (caustic soda)	• The manufacture of soap • As a cleaning agent
Ammonia (NH_3)	• The manufacture of fertilisers and in cleaning agents
Sodium bicarbonate ($NaHCO_3$)	• To make cakes rise when they cook

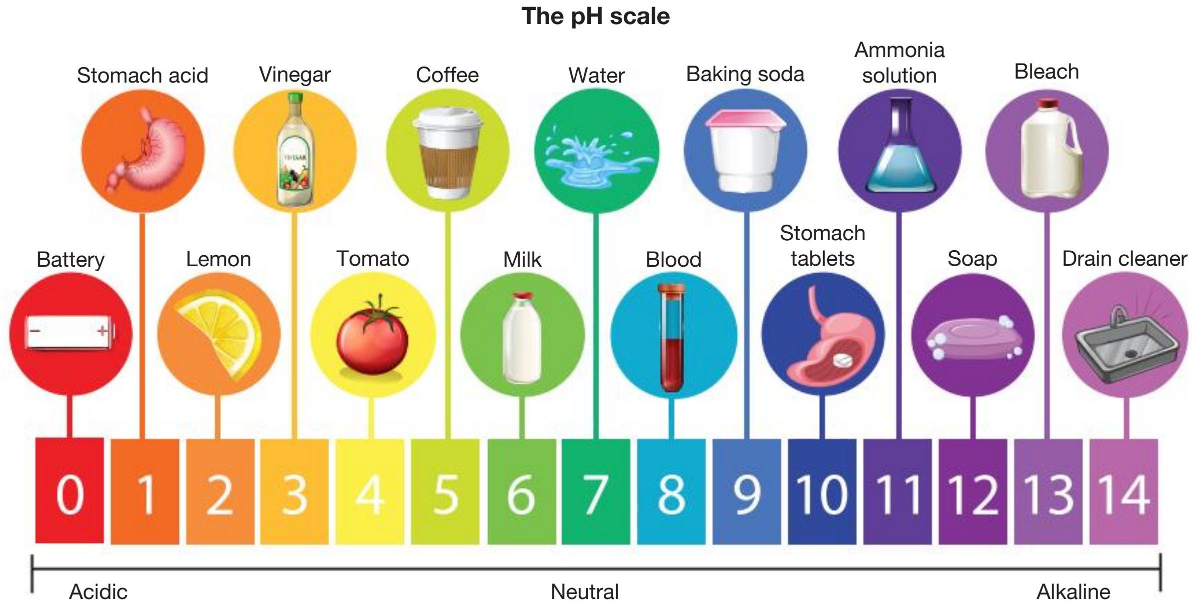
Like acids, bases can be strong or weak. Strong bases are able to react to their full extent with other substances, while weak bases do not.

6.5.2 The pH scale

The strength of an acid or base is measured by the **pH scale**, which ranges from 0 to 14. A pH lower than 7 indicates the presence of an acid (the lower the pH, the stronger the acid) while a pH greater than 7 indicates the presence of a base (the greater the pH, the stronger the base). A pH of 7 is neutral.

- Strong bases include potassium hydroxide (KOH), sodium hydroxide (NaOH) and barium hydroxide ($Ba(OH)_2$).
- Strong acids include hydrochloric acid and sulfuric acid.
- Weak bases include ammonia (NH_3), calcium carbonate ($CaCO_3$) and sodium carbonate (Na_2CO_3).
- Weak acids include citric acid and ethanoic acid (also known as acetic acid).

FIGURE 6.16 The pH scale is a measure of how acidic or basic (alkaline) a solution is.



The pH of a substance is measured with either pH paper, a universal indicator or special electronic pH meters.

ACTIVITY: pH at home

Look at the pH scale and find where weak acids and bases and strong acids and bases are located. Research where cleaning products, such as your shampoo, face cleaners and toothpaste, are located on this scale.

6.5.3 Neutralisation

Acids and bases are chemical opposites of each other. This means they can react with each other and form products with totally different properties. When an acid and a base react with each other, the products include a salt plus water. These reactions are called **neutralisation** reactions.

KEY IDEA

A neutralisation reaction occurs when an acid and a base react.

The products are water and a salt.

$$\text{acid} + \text{base} \longrightarrow \text{water} + \text{salt}$$

For example:

$$\begin{array}{ccccccccc} \text{hydrochloric acid} & + & \text{sodium hydroxide} & \longrightarrow & \text{water} & + & \text{sodium chloride} \\ \text{HCl} & + & \text{NaOH} & \longrightarrow & H_2O & + & \text{NaCl} \end{array}$$

Examples of common neutralisation reactions include:

- changing soil in the garden
- treating insect stings and bites
- relieving indigestion
- using hair shampoo and then conditioner
- using baking powder in cooking.

In the garden

The pH of soil can affect which plants grow well in it.

Some plants grow better in acidic soils, while other plants grow best in basic soils. If a soil is too acidic, it can be neutralised with a base such as lime. The added lime can make the soil less acidic, neutral or basic, depending on how much is added.

If the soil is too basic, ammonium sulfate can be added to the soil. This weak acid salt helps to neutralise the bases in the soil. These neutralisation reactions in your garden can help your plants to grow by providing soil with the most suitable.

ACTIVITY: Neutralising wee

It is claimed that the damage caused by pet urine on a garden can be neutralised by compounds such as gypsum. However, this is not exactly true. Research why this is not as simple as some websites suggest. You might like to consider these questions during your research:

- What is the expected pH of urine?
- Is pet urine more acidic or basic compared to human urine?
- What can affect the pH level?
- What is gypsum? Is it a base or an acid?
- What is the effect of gypsum on the soil?

FIGURE 6.17 Urine from pets can leave an unpleasant odour, and damage plants and lawns.

Insect bites and stings

A sting from an ant or a bee is very painful as it contains an acid — formic acid (also called methanoic acid). This can be neutralised by a base such as soap or a mixture of water and baking soda. In contrast, a wasp sting is painful because it contains a base. It can be neutralised by applying an acid such as vinegar. It is important to know what has bitten you so that the correct substance can be used to neutralise the sting.

Relieving indigestion

The hydrochloric acid in your stomach helps to break down the food you eat. It is a very strong acid, with a pH of less than 1.5. However, if you eat too quickly, or eat too much of the wrong food, the contents of your stomach become even more acidic. You feel a burning sensation because of the corrosive properties of the acid; this is called indigestion.

To relieve the pain of indigestion, you can take antacid tablets. The active ingredients in antacid tablets are weak bases such as aluminium hydroxide, magnesium carbonate and magnesium hydroxide, which neutralise the acid. For example, when magnesium carbonate is used, the equation for the reaction that causes your relief is as follows:

$$MgCO_3(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)$$

One of the products of this reaction is carbon dioxide. You burp to get this gas out of your stomach!

SAMPLE PROBLEM 2 Writing balanced equations

Another ingredient that some antacid mixtures contain is solid aluminium hydroxide ($Al(OH)_3$). This reacts with the hydrochloric acid (HCl) in the stomach to produce aluminium chloride ($AlCl_3$) and water.

Note: **The brackets are used in the formula $Al(OH)_3$ to indicate there are three lots of OH. For the purpose of balancing equations, the atoms in this formula can be counted as one aluminium atom, three oxygen atoms and three hydrogen atoms.**

Write a balanced chemical equation for this reaction.

THINK	WRITE
1. Write the word equation.	Aluminium hydroxide + hydrochloric acid ⟶ aluminium chloride + water
2. Determine the chemical formulas.	Aluminium hydroxide = $Al(OH)_3$ Hydrochloric acid = HCl Aluminium chloride = $AlCl_3$ Water = H_2O
3. Rewrite the word equation using chemical formulas.	$Al(OH)_3 + HCl \longrightarrow AlCl_3 + H_2O$
4. Count the number of atoms on each side of the equation.	On the left: Al = 1, O = 3, H = 4, Cl = 1 On the right: Al = 1, O = 1, H = 2, Cl = 3

5. Because these are not balanced, insert coefficients into the equation to achieve this. Count the number of atoms on each side to verify.	This equation can be balanced by: • placing a 3 in front of HCl • placing a 3 in front of H_2O. $Al(OH)_3 + 3HCl \longrightarrow AlCl_3 + 3H_2O$ On the left: Al = 1, O = 3, H = 6, Cl = 3 On the right: Al = 1, O = 3, H = 6, Cl = 3
6. Insert the symbols of state.	$Al(OH)_3(s) + 3HCl(aq) \longrightarrow AlCl_3(aq) + 3H_2O(l)$

PRACTICE PROBLEM 2

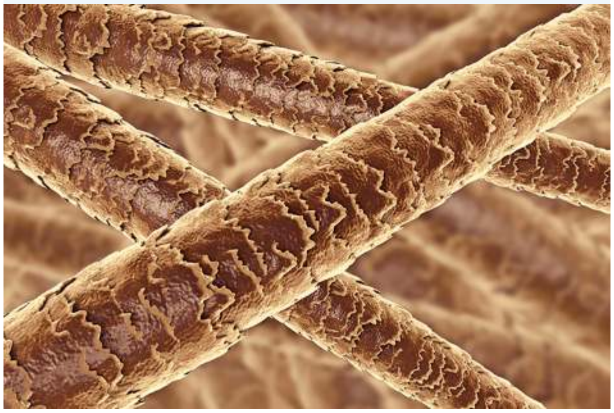
Write the neutralisation reaction for when magnesium hydroxide ($Mg(OH)_2$) powder reacts with dilute hydrochloric acid (HCl) to form magnesium chloride ($MgCl_2$) solution and water.

CAUTION: It is important to deal with spills in the science laboratory quickly and safely. The first thing to do is to let your teacher know if you have spilled any substance. Methods of dealing with spills may include acid or base neutralisers, absorption pads, mops or granules and inactivators. One thing you would not do is to try to neutralise a strong acid with a base, as the reaction could be violent and cause further problems.

Hair treatment

Hair is made from a protein called keratin. Like all proteins, keratin is susceptible to changes in pH, which can change its structure. This can result in unwanted changes to the hair, such as breakage.

FIGURE 6.18 A microscopic view of a healthy human hair



It should not be a surprise then that the correct pH is essential for healthy hair. Healthy hair has a pH between 4.5 and 5.5. However, many hair treatments deliberately change the structure of the hair in order to achieve some sort of cosmetic effect, such as colouring, curling and straightening. This is done using various chemicals, many of which are acids and bases. As these affect the pH of the hair, it is important that the hair is returned to its natural pH at the conclusion of the treatment. Neutralisation reactions are therefore often used to achieve this. Other reactions that are used in hair treatment are redox reactions (which are explored later in this lesson).

A more common hair treatment is simply washing it. As hair also contains natural oils that can build up to an undesirable level, most shampoos have a pH that is slightly basic. This is because bases are good at removing oils and fat. When a conditioner is used after shampooing, it neutralises the effects of the shampoo and returns the hair to a pH that is closer to its natural level.

EXTENSION: pH and damaged hair

Figure 6.18 shows how healthy human hair looks under a powerful microscope. Each hair strand is made up of three layers: the cortex, medulla and cuticle. Clearly visible in this photo is the outer layer — the cuticle. The cuticle protects the inner layers from the entry of chemicals that might damage the hair.

As shown in figure 6.18, the cuticle contains segments that fold down flat and tight to form a protective barrier. If the pH is too high or too low, these cuticle segments will open up. This then allows the entry of various substances and chemicals to the layers underneath. While this may be desirable in some cases, such as hairdressing treatments, it can also cause damage to the hair.

Using baking powder

Baking powder is a mixture of sodium hydrogen carbonate (also known as sodium bicarbonate) and a weak acid, both of which are in powdered form. It can be used in recipes by itself, but it is often added to flour to make self-raising flour.

The base sodium bicarbonate is more commonly known as baking soda. When it reacts with an acid, the products are a salt, water and carbon dioxide. Self-raising flour is a mixture of an acid and baking powder. When water or milk is added to self-raising flour, the acid in the baking powder (tartaric acid) and the base (sodium bicarbonate) react together. The carbon dioxide produced causes the mixture to rise when it is heated.

Two ingredients in pancakes are buttermilk (an acid) and baking soda. When the two are mixed, a salt, water and carbon dioxide are produced. The bubbles of carbon dioxide get larger as the mixture is heated, causing the mixture to rise.

The reaction between an acid and a carbonate can be described by the following equations:

$$\text{acid} + \text{base} \longrightarrow \text{water} + \text{salt} + \text{carbon dioxide}$$

The clue to carbon dioxide being produced is that the reaction involves a carbonate salt.

$$\text{hydrochloric acid} + \text{sodium bicarbonate} \longrightarrow \text{water} + \text{sodium chloride} + \text{carbon dioxide}$$
$$HCl + NaHCO_3 \longrightarrow H_2O + NaCl + CO_2$$

ACTIVITY: Investigating food

Predict the outcomes of increasing the temperature of a pancake or damper mixture by adding a warm liquid to the dry ingredients. Try making pancakes yourself or research a recipe for damper to try at home. Most recipes use self-raising flour, milk or water, salt and butter.

FIGURE 6.19 Making pancakes

CASE STUDY: Acid–base reactions in sherbet

The fizzy sensation that you get when you eat sherbet is due to an acid–base reaction. The sherbet consists of sodium bicarbonate and citric acid. Both of these substances are in powdered form in the sherbet and do not react with each other. When they dissolve in the saliva of your mouth a reaction takes place, producing carbon dioxide gas — hence the fizzing.

INVESTIGATION 6.3

Antacids in action

Aim

To investigate the neutralising action of an antacid

Materials

- Petri dish
- electronic balance
- spatula
- antacid powder
- 0.1 M hydrochloric acid
- 250 mL conical flask
- 100 mL measuring cylinder
- methyl orange indicator
- white tile or white paper

Method

1. Measure and record the mass of the Petri dish.
2. Add a small amount of antacid powder to the dish. Record the mass of the antacid and Petri dish.
3. Add 50 mL of the dilute hydrochloric acid to the 250 mL flask.
4. Add three drops of methyl orange indicator.
5. Place the flask mixture on the white tile (or paper) and use the spatula to slowly add antacid from the Petri dish bit by bit. Swirl the flask to mix. Stop adding antacid when the colour changes from red to orange.
6. Measure and record the mass of the Petri dish and its contents (the unused antacid).

Results

1. What was the mass of the antacid powder?
2. What colour change occurred when the methyl orange indicator was in the acid?
3. By subtraction, calculate the mass of antacid used to neutralise 50 mL of dilute hydrochloric acid.

Discussion

1. Compare your results with other groups in your class. Suggest reasons for the similarities or differences between your results.
2. Use your results to calculate how much antacid you would need to neutralise 500 mL of dilute hydrochloric acid.

Conclusion

Write a conclusion summarising your results. You may choose to discuss any variations in results across your class.

6.5.4 Redox reactions

You may not have heard of redox reactions but you would certainly have heard of oxidation reactions. As expected from their name, **oxidation** reactions refer to a substance reacting with oxygen. In these reactions, oxygen is added in some way to a reactant. Oxidation reactions always occur with another type of reaction called **reduction**. In many reduction reactions, oxygen is removed from a reactant.

An important example of a reduction reaction is the production of iron from iron **ore**. If you write the chemical equation for this reaction, it is easy to see how the oxygen has been removed from the ore (Fe_2O_3) to produce iron (Fe).

$$2Fe_2O_3 + 3C \longrightarrow 4Fe + 3CO_2$$

The term *redox* is a combination of these two processes (*red*uction and *ox*idation).

Some redox reactions that you are probably familiar with involve:
- combustion
- respiration
- fireworks
- bleaching.

Combustion reactions

Some of the most spectacular chemical reactions to watch, including fireworks and the launching of spacecraft, are **combustion** reactions.

Combustion reactions are those in which a substance reacts with oxygen and heat is released. Burning is a combustion reaction that produces a flame. The substance that reacts with oxygen in a combustion reaction is called a **fuel**. Many of the fuels we use for transport and heating — such as methane, butane, octane and petrol — are called **hydrocarbons**, as they are made of hydrogen and carbon. All combustion reactions are oxidation reactions.

KEY IDEA

The combustion of hydrocarbons can be summarised as:

$$\text{hydrocarbon} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water } (+\text{ energy})$$

The word *combustion* comes from the Latin word *comburere*, meaning 'to burn'.

Cooking with gas

Gas cooking is a very common example of a combustion reaction. If your house is connected to natural gas, the gas used will be methane. If you use bottled gas, then the gas will be LPG (liquefied petroleum gas), which is a mixture of propane and butane. Natural gas is formed over millions of years from the remains of plants and animals that have been trapped under rock. LPG is produced as a by-product of crude-oil refining. Both these gases are colourless and odourless, which makes them very dangerous if there is a leak. Because of this, chemicals called **odourants** are added to give the gas a detectable odour.

FIGURE 6.20 Natural gas contains methane.

Natural gas and LPG are both hydrocarbons, and will therefore produce carbon dioxide and water when combusted.

Other common fuels are also hydrocarbons, including:

- petrol (C_8H_{18})
- diesel
- kerosene (used in jet fuel).

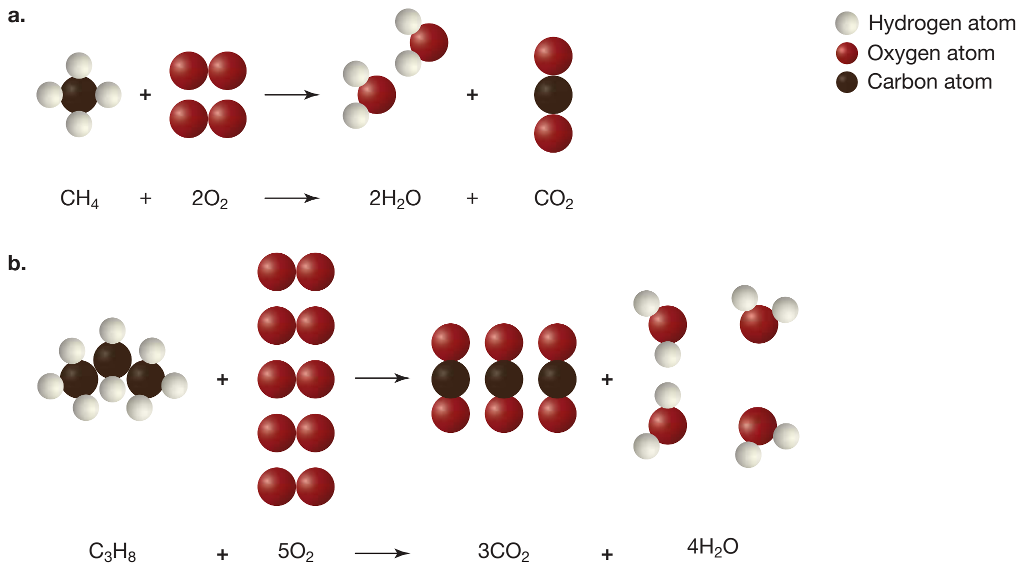
Because these are also hydrocarbons, they will produce carbon dioxide and water when they are burnt.

KEY IDEA

The equation for the combustion of methane is:

$$\text{methane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$
$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

FIGURE 6.21 Models showing the combustion of **a.** methane and **b.** propane



Respiration

A chemical reaction called **respiration** takes place in every cell of your body. Respiration is a slow oxidation reaction. The energy required by your body is released when the fuel glucose, obtained from your digested food, reacts with oxygen from the air that you breathe. The products of respiration are carbon dioxide, water and energy.

KEY IDEA

The chemical equation for respiration is:

$$\text{glucose} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

Fireworks

The reactions that occur in fireworks are examples of redox reactions that happen very quickly. When a firework explodes, chemicals in the mixture are quickly oxidised to produce a sudden burst of energy. This reaction is nearly always enhanced by the presence of chemicals in the mixture called oxidising agents.

FIGURE 6.22 Fireworks are examples of explosive redox reactions.

The colours in fireworks are produced by the presence of further chemicals that undergo reaction in the heat of the explosion; for example:
- powdered magnesium (brilliant white)
- powdered barium compounds (green)
- powdered sodium compounds (yellow)
- powdered strontium compounds (red).

Bleaching

Bleaching is used to remove stains from clothes. Bleaches work by causing redox reactions between the bleach and the stain. The reason that stains are visible is that the chemicals in them absorb and reflect light in certain ways. When a bleach reacts with the stain, new substances form. These substances absorb and reflect light in different ways, making the stain less visible or even invisible.

SCIENCE INQUIRY: Dental decay and acids

Watch the video eLesson **The effects of cola soft drinks on a tooth over a year** in the Resources panel.

In this lesson, you have learnt that acids are corrosive and that there are many acids in the food we eat and drink.

Does this raise any questions or make you curious about how our teeth are affected? Such questions are the beginning of the scientific process.

A good scientific question is one that you can answer given your resources and the time available. It is better for it to be specific rather than too broad.

The next step is to formulate a hypothesis. You can think of this as a possible answer to the question or a prediction.

The following is an example of a question and hypothesis about teeth and acids:
- Question: Are teeth discoloured more by cola soft drinks than by raspberry soft drinks?
- Hypothesis: Cola soft drinks will cause more tooth discolouration than raspberry soft drinks.

In small groups or individually, answer the following.
1. Propose three different questions about how acids might affect teeth.
2. For each question, state a hypothesis (make a reasonable prediction based upon what you already know).
3. What would be your next step in the scientific process?

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

6.5 Activities

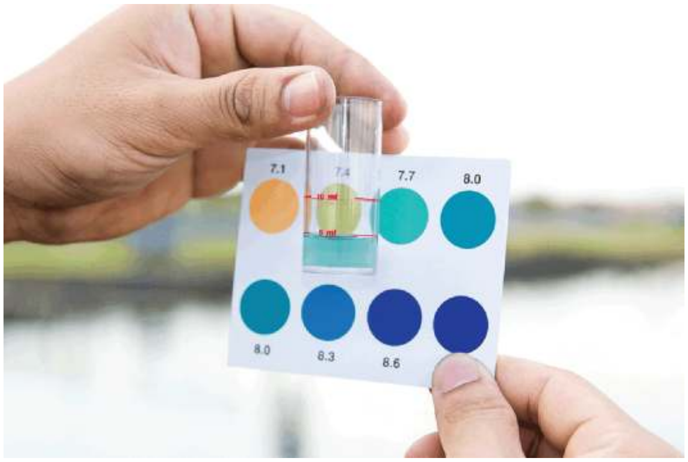
learnon

6.5 Quick quiz on	6.5 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 5, 11	2, 6, 8, 10, 14	7, 9, 12, 13, 15

Remember and understand

1. **Recall** what a corrosive substance is.
2. **Explain** why the chemical reaction between an acid and a base is called neutralisation.
3. **Identify** the missing words to complete the sentences.



   a. The substance shown in the figure has a pH value of ___________ and so it is ___________.
   b. A substance with a pH less than 7 is ___________.
   c. A substance with a pH equal to 7 is ___________.
4. MC **Identify** why soap relieves the pain of an ant sting.
   A. It cleans the bite area.
   B. It neutralises the acid in the venom.
   C. It neutralises the base in the venom.
   D. It creates an alkali.
5. **Identify** the missing words to complete the sentence.
   The characteristics that all combustion reactions have in common are that a fuel reacts with __________ and produces ___________.
6. MC **Identify** the products of all complete combustion reactions in which hydrocarbons are burned.
   A. Carbon dioxide and oxygen
   B. Carbon dioxide and water
   C. Water vapour and oxygen
   D. Carbon and water

Apply and analyse

7. SI **Describe** how an antacid tablet relieves the pain of indigestion.
8. Antacid tablets contain a base, which neutralises the excess acid coming from your stomach into your oesophagus and relieves the pain.
   Is the following statement true or false? **Justify** your response.
   When you take an antacid tablet, you would expect the pH value in your oesophagus to increase.

9. SI A pH meter is used to measure the pH of five substances. The results are shown in the table.

pH of different substances

Substance	pH value
A	6.0
B	12.0
C	3.0
D	7.0
E	8.0

a. **Identify** which substance is most likely to be:
   i. vinegar
   ii. milk.
b. **Identify** which substance could be:
   i. a weak base
   ii. pure water
   iii. a strong base.
c. **State** which two of the substances you would expect to be the most corrosive.

10. Respiration is the reaction between glucose and oxygen, releasing the energy required by your body. **State** two reasons it is classified as a combustion reaction.
11. Petrol is a mixture of hydrocarbons, of which octane is the main one. Write a word equation for when octane is burned in a car engine.
12. MC Hydrogen and oxygen are cooled to extremely low temperatures so that they can be stored as liquids in the fuel tanks of rockets.
    Identify why water, the product of the reaction, is produced as a gas.
    A. Because the reaction between hydrogen and oxygen produces a lot of heat
    B. Because the reaction between hydrogen and oxygen absorbs a lot of heat
    C. So the water can escape
    D. So the water can be captured and reused

Evaluate and create

13. **State** whether the pH is increased when a gardener adds lime to a soil that is too acidic. **Explain** your response.
14. Write a word equation that describes the chemical reaction between hydrochloric acid and calcium carbonate.
15. SI Different fuels produce different amounts of heat. The following table shows the amount of heat produced per gram of fuel.

Heat of combustion for different fuels

Fuel	Heat of combustion (kJ per gram)
Hydrogen	141
Methane	55.6
Butane	49.7
Octane	47.9

a. Write an equation for the combustion of butane.
b. **Identify** the fuel that produces the most heat per gram.

Answers and sample responses are available in your digital formats.

LESSON 6.6 Elements in disguise

LEARNING INTENTION

In this lesson you will explain why some elements are found free in nature, while others exist in compounds with other elements.

6.6.1 Reactivity

Reactivity refers to how easily an element undergoes chemical reactions with other elements to form compounds.

There are currently 118 recognised elements. However, only 91 of these occur in nature. While some of these are very common, others are extremely rare. Some of these 91 elements are very reactive, while others are very unreactive. Elements that do not react are called **inert**. This difference in reactivity has a huge influence on how an element is found in nature and how it is extracted.

6.6.2 Elements found free in nature

Elements found free in nature are often referred to as **native elements**. The most familiar example of a native element is gold, which can be found as alluvial deposits alongside rivers and streams, or as gold nuggets that can be dug up from the ground.

Other familiar metals that can be found freely in nature include:
- silver
- platinum
- copper.

Familiar non-metals found freely in nature include:
- carbon (found as diamonds, graphite and in other forms)
- sulfur (yellow sulfur deposits are frequently found around thermal vents in areas that are geologically active, as well as in pure underground deposits)
- gases such as nitrogen and oxygen, as part of the mixture we call air.

These elements involve mainly physical processes to extract them and only minimal chemical reactions.

FIGURE 6.23 A 2.5 g platinum nugget found in far eastern Russia

FIGURE 6.24 Yellow sulfur deposits at the top of Mt Etna in Sicily

The main reason some elements are found free in nature is their lack of reactivity. Another reason is their electron arrangements (the arrangement of electrons in atoms is explored in *Jacaranda Science Quest 10*). Although electron arrangements determine reactivity, they can sometimes make an element highly unreactive (inert), as seen in noble gases such as helium, argon, krypton and xenon.

Sometimes, however, elements that *are* chemically reactive *can* be found free in nature. In such cases an energy source is usually involved, which is used to produce the element in its free state. For example:

- Extreme conditions can create energy-rich situations for the production of elements free in nature. Diamonds are formed when carbon is subjected to extreme heat and pressure below Earth's surface. Sulfur is formed when gases such as hydrogen sulfide and sulfur dioxide react in the high-temperature environments of volcanoes and other similar environments.
- Oxygen is formed from photosynthesis using solar energy. Although oxygen is reactive and is being removed from the atmosphere, it is being replaced by photosynthesis.

KEY IDEA

Elements such as gold, platinum, silver and copper are found free in nature because they are unreactive. Other elements such as carbon, sulfur and oxygen occur free due to other processes that consume energy.

6.6.3 Elements not found free in nature

Earth has existed for billions of years. This means that even elements that only react slowly in the environment have had plenty of time to undergo chemical reactions. These reactions are oxidation reactions.

The compounds formed when elements react with other chemicals in Earth's crust are called **minerals**. This is the case for many of today's important metals. Although there is much variety in the composition of minerals, many of these important metals are present:

- combined with oxygen (oxides)
- combined with sulfur (sulfides)
- combined with carbon and oxygen (carbonates)
- combined with halides (chlorides and fluorides).

To extract these elements from minerals, chemical reactions are required. The original oxidation process must be reversed, so reduction reactions are therefore required. These require energy. The more reactive an element, the more energy is required to reduce it.

KEY IDEA

The main reason some elements are not found free in nature is due to their reactivity. They are found in compounds where they are combined with other elements.

EXTENSION: Oxidation and reduction

The definitions of oxidation and reduction have changed over time, and are a good example of how scientific theories evolve. The modern definitions are not limited to reactions involving oxygen and can therefore be applied to a much wider range of reactions. Today, oxidation and reduction are defined in terms of electron transfer. These new definitions do not contradict the older ones — rather, they broaden them.

Oxidation and reduction are now defined as follows:

- Oxidation reactions involve the addition of oxygen to a substance. A broader definition is that they involve the removal of electrons from something.
- Reduction reactions involve the removal of oxygen from a substance. A broader definition is that they involve the addition of electrons to something.

Another reason why some elements are not found free in nature is radioactivity. For example, the element technetium (Tc) does not occur in nature because all its atoms have decayed into other elements throughout the course of Earth's existence. Technetium is not even found in any minerals because of this!

6.6.4 Investigating reactivity in metals

There are many acids that occur naturally in the environment. Although these are nearly always very dilute, over large periods of time they can have a noticeable effect. Although there are many ways that we can investigate reactivity, reaction with acids might be a convenient and relevant place to start. A typical reaction of metals is their reaction with an acid to produce a salt plus hydrogen gas.

KEY IDEA

Metals typically react with an acid to produce a salt plus hydrogen gas.

$$\text{acid} + \text{metal} \longrightarrow \text{salt} + \text{hydrogen}$$

INVESTIGATION 6.4

Investigating reactivity of some metals

Aim

To arrange four different metals in order of reactivity

CAUTION: Obtain your teacher's approval before carrying out your experiment.

Materials

- samples of magnesium, iron, zinc and copper (or other alternatives)
- an acid, as chosen by the group
- equipment decided upon by the group

Method

Work in groups of three or four to develop a method to test how your metal samples react with your chosen acid.

Here are some points to help you get started.

- The acid chosen should be safe to use.
- The metals should be in the same physical form (e.g. all in powder form, or all in thin sheets or strips).
- You will need to decide what variables will need to be controlled. Some of the variables involved include type of acid, strength of the acid, concentration of the acid and temperature. Can you think of any others?
- What observations will be required to enable you to meet your aim?
- What are the appropriate safety issues that you should be aware of, and how will you deal with these?

1. Make a list of the equipment you will need.
2. Have your method and equipment list checked by your teacher.

Results

Carry out your experiment and keep a record of any measurements and observations that you make.

Discussion

1. List the dependent and independent variables.
2. List the variables you were able to control in your experiment.
3. Identify any variables that were uncontrolled.
4. Identify any problems you had in determining the order. Suggest an improvement to the method that might overcome this.
5. Do you think that this order would apply to other chemicals that these metals might react with? Outline some changes to your experiment to find out.

Conclusion

List the four metals in order of reactivity. Make sure that your order is supported by the observations that you obtained.

6.6.5 Minerals to metals

Three metals that are very important in today's world are copper, iron and aluminium. The processes used to extract these metals highlight their different levels of reactivity.

Copper

Although copper does occur free in nature, the large amounts that we require today are obtained from copper ores. These ores are usually in the form of sulfides, oxides or carbonates. The main chemical reaction occurring to remove these other elements and obtain the copper is reduction.

There are a number of ways that this can be done, depending on the exact make-up of the copper ore. Most of today's copper comes from sulfide ores. There are a number of steps in this process and the reactions can be complicated. A typical reaction that occurs towards the end of this process is:

$$Cu_2S + O_2 \longrightarrow 2Cu + SO_2$$

For oxide ores, heating the ore with carbon to about 800 °C will achieve extraction. A typical reaction is:

$$2CuO + C \longrightarrow 2Cu + CO_2$$

In this reaction, you will notice that CuO has had the oxygen removed from it to form Cu and has therefore been reduced. You may also notice that the C has had oxygen added to it and has therefore been oxidised.

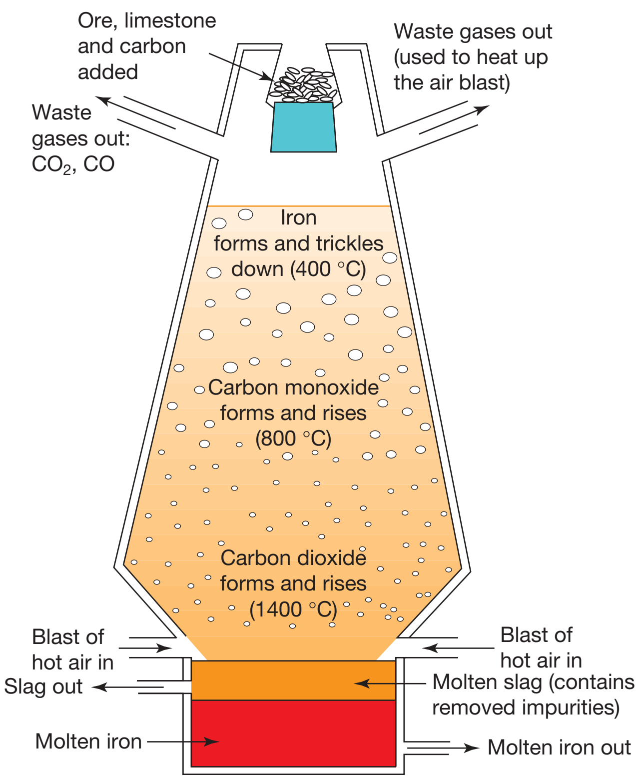
This highlights the fact that oxidation and reduction always occur together.

Iron

The main use of iron in today's society is to make steel. Steel is one of the most widely used materials in the world. Iron is not found free in nature and must therefore be extracted from its ore. For example, haematite is an iron ore that contains iron oxide (Fe_2O_3). Haematite is heated with carbon in a blast furnace at around 1500 °C to separate the iron from the oxygen. Pure iron and carbon dioxide are produced in this reaction.

$$\text{iron oxide} + \text{carbon} \longrightarrow \text{iron} + \text{carbon dioxide}$$
$$2Fe_2O_3(s) + 3C(s) \longrightarrow 4Fe(l) + 3CO_2(g)$$

FIGURE 6.25 Iron is extracted by breaking down iron oxide to form iron and carbon dioxide.



Aluminium

Aluminium is lightweight and has many uses in planes, the space industry, electronics and the canning of alcoholic beverages and soft drinks. Aluminium is obtained from bauxite ore. This ore is first purified to produce alumina (Al_2O_3), which is then reduced using electricity in a process called electrolysis. This is necessary because high temperatures alone cannot economically supply the energy necessary to bring about this reduction.

The equation for this reaction is:

$$2Al_2O_3 + 3C \longrightarrow 4Al + 3CO_2$$

alumina (aluminium oxide) + carbon ⟶ aluminium + carbon dioxide

All of these metals require energy to produce them. If the amount of energy required is compared, the order is:

copper < iron < aluminium

You will notice that this is the same as their order of reactivity. Copper is less reactive than iron, which is less reactive than aluminium. The more reactive a metal is, the harder it is to produce.

SCIENCE AS A HUMAN ENDEAVOUR: The noble gases — discovering the unreactive elements

The noble gases are found in group 18 of the periodic table and include helium, neon, argon, krypton, xenon and radon. These elements are known for being unreactive due to their full outer electron shells, which make them chemically stable and unlikely to form compounds under normal conditions.

Discovery of the noble gases

- The first noble gas, argon, was discovered in 1894 by Lord Rayleigh and Sir William Ramsay during experiments on air composition.
- Helium was first detected in the Sun’s spectrum in 1868 before being found on Earth in 1895.
- Other noble gases — neon, krypton, and xenon — were discovered later through fractional distillation of liquid air in 1898 by Ramsay and Morris Travers.
- Radon was discovered in 1900 by Friedrich Ernst Dorn.

Why did it take so long to discover them?

- Noble gases are colourless, odourless and tasteless, making them difficult to detect using early chemical techniques.
- Their lack of reactivity meant they did not easily form compounds, which made their presence harder to observe.
- Their isolation required advanced techniques like spectroscopy and gas separation, which were not available until the late nineteenth century.

Are noble gases completely inert?

- Scientists initially believed noble gases were completely inert because they did not react with other elements.
- However, in the 1960s, researchers discovered that xenon and krypton could form compounds under extreme conditions with highly reactive elements like fluorine and oxygen.
- This discovery challenged earlier assumptions and showed that scientific knowledge evolves as research methods improve.

Applications of noble gases

- Helium is used in balloons and MRI scanners.
- Neon is used in advertising signs.
- Argon is used in welding and light bulbs.
- Xenon is used in car headlights and lasers.

1. Why are noble gases so unreactive compared to other elements?
2. Why did it take scientists so long to discover noble gases?
3. How did the discovery that xenon can form compounds change scientific understanding of noble gases?

Scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)

6.6 Activities

learnon

6.6 Quick quiz on	6.6 Exercise

Learning pathways

■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 3, 5, 7	2, 6, 9, 11	4, 8, 10, 12

Remember and understand

1. **List** the following elements in order from most reactive to least reactive: copper, aluminium, platinum, iron.
2. Although copper does occur as a free metal (native copper) in nature, it is produced in large amounts from copper ores worldwide. **Explain** why this happens.
3. MC **Identify** where carbon is found naturally in the form of diamond.
   A. Where high pressures have been present
   B. Where marine animals have been buried under many layers of sediment
   C. In lava flows from volcanoes
   D. In polar regions
4. MC **Identify** which of the following statements is correct.
   A. Iron is produced by the oxidation of alumina.
   B. Aluminium is produced by the oxidation of alumina.
   C. Aluminium is produced by the reduction of haematite.
   D. Iron is produced by the reduction of haematite.
5. MC Malachite is a blue-coloured, naturally occurring mineral containing copper. It contains copper in the form of copper(II) carbonate.
   Identify which three elements would be present in malachite.
   A. Copper, sulfur and oxygen
   B. Copper, carbon and oxygen
   C. Copper, carbon and sulfur
   D. Copper, sulfur and chlorine
6. MC **Identify** a reason that most elements are *not* found in their elemental state.
   A. All elements are very reactive and easily form compounds.
   B. Being present in compound form is the natural state for most elements.
   C. Even slow reactions from unreactive elements have occurred over a long period of time.
   D. Most elements are very rare.

Apply and analyse

7. SI Four mystery elements, labelled W, X, Y and Z, were given to a student. These were then left exposed to the air. After some time, it was found that element X was heavily coated with a white powder, while elements Z and W showed mild coatings. Element Y appeared unaffected.
   In a further test, elements Z and W were reacted with acid. Element Z reacted faster than element W.
   a. **List** these elements in order from most reactive to least reactive.
   b. **Explain** why elements X and Y were not treated with acid.
8. Many minerals contain sulfur.
   a. **Identify** what this indicates about the reactivity of sulfur.
   b. **Explain** why elemental sulfur can be found around volcanoes and in other geothermal areas.
9. **List** the following steps in their correct sequence to explain the presence of minerals in Earth's crust and the subsequent extraction of useful elements from them.
   - A mineral deposit is discovered.
   - Earth is formed.
   - A mineral deposit is assessed as economically viable and becomes classified as an ore.
   - Heat causes the reaction of elements to form compounds.
   - Oxygen becomes present in the atmosphere and reacts to form compounds.
   - Ore is extracted.
   - Energy is supplied to obtain the desired element.

10. Chlorine occurs in many compounds, the most common of which is sodium chloride. As a gaseous element, it has a number of uses, including the treatment of water in public swimming pools.
Chlorine gas is made using electrical energy in a process called electrolysis.
a. **Explain** why energy is needed to produce chlorine.
b. **Suggest** why the energy required is provided electrically rather than in other forms.

Evaluate and create

11. Imagine you are a scientist exploring a new planet. You discover some elements that are found free in nature, like gold and oxygen, while others are always combined with other elements, like sodium in salt. **Explain** why some elements are found free in nature while others exist in compounds with other elements. Use examples to support your explanation.
12. **SI** In an experiment, two students compared the reactivity of zinc to the reactivity of magnesium by reacting both with hydrochloric acid. The gas given off was collected and measured at various times for ten minutes. Their results were presented in the following table, but each student wrote a separate conclusion in their report.

Experimental results

Time (min)	1	2	3	4	5	6	7	8	9	10
Mg (volume (mL) of gas collected at 20 °C)	17	32	43	43	43	43	43	43	43	43
Zn (volume (mL) of gas collected at 25 °C)	11	21	30	35	41	45	50	50	50	50

In their conclusions, one student stated that magnesium is a more reactive metal than zinc, while the other student stated that zinc is more reactive than magnesium.
a. **Evaluate** each student's conclusion with respect to the results presented.
b. **Suggest** an additional way to present this data.

Answers and sample responses are available in your digital formats.

LESSON 6.7 Green chemistry

LEARNING INTENTION

In this lesson you will explain how some of the principles of green chemistry can be used to minimise harm to the environment.

6.7.1 What is green chemistry?

Green chemistry refers to a set of twelve principles developed in 1991. These were designed to encourage ways for manufacturing materials that would be better for the environment and more sustainable. Since then, many existing processes have been modified and many completely new ones have been developed.

Three of the easiest principles to understand are:
- minimising waste
- minimising energy use
- using environmentally friendly processes.

SCIENCE AS A HUMAN ENDEAVOUR: The history of green chemistry

The origins of green chemistry can be traced back to 1962, when the American author and biologist Rachel Carson published her best-selling book *Silent Spring*. This detailed how chemicals in use at the time were having a negative effect on the environment. The most famous of these was DDT — a chemical widely used at the time to control insects. This was accumulating in the bodies of animals, particularly those at the top of the food chain such as eagles. This resulted in their eggs having thin shells and breaking as the parents sat on the nest.

FIGURE 6.26 A statue of Rachel Carson at Waterfront Park in Massachusetts, United States, honours her legacy in environmental science.

Silent Spring served as a wake-up call to industry and society in general. Over the next few decades, public awareness gradually increased. This resulted in tighter pollution controls, the establishment of regulatory bodies such as the EPA (Environmental Protection Agency) and increased funding for research.

The original approach to pollution control was a ‘clean-up’ one. Industries complied with the increasingly tough pollution controls by removing the harmful wastes they produced. Eventually, however, the focus shifted to trying to design new processes that did not create waste in the first place. In 1998, Dr Paul Anastas and Dr John Warner outlined the 12 Principles of Green Chemistry; these have served as the basis for research and development since then.

In Australia, the Centre for Green Chemistry was established at Monash University in 2000 and has since become a world leader in this field. Many other bodies and organisations have also been established. The Royal Australian Chemical Institute (RACI) is a large professional body for chemists in Australia. They recently established a *Green and Sustainable* division, which held its first national conference in 2023.

Increase your awareness of green chemistry by investigating why many manufacturers and users are adopting new green chemistry processes, such as using carbon dioxide in dry cleaning.

1. How did Rachel Carson’s book *Silent Spring* influence public attitudes towards environmental protection and chemical use?
2. Why did the focus shift from cleaning up pollution to preventing it through green chemistry principles?
3. How can green chemistry practices, such as using carbon dioxide in dry cleaning, contribute to a more sustainable future?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

6.7.2 Case study 1: Producing ammonia

Ammonia is one of the most widely used chemicals in the world today. It is currently produced in huge quantities by the Haber process.

Making ammonia uses nitrogen from the air and hydrogen. Currently, most of this hydrogen comes from **fossil fuels** and produces carbon dioxide as a waste product. However, the production of hydrogen from water using renewable energy is being extensively investigated, as the only other product from this process is oxygen.

The equation for ammonia formation is:

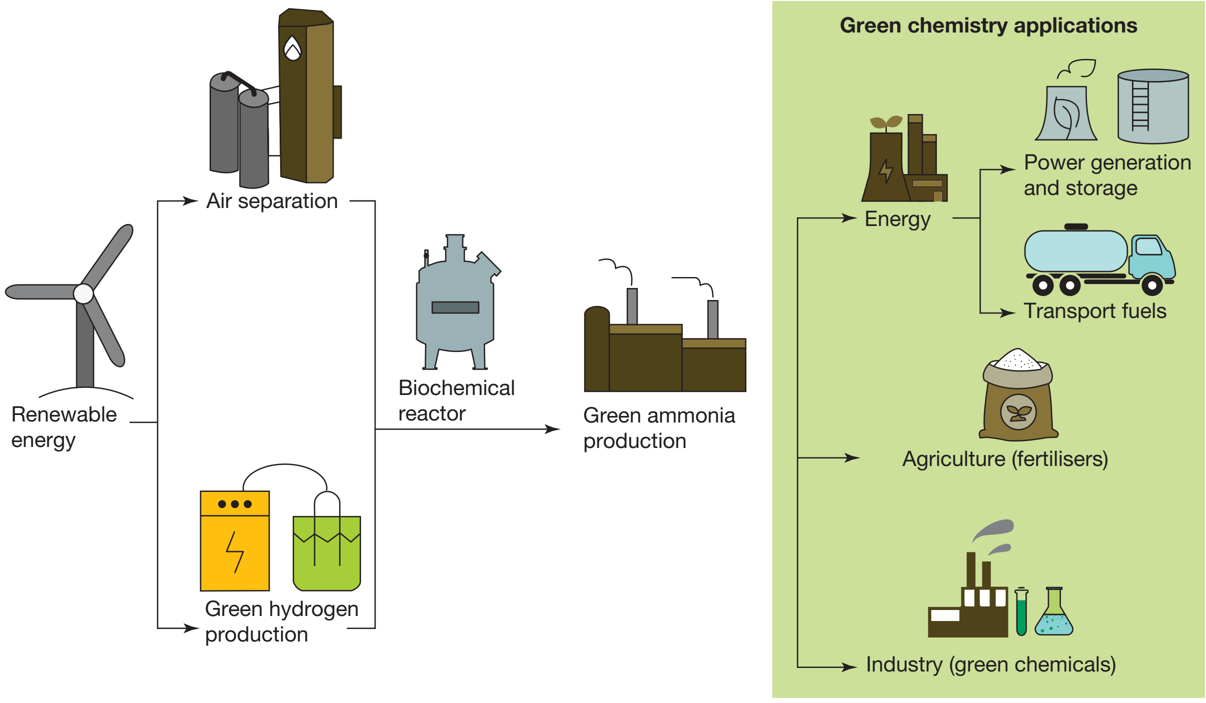
$$\text{hydrogen} + \text{nitrogen} \longrightarrow \text{ammonia}$$
$$3H_2 + N_2 \longrightarrow 2NH_3$$

This reaction produces the basic building block for ammonium nitrate fertiliser, the most important crop nutrient. Ammonia is produced both by soil bacteria and in industry. Over 50 per cent of the world's food production relies on the manufacturing of ammonia.

However, the industrial production of ammonia produces more carbon dioxide than any other chemical-making reaction. The reason for this is the Haber process of making ammonia uses high temperatures and pressures that add up to almost 1 per cent of the world's total energy production, and create approximately 1 per cent of global annual carbon dioxide emissions.

Chemists and engineers around the world are trying to make the reaction more sustainable by using renewable energy and 'green hydrogen' (discussed later in this lesson). As well as exploring better ways to supply the energy or reactants for the reaction, chemists are also looking at making the reaction better. It would be a long-term project to synthesise ammonia at low temperatures and pressure. One option being explored is looking at **biomimicry**, using the enzyme nitrogenase, which does the same reaction but at lower temperature and pressure. The production and applications of green ammonia are represented in figure 6.27.

FIGURE 6.27 Green ammonia production and applications



6.7.3 Case study 2: Extraction of metals

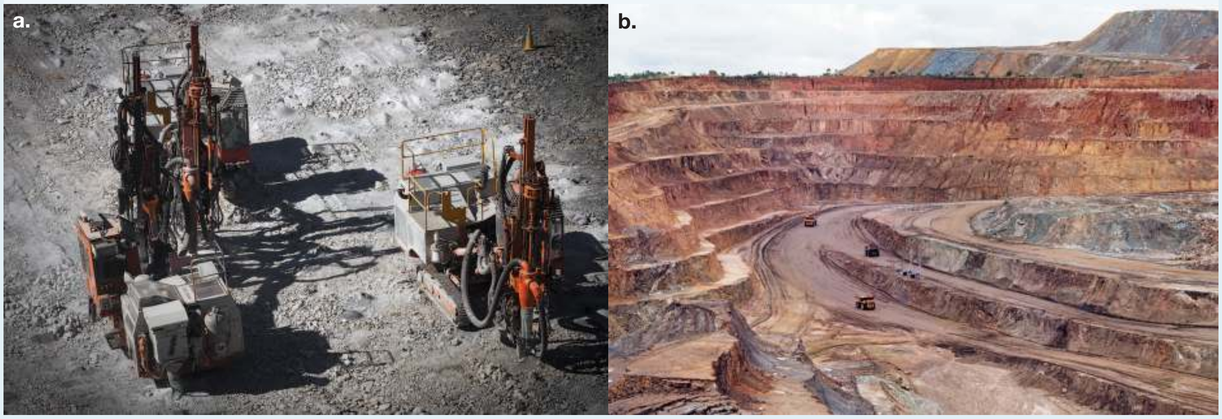
As seen in the previous lesson, the extraction of metals from their ores uses a lot of electricity and energy. It also produces a number of undesirable waste products, such as carbon dioxide gas. In addition, removing the ore from the Earth through mining causes damage to the environment. However, without the extraction of the reactive metals, we would not have chemicals for use in such things as batteries. Batteries are vital to store renewable energy, such as from wind and solar, as we move away from fossil fuels.

ACTIVITY

Nickel, cobalt and lithium are key elements used in today's high-performance batteries.

1. Research how these metals are extracted from ore and what the environmental concerns are in their mining, and in the manufacturing of this type of battery.
2. Research the recommended ways of disposing of the batteries and whether they can be sent to landfill.
3. Write a short paragraph to summarise your findings.

FIGURE 6.28 a. A lithium mine in Western Australia. In 2021, Australia was the world leader, before Chile and China, in lithium mine production. **b.** A copper mine in the Democratic Republic of Congo (DRC). Cobalt is often a by-product of copper mining. The DRC accounts for more than 70 per cent of the world's entire cobalt production.



An unfortunate effect from the extraction of a number of metals is atmospheric pollution. For example, you will recall from the previous lesson that sulfur dioxide is often produced from the smelting of copper ores. In the case of aluminium, sulfur dioxide is also generated indirectly from sulfur impurities in the coal used to generate the electricity required. Sulfur dioxide is one of the main causes of acid rain (discussed later in this lesson).

Reducing the environmental impact of metal extraction is currently the topic of much research. This research is focused on:

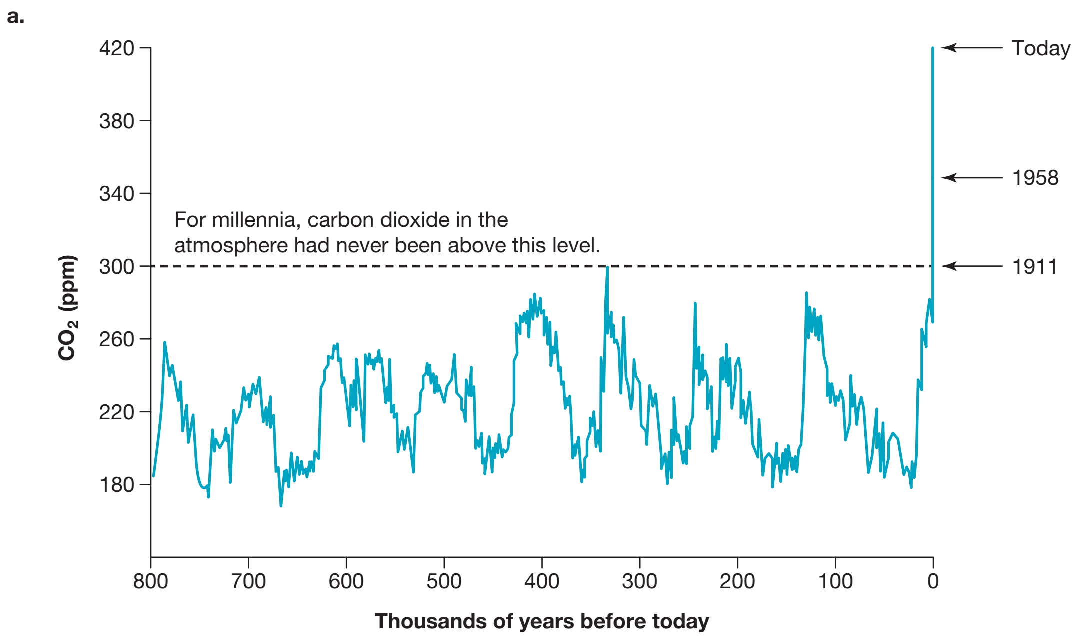
- adapting current technologies to become more energy efficient
- adapting current technologies to reduce waste products
- replacing carbon-based fossil fuels as an energy source
- developing new, low-temperature methods for metal extraction using renewable electricity
- increasing recycling rates
- developing new technologies for recycling.

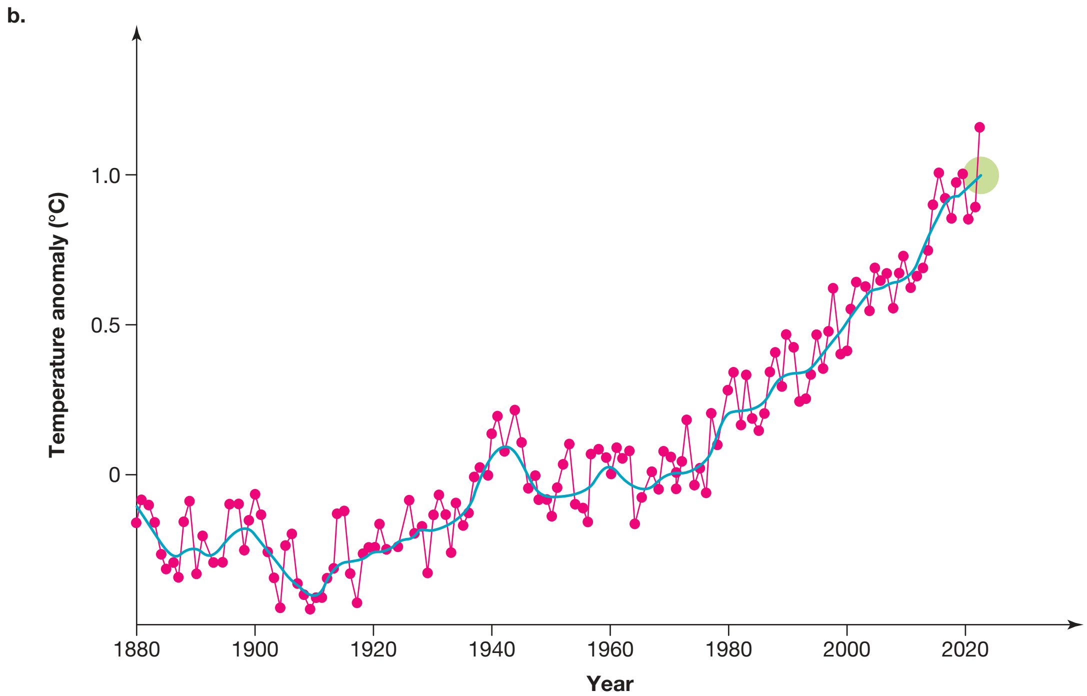
6.7.4 Case study 3: Fossil fuels

Fossil fuels such as natural gas, petrol and coal have formed from the remains of living things. They are compounds of hydrogen and carbon called hydrocarbons. The products of the combustion of fossil fuels always include carbon dioxide and water. Because of impurities in fossil fuels, other products of their combustion include sulfur- and nitrogen-rich gases. In some cases, various dangerous gases — including carbon monoxide — are also produced. Carbon dioxide, methane and nitrous oxide are the main greenhouse gases produced by human activities and make the largest contributions to the **enhanced greenhouse effect** and climate change.

Figure 6.29 clearly shows how both carbon dioxide levels in Earth's atmosphere and temperature have risen. The main contributor to this has been the use of fossil fuels in industry and transport.

FIGURE 6.29 a. The level of carbon dioxide in the atmosphere has risen dramatically due to the use of fossil fuels. **b.** Temperatures have also risen.





The simplest way to reduce the environmental effects of using fossil fuels is to reduce the amount of fuel used. Switching to green energy, such as solar or wind, rather than the inefficient use of coal to generate electricity is one way. Reducing the use of electrical energy by turning off appliances or selecting more energy-efficient ones is another option.

Another method is the use of biofuels. Biofuels are more sustainable as they are sourced from plants or waste oil. However, they too have some concerns, as crops that could be used as food are being directed to biodiesel. There are also concerns around the production of palm oil to make biodiesel, as this results in the destruction of the native habitat of orangutans and other wildlife to make way for palm trees.

EXTENSION: Antarctic and Greenland ice sheets

Scientists can estimate the carbon dioxide levels that have existed in the past by examining ice core samples from the Antarctic and Greenland ice sheets.

As snow falls over these regions, the accumulating snow on top turns the underlying layers into ice. Small bubbles of air become trapped in this ice and thus present a sample of the atmosphere at that point in time. By drilling down into this ice, scientists can go further and further back in time. There are methods by which the depth of the sample can be related to when it was formed.

In many cases, modern methods of analysis require only small samples, so it is possible to analyse these trapped air bubbles for the gases that they contain. It is also possible to analyse them to obtain a rough idea of the temperature at that time. One method to do this looks at the oxygen isotopes present in the water the ice is formed from. The ratio between the ^{16}O and ^{18}O isotopes is temperature dependent and gives a broad idea of the temperature.

Another reason why the Antarctic and Greenland ice sheets are suitable is that they are remote regions. The samples obtained represent air that has not been tainted by human activity.

Transport and electricity

The fuel used in most Australian cars is liquid **octane**. This is the major component of petrol, usually making up between 85 per cent and 95 per cent, with other fuels making up the remainder. One of these other fuels is ethanol, which is similar to octane but has fewer carbon atoms. The ethanol content of a fuel is sometimes displayed as E10, which means the fuel contains 10 per cent ethanol.

Octane is obtained from **crude oil**, which — like natural gas — is formed from the remains of marine plants and animals that died millions of years ago. The vapour of liquid octane reacts with oxygen, producing carbon dioxide and water. The reaction is started in each cylinder of a car by a spark from a spark plug. Only 30–35 per cent of the energy released during the reaction is used to turn the wheels of the car.

EXTENSION: Why is ethanol added to fuel?

Ethanol belongs to the group of compounds known as alcohols. It has the chemical formula C_2H_5OH. It is an alcohol because it contains an oxygen atom and a hydrogen atom joined together in what is called a hydroxyl group (–OH). Ethanol is added to fuel as it reduces the pollution emitted and contributes fewer greenhouse gases. The presence of oxygen in the ethanol assists the complete combustion of the petrol; this reduces the emissions of poisonous carbon monoxide (CO) and other pollutants. Another environmental advantage of using ethanol is that it can be produced from waste products of sugar production.

FIGURE 6.30 Ethanol is added to most unleaded fuel in Australia and is known as E10 fuel.

KEY IDEA

The chemical equation for the combustion of octane is:

$$\text{octane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$
$$2C_8H_{18} + 25O_2 \longrightarrow 16CO_2 + 18H_2O$$

The fuel used in jet aircrafts is **kerosene**, which is obtained from crude oil. Kerosene is a mixture of hydrocarbons and so does not have a single chemical formula. It contains between 12 and 15 carbon atoms. Like the octane in cars, the vapour of this fossil fuel reacts with oxygen and combusts to produce carbon dioxide and water. An electrical spark is used to start the reaction.

In 2019, about 76 per cent of Australia's electricity was generated by the burning of fossil fuels, largely coal. The energy released during the combustion reaction is used to heat water to produce steam. The steam turns the blades of giant turbines, transforming its energy into electrical energy.

Hydrogen fuel

The energy required to launch spacecraft is provided by a combustion reaction. The main rocket engines are fuelled by hydrogen, which reacts with oxygen in an exothermic reaction that releases enough energy to lift more than 2 million kilograms off the ground towards outer space. The only product of the reaction is water. Hydrogen fuel is a very clean energy source as it produces no carbon emissions. However, it is expensive to develop and hydrogen is difficult to transport safely. Technological developments for hydrogen as a fuel are occurring rapidly, with some countries using hydrogen fuel for their mass transport, such as buses.

KEY IDEA

The chemical equation for the combustion of hydrogen is:

$$\text{hydrogen} + \text{oxygen} \longrightarrow \text{water}$$
$$2H_2 + O_2 \longrightarrow 2H_2O$$

Most of the hydrogen produced today uses fossil fuel as a raw material and produces carbon dioxide as a product. However, the production of hydrogen by other means that are more environmentally friendly is making rapid progress. Such hydrogen is often referred to as 'green hydrogen'.

Two methods by which this can or might be done are:

- by using electricity to split water into hydrogen and oxygen in a process called electrolysis; this takes place in electrolysis cells
- by artificial photosynthesis.

For the first method to be truly friendly to the environment, it is important that the electricity used be generated in a renewable way. Using solar or wind energy are two ways to achieve this.

The technology involved in electrolysis cells is already well established, and larger and larger ones are being constructed each year. There is also a lot of research being performed on alternative designs that are more efficient and able to be used in a wider range of applications.

Making hydrogen via artificial photosynthesis is showing promise, but it is yet to be adopted on a large scale. This approach is another example of biomimicry. Natural photosynthesis uses light energy to convert carbon dioxide and water into glucose and oxygen. It is the reaction that fuels all life on Earth.

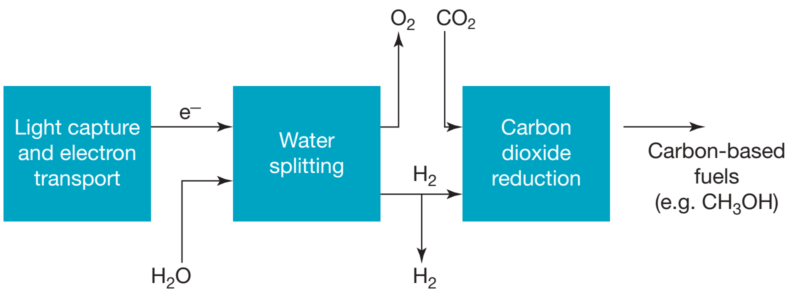
Much research is underway to develop artificial photosynthesis. This would allow a cleaner, low-temperature way to produce hydrogen and other fuels such as methanol.

When used as a fuel, methanol reacts with oxygen according to the following equation:

$$\text{methanol} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$
$$2CH_3OH + 3O_2 \longrightarrow 2CO_2 + 4H_2O$$

Using methanol produced in this fashion would be **carbon neutral**. The carbon dioxide that is put back into the atmosphere upon combustion is the same amount that was taken out of the atmosphere when the methanol was originally made. Figure 6.31 shows how such a scheme might work.

FIGURE 6.31 An artificial photosynthesis system has three important components and will be able to produce fuels such as hydrogen and methanol.



KEY IDEA

Much research is being conducted on producing hydrogen using green chemistry principles. Hydrogen is a promising energy source to replace fossil fuels.

CASE STUDY: Hydrogen-fuelled space travel

The US space program has used hydrogen fuel cells for all of their missions to space.

The Space Shuttle consumed nearly 3 million litres of liquefied hydrogen gas on each mission. On the International Space Station, hydrogen is created by splitting water into oxygen for breathing and hydrogen for fuel. In the future, hydrogen will be further recycled by recombining it with exhaled carbon dioxide to create water and methane. Hydrogen generation and recycling in space will reduce the need for supplies to be delivered from Earth and may bring us closer to a trip to Mars.

FIGURE 6.32 Cargo rocket delivering supplies to the ISS

ACTIVITY: Carbon dioxide and hydrogen

- Research the Apollo 13 mission and find out what problem they had with carbon dioxide that risked the lives of its three astronauts.
- Research NASA to find out how they are recycling the carbon dioxide and water in the current International Space Station and find some information about their plans to go to Mars.
- Discuss how carbon dioxide levels are a problem on Earth as well as in space.
- What is green hydrogen? What is blue hydrogen? Does hydrogen have any other 'colours'? Research different methods for producing hydrogen and summarise how these are related to its 'colours'.

Plastics

Fossil fuels are also used to produce plastics. Plastics were originally developed to use up a waste product, ethylene, created by the fuel industry, to make better use of this chemical found in crude oil. But this has exploded to the production of many different plastics. One reason they are used so widely is that they are lightweight and take less energy to transport compared to glass or metal containers. Plastics are cheap and very versatile; for instance, they can provide stretch and breathability in clothing.

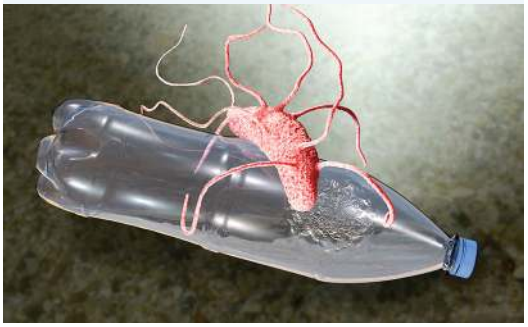
There are many issues with plastic waste due to the sheer amount of plastics being produced and thrown away. Approximately 80 per cent of plastic ends up in landfill or in the environment, such as in rivers and oceans. Chemicals added to plastics can leach into the environment. Plastics do not decompose, but they can break down into small pieces called microplastics. While microplastics may not be as visible, they have been detected in marine organisms and in drinking water.

Reducing and reusing all plastics would be one way to address this. Single-use plastics such as cups or straws are one of the main sources of plastics in the environment. Thus, finding an alternative (bamboo cups, for instance) would also help.

One alternative is biodegradable plastic, which is based on natural polymers rather than fossil fuel-based ones. Over time, biodegradable plastics would be broken down into water, carbon dioxide and compost by microbes in the soil. The aim of the chemists developing these bioplastics is for them to have similarly useful properties as synthetic plastics.

Scientists are discovering that some microbes are evolving to degrade plastic. The bacterium *Ideonella sakaiensis* can consume the plastic polyethylene terephthalate (PET), which is used for bottles and clothing.

FIGURE 6.33 *Ideonella sakaiensis* is a bacterium capable of rapidly degrading polyethylene terephthalate (PET), a plastic widely used in the manufacture of packaging and containers.



6.7.5 Acid rain

What causes acid rain?

Every year, **acid rain** causes hundreds of millions of dollars worth of damage to buildings and statues.

The photographs in figure 6.34 show the damage that has been caused to a statue over 60 years. Forests, crops and lakes are also affected by acid rain that is blown in from industrial areas.

Rain is normally slightly acidic. As clouds form and rain falls, the water reacts with carbon dioxide in the atmosphere to form very weak carbonic acid.

$$\text{water} + \text{carbon dioxide} \longrightarrow \text{carbonic acid}$$
$$H_2O + CO_2 \longrightarrow H_2CO_3$$

FIGURE 6.34 These photographs were taken in 1908 (left) and 1969 (right). You can see the damaging effects of acid rain on this statue.

Acid rain occurs when gases such as sulfur dioxide and nitrogen oxides are released into the air, especially if they are in localised areas. These gases react with water to eventually form dilute sulfuric and nitric acids. The source of the gases is mostly from the combustion of fossil fuels. Sulfur impurities in the fuel produce the sulfur dioxide, and the nitrogen oxides result from the high temperatures and the air that is used. Sulfur dioxide is also produced from the smelting of sulfide ores to produce metals.

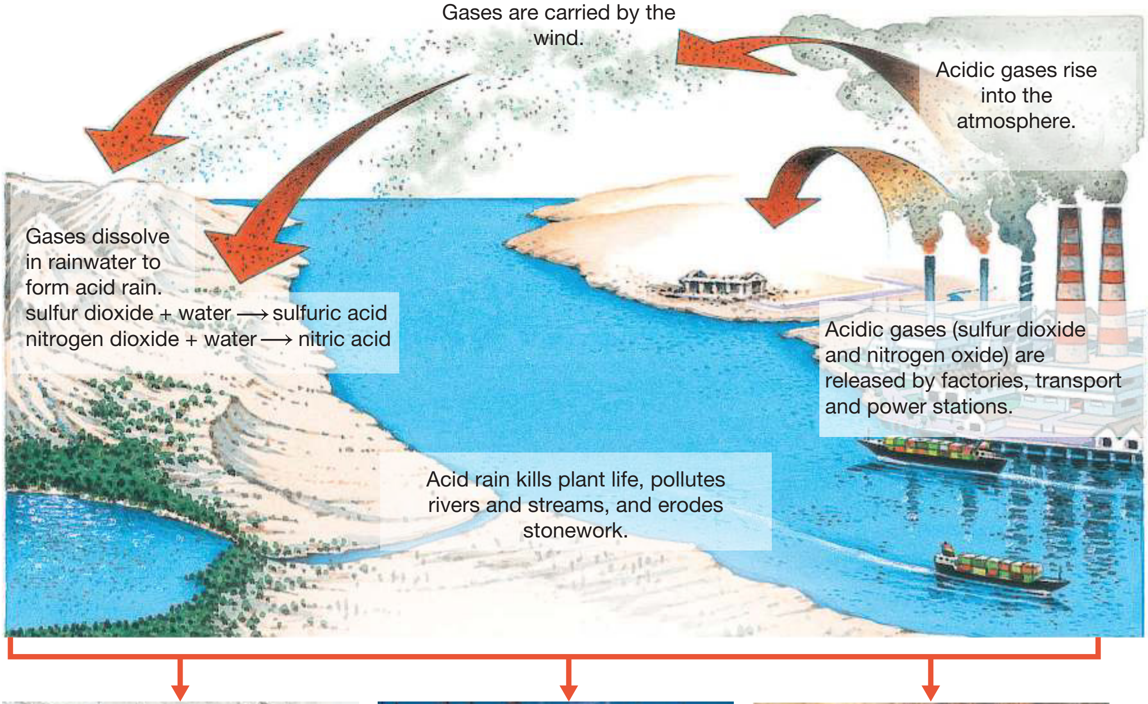
Damage caused by acid rain

Acid rain causes huge damage. It can kill plants directly, as well as by changing the pH of the soil in which they grow. When it reaches rivers and lakes, the pH of the water may drop to a level that cannot be tolerated by fish and plants, and they die. It can also cause elements such as aluminium to leach out of the soil and into waterways, resulting in further death to aquatic plants and animals. Acid rain also causes significant damage to any marble in buildings and statues. Marble contains calcium carbonate and, as we saw in lesson 6.5, this reacts with acids. A typical equation for this is:

$$\text{calcium carbonate} + \text{acid rain} \longrightarrow \text{gypsum (calcium sulfate)} + \text{water} + \text{carbon dioxide}$$

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2$$

FIGURE 6.35 The damage caused by acid rain



When acid rain eats into buildings and statues, it is reacting with calcium carbonate in the marble or limestone.

calcium carbonate + acid rain ⟶ gypsum + water + carbon dioxide

Acid rain damages the cells on the surface of leaves and affects the flow of water through plants. It also makes plants more likely to be damaged by frosts, fungi and diseases. In northern Europe, entire forests have died as a result of acid rain.

Acid rain collects in streams, rivers and lakes, making the water more acidic. Acid rain causes the pH in lakes to fall. Some aquatic plants and animals cannot tolerate these acidic conditions and die.

ACTIVITY: Queenstown, Tasmania

A famous Australian example of environmental damage due to deforestation and acid rain occurred around a copper smelting mine in Queenstown, Tasmania.

- Investigate the causes and impacts of environmental damage near the Queenstown copper smelting mine in Tasmania.
- Prepare a short report that summarises your findings.

After the mine and smelter ceased operation many years ago, some of the local residents proposed that the barren landscape be maintained by preventing any natural and planned regrowth.

- What reasons might local residents have for wanting to preserve the barren landscape instead of allowing regrowth?
- Do you agree with their proposal? Why or why not?

INVESTIGATION 6.5

Investigating acid rain

Aim

To investigate the effect of pH of acidic water on the growth of seeds

Materials

- empty milk cartons
- potting soil
- distilled water
- measuring cylinder
- vinegar (or 0.1 M hydrochloric acid solution)
- seeds (e.g. lucerne, peas, cress, beans)
- universal indicator

Method

1. Cut the milk cartons so that they are about 10 cm high. These will make suitable containers for growing the seeds. Use five seeds per container.
2. Design an experiment to test the effect of water with different pH values on the growth of the seeds. To ensure that your tests are fair, you will need to keep everything the same in your experiment, except the one thing that you are varying. In this case, you are varying the level of acidity (pH) of the water that you are putting on the plants.

Discussion

Prepare a report on your investigation. This could be a written report, a video, a wall chart or an oral presentation.

6.7 Activities

learnon

6.7 Quick quiz on	6.7 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
2, 3, 6, 10	1, 4, 7, 11	5, 8, 9, 12

Remember and understand

1. Is the following statement true or false? **Justify** your response.
   Fossil fuels are different from other types of fuel because they are formed from the remains of living things.
2. MC **Identify** the gas present in the air that makes rain slightly acidic even without air pollution.
   A. Carbon dioxide
   B. Nitrogen
   C. Oxygen
   D. Hydrochloric acid
3. MC Copper is extracted in large quantities from ores that frequently contain sulfur.
   Identify which of the following is true of this process.
   A. It is an example of biomimicry.
   B. It produces oxygen.
   C. It produces sulfur dioxide.
   D. It uses energy in the form of electricity.
4. **List** two examples of biomimicry that might be used in the future to make important chemicals.

5. MC **Identify** which of the following is *not* true about the production of aluminium.
   A. Recycling is much cheaper than its original production.
   B. It does not produce any carbon dioxide.
   C. It uses large amounts of electricity.
   D. It is produced from bauxite ore.
6. a. **Identify** whether the following statement is true or false.
   Biomimicry is the use or adaptation of processes that occur in nature.
   b. **Explain** how biomimicry aligns with the principles of green chemistry.

Apply and analyse

7. **Describe** at least two effects on the environment of the combustion of fossil fuels.
8. Research and **discuss** how kerosene and octane are extracted from crude oil.
9. Motor vehicles make a large contribution to the acid rain problem. Most of them use fuel that releases acidic nitrogen oxides when it is burned. **List** some of the ways motor vehicle pollution could be reduced over the next 30 years.

Evaluate and create

10. Think about a product you use every day, like a soap or a cleaner. **Describe** how you could make this product safer for the environment using green chemistry principles. **Explain** one or two changes you would make.
11. **Compare** traditional chemical processes with green chemistry principles. **Explain** whether green chemistry principles help in reducing pollution and conserving resources. Provide examples to support your explanation.
12. **Evaluate** the use of renewable resources in green chemistry. **Explain** why it is important to use renewable resources instead of non-renewable ones. **Discuss** how this practice can minimise environmental harm, and give examples of renewable resources used in green chemistry.

Answers and sample responses are available in your digital formats.

LESSON 6.8 Review

6.8 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
6.2	I can identify the reactants and products in chemical reactions.			
	I can use models and representations to show the rearrangement of atoms in chemical reactions.			
6.3	I can describe the Law of Conservation of Mass.			
	I can relate data obtained from open and closed systems to the Law of Conservation of Mass.			
6.4	I can balance symbol equations.			
	I can explain the rationale for balancing chemical equations with reference to the Law of Conservation of Mass.			
6.5	I can describe how acid–base and redox reactions are important in our everyday life.			
6.6	I can explain why some elements are found free in nature, while others exist in compounds with other elements.			
6.7	I can explain how some of the principles of green chemistry can be used to minimise harm to the environment.			

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Post-test	Topic 6 Post-test
eWorkbook	Topic 6 eWorkbook
Digital document	Key terms glossary

6.8 Activities

learnon

6.8 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4, 9, 10	3, 6, 8, 11, 14	5, 7, 12, 13, 15

Remember and understand

1. A particular chemical reaction can be described by the following word equation:

   hydrochloric acid + magnesium carbonate ⟶ magnesium chloride + water + carbon dioxide

   a. MC **Identify** the two reactants in this chemical reaction.
      A. Hydrochloric acid B. Magnesium chloride C. Water
      D. Magnesium carbonate E. Carbon dioxide

   b. MC **Identify** all the products of the reaction.
      A. Hydrochloric acid B. Magnesium chloride C. Water
      D. Magnesium carbonate E. Carbon dioxide

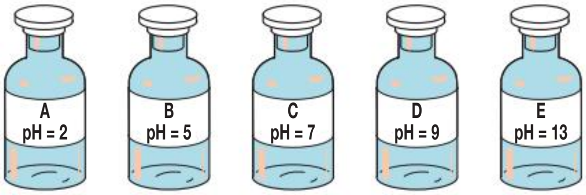
   c. MC **Identify** from which compound the atoms present in the carbon dioxide came.
      A. Hydrochloric acid B. Magnesium chloride C. Water
      D. Magnesium carbonate E. Carbon dioxide

2. MC **Identify** what observable evidence demonstrates that a chemical reaction has taken place.
   A. The apparent disappearance of a substance
   B. The appearance of a new substance
   C. A release of energy (often heating the surroundings noticeably)
   D. The absorption of energy (cooling the surroundings)
   E. All of the above
3. Use the Law of Conservation of Mass to **explain** why it is incorrect to say that when a candle burns, it disappears.
4. **Identify** the missing word to complete the sentence.
   The Law of Constant Proportions states that a compound always contains ____________ relative amounts of each element.
5. Nitrogen reacts with hydrogen to form ammonia.
   State which of the following statements is correct.
   I. This is a reaction that over 50 per cent of the world's food production relies upon.
   II. This process produces more carbon dioxide than any other reaction.
   III. Forming ammonia from decomposing organisms is being investigated as an alternative.
   IV. As ammonia is a natural product, there are no concerns with excess production.

Apply and analyse

6. MC **Identify** which of the following elements is *not* found free in nature.
   A. Platinum
   B. Oxygen
   C. Argon
   D. Aluminium
7. **Predict** the salts that would result from the neutralisation reaction between:
   a. magnesium oxide and hydrochloric acid
   b. copper(II) oxide and sulfuric acid
   c. sodium hydroxide and ethanoic acid
   d. sodium oxide and nitric acid.

8. The liquids in the bottles shown are labelled with their pH.



Identify which of the bottles is most likely to contain:
a. distilled water
b. a strong acid
c. black coffee
d. bathroom surface cleaner.

9. MC **Identify** the type of pool chemical that should be added if the water in a swimming pool has a pH that is too high for hygienic and safe swimming.
A. An acid
B. A base
C. Water
D. Carbon dioxide

10. **Identify** the missing word to complete the chemical word equation.

$$\text{acid} + \text{metal} \longrightarrow \text{\_\_\_\_\_\_\_\_\_\_} + \text{hydrogen}$$

11. There are at least two reactants in every combustion reaction. One of them is called a fuel.
a. **State** the substance that the fuel always reacts with.
b. **State** one product of every combustion reaction.
c. One product of combustion reactions is not a chemical. **Identify** what it is.

12. MC **Identify** two chemical products of combustion reactions in which fossil fuels are burned.
A. Carbon dioxide and hydrogen
B. Carbon dioxide and water
C. Water and hydrogen
D. Hydrogen and energy

13. One combustion reaction takes place in every cell of your body.
a. **State** the name of this combustion reaction.
b. **Name** the reactants in the reaction.
c. **Name** two chemical products of the reaction.
d. **State** the chemical equation for this reaction.

Evaluate and create

14. Worded equations, balanced equations and modelling reactions are three different ways to represent chemical reactions.
a. **Describe** the advantages of each method and why different ones are used at different times.
b. **Identify** which one demonstrates the Law of Conservation of Mass the best.
c. **Name** a common reaction in your body or around your home and show it in the three different ways.

15. **Describe** the extraction of elements such as aluminium and iron.
a. In what ways are they similar, and how are they different?
b. What are the environmental effects of the extractions?
c. What is a simple solution you can do to reduce these effects?

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

7 Earth's interrelated systems

CONTENT DESCRIPTION

Carbon is cycled on Earth through key processes including photosynthesis, respiration, fire, weathering, vulcanism and the combustion of fossil fuels; these processes change the composition of Earth's interrelated systems (atmosphere, biosphere, hydrosphere and lithosphere) over time (VC2S10U10)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 7.1 Overview

7.1.1 Introduction

The number of mobile phone users in the world, based on subscriptions, is approximately 8.6 billion. That is more than the number of people in the world! This staggering number raises an important question: are mobile phones harmful to the environment? If you answered no to this question, you may need to consider the **carbon footprint** generated during the making, using and recycling of mobile phones.

FIGURE 7.1 Mobile phones are commonly used.

Mobile handsets are made from rare metals. Electricity is required when extracting these metals from Earth's crust, when purifying the metals, when transporting components and in packaging. Electricity is required when you recharge your mobile phone. In Australia, most electricity is sourced from burning coal. When coal is burned completely, carbon dioxide (CO_2) and water vapour (H_2O) are produced. Per year, the amount of carbon dioxide produced from manufacturing and using mobile phones is approximately 80 kilograms. For each user, about 19 kilograms of carbon dioxide is produced via text messages, phone calls and charging per year. Just imagine if you multiplied the total mass of carbon dioxide by 6.8 billion.

You can also expect the number of mobile phone users to increase in future years, because mobile phones are fast replacing telephone lines. There is an increasing need to use mobile phones to pay for things, to listen to music, to video chat with friends, to use online platforms such as Instagram, Snapchat and TikTok, and for many other activities. Mobile phones are very versatile and are indispensable.

Many people are unaware that carbon dioxide is produced when using any electrical device. How can we use our scientific knowledge and understanding to reduce the amount of carbon dioxide released into the atmosphere now, rather than in 30 years' time?

DISCUSSION

1. What are three animal species affected by climate change?
2. Why is it a problem if the global amount of carbon dioxide continues to increase?
3. Why is it becoming more difficult for tourists to visit Kakadu National Park?
4. Is the atmosphere the same as the biosphere? Justify your response.
5. What is a carbon footprint?
6. What is cultural burning?

SCIENCE INQUIRY: Can you fight fire with fire?

Before 2019, Australian scientists calculated that net-zero carbon emissions was achievable. However, in only a short period of time during the 2019–2020 bushfire season, about 350 million tonnes of carbon dioxide were released into the atmosphere. In comparison, 530 million tonnes of carbon dioxide were released throughout the whole year in 2017. Scientists have noted that the significant increase in carbon dioxide emissions in the Australian summer of 2019–2020 was due to high-temperature bushfires — since carbon dioxide gas is produced when trees burn.

Over many generations, Aboriginal and Torres Strait Islander Peoples have used fire to manage the environment by slowly burning patches of land. This fire management approach is known as **cultural burning** or **firestick farming**. Aboriginal and Torres Strait Islander Peoples often use low-intensity fires, lit in a mosaic pattern during particular seasons, so that the burns can be controlled and to minimise risk to people, animals and the land. This technique of cultural burning reduces the fuel load, such as dry vegetation and fallen leaves, so that bushfire intensity is decreased.

FIGURE 7.2 Unburnt and burnt vegetation using cultural burning

Research cultural burning (e.g. using the Australian Museum website) and then answer the following questions.

Questioning and understanding

1. a. What are the main differences between bushfires and cultural burning?
   b. Identify the evidence that supports why scientists are concerned about bushfires.
   c. How does cultural burning reduce carbon dioxide emissions?
   d. Identify the effects of bushfires on **biodiversity**.

Planning and conducting

2. a. Describe the fieldwork and laboratory work that a scientist would need to conduct to measure the amount of smoke and carbon dioxide emitted from a plot of grass or vegetation. Explain why it is essential for the scientist to conduct their work during different times of the year.
   b. To reduce future carbon dioxide emissions, scientists need to work with Aboriginal and Torres Strait Islander Peoples. What information needs to be shared between both groups to ensure successful cultural burning practices?

Analysing and evaluating

3. a. Identify the evidence that suggests that Aboriginal and Torres Strait Islander Peoples have been using cultural burning for thousands of years.
   b. Construct a table regarding the benefits and issues of bushfires and cultural burning.

Communicating

4. Create a presentation on the benefits of cultural burning.

Valid, reproducible investigations to answer questions and test hypotheses can be planned and conducted, including identifying and controlling for possible sources of error and bias in sampling or in making observations; safe, ethical investigations include undertaking risk assessments and following protocols when accessing cultural sites and artefacts on Country and Place (VC2S10I02)

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Pre-test	Topic 7 Pre-test
eWorkbook	Topic 7 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 7 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 7.2 Global systems

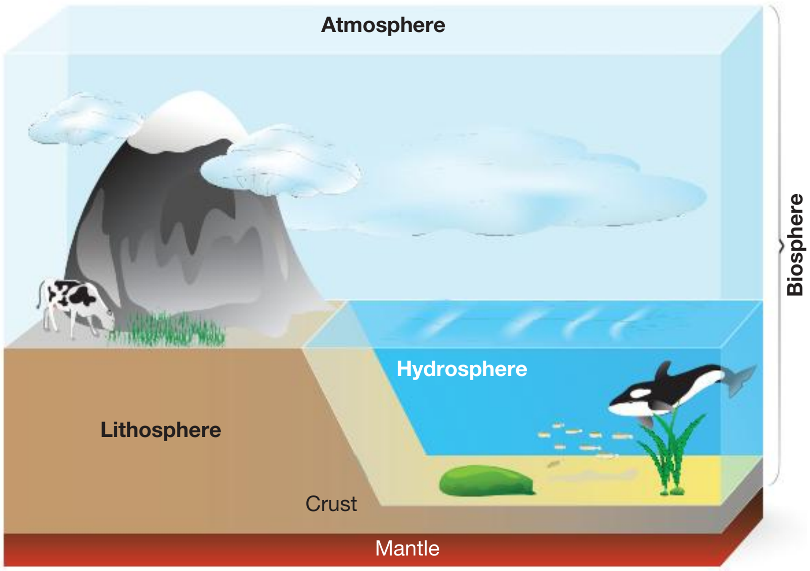
LEARNING INTENTION

In this lesson you will:
- describe how the biosphere supports all life on Earth
- describe the processes that cause carbon to be cycled to and from the atmosphere.

7.2.1 Introducing Earth's global systems

Earth is made up of a number of interconnected systems. Four of these are considered to be global systems. These are the **biosphere**, the **atmosphere**, the **hydrosphere** and the **lithosphere** (also called the geosphere). Interactions occur between all of these spheres with each other and the radiant energy of the Sun.

FIGURE 7.3 Diagram showing the relationship between the biosphere, atmosphere, hydrosphere and lithosphere



KEY IDEA

The names for the different spheres within the biosphere have a Greek root. They come from the words *atmos* ('vapour'), *hydro* ('water'), *lithos* ('stone') and *sphaîra* ('globe' or 'ball'). These combine to make:
- atmosphere — vapour globe
- hydrosphere — water globe
- lithosphere — stone globe.

The atmosphere is the layer of gases (such as nitrogen, oxygen, methane, ozone and carbon dioxide) around Earth. The hydrosphere includes the water above, on and under Earth's surface, such as the oceans, seas, lakes and rivers. The lithosphere comprises of Earth's outer crust and the uppermost part of the mantle, and includes soil and rocks. The biosphere includes all living things (**biota**) and all of the ecosystems on Earth. The biosphere extends down to the deepest oceans and beyond, where roots and microorganisms survive, and includes all the airspace where life exists too; thus, the biosphere overlaps the atmosphere, hydrosphere and lithosphere.

Within these ecosystems, nutrients and materials are cycled continuously, including carbon, nitrogen, phosphorus and water. This topic focuses on the carbon cycle and the role carbon dioxide plays in the **greenhouse effect** and its direct link to **global warming**.

KEY IDEA

The biosphere is the part of Earth that supports life, including plants, animals and microorganisms. It overlaps with the atmosphere (air), hydrosphere (water) and lithosphere (land), forming a network of ecosystems where materials like carbon, nitrogen and water are continuously cycled to sustain life.

7.2.2 The carbon cycle and interactions between Earth's spheres

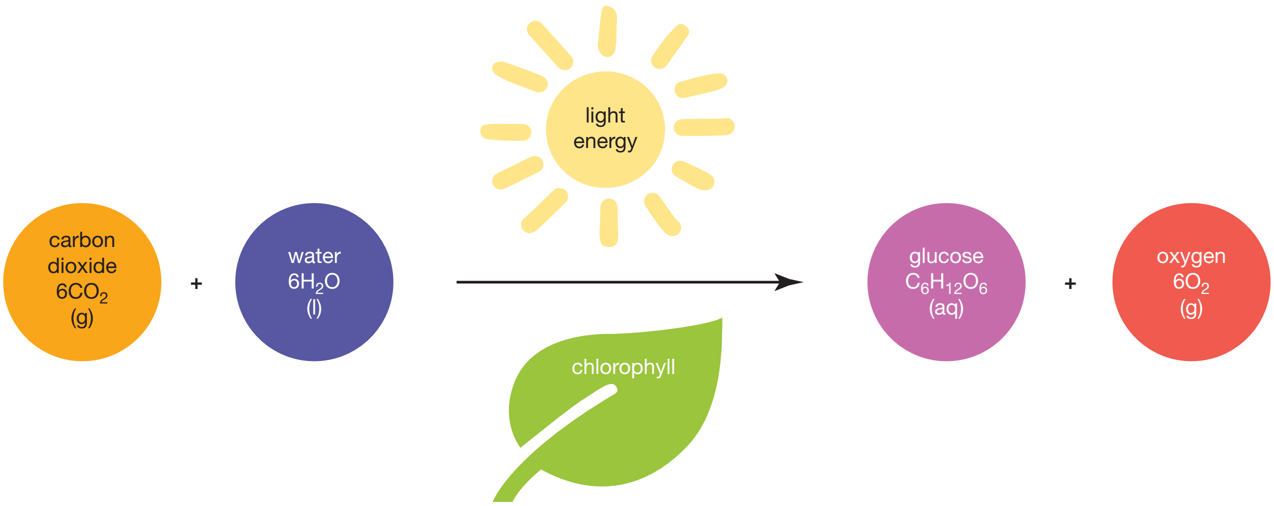
Carbon is everywhere

Carbon is present in various forms on Earth. Carbon cycles through Earth's spheres via processes such as **photosynthesis**, **respiration** and **combustion**, which absorb and release carbon dioxide (CO_2).

Photosynthesis

Photosynthesis is the process by which plants (and other **phototrophic** organisms such as algae) take in carbon dioxide (CO_2) and water (H_2O), and use light energy to make glucose ($C_6H_{12}O_6$) and oxygen (O_2).

FIGURE 7.4 The process of photosynthesis



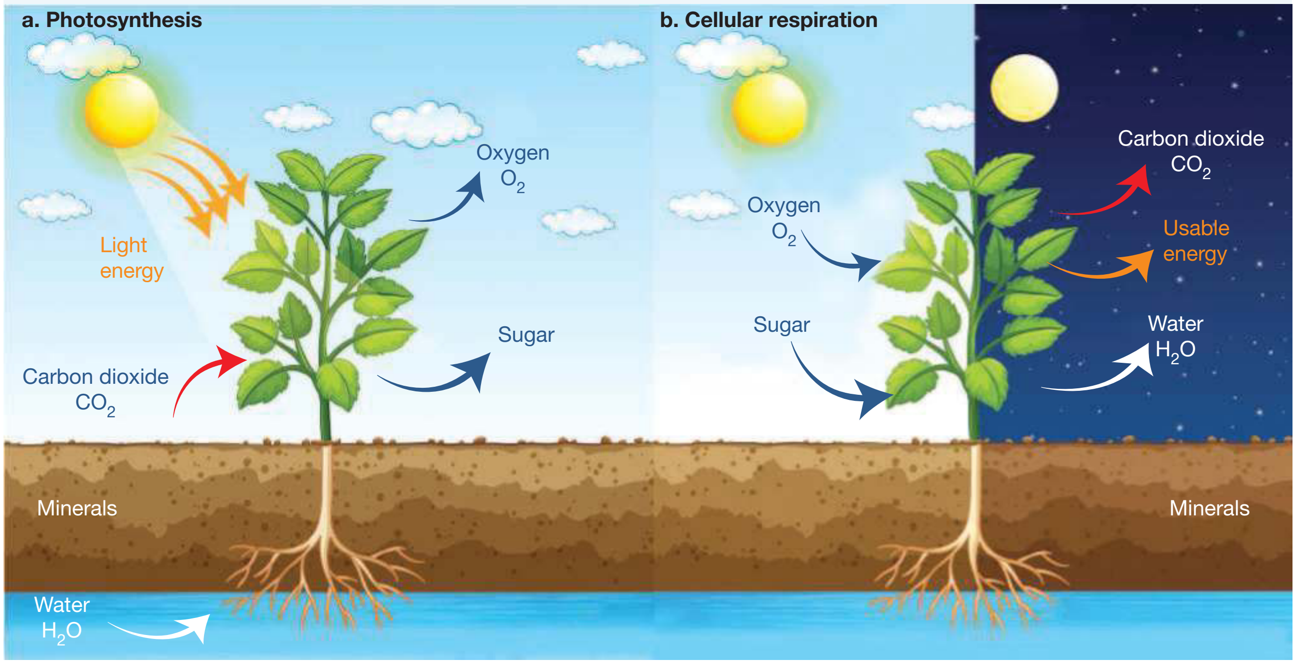
Respiration

Respiration (also known as cellular respiration) is the process by which stored glucose is converted into a form of energy that cells can use. In this reaction, glucose ($C_6H_{12}O_6$) is broken down in the presence of oxygen (O_2), and both carbon dioxide (CO_2) and water (H_2O) are produced.

FIGURE 7.5 The process of cellular respiration

glucose $C_6H_{12}O_6$ (aq) + oxygen $6O_2$ (g) $\longrightarrow$ carbon dioxide $6CO_2$ (g) + water $6H_2O$ (l) + energy

FIGURE 7.6 a. Photosynthesis occurs during the day and **b.** cellular respiration occurs during both the day and night



Combustion

Combustion is a chemical reaction in which a fuel reacts rapidly with oxygen (O_2) to produce heat energy, carbon dioxide (CO_2) and water (H_2O). Wood and grass burning in a bushfire is an example of combustion in nature.

FIGURE 7.7 A combustion reaction

carbon-based fuel + oxygen O_2 (g) $\longrightarrow$ carbon dioxide CO_2 (g) + water H_2O (l) + energy

The carbon cycle

Carbon travels from the atmosphere to living things when carbon dioxide is absorbed by plants and other phototrophic organisms during photosynthesis. Carbon dioxide is then released by living things back into the atmosphere as a result of the process of respiration. The combustion or burning of **fossil fuels** (such as coal from the lithosphere) will also result in carbon dioxide being released into the atmosphere. The carbon dioxide in the atmosphere is then available for use in photosynthesis again — and the cycle continues.

The carbon cycle models how carbon moves through the spheres in a circular loop, as shown in figures 7.8 and 7.9.

FIGURE 7.8 A simplified image of the carbon cycle

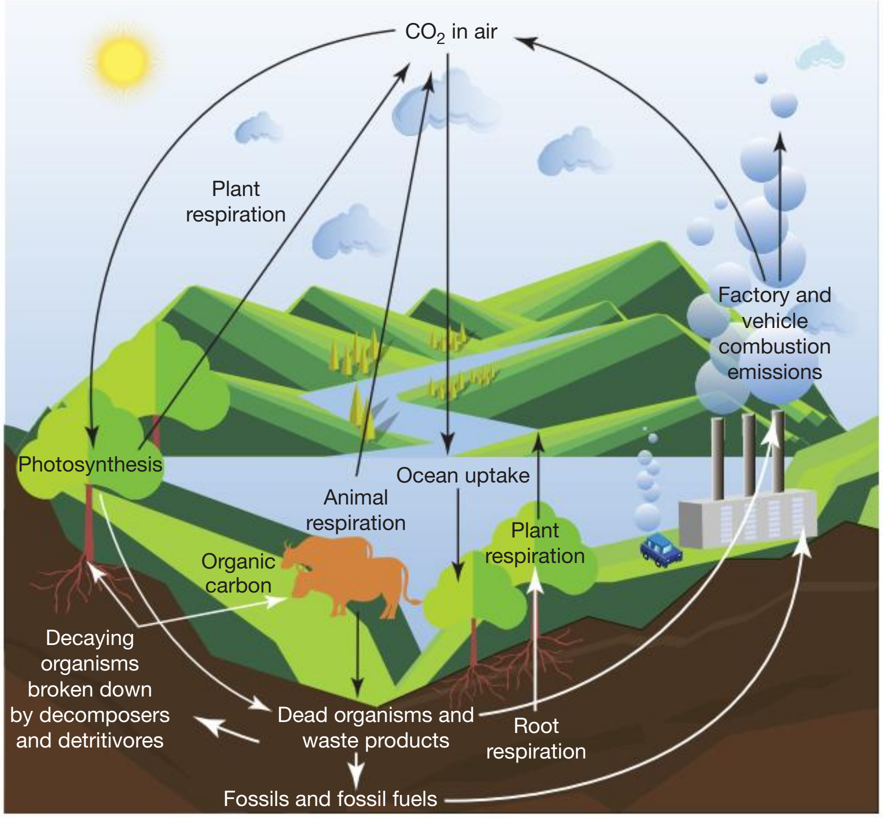
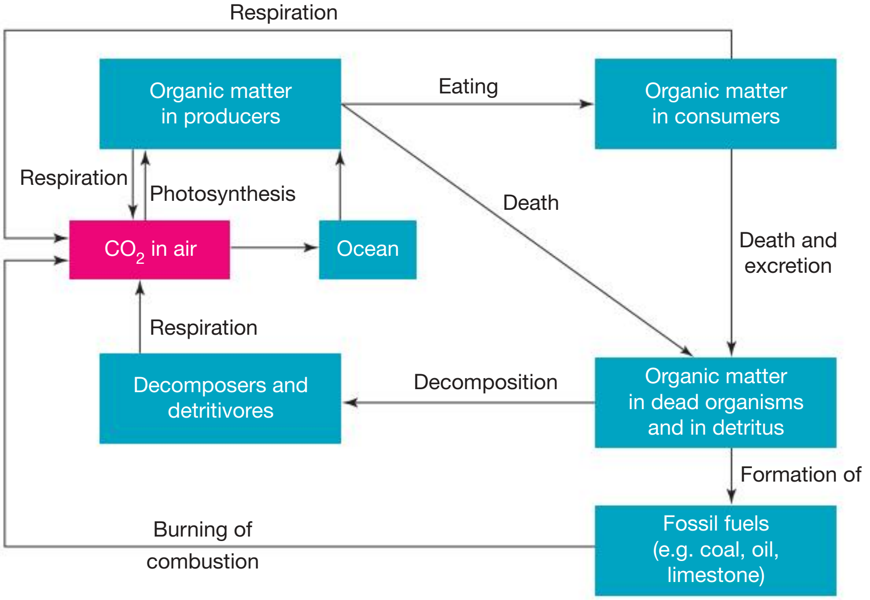


FIGURE 7.9 A simplified illustration of how carbon is cycled within an ecosystem



The atmosphere

In the atmosphere, most of the carbon exists as carbon dioxide gas, $CO_2(g)$. Figure 7.10 shows some sources of atmospheric carbon dioxide. Globally, the concentration of carbon dioxide has increased by about 12 per cent since the year 2000. In April 2025, the concentration of carbon dioxide was 428 parts per million (ppm) compared to 370 ppm in 2000.

FIGURE 7.10 Sources of atmospheric carbon dioxide: **a.** farming cattle **b.** factory emissions **c.** crops

The hydrosphere

The waters of our planet make up the hydrosphere and come from the surface of the planet, from underground and from the air (approximately 4 per cent). The water cycle demonstrates how water continually moves around in different states (solid, liquid and gas).

Why is water so important? All organisms on Earth require water to survive. For example, plants need water for photosynthesis and if they do not have water, they will die. Consequently, consumers of these plants will also perish, and so on. The evaporation of water from the sea surface is also important for the movement of heat as part of the climate system. This evaporation helps cool the surface of the ocean and helps to reduce the greenhouse effect.

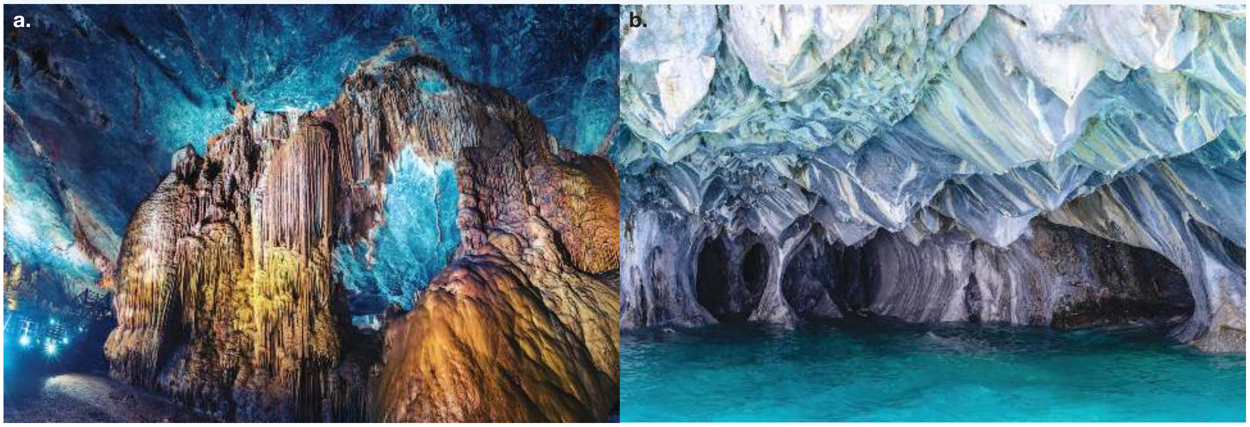
Within oceans, lakes and seas, carbon can be stored as dissolved CO_2, in shells, or deep in the ocean bed as calcium carbonate due to the decay of dead sea plants and animals over thousands of years.

FIGURE 7.11 The hydrosphere includes all water bodies, and is essential to our climate and all life on Earth. Carbon is found dissolved in oceans and in the ocean bed.

The lithosphere

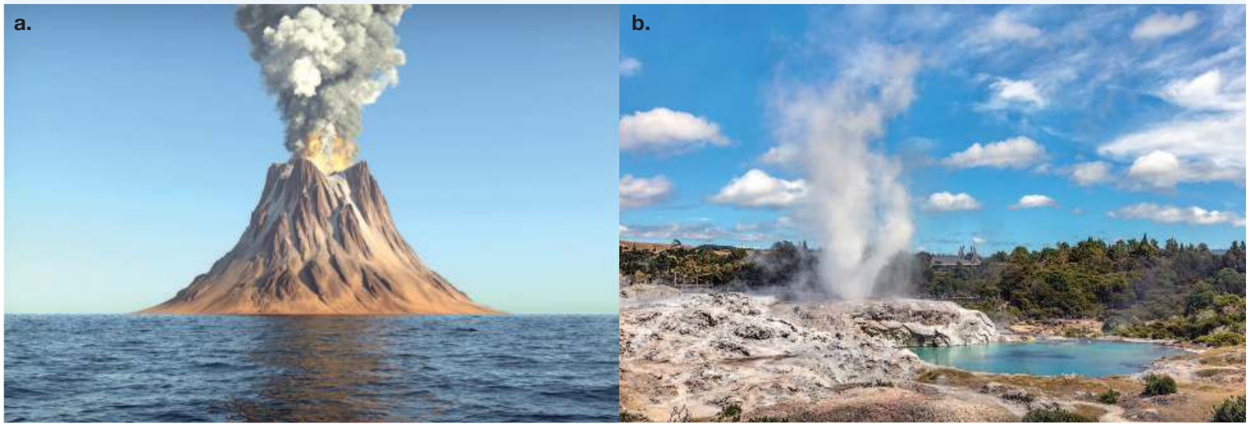
Earth's rocky crust (consisting of igneous, sedimentary and metamorphic rocks) and soil make up the lithosphere. Carbon can be found in the sedimentary rocks as calcium carbonate, a form of **limestone** or **marble**. Figure 7.12 shows examples of caves containing calcium carbonate. The deeper parts of the Earth may contain diamond and graphite, which are **allotropes** of carbon.

FIGURE 7.12 Caves containing calcium carbonate: **a.** limestone cave **b.** marble cave



Carbon dioxide can react with rain to form weakly acidic water, which can dissolve minerals on Earth's surface. These minerals may be washed away and can eventually reach the ocean to form limestone. Violent volcanic eruptions or hot spring vents can return carbon dioxide back into the atmosphere.

FIGURE 7.13 a. Volcanic eruptions and **b.** hot spring vents release carbon dioxide gas into the atmosphere.



The decomposition of organisms or parts of organisms (such as the leaves, roots and branches of plants) in the soil is another source of carbon. Decomposition involves the breaking up of a substance into smaller parts. Microorganisms, fungi and other **decomposers** that live on or in the soil assist in the breaking down of dead and decaying matter. Other organisms, called **detritivores**, also feed on decomposing organic matter and undergo cellular respiration.

DISCUSSION

As a class, discuss the following.

1. How has the concentration of carbon dioxide in the atmosphere changed since the year 2000, and why is this increase a concern for the environment?
2. Why is the hydrosphere important for regulating carbon dioxide levels and maintaining the climate system?
3. How does carbon stored in the lithosphere, such as limestone and marble, eventually return to the atmosphere?
4. What role do decomposers and detritivores play in the carbon cycle, and why are they important for maintaining ecosystems?
5. How are the atmosphere, hydrosphere and lithosphere interconnected in the carbon cycle?

SCIENCE AS A HUMAN ENDEAVOUR: The biosphere and the carbon cycle — sustaining life on Earth

As discussed previously in this lesson, the biosphere encompasses all living organisms on Earth. It interacts with the atmosphere, hydrosphere and lithosphere to sustain life. A crucial process within the biosphere is the carbon cycle, which transfers carbon between the air, water, soil and living beings.

How does the carbon cycle work?

- Photosynthesis: Plants absorb carbon dioxide (CO_2) from the atmosphere and convert it into glucose, storing carbon in their structures.
- Cellular respiration: Animals and plants release carbon dioxide back into the atmosphere through cellular respiration as they utilise energy.
- Decomposition: When organisms die, decomposers break them down, releasing carbon into the soil and atmosphere.
- Combustion: Burning fossil fuels and biomass releases stored carbon back into the atmosphere, contributing to the greenhouse effect.
- Ocean absorption: The oceans absorb carbon dioxide, where it reacts with water to form carbonates, supporting marine ecosystems.

How can we reduce carbon emissions and balance the carbon cycle?

Recent advancements highlight efforts to reduce carbon emissions and enhance the carbon cycle's balance. Examples include the following:

- Climeworks, a company based in Zurich, Switzerland, and specialising in direct air capture, has developed facilities like Mammoth in Iceland, capable of capturing up to 36 000 tonnes of carbon dioxide annually. This carbon dioxide is then stored underground, turning it into rock through mineralisation.
- Scientists at the Massachusetts Institute of Technology (MIT) in the United States of America, including Franz-Josef Ulm, Admir Masic and Yang-Shao Horn, have invented a supercapacitor made from cement and carbon black. A supercapacitor is a device that stores energy quickly and releases it rapidly. This invention has the potential to improve energy storage and support **carbon capture** by storing renewable energy efficiently.

Understanding and enhancing the carbon cycle are both vital for climate regulation and ecosystem health. Through innovative technologies and sustainable practices, we can work towards a balanced carbon cycle, ensuring a sustainable future for all life on Earth.

1. How do human activities impact the natural carbon cycle, and what are the potential consequences?
2. What role do technological innovations play in managing carbon emissions?
3. How can individuals contribute to maintaining a balanced carbon cycle?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

7.2.3 Human impact on Earth's cycles

With a greater focus on Earth's climate and human activities that have a detrimental effect on ecosystems and cycles, people are now finally understanding that changes need to be made before it's too late.

So what are the main factors that have a detrimental effect on our planet and the carbon cycle?

Deforestation

Deforestation can occur when humans clear forests to build houses or produce food. If **producers** are reduced in number or removed from ecosystems, less carbon dioxide will be removed from the atmosphere and an overall increase in atmospheric carbon dioxide may result.

The repurposing of the land after deforestation may also result in further imbalances. An increase in cattle, for example, can result in increased release of carbon dioxide and methane gas into the atmosphere. Alternately, replacing the original forest trees with crops with lower photosynthetic rates may not only result in increased carbon dioxide, but also a reduction in the amount of carbon stored in ecosystems.

Mining

Mining for precious metals used in items such as mobile phones, or for non-renewable energy sources such as coal, requires land to be cleared (deforestation). Mining also destroys rocks, which releases stored carbon. Consequently, this results in more carbon in the atmosphere.

Since mining relies heavily on using fossil fuels for energy in extraction, production and recycling, large amounts of carbon dioxide are released into the atmosphere during these processes. Mining reduces biodiversity by destroying natural habitats.

FIGURE 7.14 A birds-eye view of a mining quarry

Burning fossil fuels and combustion

Non-renewable fuels such as crude oil products (e.g. petrol, diesel, coal and natural gas) are very useful to us. Burning of these fuels in air with oxygen can result in the release of heat energy. This is an example of combustion.

When fossil fuels are burned, carbon dioxide and water vapour are also released into the atmosphere. These are both known as greenhouse gases, which can be responsible for a gradual rise in air temperature.

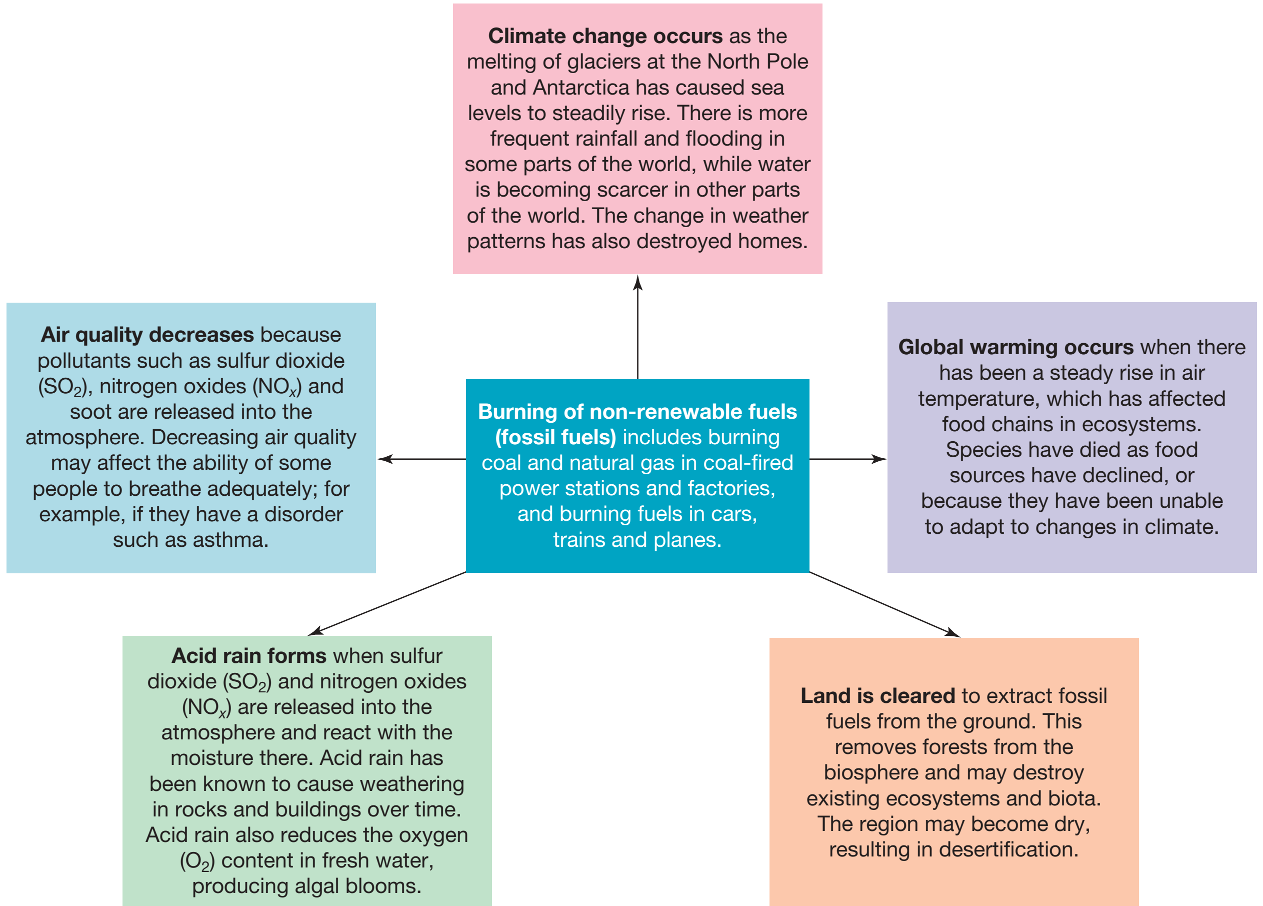
An example of this is the combustion of methane with oxygen gas to produce carbon dioxide and water:

$$\text{methane} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

The burning of non-renewable fossil fuels has had an impact on our biosphere in several ways.

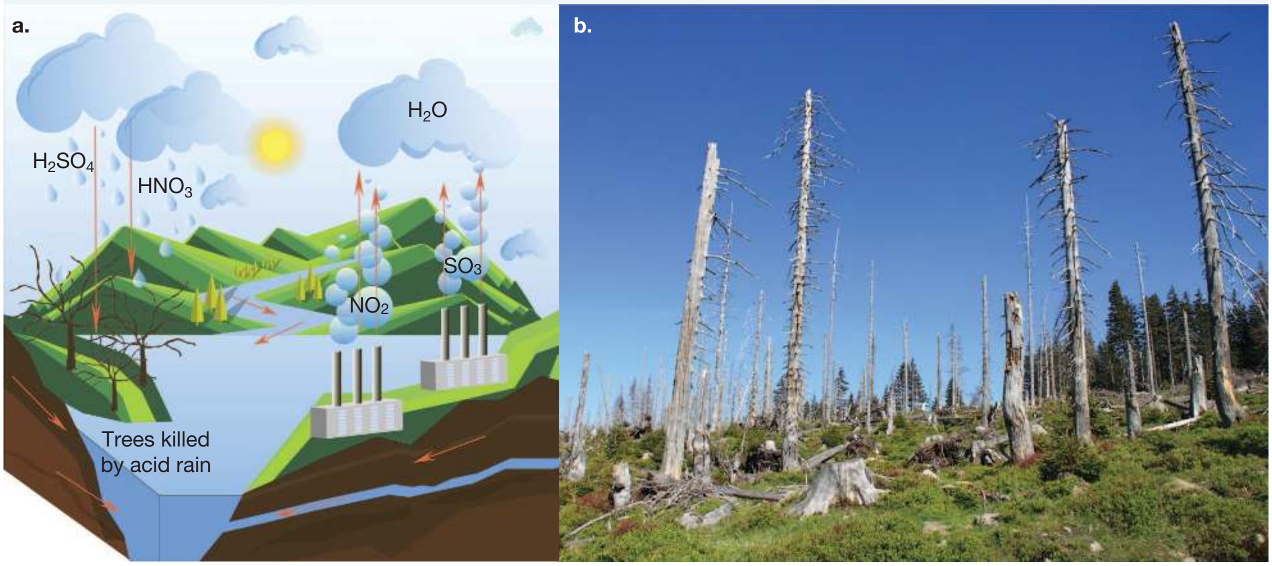
FIGURE 7.15 A summary of the effects caused by burning non-renewable fuels



Industrial wastes

Industrial wastes that contain nitrogen oxides (NO_x) are also released into the atmosphere. Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) can react with water vapour to form nitric acid (HNO_3) and sulfuric acid (H_2SO_4), respectively, and then leave the atmosphere via the water cycle as **acid rain**. This process is shown in figure 7.16a. This can change the acidity of water systems, resulting in the death of organisms (figure 7.16b).

FIGURE 7.16 a. How acid rain is produced b. The effects of acid rain on trees



Travel

Humans also need to get around, whether locally or internationally, and this often involves the use of cars and aeroplanes. As these transport options burn petrol (a carbon-based product), carbon dioxide is released into the atmosphere.

Increased levels of carbon dioxide have led to increased global temperatures, which evidence suggests is resulting in melting ice caps, rising sea levels and unusual weather patterns. These events may threaten the different cycles in the atmosphere and the survival of organisms in many ecosystems.

FIGURE 7.17 a. Cars release carbon dioxide when they burn petrol and diesel. b. Increased greenhouse gases may result in melting ice caps.

Increasing human population

A greater population increases the magnitude of the impact by humans on the environment. For example, an increase in human population creates demand for more food, which results in the need for more livestock, which in turn leads to increased deforestation and a reduction of nutrients in the soil.

With the growing population, there is a higher demand for electricity, transport, and heating and cooling. More carbon dioxide is released into the atmosphere because these daily processes are dependent on using fossil fuels.

SCIENCE INQUIRY: Plastic panic!

Plastic waste has been a global issue since the 1950s, and plastic production has exponentially increased since then. According to the United Nations Environment Programme (UNEP), over 400 million tonnes of plastic waste are produced globally each year. Plastic packages, wrappers and bottles have been dumped in the oceans, killing pelicans and turtles and destroying populations of smaller animals and plants. Figure 7.18 shows the plastic waste found in some of our oceans. Over the years, plastic waste has degraded into very tiny plastic particles called **nanoplastics**. Since one nanoplastic particle is similar in size to a red blood cell, many of the plastic particles are dispersed by wind and eventually end up in people.

FIGURE 7.18 Plastic waste found in the sea

Recent data suggests that plastic production accounted for over five per cent of global greenhouse gas emissions in 2024. If plastic production continues to grow, it is projected to contribute between 21 and 31 per cent of total emissions by 2050. This growth would make it significantly harder for the world to achieve the 2050 goal of net-zero carbon emissions, jeopardising efforts to limit global warming to 1.5 °C as targeted under the Paris Agreement (which you will learn about in lesson 7.4).

Questioning and predicting

1. **a.** What are the benefits of using plastics to society?
   b. Use your understanding of the biosphere to explain how nanoplastics have ended up in humans.
   c. What is the ratio of carbon dioxide emissions due to plastic production to burning between 2019 and 2050?
   d. Why is society concerned with increasing carbon dioxide emissions?

Planning and conducting

2. Describe how scientists make predictions on the amount of carbon dioxide emissions released from the production and burning of plastics.

Processing, modelling and analysing

3. Do you agree or disagree that increasing or reducing plastic use is beneficial or harmful? Justify your response by considering the pros and cons.

Communicating

4. **a.** Design a poster, slide presentation or documentary video suggesting conservation strategies to reduce worldwide plastic pollution and carbon dioxide emissions. You could use the **Ocean purpose project** and **Unplastify** weblinks in the Resources panel to help you with ideas and information.
   b. Present your work in a 5- to 10-minute talk to the rest of the class.

Information and processed data can be analysed and compared to identify and explain qualitative and quantitative patterns, trends, relationships and anomalies (VC2S10I05)

INVESTIGATION 7.1

Testing for photosynthesis

Introduction

Fresh soda water contains carbon dioxide gas (CO_2). When CO_2 is dissolved in water, carbonic acid (H_2CO_3) is formed and the solution becomes slightly acidic. The equation that represents CO_2 in water is as follows:

carbon dioxide gas and water produce carbonic acid

or

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$$

Bromothymol blue is an indicator that is used to determine the presence of CO_2 and acidity in water. If CO_2 is dissolved in water, then the solution is acidic and the colour of the solution is yellow. If CO_2 is absent, then the solution is neutral (less acidic) and the colour of the solution is blue.

Aim

To investigate the effect of light on photosynthesis

Materials

- 4 test tubes
- 2 test-tube racks
- 1 × 10 mL measuring cylinder
- 4 rubber stoppers
- unopened bottle of soda water
- spinach or elodea plant
- bromothymol blue indicator

Method

1. Label the test tubes A, B, C and D.
2. Mark test tubes A and B 'light' and test tubes C and D 'dark'.
3. Measure 10 mL of fresh soda water and pour it into test tube A. Add four drops of bromothymol blue and shake the contents of the test tube.
4. Repeat step 2 for test tubes B, C and D.
5. Place the spinach or elodea plant into test tubes B and D.
6. Place rubber stoppers in the test tubes.
7. Place test tubes A and B in a test-tube rack on a window ledge or underneath a lamp.
8. Place test tubes C and D in a test-tube rack in a cupboard.

Results

Construct a table and note your observations each day for approximately two weeks.

Discussion

1. Write a hypothesis about the effect of light on photosynthesis.
2. Identify the dependent and independent variables in this investigation.
3. Identify two controlled variables in this investigation.
4. State both the word and chemical equation for photosynthesis.
5. How is photosynthesis linked to the carbon cycle?
6. Describe a modification to the method to investigate how the intensity of light affects the rate of photosynthesis.

Conclusion

Summarise the findings for this investigation.

INVESTIGATION 7.2

Rate of melting ice on land and in the sea

Introduction

Most of Earth's land ice appears as sheets of ice in Antarctica and Greenland, or in the form of glaciers and icebergs. Sea ice is frozen ocean water, which forms, grows and melts in the ocean. Sea ice floats on the ocean surface and is moved by climatic changes, such as wind direction and ocean current. Both melting ice on land and in the sea increase ocean levels.

Aim

To investigate the rate of melting ice on land and in the sea

Materials (per group)

- 2 identical clear, plastic containers (at least 15 cm × 15 cm)
- plasticine or rock (enough to fill half of each container)
- tray of ice cubes
- timer or stopwatch
- cold water
- salt water
- 1 × 100 mL measuring cylinder
- ruler

Method

1. Label the two plastic containers 'land' and 'seawater'.
2. Half-fill each container with plasticine. If plasticine is not available, half-fill each container with rocks or stones.
3. Using the measuring cylinder, add cold water into the 'land' container until the water level is about two-thirds the height of the plasticine or rocks in the container. Note the volume of cold water added to the 'land' container.
4. Add the same volume of salt water (noted in step 3) to the 'seawater' container.
5. Add ice cubes to the plasticine in the 'land' container.
6. Add the same number of ice cubes to the salt water in the 'seawater' container.
7. Use a permanent marker to mark the height of water in each container. Start a timer or stopwatch.
8. Measure the height of the water in each container in equal time intervals (e.g. every 2 minutes).

Results

Copy and complete the following table. Remember to give your table an appropriate title.

Time* (minutes)	Water depth (land ice) (mm)	Water depth (sea ice) (mm)
0		
2		
4		
6		
8		
10		
12		
14		
16		
18		
20		

*Additional time may be required to see the effect of melting ice on land compared to melting ice in the sea.

Discussion

1. Identify the dependent and independent variables in this investigation.
2. Identify two controlled variables in this investigation.
3. Which melts faster: land ice or sea ice? Give a reason for your choice.
4. How is melting ice linked to the carbon cycle?
5. Describe a modification to the method to investigate the rate of melting ice in freshwater and seawater.

Conclusion

Summarise the findings for this investigation.

EXTENSION: Will planting more trees solve our problems?

Research land clearing and deforestation in Australia since around 1990, and answer the following questions. You could use the information about land clearing from the **Australian State of the Environment: Land** weblink in the Resources panel to help you.

1. a. How has land clearing in Australia changed during this time? Describe any patterns observed.
   b. Determine the period that has had the smallest amount of land clearing. Explain why.
2. Research what desertification is and determine if it is possible that parts of Australia are experiencing desertification. What other information would you need in order to confirm whether it is happening or not?
3. Would planting more trees solve the issue of deforestation? Justify your reasoning.

7.2 Activities

learnon

7.2 Quick quiz on	7.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 5, 7, 11, 12	2, 4, 6, 9, 13, 16	8, 10, 14, 15, 17

Remember and understand

1. **State** the name of the life-support system of our planet.
2. **Identify** the missing words to complete the sentence.
   The ________ consists of the atmosphere, lithosphere, hydrosphere and biota (living things), the _________ between them and the ________ energy of the Sun, and is considered to be the ________ system of our planet.
3. **Identify** which of the terms on the left matches each of the descriptions on the right.

Parts of the biosphere

Term	Description
a. Atmosphere	1. Includes soil, rocks (e.g. limestone), coal and oil
b. Lithosphere	2. Includes living organisms within a region
c. Biota	3. Includes water and dissolved carbon dioxide
d. Hydrosphere	4. Includes nitrogen, oxygen, methane, ozone and carbon dioxide

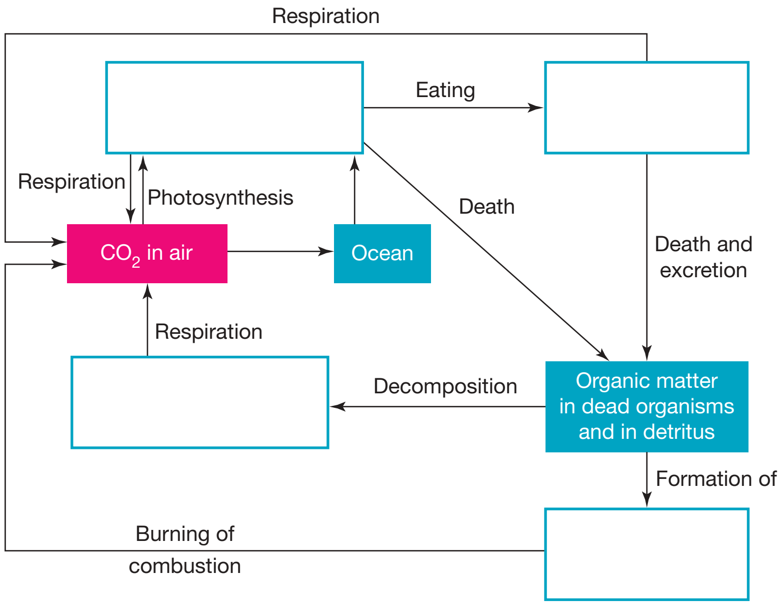
4. **Explain** the importance of the lithosphere.
5. **Describe** how acid rain forms and the effects it may have.

6. **Identify** four gases that you would find in the atmosphere from the burning of fossil fuels.
7. **Explain** how the carbon cycle is linked to the biosphere.

Apply and analyse

8. Clearly **outline** how excessive clearing and deforestation impacts the carbon cycle.
9. **Identify** where and how the non-living parts of the biosphere (atmosphere, lithosphere and hydrosphere) and the living parts (biota) interact in the carbon cycle.
10. **Explain** why an increase in the use of non-renewable fuels is of concern for the atmosphere. **Describe** the recommendations you would suggest regarding the use of non-renewable fuels.
11. a. **Suggest** how photosynthesis and respiration link to the carbon cycle.
    b. With respect to these processes, **explain** how an increasing population would affect these cycles.
12. a. **Identify** and label the missing terms in the following figure of a simplified view of the carbon cycle, using the word bank provided.

    decomposers and detritivores, fossil fuels, organic matter in consumers, organic matter in producers



    b. **Describe** the effect on the carbon cycle if decomposers and detritivores were removed from the ecosystem.
13. **Explain** why a small part of the hydrosphere contains water that is suitable for drinking.
14. **SI** Write the chemical equations to represent the reactions involved in the formation of acid rain.

Evaluate and create

15. **Describe** the carbon cycle and explain how carbon moves between the atmosphere, plants, animals and the soil. **Explain** why this cycle is important for life on Earth.
16. Think about the plants and animals you see around you. **Explain** how they depend on each other and the environment to survive, and how the biosphere supports their life.
17. **Evaluate** the impact of human activities on the carbon cycle. **Describe** how activities like burning fossil fuels and deforestation affect the carbon cycle and the biosphere. **Discuss** the potential consequences for life on Earth.

Answers and sample responses are available in your digital formats.

LESSON 7.3 The greenhouse effect

LEARNING INTENTION

In this lesson you will:
- explain how carbon dioxide emissions cause an enhanced greenhouse effect and global warming
- describe evidence of global warming.

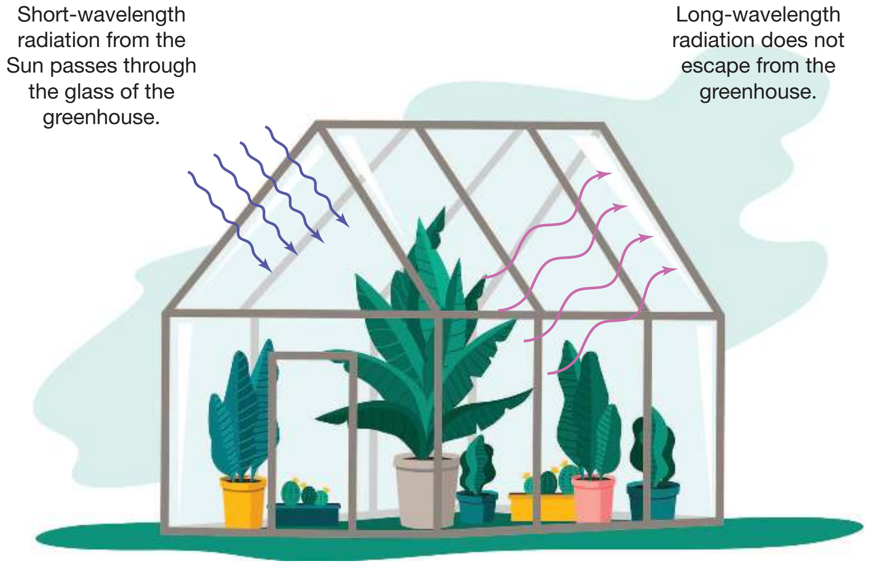
7.3.1 Global warming and the enhanced greenhouse effect

Life exists on Earth because its atmosphere contains oxygen gas and protects living organisms from the harmful **ultraviolet (UV)** radiation from the Sun's rays. The temperature on Earth is kept within a specific range of temperatures to allow all animals and plants to live.

The greenhouse effect

A **greenhouse** is made of glass and often contains flowers and vegetables. A greenhouse is commonly used to grow plants during the winter months, as the temperatures are too cold for growth.

FIGURE 7.19 A greenhouse

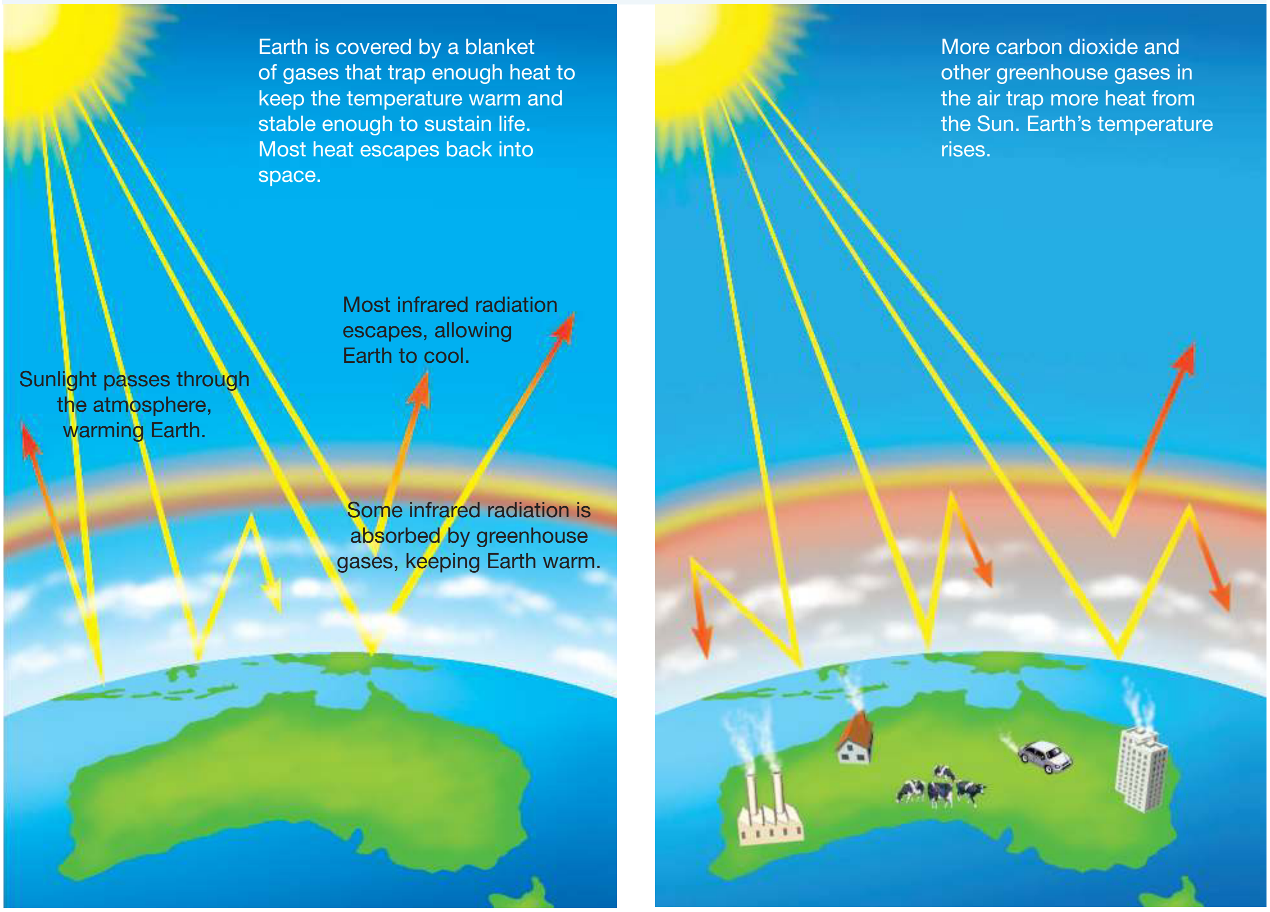


Sunlight or short-wavelength **radiation** passes through the greenhouse during the day, heating the plants and soil inside. The glass of the greenhouse prevents the longer-wavelength radiation, such as **infrared**, from escaping. Since radiation cannot leave the greenhouse, the greenhouse heats up considerably during the day.

Earth's atmosphere behaves like a greenhouse. The Sun's radiation passes through each layer of the atmosphere and is absorbed by the soil and oceans, increasing their temperatures. **Greenhouse gases** such as carbon dioxide, water vapour and methane are able to prevent most of the infrared radiation from escaping. These gases scatter the infrared radiation back to Earth. Since infrared radiation cannot enter space, Earth's oceans and land become warmer. This process is known as the greenhouse effect.

Carbon dioxide gas is the main contributing gas to the greenhouse effect. Nitrous oxide, methane gas and water vapour also contribute to the greenhouse effect. Between the early 1800s and the 2020s, the amount of CO_2 released into the atmosphere increased from 280 ppm to about 420 ppm. The global temperature of Earth has risen, and this phenomenon is known as global warming or the **enhanced greenhouse effect**. Figure 7.20 shows how infrared radiation is trapped in the enhanced greenhouse effect.

FIGURE 7.20 Greenhouse gases and the enhanced greenhouse effect



7.3.2 Evidence of global warming

In Australia, global warming has increased average temperatures and sea levels over the past 60 years. There are fewer cold days and more floods. Similar events have occurred across the world.

The Great Barrier Reef

The Great Barrier Reef is a large coral reef, about 2000 km long, found off the coast of Queensland (figure 7.21). The coral is the home of many ocean ecosystems as it contains thousands of fish and other small animals and plants. It has taken many millions of years for the coral to slowly grow using the calcium carbonate deposits in skeletons and the remains of dead marine organisms.

FIGURE 7.21 The Great Barrier Reef

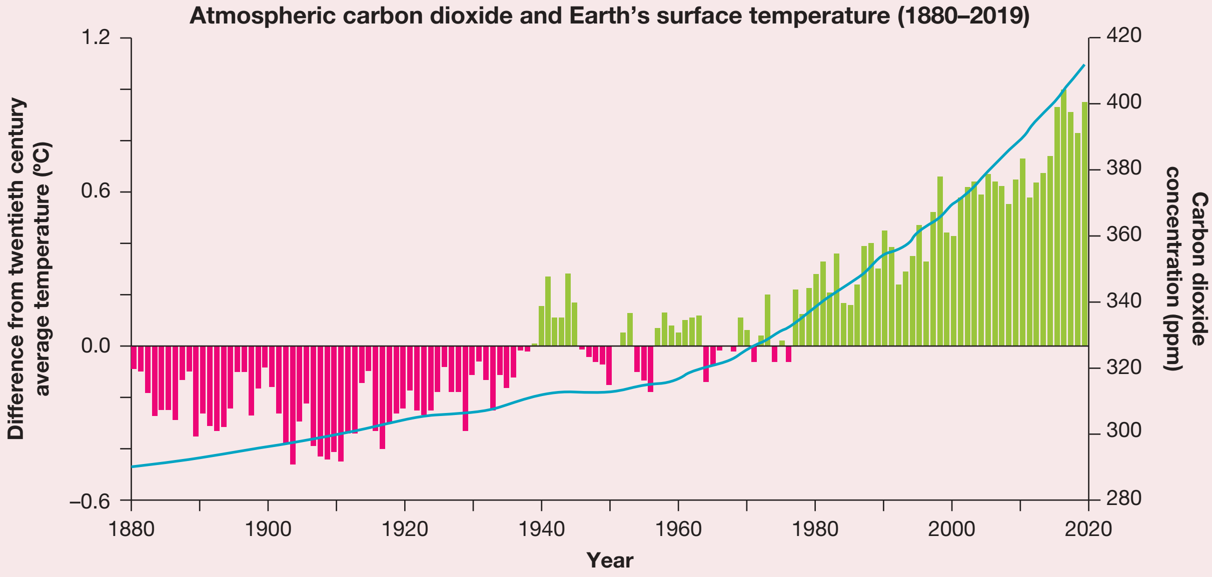
The increased absorption of CO_2 by the ocean over recent decades has increased its acidity. Not only has the ocean acidity increased, but so too has the temperature of the ocean. This event has decreased the number of organisms populating the coral reef. The change in pH has dissolved the coral reef, making it more susceptible to destruction in stormy weather and providing even less protection to the living inhabitants. The existence of many species is under threat (figure 7.22).

FIGURE 7.22 Increased acidity has caused the Great Barrier Reef to bleach.

SCIENCE AS A HUMAN ENDEAVOUR: Global coral reef restoration

In 2023, the average global temperature rise was approximately 1.45 °C, making it the warmest year on record. This marked the ninth consecutive year in which the average global temperature rise exceeded 1 °C. It is crucial for everyone to collaborate and take action to reduce global carbon dioxide emissions to net zero by 2050, ensuring that the temperature increase remains below 1.5 °C to mitigate the worst impacts of climate change.

FIGURE 7.23 Relationship between carbon dioxide emissions and global temperatures



Marine biologists recognise the importance of conserving the biodiversity in the ocean, by growing new coral and establishing more habitats for the organisms to survive and thrive. In the near future, the tourism industry could benefit from these projects as new coral growth enhances the beauty of underwater landscapes. The fishing industry may also see improvements as fish populations grow around these restored habitats. To encourage coral growth, reef restoration projects are being carried out worldwide. These projects involve placing steel structures, like hexagonal shapes or cages, on the ocean floor and attaching strong, fast-growing coral fragments to them (figure 7.24).

FIGURE 7.24 A deep-sea diver working with the steel cages

The Mars Assisted Reef Restoration System (MARRS) has contributed significantly to coral reef restoration. Over 330 000 reef fragments have been installed in many areas, such as Australia's Great Barrier Reef, Mexico's Mesoamerican Reef and several other countries in the Pacific, Indian and Atlantic Ocean. In two years, MARRS has achieved amazing results, with the amount of coral increasing from 10 per cent to 60 per cent.

1. Why is coral reef restoration important for both the environment and human economies?
2. How does the MARRS system contribute to sustainable solutions for coral reef restoration?
3. What challenges might scientists face when restoring coral reefs, and how could they overcome them?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

INVESTIGATION 7.3

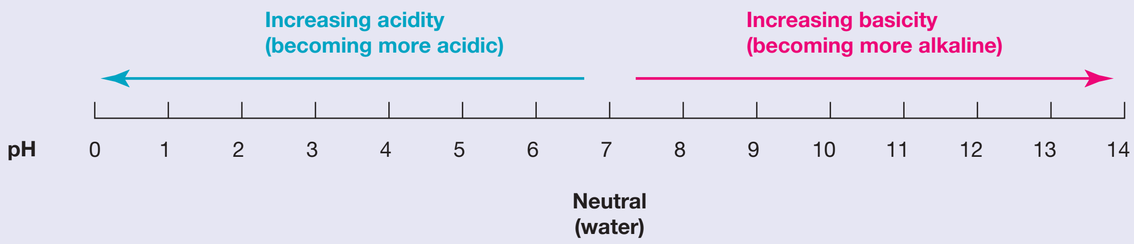
Effect of carbon dioxide on ocean acidity

Introduction

Carbon dioxide from the atmosphere is dissolved into oceans and lakes, producing carbonic acid (H_2CO_3).

Fresh soda water contains carbon dioxide gas (CO_2) dissolved in it.

Scientists use the pH scale to measure the acidity of solutions. The scale is based on a logarithmic scale, as shown in the figure below.



A pH of 6 means that the solution contains more carbon dioxide gas dissolved in it, and it is more acidic than a solution that has a pH of 7. Water is regarded as neutral, as it is neither acidic nor alkaline.

Aim

To investigate the effect of carbon dioxide on ocean acidity

Materials

- 5 × 250 mL beakers
- 250 mL fresh soda water
- glass rod
- 2 × 100 mL measuring cylinders
- pH probe or universal indicator
- 250 mL seawater or salty* water (3%)

*The concentration of seawater is approximately 3% m/v. If seawater is unavailable, salty water can be prepared by dissolving 3 g of salt in 100 mL of deionised water.

Method

1. Label the five beakers A, B, C, D and E.
2. Refer to the following table and add the volumes of soda water and seawater, respectively, to each beaker.

Beaker	Volume of soda water (mL)	Volume of seawater (or salty water) (mL)
A	100	0
B	75	25
C	50	50
D	25	75
E	0	100

3. Use a clean stirring rod to mix the contents of each beaker.
4. Keep the temperature of the beakers constant.
5. Measure the pH of the solution in each beaker using a pH probe. Alternatively, add 10 drops of universal indicator to each beaker and use a universal indicator chart to determine the pH of the solution.

Results

Construct a table and note your pH measurements.

Discussion

1. Write a hypothesis about the effect of carbon dioxide on ocean acidity.
2. Identify the dependent and independent variables in this investigation.
3. Explain why beaker E had no soda water.
4. Why is the temperature kept constant in this investigation?
5. Suggest a modification to the experimental design that would improve the reproducibility of the results.
6. Explain why ocean acidification is a global concern.

Conclusion

Summarise the findings of this investigation.

Uluru

Uluru (figure 7.25) sits upon the lands of the Anangu people in the Northern Territory. It is one of the largest rocks in the world and is known for its vivid orange-red colour at sunset. Uluru is a special landmark for Aboriginal and Torres Strait Islander Peoples as it signifies the beginning of time. It is believed that this rock started forming about 550 million years ago. Many people have travelled from all parts of Australia and the world to visit Uluru.

Due to increasing global temperatures, scientists predict that there will be 100 days each year of temperatures of 35 °C or more around 2030, and 160 days each year by 2090, making it likely that the number of tourists visiting Uluru will decrease.

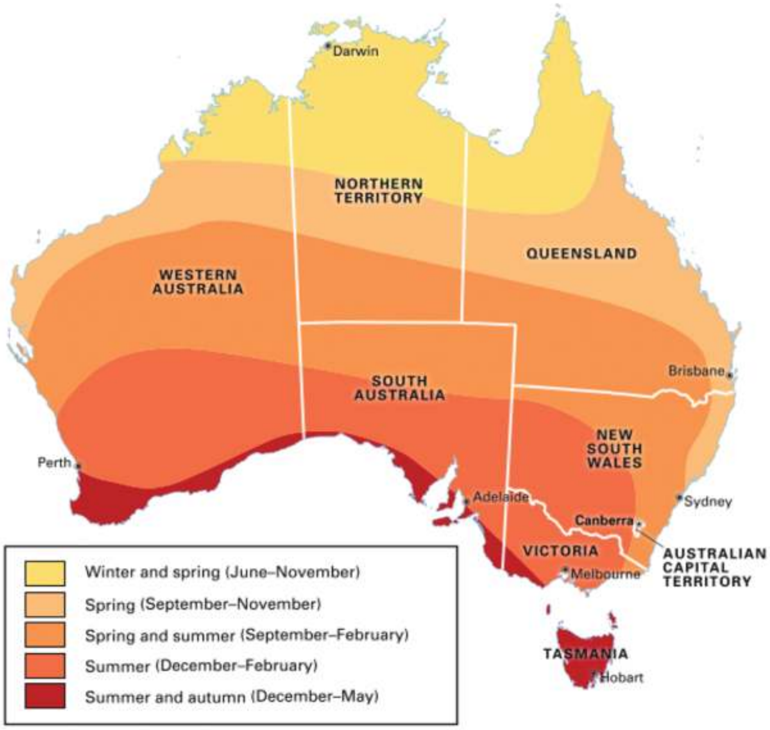
FIGURE 7.25 Uluru

Bushfires

Bushfires are high-temperature fires that burn uncontrollably. Since 2019, the frequency and intensity of bushfires has increased. The rise in global temperatures has dried forests and plants earlier in the summer, rather than towards the end of the season. Many outback properties and animal habitats have been destroyed due to rapid burning of grasslands, which spreads uncontrollably in seconds.

FIGURE 7.26 A high-temperature bushfire

FIGURE 7.27 Bushfire seasons in Australia



Ice melting

Antarctica consists of a large block of land ice. Many scientists have indicated that in 2022, Antarctica was melting at its fastest rate for over 5500 years, due to increasing global CO_2 emissions. Scientists suggest that the sea levels will rise by 70 metres and that some of the cities will be underwater if Antarctica completely melts. New infrastructure would need to be developed if people are to live underwater.

FIGURE 7.28 An artist's illustration of what an underwater city might look like in the future

SCIENCE AS A HUMAN ENDEAVOUR: Innovators leading the fight against global warming

As the world confronts the challenges of the enhanced greenhouse effect and global warming, several individuals and organisations have emerged as leaders in developing innovative solutions to reduce carbon dioxide (CO_2) emissions.

Gaurav Sant, founder of start-up Equatic and the Director of the University of California's Institute for Carbon Management, has led efforts to enhance the ocean's natural ability to capture and store carbon. Equatic's facilities use electrical currents through seawater to sequester carbon dioxide and produce green hydrogen, offering a dual solution to carbon removal and clean energy production. Their North American plant aims to remove 109 500 metric tonnes of carbon dioxide and produce 3600 metric tonnes of green hydrogen in its first year.

FIGURE 7.29 Guarav Sant

Climeworks (mentioned previously in this topic) was founded by engineers Jan Wurzbacher and Christoph Gebald. It has developed direct air capture technology to remove carbon dioxide from the atmosphere. Their large-scale plant in Iceland, named 'Orca', launched in 2021, and is capable of capturing significant amounts of carbon dioxide annually, which is then stored underground through mineralisation. Climeworks was recognised as one of the 'world's most innovative companies' in 2024.

FIGURE 7.30 Jan Wurzbacher and Christoph Gebald

In December 2024, tech companies like Google, Salesforce and H&M invested $32.1 million in start-up company CREW at wastewater treatment facilities, and $48 million in start-up CO280 to capture CO_2 emissions from pulp mills. These efforts are part of a larger $80 million plan facilitated by Frontier, a carbon-removal initiative led by Stripe, Google, Shopify and McKinsey Sustainability.

These innovators have been publicly applauded for their contributions to combating climate change. Their work not only advances technology, but also inspires global efforts to develop sustainable solutions for reducing CO_2 emissions and mitigating the effects of global warming.

1. How do the technologies developed by Equatic and Climeworks contribute to reducing atmospheric CO_2 levels?
2. How do investments in start-up companies like CREW and CO280 help develop carbon-capture technology, and what challenges might these companies face as they grow?
3. Why is it important for tech companies to invest in carbon-capture initiatives, and what impact can their involvement have on global efforts to combat climate change?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

INVESTIGATION 7.4

Carbon footprint activity

Introduction

A carbon footprint is a measure of the amount of greenhouse gases (mainly carbon dioxide and methane) that are released into the atmosphere due to a person's use of products, and their activities, hobbies and interests, community events, travel and transport.

Just about anything you do determines the value of your carbon footprint. For example, the clothes you wear, what electrical devices you use — even playing soccer or basketball — will affect your own personal carbon footprint.

The units used for carbon footprint are CO_2 equivalent emissions, or CO_2e. The average worldwide CO_2 footprint is about 4.8 tonnes per year, while the average footprint in Australia is about three times that at 15.48 tonnes per person per year.

Aim

To determine the factors that affect a person's carbon footprint

Materials

Use the **WWF footprint calculator** weblink in the Resources panel to complete the following questions.

Discussion

1. Is the carbon footprint calculator website reliable or not? Justify your response.
2. Hypothesise how many Earths would be required to sustain your current lifestyle.
3. Answer each question in the calculator to the best of your ability, adding details to improve the accuracy of your footprint. Explain the outcome of your footprint after entering your data. Do you think this is an accurate representation of your footprint?
4. Identify ways you could reduce your footprint so that fewer Earths would be required.
5. Is it possible for your answers to question 4 to be implemented by the rest of society? Justify your reasoning.
6. Scientists like to formulate questions to investigate scientifically in the hope of discovering new ways to reduce carbon and greenhouse gas emissions. Formulate two questions you would want to investigate as a scientist, and identify how you would collect the information required and what you would need to find out to help answer the question.

Conclusion

Summarise the findings of this investigation.

DISCUSSION

1. Which of the following actions would you be prepared to take so that you can contribute to the fight against global warming?
   - Walk, cycle or use public transport rather than relying on someone to drive you to school, work or leisure activities
   - Change your diet so that you eat less meat and more fruit and vegetables
   - Recycle paper, aluminium and steel cans, glass and plastics
   - Stop using electric clothes dryers, and instead use outdoor clothes lines in dry weather and indoor folding clothes airers in wet weather
   - Buy fewer clothes or buy clothes second-hand
2. Select one of the actions in question 1 that the government could enforce by passing new laws, and explain how it could be done.

7.3 Activities

learnon

7.3 Quick quiz on	7.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 5, 7, 8	2, 6, 9, 11, 12	10, 13, 14, 15, 16

Remember and understand

1. Consider the statements about the greenhouse effect in the following table. **Identify** the correct order of events, starting at the Sun, by writing the numbers 1–6 beside the statements.

How the greenhouse effect works

Number	Statement
	When solar energy waves hit Earth's surface, they slow down and form longer heat (thermal) energy waves.
	Some solar energy waves reflect off from the clouds, and greenhouse gases such as carbon dioxide gas is returned to space.
	These longer heat-energy waves have trouble getting back out into space through carbon dioxide gases.
	Heat trapped in the atmosphere warms the planet.
	Other solar energy waves make it to Earth's surface.
	Short-wave solar (radiant) energy waves enter the atmosphere from the Sun.

2. a. **Identify** whether each of the following statements is true or false.
   i. Carbon dioxide is the only greenhouse gas.
   ii. Carbon dioxide emissions cause a rise in global temperatures.
   iii. The emission of carbon dioxide gases has only changed the acidity of the oceans.
   iv. There are net carbon dioxide emissions in the world.
   b. Rewrite any false statements to make them true.
3. **State** three pieces of evidence that rising atmospheric temperatures are occurring in Australia.
4. **Define** the greenhouse effect and state how this differs to the enhanced greenhouse effect.
5. **Explain** why plants are regarded as a fuel.
6. **Describe** the factors that create a favourable environment for bushfires to occur.
7. **State** five different ways you could reduce your carbon footprint.

Apply and analyse

8. a. **Identify** the causes of coral bleaching.
   b. **Identify** the triggers for coral bleaching.
   c. **Explain** how coral bleaching affects the biodiversity of organisms living in coral.
9. **Describe** three pieces of evidence that global warming is occurring worldwide.
10. **State** how scientists predict future bushfires. **Explain** your response.
11. **Describe** two factors directly related to a rise in sea levels.

Evaluate and create

12. The temperature on Venus is above the boiling point of water. **Describe** what would happen to the amount of CO_2 and Venus' temperature if all the oceans evaporated.
13. Imagine you are a climate scientist. **Explain** how carbon dioxide emissions contribute to the enhanced greenhouse effect and global warming. Additionally, **describe** some evidence that shows global warming is happening. Use examples to support your explanation.
14. SI **Explain** how technology is used to save the world's coral reefs.
15. **State** whether the Sun is to blame for rising global temperatures. **Justify** your response.
16. Design an investigation that determines the effect of ocean acid on the strength of seashells. You are provided with the following materials:
    - 10 mL measuring cylinder
    - 0.10 M hydrochloric acid
    - seashells
    - electronic scales
    - 5 × 250 mL beakers
    - pH probe or universal indicator
    - universal indicator chart
    - seawater (30% m/v)

    The hydrochloric acid will acidify the seawater. This action will be like acidifying ocean water with dissolved carbon dioxide gas.
    a. **Identify** the dependent and independent variables.
    b. **State** an aim and hypothesis for the investigation.
    c. **Describe** a method that determines the effect of ocean acid on the strength of seashells.

Answers and sample responses are available in your digital formats.

LESSON 7.4 Reducing carbon dioxide globally

LEARNING INTENTION

In this lesson you will discuss how carbon dioxide emissions can be reduced on a global scale.

7.4.1 Future global net carbon dioxide emissions

Hundreds of thousands of years ago, the amount of carbon dioxide in the atmosphere worldwide was between 170 and 300 ppm. Carbon dioxide levels have increased to just over 420 ppm, causing global warming around the world. A major treaty was signed by world leaders in 2015 in Paris, promising to reduce carbon dioxide emissions to 0 ppm by the year 2050. According to international climate agreements, Australia will reduce greenhouse gas emissions to 30 per cent below current levels by 2030.

Over 200 scientific organisations have reached the consensus that global temperatures are rising because of increasing atmospheric emissions of carbon dioxide gas and other greenhouse gases directly produced from the burning of fossil fuels, which are required for transport, factories and homes. The following agreements have been integral in addressing this current issue.

UN Framework Convention on Climate Change (UNFCCC), 1992

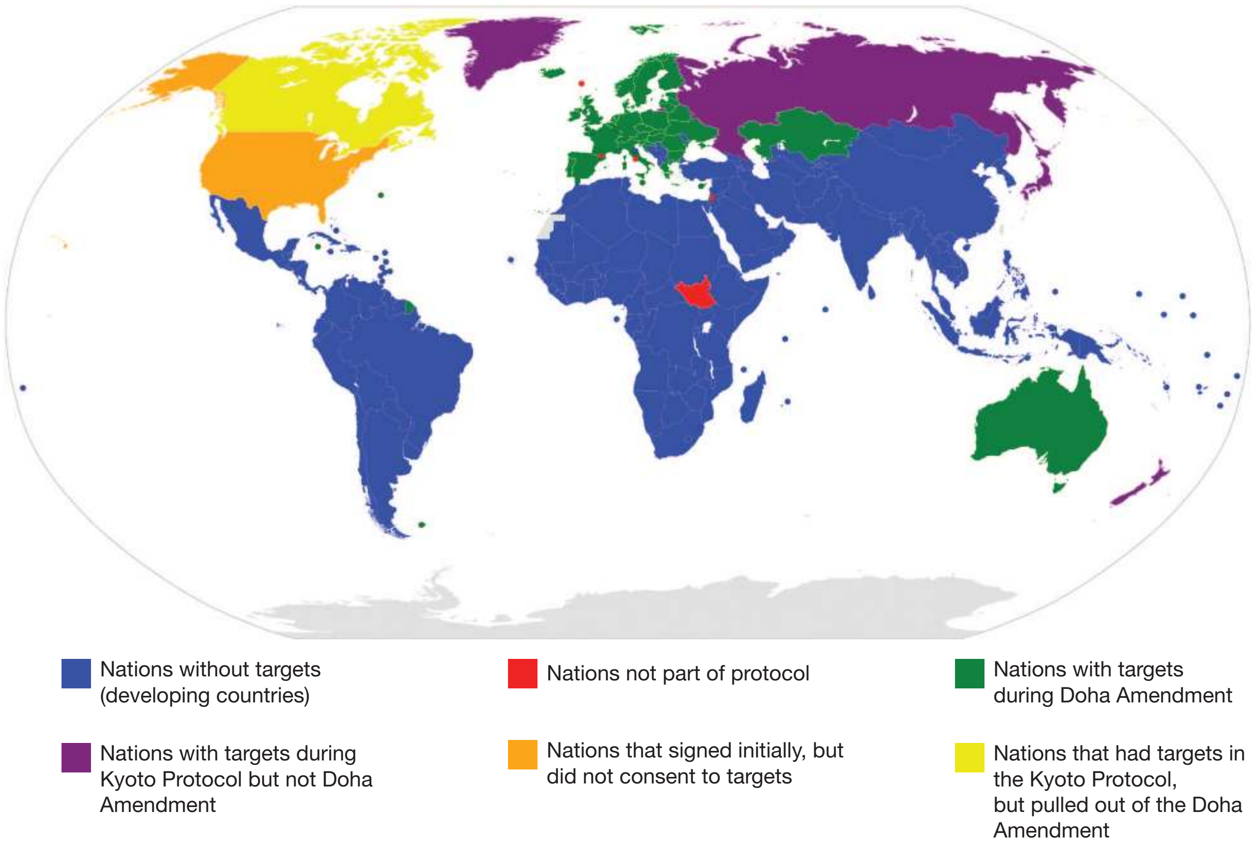
The UNFCCC agreement was supported by 197 countries. It was the first treaty that focused on reducing carbon dioxide and other greenhouse gases in the atmosphere.

Kyoto Protocol, 2005

The Kyoto Protocol was created in 1997 and enforced in 2005, supported by 152 countries. The goal was to reduce emissions by an average of 5 per cent below 1990 levels. China and India did not participate in the protocol. Although the United States of America initially agreed with the terms, they decided a few years later to withdraw.

In December 2012, the Kyoto Protocol was extended and became the Doha Amendment. This amendment added new emission reduction targets for the period 2012 to 2020 and was adopted by most of the parties of the Kyoto Protocol.

FIGURE 7.31 Different involvements around the world in the Kyoto Protocol and the Doha Amendment



Paris Agreement, 2015

The main difference between the Kyoto Protocol and the Paris Agreement is that the latter requires all countries to reduce the global average temperatures from rising by 1.5 °C by 2050 and to achieve net-zero carbon emissions after 2050. As shown in figure 7.32, 146 countries have accepted or ratified (formally approved) the agreement, 48 countries have signed the agreement and 3 countries have not accepted the agreement.

Preventing the global temperature rise of 1.5 °C is critical. Based on research data collected from satellites and field work, scientists have predicted that the following events will occur if this is not achieved:

- The frequency and longevity of heat waves will make temperatures more unbearable for people.
- More droughts and floods may lower the amount of food grown from crops, and reduce the populations of land animals and plants.
- Arctic ice will melt, causing sea levels to rise to the point that some coastal cities, towns and villages will be eventually submerged.
- Ocean acidity will destroy coral reefs, which will in turn reduce the number of animal species living in the ocean. A food shortage will be caused by decreasing fish populations.

FIGURE 7.32 Status of acceptance in the Paris Agreement

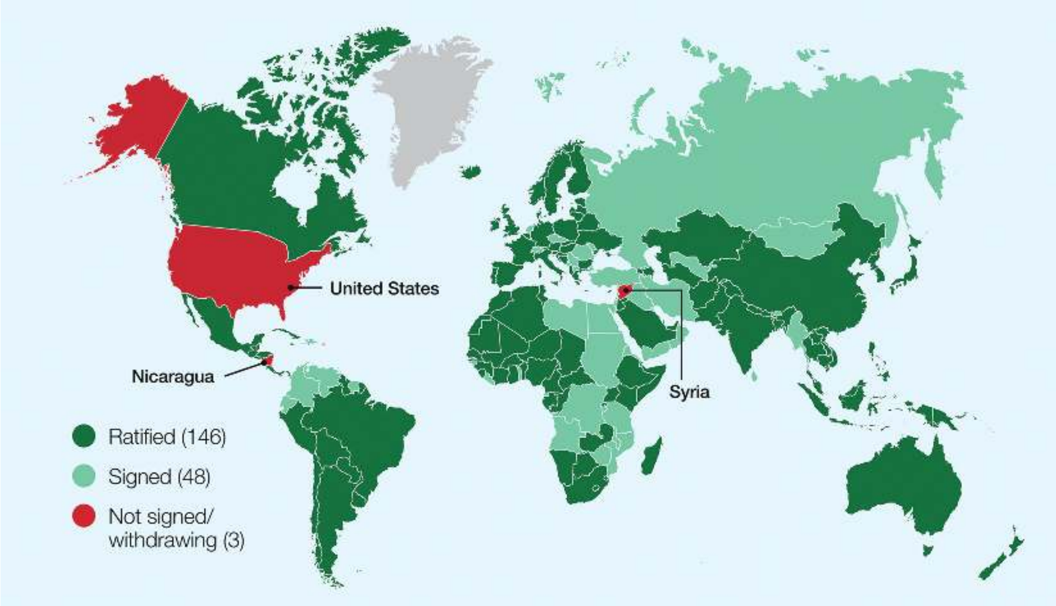


FIGURE 7.33 Consequences of not achieving a global rise of 1.5 °C: a. drought b. floods c. sea rising d. endangered species

During the 2023 UN Climate Summit in Dubai, UAE, it was concluded that governments need to do more to prevent the global average temperature from rising by 1.5 °C. The rest of this lesson outlines the strategies that can be used to reduce carbon dioxide gas emissions globally (and therefore reduce global temperature rise).

7.4.2 Using green energy sources

A green energy source is a sustainable energy source that does not produce any CO_2 emissions when used and does not produce pollutants that may harm the environment. Examples include solar energy, wind energy and **hydroelectricity**.

Solar energy

Solar energy is a good alternative to burning coal for electricity. When solar or photovoltaic cells absorb sunlight, the photons or light particles remove electrons from atoms, converting the solar energy into electricity. Solar panels provide electricity to individual homes, whereas solar farms provide enough electricity to power thousands of homes. The disadvantage of using solar energy is that electricity cannot be produced at night — solar energy is converted into electrical energy only during the daytime.

FIGURE 7.34 Solar cells convert sunlight to electricity.

Wind energy

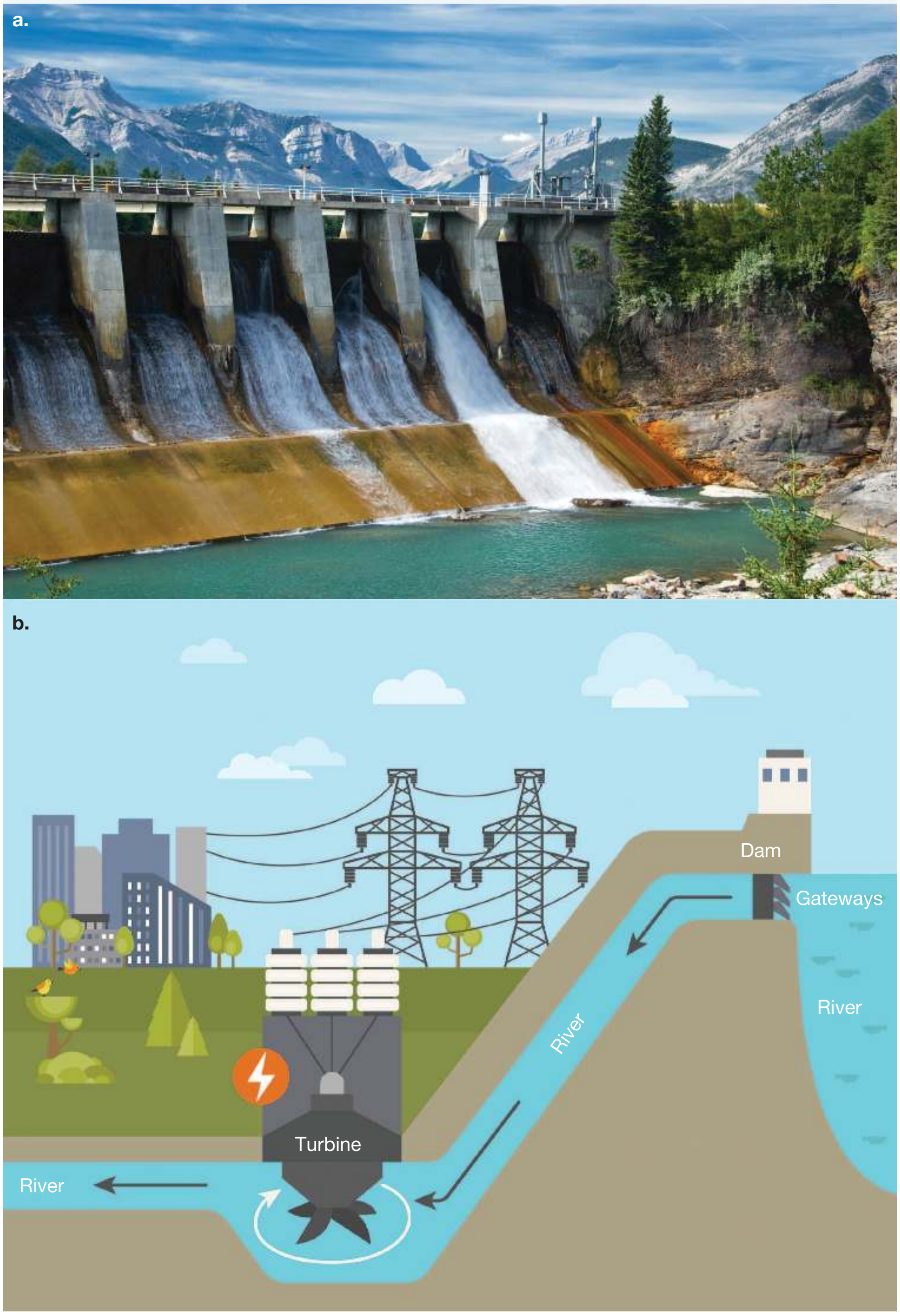
Wind turbines are used to produce electricity. The blades are attached to a shaft that produces electricity when the blades are turned by wind currents. In terms of size, the wind turbines are as high as a building (about 70 m). The wind turbine blades are about 50 m long. Wind farms vary in the number of wind turbines they have, from 5 to 150. An average turbine can provide electricity to 900 homes.

FIGURE 7.35 A wind turbine farm generating electricity using wind power

Hydroelectricity

When water flows rapidly from a dam or reservoir, it spins the turbine blades of a generator to produce electricity. As the water flows from a high point of the dam or reservoir, it gains potential energy and converts this to kinetic energy. The kinetic energy is used to spin the turbine blades, and electricity is formed in a generator. The rate of flow of water is controlled.

FIGURE 7.36 a. Dam **b.** Hydroelectric power generator



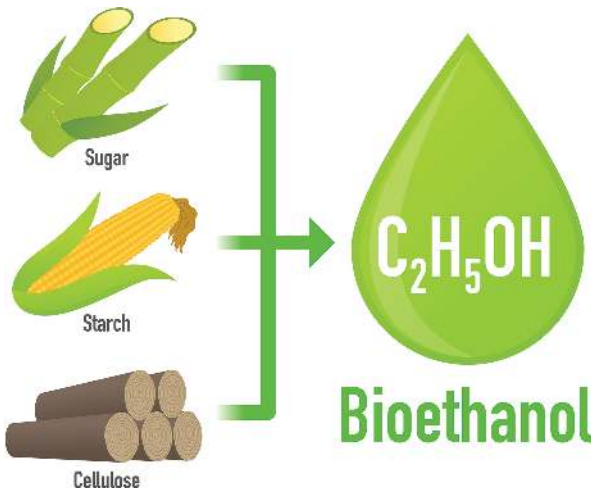
7.4.3 Renewable fuels

The fuels bioethanol and biodiesel are both biodegradable. If their wastes are introduced into waterways or soil, they will not harm the environment when they are decomposed by bacteria. Some carbon dioxide emissions are produced to make bioethanol and biodiesel, when farm machinery is used for cropping, transporting resources or during manufacturing (though these emissions are less than those from petrol or other non-renewable fuels). Bioethanol and biodiesel are therefore considered to be renewable fuels rather than green fuels.

Bioethanol

To reduce the amount of carbon dioxide emissions into the atmosphere, one alternative is to add bioethanol to petrol for use in motor vehicles. Bioethanol is a suitable alternative to petrol since it is produced from plant crops such as sugar cane and corn, and it can be produced relatively quickly compared to fossil fuels. Bioethanol emits considerably less carbon dioxide than petrol, which is a non-renewable energy source.

FIGURE 7.37 Sources of bioethanol



A bioethanol blend of E5 means that it contains 5 per cent bioethanol and 95 per cent petrol. E10, E25, E85 and E100 are also available globally. Currently, the E10 blend fuel has been approved by Australian regulators, since its use does not require any modifications to the petrol engines of most cars. However, engines will need to be modified if higher concentrations of bioethanol are used.

One disadvantage of using bioethanol is that it produces less energy than petrol — about 60 per cent of petrol for the same amount of fuel.

FIGURE 7.38 E10 fuel offers a cleaner blend of petrol.

Biodiesel

Biodiesel is made from animal and plant waste (examples include algae, sewage, food waste and plant oils) and is regarded as a renewable fuel. Biodiesel is used as fuel for vehicles and to generate electricity.

FIGURE 7.39 Many different types of materials can be used to make biodiesel, including **a.** coconut oil, **b.** sugar cane, **c.** wood chips and **d.** food waste.

ACTIVITY: Bioethanol and biodiesel

1. Why are bioethanol and biodiesel considered renewable fuels, and how do they differ from non-renewable fuels like petrol?
2. What are the environmental benefits and challenges of using bioethanol as a fuel compared to petrol?
3. Do you think governments should promote the use of bioethanol and biodiesel more widely? Why or why not?

7.4.4 Carbon capture and storage (CCS)

Carbon capture and storage (CCS) is a technique used to prevent or reduce CO_2 emissions into the atmosphere, by storing this gas underground. This technique allows industries to continue to use electricity (from non-renewable fuels) to make products. CCS involves three steps: capture of CO_2, transportation and storage.

CO_2 capture

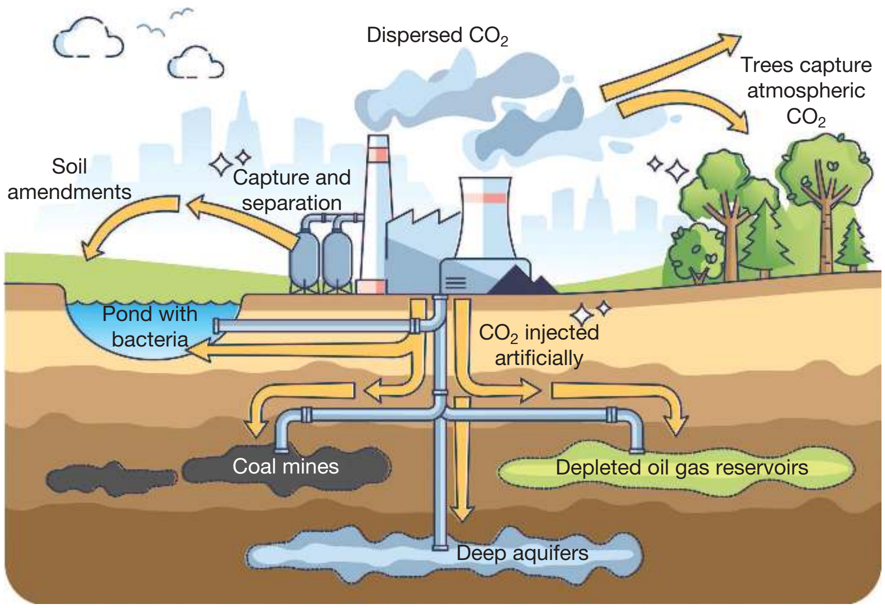
CO_2 is separated from the exhaust of power stations, factories and plants. The fuel is burned in an oxygen-rich (O_2) environment instead of air (which contains only 21 per cent O_2). More concentrated amounts of CO_2 emissions are obtained using an oxygen-rich environment. This makes it easier and cheaper to capture.

Transportation and geosequestration

The captured CO_2 is compressed and chilled to a liquid. Using pipelines or ships, the chilled CO_2 liquid is transported to a storage site.

The CO_2 is stored at a depth of 800 m or more below the ground. At this depth, it is a **supercritical** liquid. Storing CO_2 underground is also known as **geosequestration**.

FIGURE 7.40 Outline of carbon capture and geosequestration

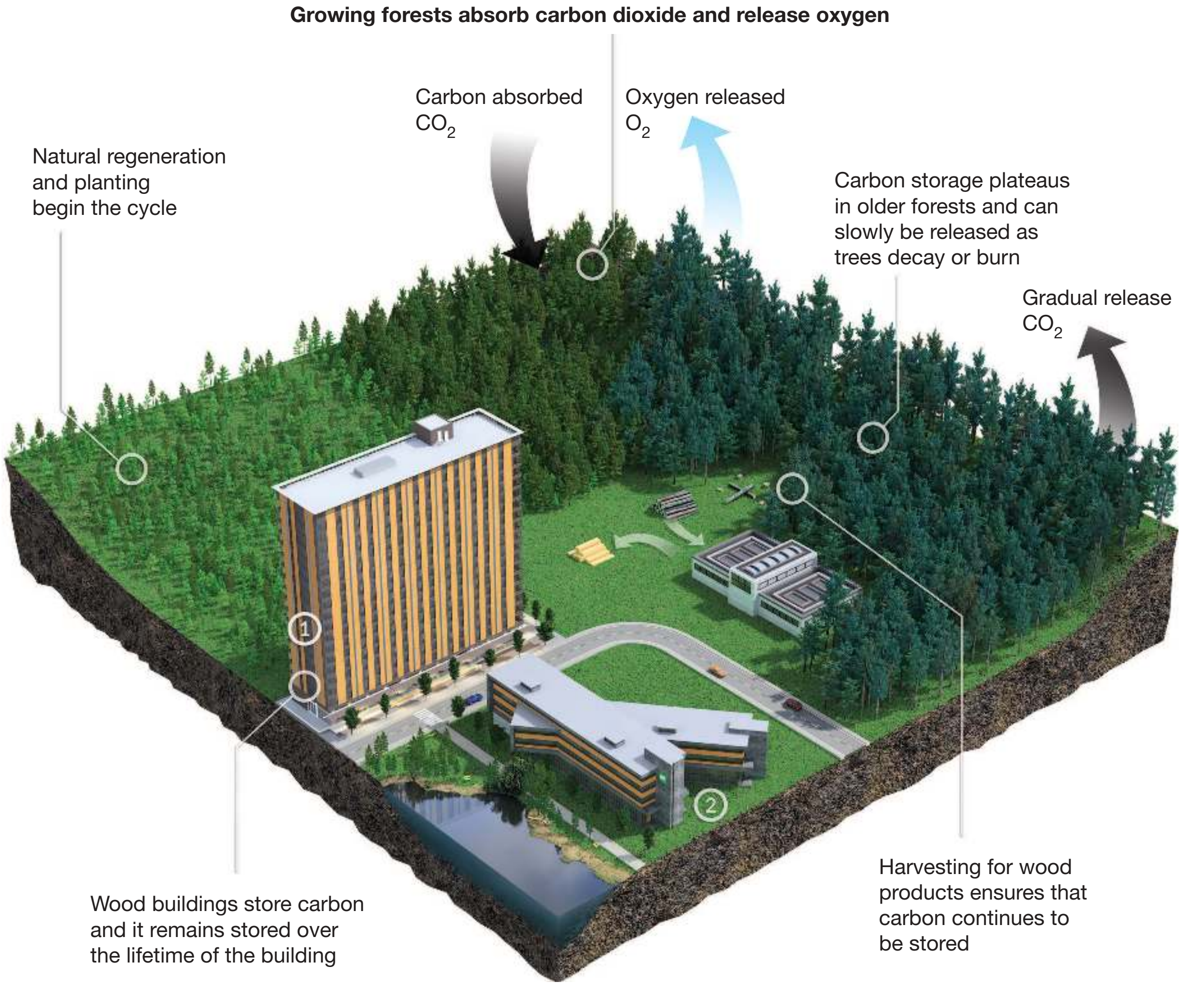


7.4.5 Sustainable forests

Trees use the carbon dioxide from the atmosphere when they undergo photosynthesis. It is recognised that 50 per cent of each growing tree contains carbon stored in the branches, leaves, trunk and roots. Trees improve the soil content and provide shelter for organisms. They may also improve the variety of plants and animals living in a specific habitat. Wood products from trees contain stored carbon. These products are used to build the timber frames of houses and buildings, and in furniture and floorboards. Since 4 million tonnes of carbon are stored in Australia's national forests per year, it makes sense to continue maintaining the forests (such as replacing older or dying trees) to tackle climate change.

FIGURE 7.41 Eucalyptus trees store carbon for many decades.

FIGURE 7.42 How carbon stored in wood can be locked away, rather than being released into the atmosphere. Would burning wood be another way to store carbon?



7.4.6 Electric vehicles

Electric vehicles (EVs) have many environmental benefits compared to petrol-fuelled cars. EVs do not produce CO_2 when driven. However, it is not entirely true to say that an EV has zero emissions, because electricity is used and CO_2 is released to make the car panels and put them together during the manufacturing process.

EVs are also a better solution than petrol-fuelled cars because of the rising cost of fuel. However, the time it takes to recharge an EV varies from 30 minutes to 12 hours, so this may be considered to be a small disadvantage.

By 2025, it is estimated that 20 per cent of car sales will be electric. A further increase to 40 per cent is expected by 2030.

FIGURE 7.43 Charging an electric vehicle

INVESTIGATION 7.5

Measuring carbon storage in trees (field work)

Introduction

Trees take in carbon dioxide and use water to produce glucose during photosynthesis. While some carbon dioxide is released into the atmosphere during respiration, about half the amount of glucose produced during photosynthesis is stored as biomass in trees. This form of carbon capture is known as forest or carbon sequestration. Forest sequestration is a useful strategy in reducing the amount of carbon dioxide in the atmosphere. The diameter or height of trees can be used to determine how much carbon is stored in a tree or shrub.

Aim

To measure the carbon storage in a local area

Materials

- measuring tape

Method

1. Divide the area of investigation (e.g. a forest or park) into sections or quadrants of 5 sq m. Your teacher may decide to change this number.
2. Record the type of tree (native hardwood, such as gum tree; softwood, such as pine; or other) and measure the circumference in centimetres.
3. Measure and record the height of any shrubs in the section.

Results

1. Use the **Measuring carbon storage** digital document in the Resources panel to determine the amount of carbon stored in the trees and shrubs.
2. Represent the class results in a table.

Discussion

1. What is the process by which carbon is produced in trees and plants?
2. How does carbon storage in trees link to the amount of CO_2 released into the atmosphere?
3. Use the results to identify any trends in the results table.

Conclusion

Summarise the findings of this investigation.

SCIENCE INQUIRY: Reducing carbon dioxide emissions — global solutions for a sustainable future

The need to reduce carbon dioxide emissions

Carbon dioxide emissions are one of the primary contributors to global warming and the enhanced greenhouse effect. Reducing these emissions is crucial to slowing climate change and ensuring a sustainable future. Scientists, governments and industries are working together to find global solutions to this pressing issue.

Key strategies to reduce carbon emissions

Renewable energy sources

Transitioning to solar, wind and hydroelectric energy reduces reliance on fossil fuels. Countries like Iceland and Norway already generate over 70 per cent of their electricity from renewable sources.

Energy efficiency

- Using energy-efficient appliances, LED lighting and insulation reduces energy consumption and emissions.
- Urban planners design sustainable cities with green buildings and public transport systems to reduce energy use.

Carbon capture and storage (CCS)

- Technologies like Climeworks' direct air capture remove carbon dioxide directly from the atmosphere and store it underground as rock.
- Companies like Equatic combine carbon removal with hydrogen production to create clean energy solutions.

Reforestation and conservation

- Planting trees and protecting forests increases carbon sinks to absorb carbon dioxide from the atmosphere.
- Projects like the Billion Tree Campaign aim to restore ecosystems globally.

FIGURE 7.44 Working together to plant trees helps build a greener future.

International agreements

Treaties like the Paris Agreement encourage countries to set emission reduction targets and work together to achieve net-zero emissions by 2050.

1. What are some ways individuals and communities can reduce their carbon footprint?
2. Why is international cooperation important in addressing carbon dioxide emissions on a global scale?
3. How does carbon capture technology help reduce atmospheric carbon dioxide, and what challenges does it face?
4. Why is it important to balance carbon reduction strategies with economic and social considerations?

Information and processed data can be analysed and compared to identify and explain qualitative and quantitative patterns, trends, relationships and anomalies (VC2S10I05)

7.4 Activities

learnon

7.4 Quick quiz on	7.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4, 7, 13	5, 8, 10, 12, 14, 16	3, 6, 9, 11, 15

Remember and understand

1. **State** the difference between a green energy resource and a renewable energy resource.
2. **Identify** two examples of green energy sources.
3. **Discuss** why biofuels are better to use than petrol or natural gas.
4. **Explain** why carbon capture is important.
5. **Identify** the alternative that can be added to petrol for use in motor vehicles to reduce the amount of carbon dioxide emissions into the atmosphere.
6. **Suggest** a benefit of growing forests.

Apply and analyse

7. **Identify** two disadvantages of using bioethanol as a fuel.
8. **Explain** why it is important for the world to address the problem of global warming.
9. Imagine your suburb/town is planning to build a new hydroelectric power plant to generate electricity. **Discuss** the benefits and potential environmental impacts of using hydroelectricity.
10. **Explain** how recycling will help to slow global warming.
11. **Discuss** the advantages and disadvantages of electric vehicles versus petrol-fuelled vehicles.

Evaluate and create

12. SI **State** whether biogas is a green fuel. **Justify** your answer.
13. SI **Discuss** two issues in running a wind-energy farm.
14. SI **Discuss** how the principles of green chemistry are used to reduce or minimise global CO_2 emissions.
15. Consider the use of green hydrogen as an energy source. **Suggest** what you think the advantages and disadvantages of using green hydrogen are. **Explain** your reasoning.
16. **Construct** a fact sheet about carbon capture and storage (CCS) and explain how various technologies may be used for this process.

Answers and sample responses are available in your digital formats.

LESSON 7.5 Review

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7.5 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
7.2	I can describe how the biosphere supports all life on Earth.			
	I can describe the processes that cause carbon to be cycled to and from the atmosphere.			
7.3	I can explain how carbon dioxide emissions cause an enhanced greenhouse effect and global warming.			
	I can describe evidence of global warming.			
7.4	I can discuss how carbon dioxide emissions can be reduced on a global scale.			

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Post-test	Topic 7 Post-test
eWorkbook	Topic 7 eWorkbook
Digital document	Key terms glossary

7.5 Activities

learnon

7.5 Review questions

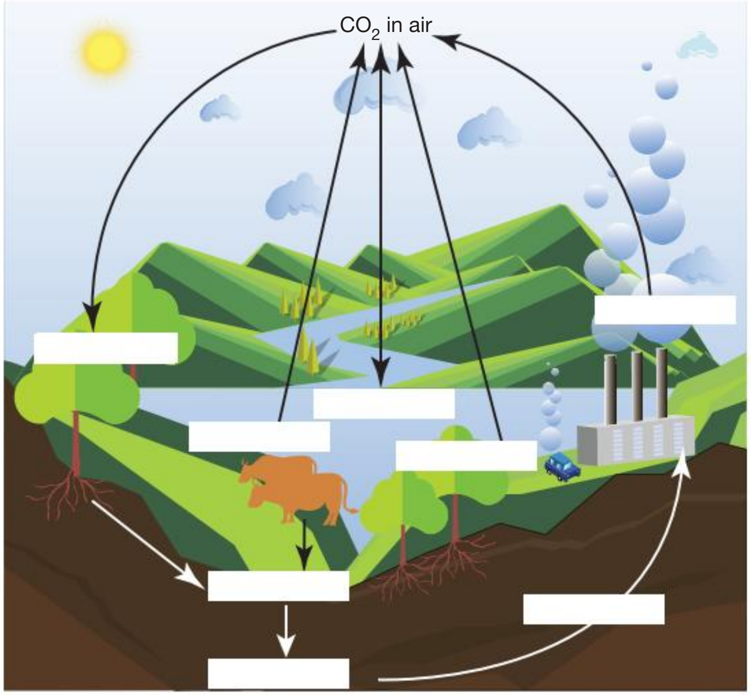
LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 4, 9	5, 7, 11, 12	6, 8, 10, 13, 14

Remember and understand

1. **Discuss** why the carbon cycle is important.
2. **Identify** important benefits of the carbon cycle.
3. **State** whether bioethanol is a green energy source. **Explain** your answer.
4. **Discuss** the effect of deforestation on the carbon cycle.
5. a. **Explain** how carbon sequestration affects global carbon dioxide emissions.
   b. **Describe** where carbon sequestration occurs.
   c. **Identify** a major problem with carbon capture and storage strategies.
6. **Outline** six ways that everyone can help to reduce their carbon footprint.

7. **Identify** and label the missing chemical reactions/processes from the following figure of the carbon cycle, using the word bank provided.

   photosynthesis, extraction, decomposition, sedimentation, animal respiration, plant respiration, combustion, ocean uptake and release



Apply and analyse

8. **State** whether the Paris climate agreement is sufficient to reduce global temperatures by 2050. **Justify** your answer.
9. The world is moving towards green energy. **State** whether this means we can stop using fossil fuels now. **Justify** your response by considering the benefits and disadvantages of using fossil fuels.
10. **Discuss** the environmental, social and economic reasons why reducing your carbon footprint is important.
11. **Discuss** the benefits of reducing carbon dioxide gas emissions.
12. **Explain** why scientists agree that a global temperature rise of 1.5 °C is important to acknowledge.

Evaluate and create

13. SI **State** whether the internet creates any carbon footprint. **Explain** your response.
14. SI Consider the pros and cons of bioplastics. **State** whether bioplastics could reduce future carbon dioxide emissions. **Justify** your response.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

8 Waves

CONTENT DESCRIPTION

Wave and particle models can be used to describe energy transfer (conduction, convection and radiation) through different media; waves (electromagnetic and mechanical) have different properties, features (including amplitude, wavelength, frequency and speed) and applications (VC2S10U14)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 8.1 Overview

8.1.1 Introduction

FIGURE 8.1 Your brain relies on energy transfers to communicate. The electrical impulses travel along the nerve fibres.

If you take apart a smartphone, you will find plastic, glass, computer chips, copper wire as well as other components. But you will not find the 'energy' that powers it. Energy is not a tangible object. It cannot be seen, does not take up space and has no mass. Instead, energy is a concept — an idea that explains how things happen in the universe. Everything that we call energy is associated with movement or the potential for movement.

Energy comes in many forms, and its transfer or transformation is what enables events and processes in the world. Electrical energy, for instance, involves the movement of electrons, or their potential to move, as in static electricity. Sound energy is the transfer of energy through vibrating particles in the air. Chemical energy is stored within the bonds of molecules and is released during chemical reactions. Kinetic energy is the energy of motion, such as when a ball rolls down a hill, while gravitational potential energy describes the energy stored when an object is elevated, ready to fall.

We only notice energy when it is transferred between objects or transformed into another type. For example, when you touch a flame, heat energy is transferred from the rapidly moving particles in the fire to your skin, causing a warming sensation. Light energy is another form that we cannot directly see. It is only when light energy is converted into electrical impulses by our retinas and processed by our brains that we perceive light. Similarly, we hear sound waves when the kinetic energy of vibrating air particles transfers to the moving parts in our ears.

Waves are a fundamental way that energy is transferred across the universe. In this topic, we will explore how waves — both electromagnetic and mechanical — carry energy through different media. By studying their properties — such as amplitude, wavelength, frequency and speed — we will see how waves make energy transfer possible. We will also examine real-world applications, such as communication technologies, and explore the ways Aboriginal and Torres Strait Islander Peoples have used their knowledge of sound waves in traditional instruments for music, hunting and storytelling. These examples illustrate the remarkable interplay between scientific principles and cultural practices.

DISCUSSION

1. Why is it that of all the planets, only Earth seems to support life?
2. Why do I feel so cold when I get out of the ocean, even on a hot sunny day?
3. Why do some things emit light while others don't?
4. How does information get from one smartphone to another?
5. Will we ever be able to improve on our eyes and ears?
6. How can the blind see?
7. How will we be communicating in the future?

SCIENCE INQUIRY: Using energy to communicate

Since prehistoric times, we have had a need to communicate over a distance. Our early ancestors would make noise to warn of approaching predators. The communication range was short, but it was enough to serve the purpose.

Once humans started to make settlements, we started to see the need for a form of communication that could take information a greater distance. Smoke signals, large bonfires and drums were used to send simple messages. Anything more complex required the delivery of handwritten letters, which only happened after the invention of writing around 6000 years ago. Shortly after writing was invented came messenger services. Important messages would be given to runners who would hand-deliver news. Due to the likelihood of these messages being intercepted by an enemy, codes and encryption were also invented soon after.

With the invention of the ship for ocean navigation and the exploration of the globe, communication eventually became a global issue. In March 1791, Captain Arthur Phillip, Governor of New South Wales, wrote a letter to his employer, King George III in London, asking for some time off work. The only way to get the letter to London was by sailing ship. The letter took eight months to get to King George III, and his reply took a further eight months to reach Sydney. A faster technology was clearly needed if we were to regularly communicate around the planet.

FIGURE 8.2 Global communication began with ships.

Although the transmission of matter is a lot faster today, a letter sent from Sydney to London via airmail would still take about five days to arrive and at least another five days for the reply to be received in Sydney. A much faster method of communication is via telephone, messaging or email, which only take seconds for the reply to arrive. There is no longer any need for matter, such as letters, to be transported. The message sent between Sydney and London via the transmission of energy can be sent at the speed of light — 300 000 km/s. Over long distances, there are many advantages of energy transmission without the transmission of matter.

Answer the following questions about how we use energy to communicate.

1. What has changed since 1791 to reduce the physical communication time from Sydney to London and back from 16 months to 10 days?
2. What are all of the options now available for sending a message from Sydney to London? Which options do not require the movement of matter from Sydney to London and back? How fast is this communication?
3. If matter does not move from one place to another when a message is sent over a long distance, what does move?

Even over a short distance, the transmission of energy is faster than the transmission of matter. Imagine that you want to warn a couple of friends that they are about to be hit by an out-of-control skateboarder. Your options for saving them include:

I. yelling at them to get out of the way
II. yelling and pointing at the skateboarder
III. waving your arms in the air and pointing
IV. holding up a sign that says 'Watch out!'
V. running across the road to push them out of the way.

4. Which of the options I–V involves:
   a. the transmission of matter
   b. the transmission of energy
   c. the transmission of both matter and energy?
5. In your opinion, which of the options I–V is the:
   a. fastest b. slowest c. least safe?
6. Write as much as you know about the following types of invisible waves.
   a. Sound b. Ultrasound c. Visible light d. Microwaves e. Infrared f. Radio waves

Investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)

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Pre-test	Topic 8 Pre-test
eWorkbook	Topic 8 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 8 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 8.2 Heat transfer

LEARNING INTENTION

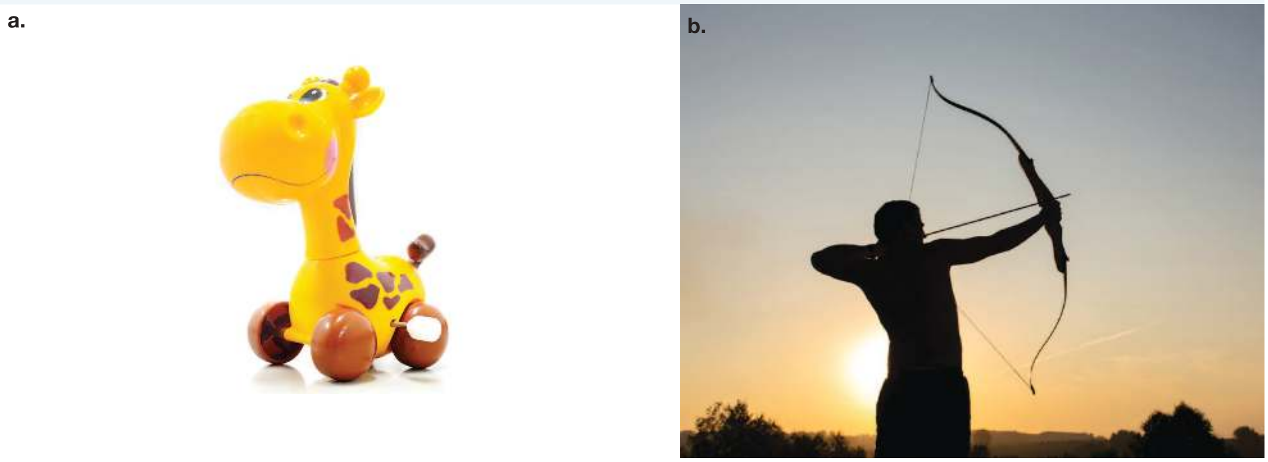
In this lesson you will:
- distinguish between heat and temperature
- define absolute zero
- describe the key mechanisms of energy transfer in terms of the particle model.

8.2.1 What is energy?

Have you ever felt like you were 'full of energy'? If so, you probably felt like moving around or doing something active. Objects can have energy too. We cannot always see the energy that they possess, but we can often observe the effects of objects gaining or losing energy. Winding up a toy or pulling back the string of an archery bow gives these objects lots of energy.

FIGURE 8.3 a. Winding up a toy or **b.** pulling back the string of an archer's bow provides these devices with energy to move and/or change.

a. b.



KEY IDEA

Energy is defined as the ability to exert a force and cause change (such as moving or deforming an object).

Energy may cause an object or other nearby objects to move, such as firing an arrow from a stretched bow. The energy of an object can also give objects the potential to move or to create sound, **heat** or light.

TABLE 8.1 The different forms of energy

Types of energy			
Potential energy Stored energy that, when released, is converted to other forms such as sound, heat or light energy		**Other types of energy** Often converted from potential energy, these are more easily observed by our senses	
Gravitational Potential energy of an object elevated above the ground		**Kinetic** Energy possessed by objects that are moving	
Elastic Energy stored by an elastic object that is stretched, such as a spring or rubber band		**Heat** Energy that causes objects to gain temperature	
Chemical Energy stored in chemicals that, when reacted together — such as in burning reactions — release heat, sound or light		**Light** Energy that may be released, for example, when an object is hot or by a nuclear reaction in a star	
Nuclear Energy stored in the nucleus of atoms that can release energy slowly, such as in a nuclear reactor; or quickly, such as in a nuclear explosion		**Sound** Energy carried by the air in a room and detected by the ear	
Electrical (static) Energy stored by the build-up of charge		**Electrical (current)** Energy provided by the movement of electrons	
Magnetic Energy stored in magnets or metals placed in a magnetic field			

FIGURE 8.4 The chemical energy in household batteries is an example of potential energy that powers many household devices, including remote controls.

FIGURE 8.5 All objects that are moving have kinetic energy. The faster an object moves, the more kinetic energy it has. Moving objects can do work by travelling distances or by colliding with other objects.

8.2.2 Transferring and transforming energy

Energy can be transferred, or passed on, to another object or to the surrounding environment. For example, if you hug a hot-water bottle, the heat is transferred from the bottle to you. The heat has been transferred from one object to another, but has not changed form.

INVESTIGATION 8.1

Popping corn

Aim

To investigate the transformation of energy

Materials

- saucepan with lid
- popping corn
- matches
- vegetable oil
- Bunsen burner
- heatproof mat

Method

1. Pour a little cooking oil in the saucepan.
2. Pour enough popping corn into the saucepan to cover the base and place the lid securely on top.
3. Light the Bunsen burner and heat the saucepan over a blue flame, making sure the flame is spread evenly over the base of the saucepan.
4. Heat the corn until the popping stops.
5. Turn off the Bunsen burner, put the saucepan on the heatproof mat to cool and take the lid off the saucepan to observe any changes.

Results

Record the types of energy that you observed in the experiment.

Discussion

1. What type of energy did the popping corn have before heating? What type did it have during heating?
2. Even though you could not see the corn when the lid was on, how do you know that an energy transformation took place?

Conclusion

Write a conclusion for your investigation, remembering to refer back to the aim.

Energy can also be transformed, or converted, into other forms of energy. For example, the electric motor in a hair dryer transforms electrical energy into kinetic energy: that is, the energy of the moving fan blades. Sometimes, during a transformation of energy, not all of the energy is transformed into useful forms.

Some of the energy may be transferred to the surrounding environment as unwanted heat, or transformed to light or sound. For example, not all of the energy you use to ride a bike up a very steep hill goes into making the pedals move. Some of the energy is 'wasted' as your body gives off heat, or as heat is produced by friction in the gears.

FIGURE 8.6 Electrical energy supplied to this light globe is *transformed* into heat and light energy in the filament. The light is the desirable energy, but the heat is considered 'wasted' as it has no benefit to us.

FIGURE 8.7 In a game of pool, the white cue ball is struck, providing it with kinetic energy. The kinetic energy of the white ball is then *transferred* to the coloured ball.

FIGURE 8.8 A computer *transforms* electrical energy into light energy in the screen, and sound energy when music and videos are played.

FIGURE 8.9 A stove top *transforms* electrical energy into heat energy in the glowing hotplate, which is then *transferred* to the pot and water.

8.2.3 Heat and temperature

The amount of heat energy (or thermal energy) that an object has is due to the total **kinetic energy** of every particle in the object. You may have seen in science fiction movies that space is cold. This is true; it is approximately –270 °C. At this temperature, particles almost stop moving; just three degrees cooler and they would stop completely. This is what we call **absolute zero**. You cannot get colder than this.

FIGURE 8.10 Liquid nitrogen is comparatively warm compared to space, at only –196 °C. An object placed in liquid nitrogen will become brittle and may shatter as its particles slow down, causing the object to contract.

The **temperature** of any substance is linked to the average kinetic energy of the particles of that substance. As the substance is heated, some of the absorbed energy is stored in the particles and some increases the motion of the particles. This causes an increase in the temperature of the substance.

Clearly, there is a link between the idea of heat and temperature, but they are not the same thing. A typical sparkler will throw off sparks with a temperature of over 1000 °C, but as the particles in the sparks have a small mass, their heat energy is quite low, making them practically harmless. The sparks are at a temperature that makes them glow with **visible light**. Each spark is safe, but the larger mass of the sparkler itself makes it dangerous to touch.

However, we know that if you spill boiling water on yourself it will burn you. The water at 100 °C is much cooler than the spark, but as there are so many more particles involved there will be a much greater heat energy. At any given temperature, not all the particles of any substance have the same kinetic energy. Instead, the particles possess a wide range of kinetic energies. Temperature is only a measure of the average kinetic energy of the particles that make up an object, not the total energy in the object.

FIGURE 8.11 The tiny sparks of this sparkler have a very high temperature, but their small mass means their heat energy is low.

FIGURE 8.12 Boiling water has a temperature of only 100 °C but there are many particles of boiling water.

KEY IDEA

Temperature is a measure of the average kinetic energy of the particles that make up an object, not the total energy in the object. This is vital to understand in the context of such issues as climate change. A rise in temperature of one degree doesn't sound like a lot, but when you think about all of the particles in the atmosphere you realise that this means a huge amount of extra energy will be in the atmosphere.

DISCUSSION

If you have an object at 0 °C and you double the energy content, do you just double the temperature?

ACTIVITY: Heat versus temperature

Investigate the difference between heat and temperature by filling two beakers with a different volume of water. Heat each beaker on an identical hotplate, on the same setting, for the same amount of time, thus supplying the same amount of heat energy to each beaker. Does an equal change in heat energy result in the same change in temperature?

8.2.4 Heat flow

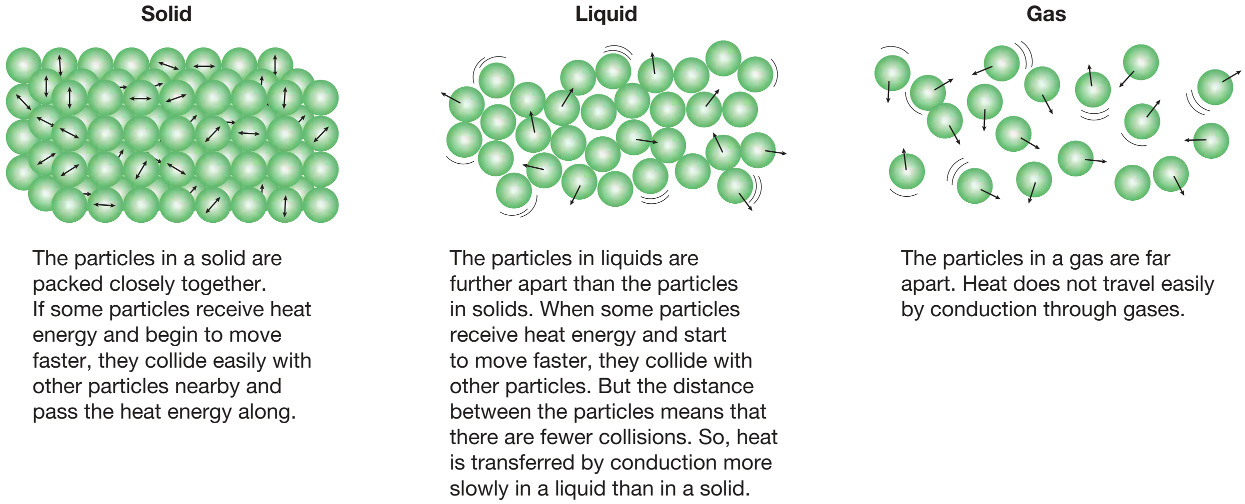
When an object is warmer than its surroundings, heat energy will flow out of it in one or more ways. These are **conduction**, **convection** and **radiation**.

Conduction

Conduction occurs when a particle passes kinetic energy on to another particle. This can happen during collisions. For example, when an oxygen molecule in the air hits your arm, it will leave more quickly than it arrived as the faster particles in your arm transfer energy to the oxygen molecule.

More commonly, we think of conduction as heat transfer in a solid. Most solids are better conductors than liquids and gases because their particles are more tightly bound and closer together than those of liquids and gases. Conduction is a slow way to transfer energy in liquids and gases.

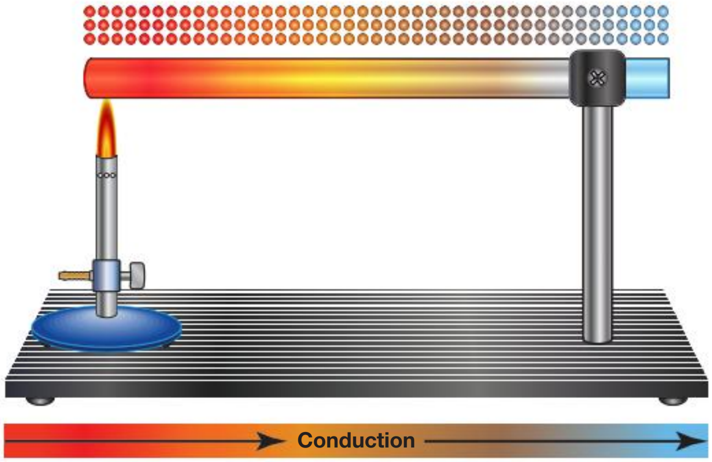
FIGURE 8.13 Heat transfer in a solid, a liquid and a gas



The particles in a solid have bonds between them. These help to transfer the energy from the hot region to the cold region. Imagine one end of a metal bar is heated by contact with the hot gases from a Bunsen burner — consider what happens next:

- The particles at the warm end gain kinetic energy.
- This means they vibrate more.
- As the faster particles are connected to other particles by bonds, the neighbouring particles are pulled around more.
- This means that energy has been transferred.
- This transfer of energy continues down the bar towards the colder end.
- This will only stop when the bar is the same temperature at all points and the energy is shared evenly between the particles.

FIGURE 8.14 In a solid, heat energy will be transferred from a hot region to a cold region by conduction.



Metals are the best conductors of heat. The electrons of metals are freer to move than those of other solids, and are therefore able to transfer their kinetic energy more readily to neighbouring electrons and atoms. We use metals to efficiently transfer heat in many situations. A common use is in computers and phones, where metal **heat sinks** prevent the processors from overheating.

Materials that are poor conductors are called **insulators**. Materials such as polystyrene, foam, wool and fibreglass batts are effective insulators because they contain pockets of still air. Air is a very poor conductor of heat.

INVESTIGATION 8.2

Heat conduction in solids

Aim

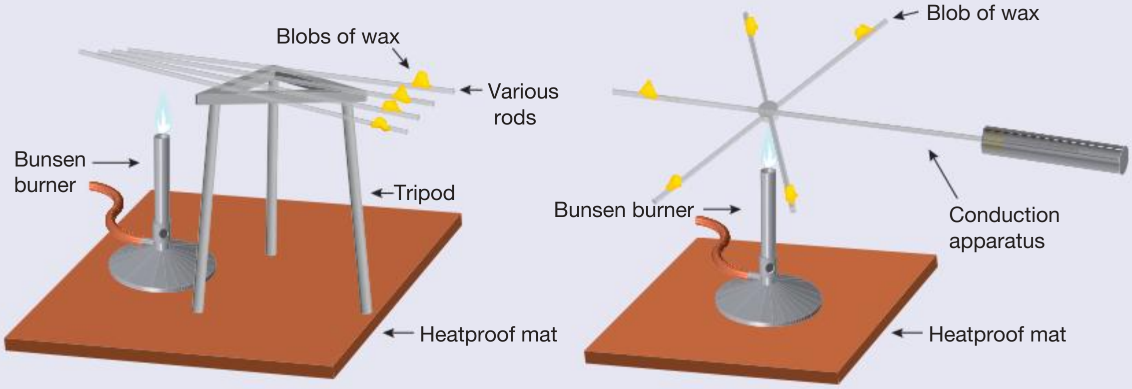
To compare the conduction of heat through different metals

Materials

- set of 3 or 4 metal rods (different metals but identical in size) or a heat conduction apparatus
- wax candle
- Bunsen burner and heatproof mat
- matches
- tripod
- ruler
- stopwatch

Method

1. Set up the tripod and rods or heat conduction apparatus as shown in the figure.
2. Light the candle and melt a blob of wax onto one end of each rod. Ensure that each wax blob is the same distance from the end that will be heated by the Bunsen burner flame.
3. Use the blue flame of the Bunsen burner to heat the end of each rod. Start the stopwatch at the instant that heating begins.
4. Record the time taken for each blob to produce its first droplet of wax.
5. Repeat steps 1–4 for each different metal rod.



Results

1. Record your data in a suitable table. Remember to include a title for your table.
2. Present your data as a bar or column graph. Consider why these are the best choices to plot your data.

Discussion

1. According to your data, which of the metals is the best conductor of heat?
2. According to your data, which of the metals is the poorest conductor of heat?
3. Identify the independent and dependent variables in your investigation.
4. Compare your data with that of others in your class. Comment on the consistency of the conclusions within your class. If there was inconsistency, suggest one or more reasons for it and some suggestions to improve the experiment.

Conclusion

Write a conclusion to your investigation, remembering to refer back to the aim.

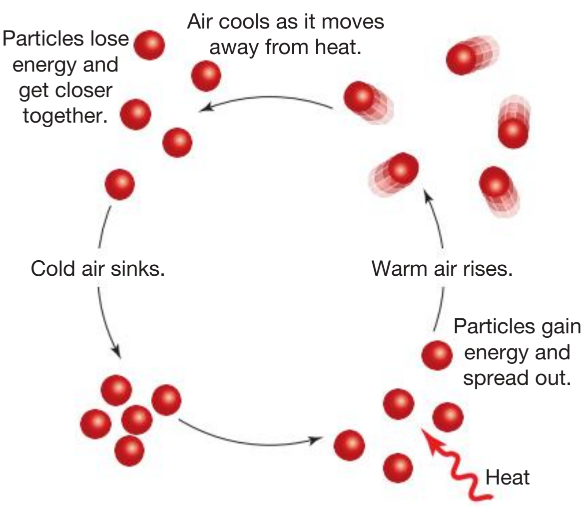
Convection

Unlike the particles that make up solids, those of liquids and gases are able to move around. In liquids and gases, heat can be transferred from one region to another through the net movement of particles. This type of heat transfer is called convection.

Figure 8.15 shows how convection takes place in air.

- Particles are heated. They gain kinetic energy and move around more.
- The heated air is now less dense.
- Less dense things float on more dense things and so the hot air rises.
- This also means that cold air must sink down to take the place of the hot air.
- As the faster-moving particles rise, they collide with other particles, sharing out the energy.
- The once hot air is now cooler and will now take up less space, become denser and sink.
- The process repeats until all of the air is the same temperature.
- We call this cycle of ‘heat, rise, cool, fall, repeat’ a **convection current**.

FIGURE 8.15 Modelling heat transfer in air

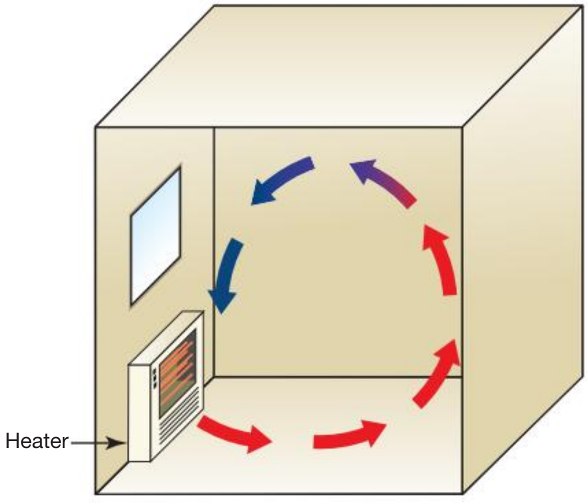


In Earth's mantle, convection currents carry heat from Earth's core towards the surface. This heat from the core causes the rock in the mantle to expand and rise towards the surface, where the heated rock cools down, contracts, and then sinks back down towards the core. Once near the core again, the rocks are reheated and rise once more, and the cycle continues.

These convection currents enable the drift of the tectonic plates, which is why continents move.

Home heating systems create convection currents that move warm air around. When ducted heating vents are in the floor, warm air rises and circulates around the room until it cools and sinks, being replaced with more warm air. Powerful fans are not necessary. Gas wall heaters have fans to push warm air across the room near floor level so that it heats the entire room. Ducted heating vents in the ceiling require powerful fans to push the warm air downwards so that it can circulate more efficiently.

FIGURE 8.16 Convection currents circulate warm air pushed out by heaters around the room.

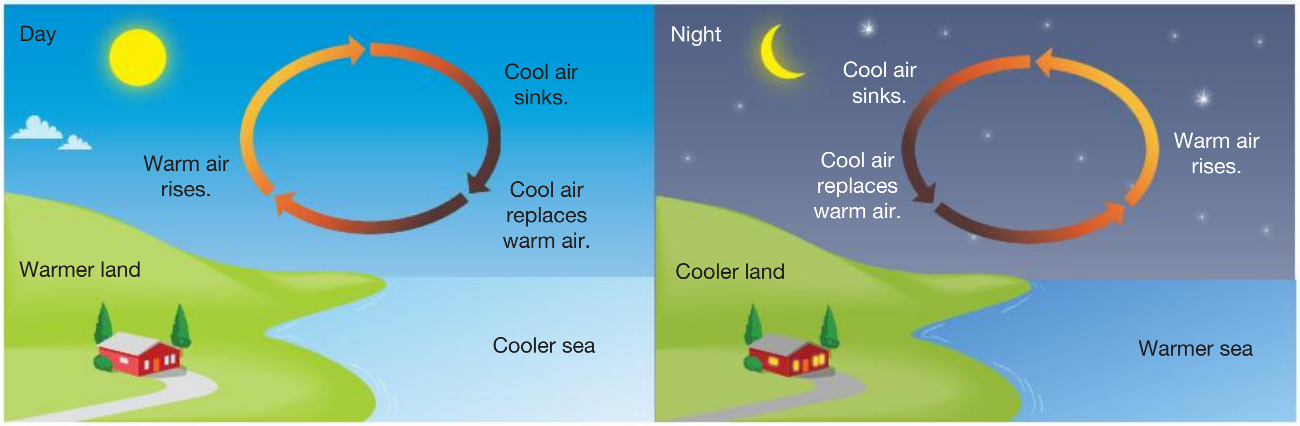


Hot summer days by the sea

Coastal areas usually experience less extreme maximum temperatures on hot summer days as a result of **sea breezes**. This occurs by the following process:

- During hot summer days, radiant energy from the Sun heats the land and the sea.
- As a result of the different properties of the land and water, after a few hours the land has a higher temperature than the sea.
- The hot air over the land expands, becoming less dense than the cooler, denser air over the sea.
- The air over the land becomes hot as a result of conduction.
- The cooler air over the sea rushes in towards the land, replacing the rising warm air, causing a sea breeze. At night, if the sea temperature is higher than the land temperature, the convection currents move in the opposite direction, creating a flow of air towards the sea.

FIGURE 8.17 A sea breeze is caused by convection currents in the air during warm summer days. At night, the convection currents are reversed.



Radiation

Heat can be transferred without the presence of any particles at all, as electromagnetic radiation or light. Heat transferred in this way is called **radiant heat**. As you will see later in this topic, not all forms of light are visible to our eyes. One type of light that you can't see but can feel is infrared light. If you hold your hand over a hot object, you can feel the heat even if it is not glowing with visible light.

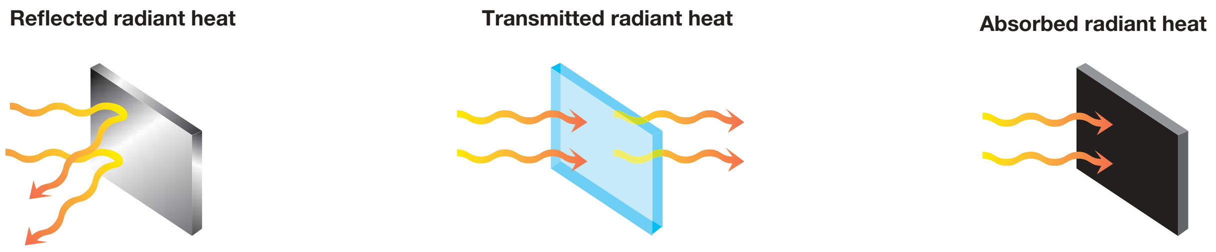
Heat from the Sun reaches Earth by radiation, most of it in the form of **infrared radiation**. There are not enough particles between the Sun and Earth for heat transfer by either conduction or convection.

There are three things that can happen when electromagnetic radiation meets an object. As an analogy, let us imagine a bullet fired at a target. What could happen?

- If the energy of the bullet is too little, it may just bounce off the target: it would be reflected.
- If the energy is high enough, it may pass through the target: it would be **transmitted**.
- If the energy is within a narrow range, it may stick in the target without passing through: it would be **absorbed**.

In a similar way, when the infrared light waves that we call radiant heat meet an object, they can be reflected, transmitted or absorbed. How much energy is reflected, transmitted or absorbed depends on the properties, including colour, of the surface. The greenhouse effect (see topic 7) is an example of the radiant heat from the Sun being absorbed and reflected by greenhouse gases — such as carbon dioxide, water vapour and methane — that are present in the atmosphere.

FIGURE 8.18 Heat may be reflected, transmitted or absorbed.



Shiny or light-coloured surfaces tend to reflect light and radiant heat away. The temperature of these objects does not change quickly when heat reaches them by radiation.

Clear objects, like glass, allow light and radiant heat to pass through them. The temperature of these objects does not increase quickly when heat reaches them by radiation.

Dark-coloured objects tend to absorb light and radiant heat. Their temperatures increase quickly when heat reaches them by radiation.

8.2 Activities

8.2 Quick quiz	8.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4, 7	2, 6, 8, 10	5, 9, 11

Remember and understand

1. **Explain** which form of energy particles transfer to each other as heat flows through a conductor.
2. **Explain** why air near a wall furnace rises when it gets warmer. **Name** the process and **explain** how the process can keep going.

3. **Identify** the missing words to complete the sentence.
Solids such as polystyrene foam and wool are _________ conductors of heat because they have many small _________ filled with _________, which is an _________ because the molecules are so _________ apart that they hardly collide and so transfer very little _________ energy.
4. The three things that can happen to radiant heat when it arrives at any surface are that it can be *absorbed*, *reflected* or *transmitted*. For each of the following materials, **state** which of the three behaviours is most likely.
   a. A mirror
   b. A black car seat
   c. A window

Apply and analyse

5. **Explain**, with the aid of a diagram, how a coastal sea breeze results from convection currents.
6. **Explain** whether a puddle is likely to dry out faster or slower if you spread it out more.
7. **Suggest** why metal saucepans usually have plastic or wooden handles.
8. **Identify** the missing words to complete the sentence.
Many sportspeople wear _________ coloured clothing when competing on hot summer days because this colour tends to _________ the radiant heat from the Sun.

Evaluate and create

9. SI **Construct** a fair experiment to investigate the relationship between the material of a camp oven and the time taken to cook a roast. **Identify** three experimental variables that need to be controlled and **state** a prediction about the expected outcome.
10. SI During an experiment investigating the time taken to heat frying pans of various thicknesses, the following data were obtained.

Frying-pan thickness and heating time

Frying-pan thickness (mm)	Heating time (seconds)
2	110
4	215
6	330
8	445
10	540
12	650

   a. **Construct** a line graph of the data. **State** what the trend shows and predict the amount of time it would take to heat a 1 mm frying pan.
   b. Use your scientific knowledge to:
      i. **explain** why a 12 mm pan takes longer to heat
      ii. **suggest** what effect a thick 12 mm pan might have on cooking time for an egg when compared to a thin 2 mm pan, if they are both heated to the same hot temperature before adding the egg.
11. **Identify** the form of heat transfer that the following statements apply to.
   a. Energy is transferred at the speed of light.
   b. Particles move from one place to another.
   c. No particles are required for energy transfer.
   d. Free electrons in metals improve the efficiency of this type of heat transfer.
   e. The fastest particles leave the substance and cool it in this type of energy transfer.

Answers and sample responses are available in your digital formats.

LESSON 8.3 Matter and energy — waves

LEARNING INTENTION

In this lesson you will describe a wave in terms of its nature, frequency and amplitude.

8.3.1 Transmitting energy with waves

When a wave is made in a still lake by dropping a rock into it, the wave spreads out. However, the particles of water do not move along the surface — they just move up and down. A duck sitting on the lake will just bob up and down when the wave hits it. Energy has been transmitted from the rock to the duck by the wave, without any movement of the matter in between. A **wave** is able to transmit energy from one place to another without moving any matter over the same distance.

DISCUSSION

Why do you sometimes see people in movies fishing using dynamite? What is the connection between this situation and waves?

8.3.2 Two types of vibrations

Waves travel through **vibrations** of particles or energy. Vibrations can be either forwards and backwards or up and down.

Transverse waves

If a vibration goes up and down, sending a wave out at right angles to the vibration, we call this a **transverse wave**. Transverse waves can be made on a slinky. As shown in figure 8.19, the moving particles in a transverse wave travel at right angles to the direction of energy transfer.

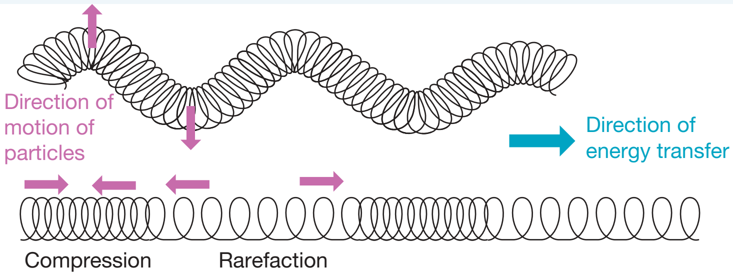
Examples of transverse waves are:
- ripples on a pond
- vibrations of a string
- light
- S-waves in earthquakes (shake buildings side to side).

Longitudinal waves

If a vibration goes forwards and backwards and the energy is carried away in the same direction, we call this a **longitudinal wave**. It is sometimes called a **compression wave** as the particles need to be compressed to send a pulse.

Examples of longitudinal waves are:
- shock waves
- P-waves in earthquakes (push buildings up and down)
- sound waves.

FIGURE 8.19 Two types of energy transfer: a transverse wave (top) and a longitudinal or compression wave (bottom). The transfer of sound energy can be modelled using compression waves in a slinky.



INVESTIGATION 8.3

Moving energy without matter

Aim

To model sound using waves on water and a slinky

Materials

- deep tray
- ribbon
- small cork
- slinky
- eye dropper
- water

Method

Part A

1. Half-fill the tray with water and place the cork on the water's surface.
2. Use the eye dropper to release drops of water near the cork.
3. Observe the motion of the small waves made by the drops.
4. Observe the motion of the cork.

Part B

1. Tie a ribbon around a coil near the centre of the slinky.
2. Take your slinky with your partner and stretch it out, with each person holding one end of the slinky. The other person should not move or wiggle the slinky.
3. Use a quick flick of the wrist to lift up your end of the slinky and then bring it back to the original height in a fraction of a second.
4. Keep making waves in the slinky.
5. Observe the motion of the wave in the slinky.
6. Observe the motion of the ribbon.

Part C

1. Make a different type of wave by quickly pushing your end of the slinky just a few inches towards the person holding the other end of the slinky, and then bring it back to the original length in a fraction of a second.
2. Keep making waves in the slinky.
3. Observe the motion of the wave in the slinky.
4. Observe the motion of the ribbon.

Results

1. Describe the motion of the cork on the small waves.
2. Describe the motion of the ribbon as the waves made by flicking move along the slinky.
3. Describe the motion of the ribbon as the compression wave moves along the slinky.

Discussion

1. Is there any evidence to suggest that any water moves in the same direction as the waves?
2. In each of the slinky waves you produced, energy was transferred from one end of the slinky to the other.
   a. Where was the ribbon after the wave had passed in each case?
   b. Did any particle on the slinky move from one end to the other?

3. Which properties of sound waves can be modelled by waves on water?
4. Identify strengths and limitations of this model.

Conclusion

What conclusions can you make about the similarity of sound waves and water waves?

8.3.3 Two types of waves

Another distinction that is useful in waves is their method of transport for the energy.

- **Mechanical waves** require particles to carry the energy.
- **Electromagnetic waves** do not need particles to carry the energy. They transfer their energy using **fields**, as we will see later.

If a wave requires particles to carry the energy, those particles are referred to as the **medium**. For instance, sound waves cannot travel in a vacuum — a medium, such as air or water, is required.

8.3.4 Measuring waves

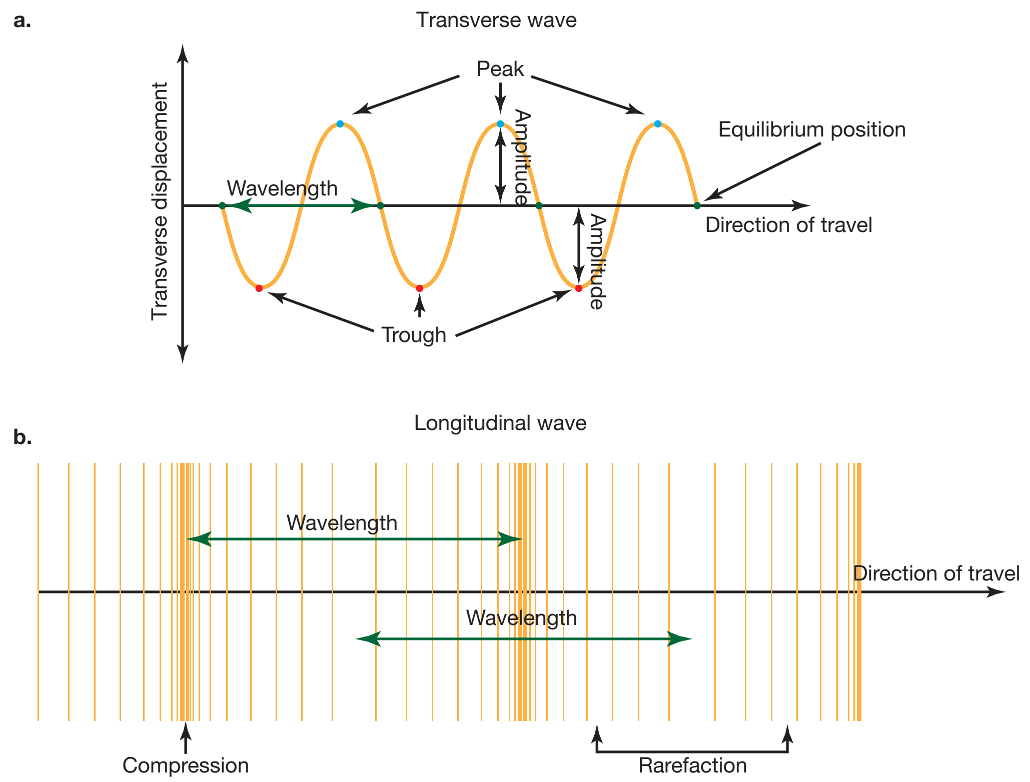
As always in science, we need to measure something before we can figure out how it works and how we can use it.

The most important properties of a wave to measure are **wavelength**, **frequency** and **amplitude**. How they are measured in transverse and longitudinal waves is shown in figure 8.20.

Wavelength

When a vibration occurs in a transverse wave, something is vibrating up and down. In one vibration it will make one wave. How far that wave travelled in that time is the wavelength. To find the wavelength, you measure the distance between two peaks, or two troughs, or the distance between any two corresponding points on neighbouring waves (figure 8.20).

FIGURE 8.20 Representations of **a.** transverse and **b.** longitudinal waves



In the case of a compression wave, the wavelength is the distance between the centre of two neighbouring **compressions** (high pressure), or two neighbouring **rarefactions** (low pressure). The wavelength of sound made during normal speech varies between approximately 5 cm and 2.5 m.

Frequency

How often do you eat a meal? If you eat breakfast, lunch and dinner, then you have a meal frequency of three meals per day.

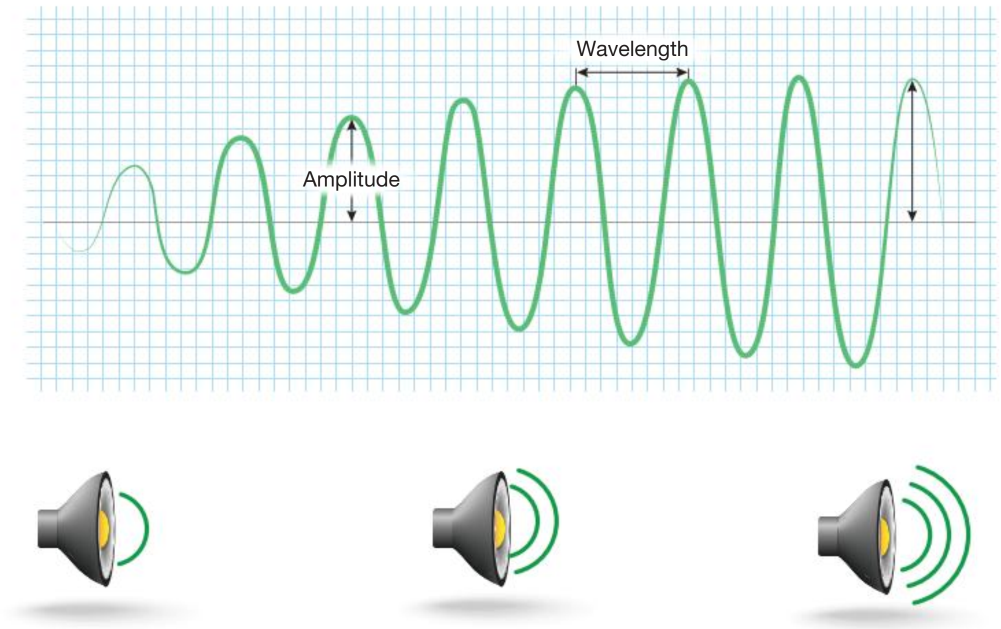
In the same way, the frequency of a vibration or wave is the number of complete vibrations or waves made in one second. In musical contexts, we call the frequency of sound waves **pitch**. High-frequency vibrations produce high pitch, and low-frequency vibrations produce low pitch. The unit of frequency is the hertz (Hz). A frequency of 1 Hz means one vibration per second.

As the frequency of a sound gets higher — that is, as more compressions are produced per second — the compressions become closer together.

Amplitude

The amplitude of a wave is the maximum distance that each particle moves away from its usual resting position. In sound waves, higher amplitudes correspond with louder sounds due to the higher pressure in the compressions. If we plot a graph of how pressure changes, we can represent a longitudinal wave as a transverse wave (figure 8.21).

FIGURE 8.21 A longitudinal wave represented as a transverse wave, showing how the amplitude changes as the volume of a sound increases



8.3 Activities

learnon

8.3 Quick quiz on	8.3 Exercise

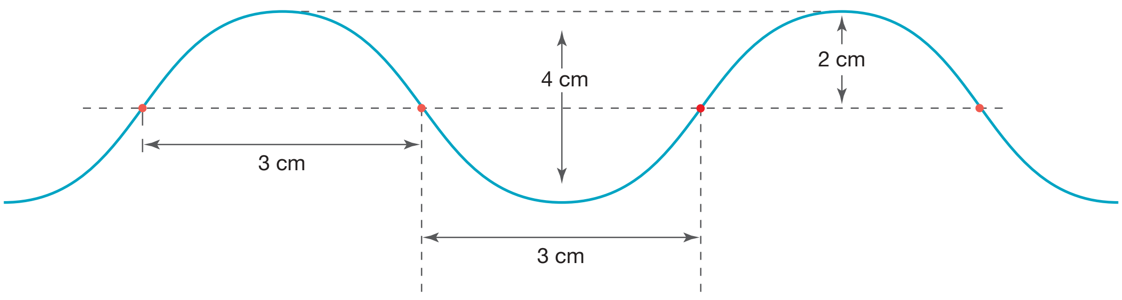
LEVEL 1	LEVEL 2	LEVEL 3
1, 2	3, 5	4, 6

Remember and understand

1. MC **Identify** the primary cause of all sound waves.
   A. Vibrations
   B. Echoes
   C. Compressions
   D. Rarefactions
2. **Identify** the missing words to complete the sentence.
   A compression is a region of _________ pressure, where the particles are _________ together, and a rarefaction is a region of _________ pressure, where the particles are more _________ apart.
3. MC **Identify** which of the following correctly gives the unit of frequency and what it measures.
   A. Hertz (Hz) — the length of the wave
   B. Metres (m) — the length of the wave
   C. Hertz (Hz) — the loudness of the wave
   D. Hertz (Hz) — the number of vibrations per second

Apply and analyse

4. MC **Identify** how the amplitude of a wave affects energy transfer.
   A. Higher amplitude leads to greater energy transfer.
   B. Lower amplitude leads to greater energy transfer.
   C. Amplitude does not affect energy transfer.
   D. Energy transfer is dependent only on wave frequency, not amplitude.
5. **Describe** the wavelength and amplitude of the transverse wave shown in the following diagram.



Evaluate and create

6. a. **Construct** and label a wave with twice the frequency but the same amplitude as the wave shown in question 5.
   b. **Construct** and label a wave with half the frequency and twice the amplitude as the wave shown in question 5.

Answers and sample responses are available in your digital formats.

LESSON 8.4 Energy transfer by sound

LEARNING INTENTION

In this lesson you will describe sound as a pressure wave in a medium and calculate its speed.

8.4.1 A happy medium

Imagine that you are on a spacecraft on the way to Mars and a passing asteroid explodes. Would you hear the explosion before or after you saw it? Or would you even hear it at all?

Because sound is transmitted as a compression wave, it can travel only through a medium that contains particles that can be forced closer together or further apart. Sound cannot be transmitted in a vacuum because there are no particles to push closer together or spread out.

As sound travels through a medium, some of its energy is absorbed by the particles in the medium and is not transmitted to neighbouring particles. Sound moves more effectively through elastic materials, like metals, rather than through inelastic materials, like foam. In elastic materials, the particles tend to return to their original positions with minimal energy loss, allowing sound to travel efficiently. However, in inelastic materials, the sound wave rapidly loses its energy, making it less effective for transmitting sound.

8.4.2 Sound waves

Sound is a compression wave. All sounds are caused by vibrations. Vibrations cause air to compress (like the lower wave pattern shown in figure 8.22). As the particles vibrate, they move neighbouring particles, transmitting the sound further through the medium. Figure 8.23 shows how a vibrating ruler makes compression waves in air. As the ruler moves up, a *compression* is created as air particles above the ruler are pushed together. Air particles below the ruler are spread out, creating a *rarefaction*. When the ruler moves down, a rarefaction is created above the ruler, while a compression is created below it. Each vibration of the ruler creates new compressions and rarefactions to replace those that are moving through the air.

FIGURE 8.22 Modelisation of sound waves

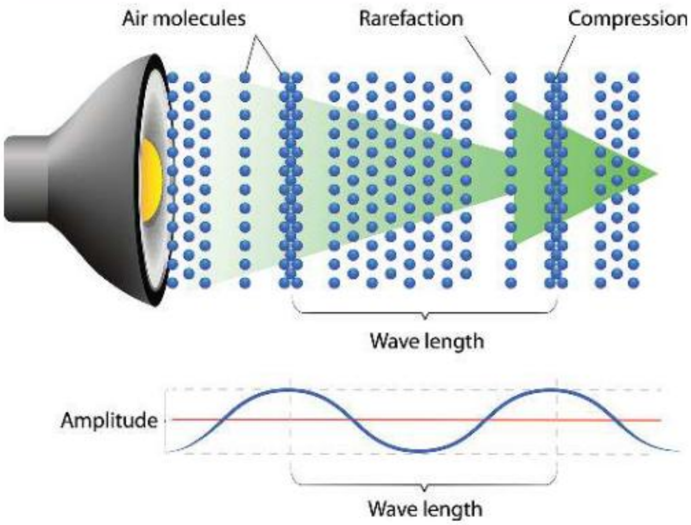
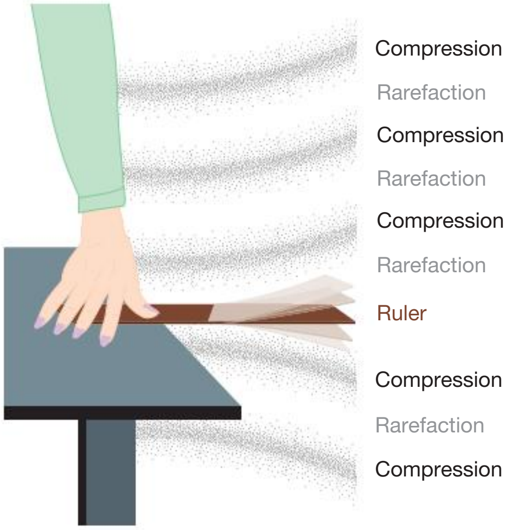


FIGURE 8.23 Sound is a compression wave caused by vibrations.



SCIENCE INQUIRY: Investigating the properties of sound waves

Sound waves are a type of compression wave that travel through a medium, such as air, water or a solid. These waves are generated by vibrations, which create alternating regions of compression (where particles are pushed closer together) and rarefaction (where particles are spread farther apart).

The properties of sound waves — such as frequency, amplitude and speed — can be explored using simple experiments and modern digital tools. For example, a smartphone app that measures sound frequency can be used to visualise the relationship between the frequency of a vibrating object and the pitch of the sound it produces.

Similarly, by using a microphone and sound analysis software, you can examine how changes in amplitude affect the loudness of a sound wave. The speed of sound can also be calculated by measuring the time it takes for sound to travel a known distance through different materials, such as air, water and metals.

1. What is the difference between compressions and rarefactions in a sound wave?
2. How do changes in frequency affect the pitch of a sound?
3. What role does amplitude play in the perception of sound loudness?
4. Propose an experiment to measure the speed of sound in air using a smartphone and a tape measure. Describe your method and the equipment needed.
5. Using simple equipment like a stopwatch, a trundle wheel and a pair of cymbals from a drum kit, design an experiment to measure the speed of sound in air. Describe your method and how you would ensure accurate results.
6. How would you use a microphone and sound analysis software to compare the amplitudes of two different sounds?
7. Why do sound waves travel faster in solids than in gases? Provide an example from everyday life where this property is useful.
8. If you increase the frequency of a vibrating string, what happens to the sound wave it produces? How can this be measured using digital tools?

Equipment can be selected and used to generate and record data sets that show precision, including consideration of sample size and using digital tools as appropriate (VC2S10I03)

ACTIVITY: Creating different tones

Position a ruler on the table with a portion overhanging the edge. Place your hand firmly on the ruler to fix it in position on the table. Flick the overhanging side of the ruler to create a sound. Change the length of the overhang to create different tones.

What do you notice about the length of overhang and the tone produced?

8.4.3 Speed of sound

The speed of sound in a particular medium depends on how close the particles are to each other and how easy they are to push closer together. In liquids and solids, the speed is much greater because the particles are more closely bound together. Table 8.2 shows the speed of sound in some common substances at 0 °C.

FIGURE 8.24 A jet flying faster than the speed of sound can form a condensation cloud.

TABLE 8.2 Speed of sound in some common substances

Substance	Speed of sound (m/s)
Carbon dioxide (at 0 °C)	260
Dry air (at 0 °C)	330
Hydrogen (at 0 °C)	1300
Water	1400
Seawater	1500
Wood	4000–5000
Glass	4500–5500
Steel	5000
Aluminium	5000
Granite	About 6000

SAMPLE PROBLEM 1 Finding the distance from a sound

If we see a distant flash of light from, for example, a firework, we can calculate how far away it is by timing how long it takes the sound to get to us. As light travels at 300 000 000 m/s, we can assume that the time it takes for the light to reach us is zero.

If it takes 2 seconds to pass between flash and bang, how far away is the firework?

THINK	WRITE
1. Use the simple equation for velocity.	$\text{Velocity} = \frac{\text{distance}}{\text{time}}$
2. Rearrange the equation to find the distance.	$\text{Distance} = \text{velocity} \times \text{time}$
3. If the air is dry, the speed is 330 m/s.	$\text{Distance} = 330 \times 2$
4. Calculate the distance to the firework.	$\text{Distance} = 660\ \text{m}$

The speed of sound changes

When people say ‘the speed of sound’, which speed do they mean? Speed is different in all substances. Even when just talking about air, the speed of sound can change a lot depending on atmospheric conditions. The speed of sound in air is greater at higher temperatures. At sea level in dry air at 0 °C, it is about 330 m/s. At a temperature of 25 °C, it is about 350 m/s. The speed of sound in air is lower at higher altitudes. At an altitude of 10 km above sea level, it is about 310 m/s.

DISCUSSION

Why is the speed of sound slower at higher altitudes than at lower ones?

INVESTIGATION 8.4

Sound in different media

Aim

To investigate the transmission of sound in different media

Materials

- ticking watch
- metre ruler
- teaspoon (or spatula)
- cotton thread (or light string)

Method

1. Place a ticking watch against your ear and listen to the tick. Have your partner slowly move the watch away from your ear until you can no longer hear the ticking.
2. Measure the distance from your ear to this point.
3. Place a metre ruler gently against the same ear and rest the watch on it against the ear. Have your partner slowly slide the watch along the ruler to a point where you can no longer hear the ticking.
4. Measure the distance from your ear to this point.
5. Tie about 80 cm of cotton thread to a teaspoon. Swing the teaspoon slowly so that it gently strikes the side of a bench, wall or cupboard. Listen to the sound made.
6. Place the free end of the cotton thread carefully against your ear and again gently strike the teaspoon against the same surface. Listen to the sound made.

Results

1. Record the distance from the ticking watch to your ear when you can no longer hear the sound.
2. Record the distance on the metre ruler when you can no longer hear the watch ticking.
3. What did you observe when the cotton thread and spoon were struck against the bench, and when the thread was placed against your ear and the spoon was struck against the bench?

Discussion

1. What effect did the ruler have on the distance over which you could hear the sound of the ticking watch?
2. What difference does the cotton thread make to the sound heard when the spoon strikes a surface?
3. Is sound conducted better through air or through solids?
4. What property of the solids do you think makes the difference?

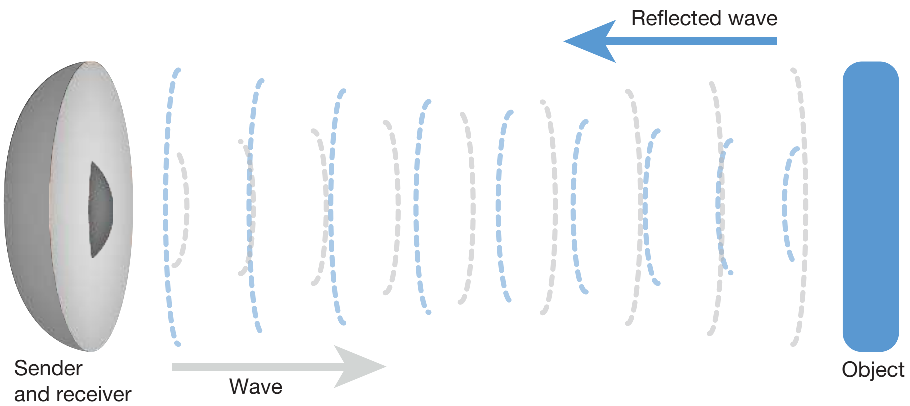
Conclusion

What conclusion can you make about how sound travels in different mediums?

8.4.4 Echoes in nature

An **echo** is what we call the reflection of a sound wave. We can estimate the distance between ourselves and a large object by shouting and timing how long it takes for the echo to return.

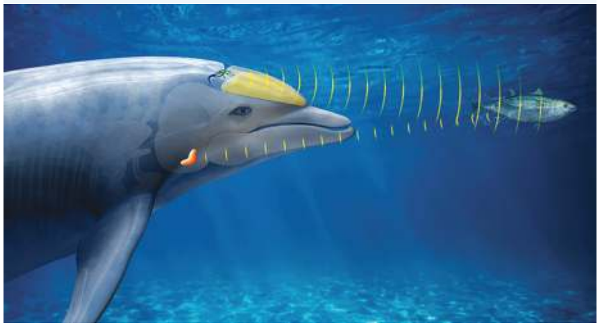
FIGURE 8.25 In all echoes, a sound that is sent out is reflected from an object and detected by the object that originally produced the sound.



The only difference between finding the distance to an object making a noise and an object reflecting a noise is that we must *halve* the time measurement, as the distance the wave travels is *twice* the distance between the sound emitter and the sound reflector.

Many animals use echoes to find their way in the dark or to hunt their prey. This is called **echolocation** and is used by animals such as bats and dolphins.

FIGURE 8.26 Dolphins hunt in deep, dark water by mapping their surroundings using echoes.



DISCUSSION

How can bats hunt their prey in complete darkness?

8.4.5 Technology and echoes

Sound waves and echoes play a vital role in technology, helping us explore hidden landscapes, improve medical imaging and even assist with navigation. Whether mapping the ocean floor with **sonar** or using **ultrasound** to visualise the human body, echoes allow scientists and engineers to unlock valuable information about the world around us.

SCIENCE AS A HUMAN ENDEAVOUR: Using echoes

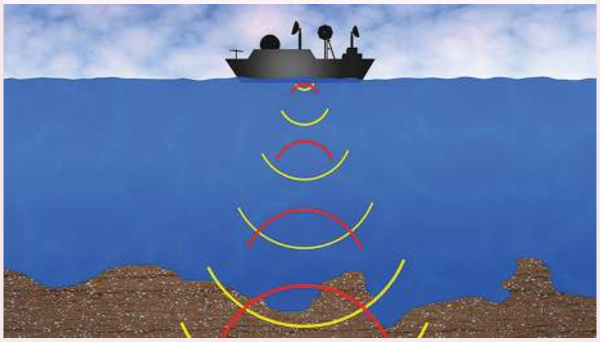
We could not have learned about the movement of Earth's crust if we had not mapped the bottom of the oceans. The technology used allowed us to understand the structure of the planet and the formation of Earth's magnetic field, and gave us the ability to map 70 per cent of the planet's surface, which is hidden under the water. That exact same technology is also used to see inside the womb and build pictures of a baby without causing harm, and is now also being used to let the blind see.

Sonar

A knowledge of the speed of sound is used in sonar (short for sound navigation and ranging). Sonar is used on ships to map the ocean floor, detect schools of fish and locate other underwater objects such as shipwrecks and submarines. The process is as follows:

- Transmit high-frequency sound from the ship.
- Measure the time taken for the echo to return to the ship.
- Use the speed of sound in water to calculate the distance to the floor of the ocean or to the underwater object.
- Remember that the time taken is the time for the pulse to go to the sea floor and back, so it must be halved.
- Add many measurements to map the sea floor.
- Use higher frequency waves, which have smaller wavelengths so can be used to form an image in more detail.

FIGURE 8.27 Sonar mapping the sea floor



Ultrasound

Although called by a different name, echolocation is also used by engineers to locate cracks in metals, and it is used extensively in medicine. The high-frequency sound used in both industry and medicine is called ultrasound. Ultrasound has frequencies higher than humans can hear.

Echolocation with ultrasound is used in medicine to:

- produce images of unborn babies in the womb during pregnancy
- search for circulation problems
- remove some cancers
- treat an eye condition called glaucoma
- shatter kidney stones and gallstones in a process called shockwave therapy
- speed up the healing of muscle damage.

It can also be used to clean surfaces, mix paint, homogenise milk and cut into glass and steel.

FIGURE 8.28 A modern three-dimensional ultrasound is used to produce an image of the face of a full-term baby in the womb.

Humans can echolocate

There have been cases of humans who can echolocate. A growing number of people with severe vision impairment have begun clicking with their tongues. Their brains adapt to become able to perceive the slight difference in the sound when reflected back at them from different surfaces. Some become so good at the talent that they can ride a bike down a street while safely detecting and avoiding obstacles. Try echolocating yourself by closing your eyes and clicking your tongue in an empty space, then do it again while holding a book in front of your face. You should be able to hear the difference. There are also glasses in development that use echolocation to activate pins in a pad stuck to the tongue. This effectively prints a picture of the world on the tongue, which the brain learns to interpret as an image.

1. How does sonar work to map the sea floor?
2. Why is it necessary to halve the time taken for the sound pulse to travel to the sea floor and back?
3. Explain why higher frequency waves are better for creating detailed images in sonar.
4. What are some medical applications of ultrasound, and why is it effective for these purposes?
5. Describe how ultrasound frequencies differ from the range of sound that humans can hear.
6. How is echolocation with ultrasound used in industry, and what benefits does it provide?
7. How do people with severe vision impairment use echolocation to navigate their environment?
8. Try the tongue-clicking echolocation experiment described in the text. What did you notice about the sound reflections?
9. What technologies are being developed to enhance human echolocation? How might these impact visually impaired individuals?
10. What does the development of sonar and ultrasound tell us about the interplay between scientific knowledge and technological innovation?
11. In what ways can the use of echolocation in humans inspire future technologies?
12. How do societal needs influence the direction of scientific research, as seen in the examples of sonar and ultrasound?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

SAMPLE PROBLEM 2 Using sonar to determine the depth of water

A sonar pulse is sent from a ship and returns 0.5 seconds later. Given the speed of sound in seawater is 1500 m/s, what is the distance to the sea floor?

THINK	WRITE
1. Use the simple equation for velocity.	$\text{Velocity} = \dfrac{\text{distance}}{\text{time}}$
2. Rearrange the equation to find the distance.	$\text{Distance} = \text{velocity} \times \text{time}$
3. The sonar pulse took 0.5 seconds to reach the sea floor and return to the ship. If we halve the time, we know how long it took for the pulse from the ship to reach the sea floor.	$\dfrac{0.5}{2} = 0.25\ \text{seconds}$
4. The speed of sound in seawater is 1500 m/s.	$\text{Distance} = 1500 \times 0.25$
5. Calculate the distance from the ship to the sea floor.	$\text{Distance} = 375\ \text{m}$

8.4.6 Traditional instruments of Aboriginal and Torres Strait Islander Peoples

Aboriginal and Torres Strait Islander Peoples have a deep understanding of materials and their acoustic properties, developed over thousands of years. Instruments serve diverse purposes, such as creating music, storytelling, hunting and communicating.

Traditional instruments of Aboriginal Peoples

Music and dance are important to the cultures of Aboriginal Peoples, with several traditional instruments used for ceremonies and performances.

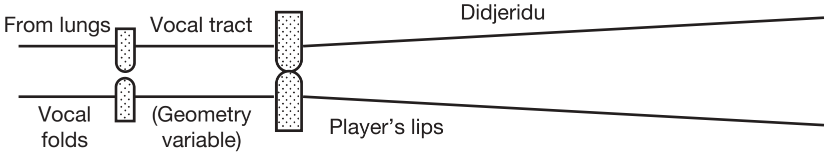
Didjeridu

Aboriginal people have traditionally used the didjeridu — a simple, wooden, hollow tube made from eucalyptus or bamboo that is typically 1.2 to 1.5 m long. A ring of beeswax around the mouthpiece helps seal airflow, while natural hollowing by termites ensures the right internal structure for sound production. Dense woods produce a richer, deeper sound.

The didjeridu originated in the northern parts of Australia but spread south through trade, and was traditionally played only by men. The instrument produces a variety of sounds, influenced by the player's lips, tongue position, vocal tract shape and vocal cords. Players use circular breathing — storing air in their cheeks while inhaling through the nose — to maintain continuous sound.

FIGURE 8.29 A collection of didjeridus

FIGURE 8.30 A schematic diagram of the acoustic system of a didjeridu



Clapsticks (bilma)

Clapsticks, or bilma, are wooden sticks struck together to create rhythmic beats. Hardwoods like ironwood produce sharper, clearer sounds that complement ceremonial songs and dances.

Bullroarer

A bullroarer is a flat piece of wood spun on a string to create a low-pitched whirring sound. Made from lightweight yet strong wood, it ensures effective rotation and sound production.

Message sticks

Message sticks were traditionally used for communication rather than sound production. However, they were often accompanied by spoken word or song, carrying encoded messages between groups.

Boomerang

The boomerang serves both as a hunting tool and a musical instrument. When struck or whirled, it produces sound, with dense, flexible woods enhancing durability and efficiency in sound production.

Traditional instruments of Torres Strait Islander Peoples

Music and dance play a central role in cultural traditions of Torres Strait Islander Peoples, often influenced by Melanesian music, and featuring chanting, drumming and stringed instruments. Torres Strait Islander Peoples' musical practices are distinct from those of Aboriginal Peoples, with unique instruments used in ceremonies and storytelling.

Warup (drum)

The warup drum is a significant instrument in Torres Strait Islander music. Made from hollowed-out logs and covered with goanna or snake skin, it produces deep, resonant beats essential for dance and cultural celebrations.

FIGURE 8.31 A warup drum

Marup (drum)

Similar to the warup, the marup drum is used in ceremonial and storytelling traditions, reinforcing rhythm in musical performances.

Kulaps (dance rattles or shakers)

Kulaps are traditional dance rattles or shakers, commonly crafted from seashells, seeds or wood. They produce rhythmic sounds when shaken, enhancing dance performances and ceremonial rituals.

Clapsticks and percussive instruments

Like Aboriginal cultures, clapsticks and other percussive instruments are commonly used in Torres Strait Islander dances and ceremonies, maintaining strong rhythmic elements in performances.

By recognising the distinct musical traditions and instruments of both Aboriginal and Torres Strait Islander Peoples, we acknowledge the richness and diversity of their cultures across Australia.

ACTIVITY: How material properties affect sound energy transfer in traditional instruments

As a class, discuss the following:
- How do different materials influence sound volume and tone?
- Why might Aboriginal and Torres Strait Islander Peoples have chosen specific materials for their instruments?
- How does the cultural significance of these instruments enhance understanding of sound?

8.4 Activities

learnon

8.4 Quick quiz on | 8.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 4, 8, 11	3, 5, 6, 7, 9, 10, 12	13, 14, 15, 16, 17

Remember and understand

1. MC **Identify** the main reason sound cannot travel through outer space.
   A. There is too much light energy.
   B. Sound waves cannot travel through gases.
   C. Sound requires a medium with particles to compress and expand.
   D. Space is too cold for sound to move.
2. MC **Identify** which property of a material would allow sound to travel through it most effectively.
   A. Being able to reflect light
   B. Being soft and flexible
   C. Having high elasticity and tightly packed particles
   D. Being light and spongy
3. Complete the following table to describe how sound travels through different materials. Your response should be based on the idea that sound travels faster when particles are tightly packed and can transfer vibrations efficiently.

Sound travel

Material	Speed of sound (m/s)	Why sound travels this way
Air	330	
Water	1400	
Steel	5000	

4. **Explain** why sound waves are unable to travel through a vacuum.

Apply and analyse

5. A ticking watch is placed at one end of a wooden ruler. When the ruler is lifted off the table and held firmly at one end, the ticking is easier to detect by placing your fingers on the surface. **Explain** why the ticking is more noticeable through the solid ruler than through the air.
6. A student set up an experiment to compare the transmission of sound through air, water and metal using a smartphone and a sound sensor. **Describe** how the student could ensure a fair comparison between the three materials.
7. During a school experiment, a student uses a ruler to produce different tones by changing how far it overhangs the table. **Explain** how the vibration of the ruler produces sound, and why the pitch changes as the overhang length changes.
8. Use your understanding of compressions and rarefactions to **explain** how sound travels through air after a door slams shut in a quiet room.

Use the data given in table 8.2 to answer questions 9–11.

9. SI In general, how does the speed of sound in solids compare with that in liquids and gases? **Explain** your answer.
10. SI **Identify** the substance that doesn't seem to fit the pattern. **State** comparison values to demonstrate why this value seems anomalous.
11. SI Why do you think such a large range of speeds is given for wood? How could you investigate whether your answer is correct? Explain your answer.
12. Using your understanding of particle behaviour, **explain** why solids like steel or glass allow sound to travel faster and more clearly than gases like air.
13. **Suggest** why the speed of sound depends on altitude and temperature.

Evaluate and create

14. Imagine that you are one of two astronauts walking on the Moon.
    a. Would you be able to conduct a conversation with your partner without radios? **Explain** why.
    b. Imagine that both of your radios stopped working because you forgot to recharge the batteries. **Explain** how you would still be able to speak with your partner (no sign language or writing allowed).
15. Imagine that you are standing near a steep, rocky cliff. You shout 'Hello' and one second later you hear the echo. The air temperature is about 25 °C, so you estimate that the speed of sound is about 350 m/s. **Calculate** how far away you are from the cliff.

16. A ship sends a sonar pulse down into the water. After 0.2 seconds, an echo is detected. You estimate that the speed of sound is about 1500 m/s. **Calculate** how deep the water is.
17. The speed of sound in air at a temperature of 25 °C is about 350 m/s. **Calculate** how long it would take for sound waves to travel from Melbourne to Sydney, a straight distance of about 700 km, when the air temperature is 25 °C.

Answers and sample responses are available in your digital formats.

LESSON 8.5 Energy transfer by light

LEARNING INTENTION

In this lesson you will:
- describe light as an electromagnetic wave and name the key regions of the spectrum
- describe the link between energy and frequency of light.

8.5.1 Using models to understand natural phenomena

The representation of light as waves is an example of a **model**. A model provides a useful way of investigating the properties and behaviour of something that you can't see.

During the seventeenth century, there were two 'opposing' models of light. One was a wave model similar to the one we use today. The other model, a particle model proposed by Sir Isaac Newton, was more popular at the time. Newton proposed that light consisted of a stream of tiny particles that he called corpuscles. This model successfully explained the reflection of light. However, the only way that Newton's model could explain light bending when it moves from air to water was if it travelled faster in water. Of course, at that time there was no way to measure the speed of light in water. We now know that light travels more slowly in water.

The wave model is successful at explaining most properties of light. However, in the early twentieth century, Albert Einstein — more famous for his theories of relativity — proposed another successful model that explained how light could also be seen as a stream of particles, which were later named **photons**. Photons are 'packets of energy' that have properties of both particles and waves. We say that photons have **wave-particle duality**.

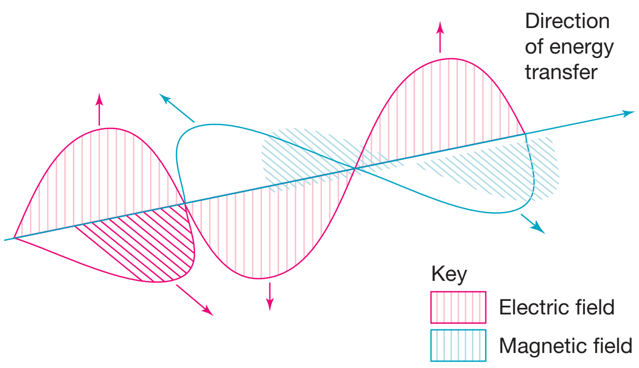
8.5.2 What is electromagnetic radiation?

Around any charged particle there is an electric field. If that charge moves, the electric field also moves, sending a 'ripple' through the field. We will see later in this topic that when you get a changing electric field you make a changing magnetic field. A changing magnetic field causes a changing electric field and so on. This is electromagnetic radiation.

This means that whenever a charged particle vibrates — for instance, because it has heat energy — it will produce a changing electromagnetic field that carries energy away. When this wave hits another charged particle it will be absorbed, causing the particle to vibrate and then emit a wave of electromagnetic radiation.

Visible light and heat are examples of electromagnetic radiation.

FIGURE 8.32 A representation of part of an electromagnetic wave



8.5.3 The electromagnetic spectrum

Take a pen and draw a low-frequency wave from one side of a piece of paper to another. Use a stopwatch to time yourself doing this. When you are done, draw another wave of much higher frequency but the same amplitude *and taking the same amount of time*. Which drawing required more energy?

You should have found that high-frequency waves are also high-energy waves.

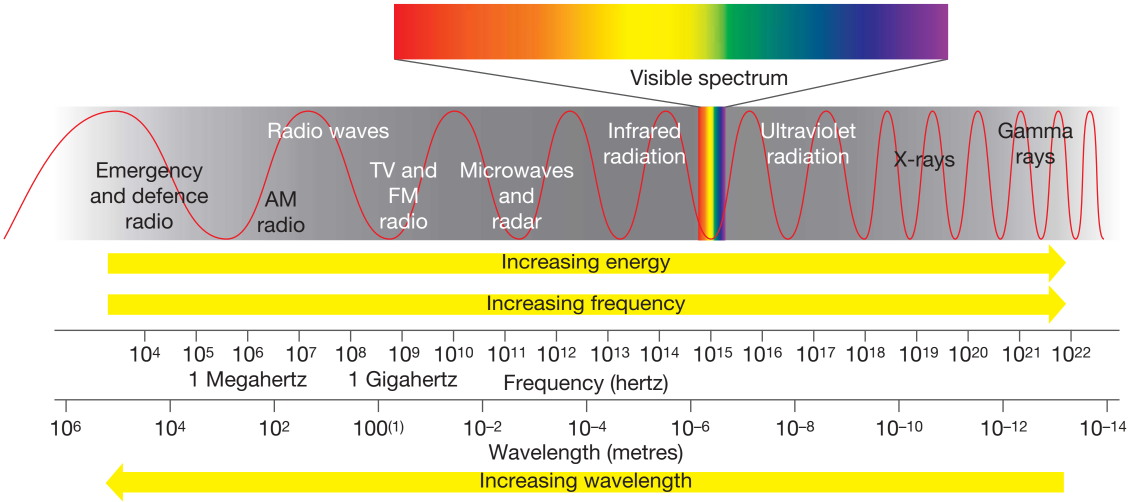
- Objects that are cold have little energy to lose and so produce long-wavelength, low-frequency electromagnetic radiation waves.
- The hotter an object is, the higher the frequency, higher the energy and shorter the wavelength produced.

Despite their different energies, all types of light travel at the same speed in a vacuum. The speed of light and all other types of electromagnetic radiation is approximately 300 000 000 m/s. However, it does slow down when passing through matter. For example, light travels through glass at a leisurely 200 000 000 m/s.

There is a huge range, or spectrum, of energies of electromagnetic radiation that can be produced. These include:

- radio waves
- infrared radiation
- visible light
- ultraviolet radiation
- x-rays
- gamma rays.

FIGURE 8.33 The electromagnetic spectrum

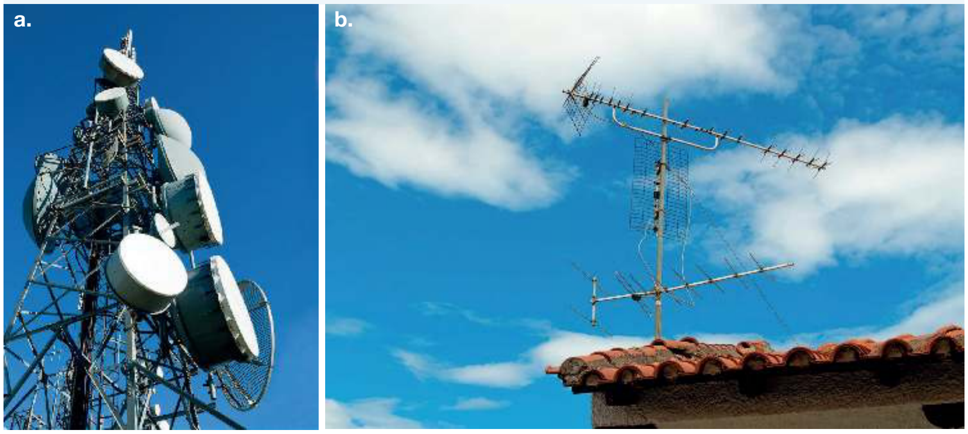


Radio waves

Radio waves are low-energy waves that have many desirable properties that make them useful for communication over long distances. The main advantage of using radio waves is that they are able to pass through buildings, trees and any weather conditions due to their large wavelength. This means that the **transmitting antenna** does not need to have a direct line of sight to the **receiving antenna**. This is why walkie-talkies work when you cannot see the person you are talking to. The visible light is blocked by obstacles, but the radio waves are not.

Another useful property of radio waves is that they tend to reflect off objects instead of being absorbed. **Radar** is a technology that uses this property of radio waves to be able to detect the location of objects, how fast they are going and in what direction. By transmitting radio waves and then measuring the time for them to return after they have reflected off an object, it is possible to calculate how far away that object is.

FIGURE 8.34 Compare the sizes of these a. transmitting and b. receiving antennae. Why are they different?



Microwaves

Microwave radiation is used to heat food in microwave ovens. Microwaves work by making molecules, such as the water and fats in your food, spin very quickly. This spinning causes them to heat up, which is then conducted to the surrounding molecules. Since microwaves have a longer wavelength than radio waves, they do not penetrate the food very well, and so the middle of your food gets hot only when enough heat has been conducted.

Other parts of the microwave spectrum can be used for modern mobile phone communication. Using shorter wavelengths than radio waves has some trade-offs. While microwaves are not able to penetrate through buildings as well as radio waves, more data can be sent more quickly with microwaves, which is a much greater concern in today's world.

FIGURE 8.35 Microwave radiation is used to heat food in microwaves.

SCIENCE AS A HUMAN ENDEAVOUR: Wi-Fi

In the 1990s, Dr John O'Sullivan and his team of scientists at Australia's national science agency, CSIRO, invented fast, reliable, indoor wireless communications technology that we now call 'Wi-Fi'. The impact of this technology has transformed how we connect and communicate with each other across the globe.

The widespread and rapid adoption of mobile technology owes its thanks to the ease at which these devices can connect via wireless network technology. This has had social impacts on how and where we consume media, as we now have the luxury of accessing it from our home or in the coffee shop.

FIGURE 8.36 Wi-Fi technology is everywhere in our lives.

The economic impact of Wi-Fi around the globe is estimated to be trillions of dollars in value. The success of entire industries can trace their roots back to the global adoption of Wi-Fi, and the value is only growing. Businesses can digitise their operations, leading to greater efficiency, or give consumers value by providing free public Wi-Fi access as a solution for populations that cannot afford individual internet subscriptions.

An Australian invention, Wi-Fi has had a significant global impact and will continue to do so as people use the advantages of the technology to innovate and improve our lives.

1. Who led the team that invented Wi-Fi, and where was this groundbreaking work carried out?
2. What specific problem did the team aim to solve when developing Wi-Fi technology?
3. In what ways has Wi-Fi improved global connectivity and communication?
4. Describe how Wi-Fi has changed the way people consume and share media. How does this differ from media consumption before its invention?
5. Explain how Wi-Fi has contributed to economic growth on a global scale. What industries have particularly benefited from this technology?
6. How does providing free public Wi-Fi improve access to the internet for underprivileged populations?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

EXTENSION: Can you hear the Big Bang?

Radio waves and microwaves are low energy and generally quite safe. You are constantly bathed in radiation left over from the Big Bang! You can hear evidence of this radiation when you tune a radio between stations.

Microwaves that are used to cook are actually tuned to be exactly the right frequency to be absorbed by water, making the water hotter and cooking food from the inside.

Infrared radiation

Infrared radiation is emitted by all objects and is sensed as heat. The amount of infrared radiation emitted by an object increases as its temperature increases. This means that satellites that orbit Earth can measure changes in the temperature of Earth's surface by detecting the amount of emitted infrared radiation from the ground. Called **remote sensing**, scientists can monitor the progress of global warming, bushfires and other areas of scientific importance using a part of the electromagnetic spectrum that would otherwise be invisible to the human eye.

FIGURE 8.37 A gentle push of a button sends infrared radiation to this television set at 300 million m/s.

Visible light

Visible light represents only a very small part of the electromagnetic spectrum. It is necessary for our sense of sight. Some animals can also see infrared or ultraviolet radiation in addition to visible light. The process of photosynthesis in green plants cannot take place without visible light.

Ultraviolet radiation

Like infrared radiation, **ultraviolet radiation** is invisible to the human eye. It is needed by humans to help the body produce vitamin D; however, too much exposure to ultraviolet radiation causes sunburn, as it has enough energy to penetrate the outer layers of the skin and damage the delicate tissues underneath. It is this property of ultraviolet radiation, however, that allows for the **sanitation** of food, water, air and surfaces. By shining ultraviolet light on bacteria or viruses, these microorganisms die or become unable to reproduce.

FIGURE 8.38 Washing hands in ultraviolet light illustrates bacteria and viruses on hands and the importance of good hygiene.

X-rays

X-rays have enough energy to pass through human flesh. They can be used to kill cancer cells, find weaknesses in metals and analyse the structure of complex chemicals. X-rays are produced when fast-moving electrons give up their energy quickly. In x-ray machines, this happens when the electrons strike a target made of tungsten.

Some parts of the human body absorb more of the energy of x-rays than others. For example, bones absorb more x-ray energy than the softer tissue around them. This makes x-rays useful for obtaining images of bones and teeth. To obtain an image, x-rays are passed through the part of the body being examined.

The x-rays that pass through are detected by photographic film on the other side of the body. Because bones, teeth and hard tissue such as tumours absorb more energy than soft tissue, they leave shadows on the photographic film, providing a clear image.

CT scanners (or CAT scanners) consist of x-ray machines that are rotated around the patient being examined.

FIGURE 8.39 X-ray showing a fracture of a radius and ulna in a forearm

Gamma rays

Gamma rays are unusual in that they are not made in the same way as other forms of light. Rather than being produced by vibrating atoms or accelerating electrons, they are made in nuclear decay. They have even more energy than x-rays and can cause serious damage to living cells. They can also be used to kill cancer cells and find weaknesses in metals. Gamma rays are produced when energy is lost from the nucleus of an atom. This can happen during the radioactive decay of nuclei or as a result of nuclear reactions.

SCIENCE AS A HUMAN ENDEAVOUR: Using gamma rays in medicine

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering *(VC2S10H02)*

Gamma cameras are used in PET (positron emission tomography) scans to obtain images of some organs. To obtain a PET scan, a radioactive substance that produces anti-matter versions of electrons, called positrons, is injected into the body (or in some cases, inhaled). As it passes through the organ being examined, the positrons collide with electrons and annihilate each other in a microscopic nuclear explosion! This sounds bad, but the energies involved are small and you feel nothing. The explosion produces gamma rays, which are detected by the camera.

FIGURE 8.40 A patient undergoing a PET scan of her brain

1. What is the purpose of gamma cameras in PET scans, and how do they work to create images of internal organs?
2. Describe the role of positrons and electrons in the process of creating gamma rays during a PET scan.
3. Why are gamma rays used in this medical technology, and what advantages do they offer?
4. How have advances in technology, such as PET scans, improved our ability to diagnose and treat medical conditions?
5. What are some other medical applications of gamma rays besides PET scans?
6. Explain how the development of PET scan technology demonstrates the interplay between science and engineering.
7. What are the safety considerations involved in using radioactive substances in medical imaging? How are patients protected?
8. Discuss how PET scans have influenced the early detection and treatment of diseases like cancer.
9. How might future advancements in medical imaging improve upon the current use of gamma rays in diagnostics?
10. How might access to advanced imaging technologies like PET scans differ globally, and what can be done to ensure equitable access?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

DISCUSSION

If light can travel forever until absorbed and the universe is infinite, then there must be stars in every direction that we look. So why is the night sky black?

8.5.4 Comparing light and sound

Some differences between sound waves and electromagnetic waves are summarised in table 8.3.

TABLE 8.3 Comparison of sound waves and electromagnetic waves

Sound waves	Electromagnetic waves
Compression (longitudinal) waves	Transverse waves
Travel through all solids, liquids and gases, but are unable to travel through a vacuum	Unable to travel through some substances but travel through a vacuum
Speed in air between about 330 m/s and 350 m/s, depending on temperature	Speed in air about 300 000 000 m/s

8.5 Activities

learnon

8.5 Quick quiz on	8.5 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3, 8	4, 5, 7	6, 9, 10

Remember and understand

1. MC Electromagnetic waves are
   A. longitudinal waves.
   B. compression waves.
   C. transverse waves.
   D. mechanical waves.
2. **Identify** the missing words to complete the sentences.
   All electromagnetic waves have a number of things in common. They are all __________ waves, and they can all travel through a __________ with a speed of approximately __________ m/s.
3. **Identify** the missing words to complete the sentences.
   There are differences between sound waves and electromagnetic waves. Sound waves are __________ waves, whereas electromagnetic waves are __________ waves; sound waves need __________ to travel through, whereas electromagnetic waves do not; and the speed of sound is much __________ than the speed of electromagnetic waves.
4. **List** the following regions of the electromagnetic spectrum in order from lowest energy to highest energy.
   X–ray Infrared Ultraviolet Gamma ray Visible light Radio waves
5. **List** the following regions of the electromagnetic spectrum in order from highest frequency to lowest frequency.
   X–ray Infrared Ultraviolet Gamma ray Visible light Radio waves
6. **List** the following regions of the electromagnetic spectrum in order from longest wavelength to shortest wavelength.
   X–ray Infrared Ultraviolet Gamma ray Visible light Radio waves

Apply and analyse

7. **Explain** why you always hear thunder after you see the lightning that caused it.
8. High doses of x-rays can have detrimental health effects. X-rays have enough energy to pass through human flesh but cannot go through 0.5 mm of lead. **Explain** why x-ray technicians wear lead aprons in medical facilities.

Evaluate and create

9. MC **Identify** the three properties of sound waves that make them different from electromagnetic waves.
   A. They are compression waves.
   B. They are transverse waves.
   C. They need particles to travel.
   D. They do not need particles to travel.
   E. The speed of sound is much smaller.
   F. The speed of sound is much larger.
10. **Explain** why the behaviour of electromagnetic waves cannot be modelled using compression waves in a gas or a slinky.

Answers and sample responses are available in your digital formats.

LESSON 8.6 Wave behaviour of light

LEARNING INTENTION

In this lesson you will describe the behaviour of light during reflection and refraction.

8.6.1 Understanding water waves to understand light

In the distant past, people living at the coast observed that the waves in the ocean showed some predictable behaviour:

- Waves could *reflect* from a rock.
- As the water depth changed, waves would slow and often change direction in a process called *refraction*.
- Water waves clearly carried *energy*.

Eventually, it occurred to scientists that as light could also reflect, refract and carry energy, maybe it too was a wave. In this lesson, we look at how we can use the wave behaviour of light to our advantage.

FIGURE 8.41 Waves reflect, refract and carry energy.

SCIENCE AS A HUMAN ENDEAVOUR: DNA

DNA (deoxyribonucleic acid) is the code for life on Earth, but prior to the 1950s we had little understanding of what it looked like. We did not even know if every organism contained DNA. To get to the bottom of this, scientists in this era used the wave behaviour of light to gather evidence.

The discovery of the double-helix structure was reported and published by James Watson and Francis Crick in 1954. However, like most scientific discoveries, they acknowledged that their report would have been 'most unlikely, if not impossible' without the critical work of fellow scientists Rosalind Franklin and Raymond Gosling.

Franklin and Gosling's contribution to the discovery of the double-helix structure relied on the observation that light demonstrated wave-like behaviour. Using an effect observed in waves called diffraction, light would spread out in a pattern as it passed through the small structures and gaps of the DNA molecule. The pattern depended on the structure of the molecule, and therefore each molecule had its own signature pattern of light. These patterns were captured in a series of photographs, the most important of which is simply called 'Photo 51' (see figure 8.42), which helped determine the structure of DNA.

FIGURE 8.42 'Photo 51'

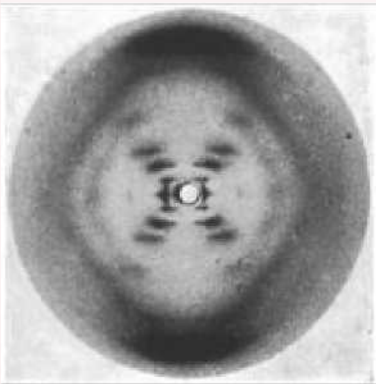


FIGURE 8.43 The double-helix structure of DNA

1. Who were the key scientists involved in the discovery of DNA's double-helix structure, and what were their contributions?
2. Why was Rosalind Franklin's 'Photo 51' critical to the discovery of the structure of DNA?
3. How did the understanding of light's wave-like behaviour play a role in uncovering the structure of DNA?
4. What is diffraction, and how was it used to reveal the structure of DNA?
5. How does a photograph produced by diffraction patterns provide insight into molecular structures?
6. Explain why Watson and Crick acknowledged that their discovery relied heavily on Franklin and Gosling's work.
7. Why is the discovery of DNA's double-helix structure considered one of the most important in modern science?
8. What role does the double-helix structure of DNA play in understanding genetics and heredity?
9. How has this discovery impacted fields such as medicine, agriculture and forensic science?
10. Rosalind Franklin's contributions were initially under-recognised. Discuss how this reflects broader issues of equity in science.
11. How does collaboration and acknowledgment of others' work contribute to the progression of scientific knowledge?
12. Why is it important for scientific findings to undergo peer review and consensus before being widely accepted?

Scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)

8.6.2 Ray tracing

Most of the objects that you see are **non-luminous**. **Luminous** objects are those that emit their own visible light. The Sun and the flame of a burning match are examples of luminous objects. However, non-luminous objects will still produce light of lower energies that our eyes cannot see. Once this light has been emitted, how can we determine where it will go?

Light travels in straight lines as it travels through empty space or through transparent substances like air or water. The lines that are used to show the path of light are called **rays**. You cannot see a single light ray. A stream of light rays is called a **beam**. A beam of white light will contain countless individual waves, usually with a range of energies.

By knowing how to guide a beam of light, we can make a huge array of optical devices, from the simple mirror to the Hubble Space Telescope.

Seeing beams of light

You can see beams of light only when particles in substances like air scatter the light, as shown in the photograph in figure 8.44. Some of the scattered light enters your eye, allowing you to see the particles within the beam.

A beam of light can be seen if there is smoke or fog in the air. Light is scattered by the tiny particles. Some of the scattered light enters your eye, allowing you to see the particles within the beam.

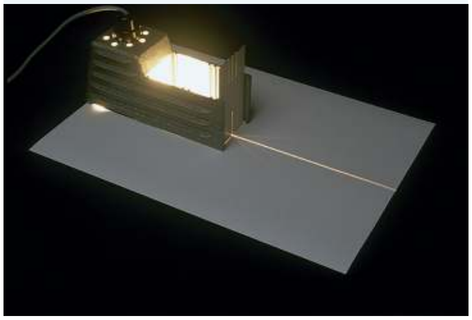
FIGURE 8.44 Beams of light can be seen in fog.

Ray boxes

The ray box shown in figure 8.45 provides a way of tracing the path of light. It contains a light source and a lens that can be moved to produce a narrow or wide beam of light that spreads out, converges or has parallel edges. The light box is placed on a sheet of white paper, making the beam visible as some of the light is reflected from the paper into your eyes.

Black plastic slides can be placed in front of the source to produce a single thin beam or several thin beams. The beams are narrow enough to trace with a fine pencil onto the white paper. The fine pencil line can be used to represent a single ray. You can think of a single ray as the path of a photon. This convention of representing the path of light is based on the particle model of light.

FIGURE 8.45 A ray box provides a way of tracing the path of light.



8.6.3 Light interacting with matter

As we have seen so far, when light meets a boundary between two different substances, a number of things can happen.

On the rebound

The light may bounce off the surface of the substance. This is called **reflection**, and is what allows you to see non-luminous objects. Light can also be reflected from particles within substances. This is called **scattering** because the light bounces off in so many different directions. Light is scattered by the particles of fog, dust and smoke in the atmosphere. Scattering is also evident in cloudy water. A luminous object in very deep or dirty water is not visible from the surface because all of the light is scattered before it can emerge. The same object is more likely to be visible on the surface of shallower or cleaner water because less light would be scattered.

Just passing through

The light may travel through the substance. Some light is always reflected when light crosses a boundary between two substances. If most of the light travels through the substance, the surface is called **transparent** because enough light gets through for you to be able to see objects clearly on the other side (figure 8.46a). Some materials let just enough light through to enable you to detect objects on the other side, but scatter so much light that you can't see them clearly. The frosted glass used in some shower screens is an example. Such materials are said to be **translucent** (figure 8.46b).

Lost inside

The light may be absorbed, transferring its energy to the particles in the substance. Substances that absorb or reflect all the light striking them are said to be opaque. Most objects in your classroom are **opaque** (figure 8.46c).

FIGURE 8.46 **a.** Transparent, **b.** translucent and **c.** opaque materials

ACTIVITY: Scavenger hunt

Find three items that are transparent, three that are translucent and three that are opaque, and share these with the class.

8.6.4 Reflections

Whenever light is reflected from a smooth surface, it bounces away from the surface at the same angle from which it came. More scientifically, we say that the angle of incidence equals the angle of reflection. This observation is known as the **Law of Reflection**.

ACTIVITY: Law of Reflection

Investigate the Law of Reflection by rolling a ball against a wall, or a ball on a pool table, at different angles. Observe how the outgoing angle relates to the incoming angle each time.

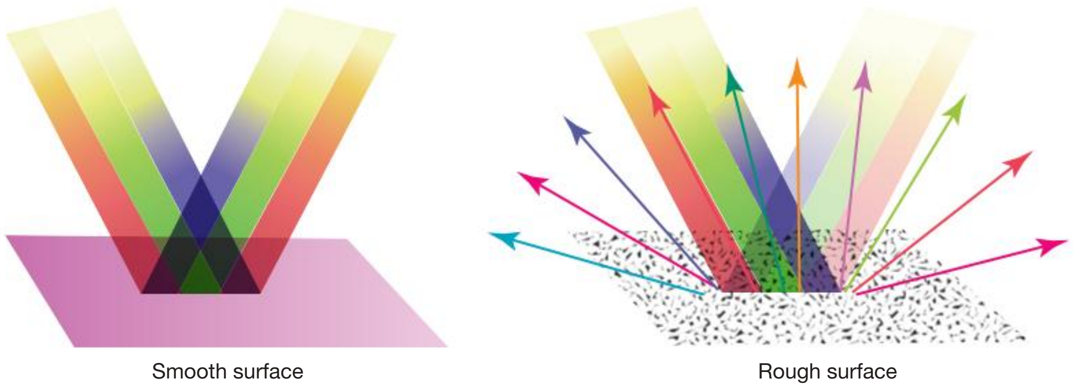
When you look in a mirror, you see an image of yourself. If the mirror is a plane or flat mirror, the image will be very much like the real you. If the mirror is curved, the image might be quite strange.

The images in mirrors are formed when light is reflected from a very smooth, shiny metal surface behind a sheet of glass. Early mirrors were polished metal. If you could not afford a mirror, you could see your image reflected on the surface of water in a bucket.

Why can't you see your image in a wall?

When you look very closely at surfaces like walls, you can see that they are not as smooth as the surface of a mirror. The laws of reflection are still obeyed, but light is reflected from those surfaces in all directions. It doesn't all appear to be coming from a single point. There is no image.

FIGURE 8.47 Rays of light reflect off very smooth surfaces all at the same angle. Rough surfaces scatter light in various directions.



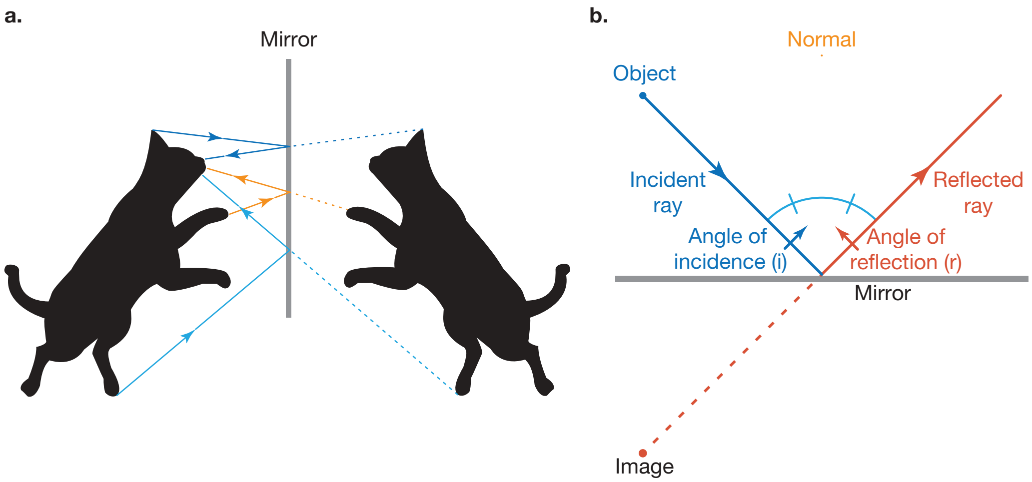
8.6.5 Using mirrors

The Law of Reflection can be used to find out where your image is when you look into a mirror.

Figure 8.48 shows how the Law of Reflection works. To help us measure angles correctly, we draw an imaginary line at right angles to the surface of the mirror. We call this the **normal**. Note that we measure the **angle of incidence** from the **incident ray** to the normal, not to the surface of the mirror. We also measure the **angle of reflection** from the **reflected ray** to the normal.

Almost all of the light coming from the object and striking the mirror is reflected. (A very small amount of light is absorbed by the mirror.) All of the reflected light appears to be coming from the same point behind the mirror, and that is exactly where the image is. The image is the same distance behind the mirror as the object is in front of the mirror, and it is the same size. However, it is also laterally inverted. For example, if you wave at your reflection with your right hand, it appears to be your left hand.

FIGURE 8.48 **a.** The reflected light appears to be coming from just one place. The image seems to be behind the mirror. **b.** The angle of incidence is equal to the angle of reflection.



> **KEY IDEA**
>
> The Law of Reflection: the angle of incidence equals the angle of reflection.

Lateral inversion

The sideways reversal of images that you see when you look at yourself in a mirror is called **lateral inversion**. The sign on the ambulance in figure 8.49 is printed so that drivers in front of it can easily read the word 'AMBULANCE' in their rear-view mirrors.

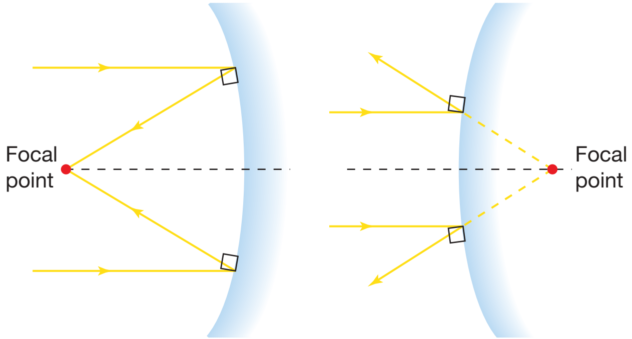
FIGURE 8.49 Why is the word 'AMBULANCE' printed in reverse?

Reflection from curved mirrors

Curved mirrors may be **concave** (curved inwards) or **convex** (curved outwards). Light reflecting from concave and convex mirrors also follows the Law of Reflection, such that the parallel rays of light are reflected to a **focal point**, as shown in figure 8.50.

Images in convex mirrors are upright but distorted and smaller. They can reflect light from a wide range of angles. This means they are useful as security mirrors in shops or as wing mirrors on cars.

FIGURE 8.50 Reflection of light from concave and convex mirrors



Images in concave mirrors are usually upside down until you get closer, when they give a magnified image. This makes them useful as shaving or make-up mirrors. They can also be used to redirect light forward in a beam, as in a torch or headlights.

FIGURE 8.51 Uses of convex and concave mirrors

INVESTIGATION 8.5

Looking at images

Aim

To observe and compare the reflection of light from plane mirrors and curved mirrors

Materials

- plane mirror
- shiny tablespoon or soup spoon

Method

1. Look at your image in the back of a spoon. This surface is *convex*. Convex means curved outward. Move the spoon as close to your eyes as you can and then further away. Is the image small or large? Right-side up or upside down? Is there anything strange about the image? Record your observations in a table like the one provided.
2. Look at your image in the front of the spoon. This surface is *concave*. Concave means curved inward. Move the spoon closer to you and then further away. Record your observations in the table.

3. Look at the image of your face in a plane mirror. Wink your right eye and take notice of which eye appears to wink in the image.
4. Write the word IMAGE on a piece of paper and place it in front of the mirror so that it faces the mirror. Write down the word as you see it in the image.
5. Write down how you think an image of the word REFLECTION would look in the mirror. Test your hypothesis about the image of the word REFLECTION.

Results

Copy and complete the following table and give it an appropriate title.

	Observations of image		
	First observation	**When you move closer**	**When you move further away**
Convex side			
Concave side			

Discussion

1. Which eye in the plane mirror image appears to wink?
2. Which letters in the image of the word IMAGE look different? Which look the same?
3. Was your hypothesis about the word REFLECTION correct?
4. List some places where you have seen curved mirrors. State whether the mirrors were convex or concave and explain why they are used.

Conclusion

What can you conclude about the images formed in plane compared to those in curved mirrors?

8.6.6 Refraction

When a wave enters a region where it meets resistance it slows down. The waves ‘bunch up’ and the wavelength decreases. This happens to water waves as they approach the beach. Sound waves slow down when moving into cooler air and light waves slow down below the speed of light in transparent and translucent substances. The frequency of the waves, however, does not change.

When the light hits the new substance head on, the beam slows down but stays in a straight line. Things change when the light hits the new substance at an angle. Here, one side of the beam slows down before the other. The effect of this is that the beam changes direction. This is **refraction**.

To describe the change in direction, we measure the angles between the light beam or ray and the normal.

- When a beam enters the glass, it will refract *towards* the normal.
- When the beam leaves the glass, it will move *away from* the normal.

TIP: Use the acronym **FAST** to remember the changes in direction in refraction:

Faster = **A**way from normal
Slower = **T**owards normal

Refraction effects

Water can make a bowl of water, a swimming pool or any body of clear water appear shallower than it is. Light leaving the surface of the water changes direction. The eye sees the light appearing to travel in a straight line. This gives the illusion that the water is not as deep as it is. Objects that are part in the water and part out can appear broken from some angles, as the light travelling through the water will enter your eyes from a different angle to the light from the part of the object sticking out of the water.

FIGURE 8.52 The wavefront is a line connecting the crests of the waves in the beam that were emitted at the same time. The wavelength is the distance between wavefronts. The wavefronts 'bunch up' in the glass because the wave slows down.

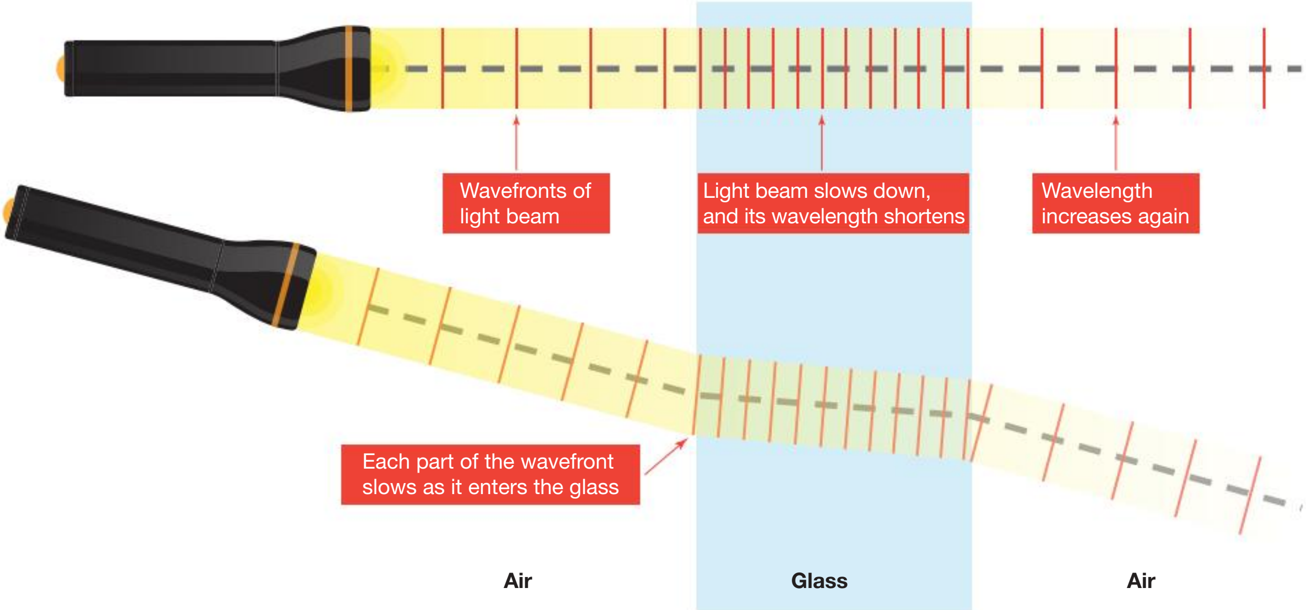


FIGURE 8.53 A ray of light will refract towards the normal when it enters a substance that slows the light.

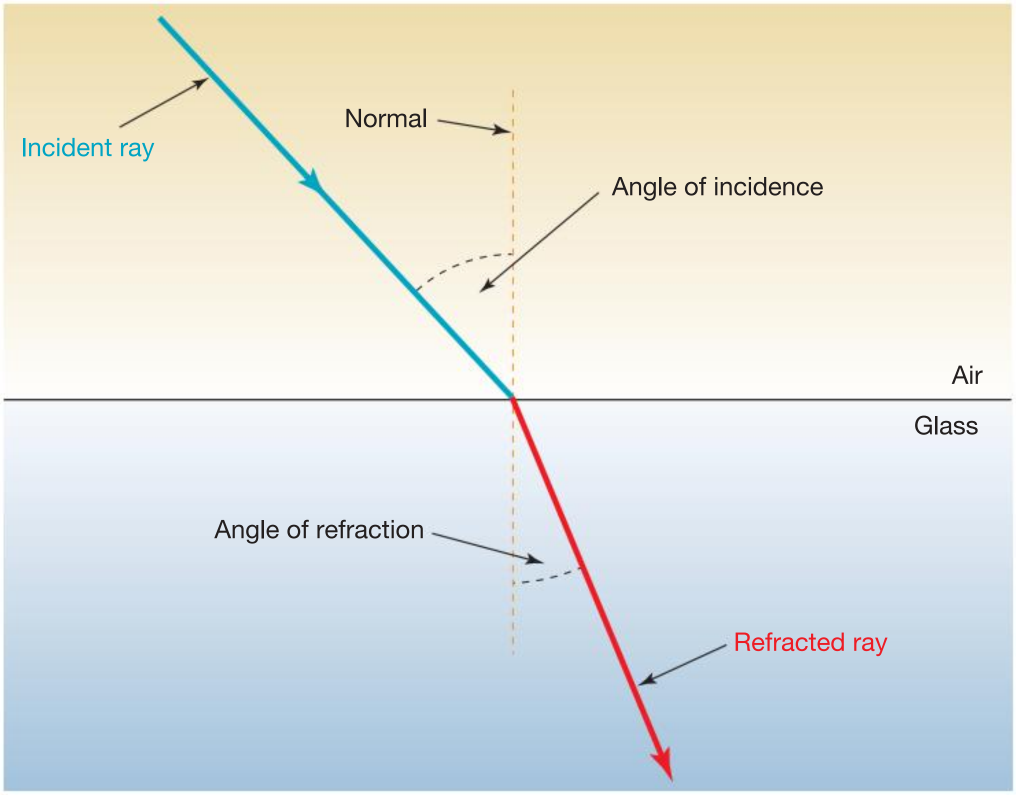
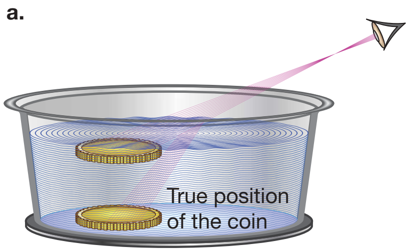


FIGURE 8.54 **a.** The coin appears to be higher in the water than it is, due to refraction. **b.** The pencil appears broken due to refraction.



How much a material bends light is called the **refractive index**.

INVESTIGATION 8.6

How much does it bend?

Aim

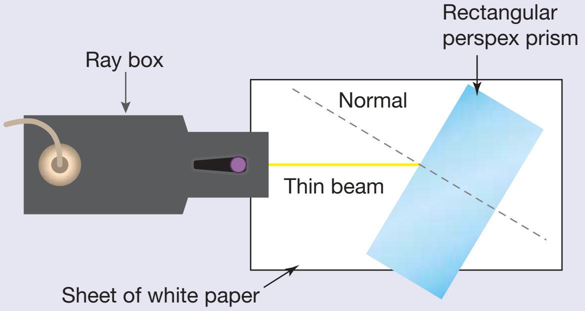
To investigate the refraction of light as it travels into and out of a rectangular prism

Materials

- ray box kit
- power supply
- sheet of white paper

Method

1. Connect the ray box to the power supply.
2. Place a sheet of white paper in front of the ray box.
3. Project a single thin beam of white light towards a rectangular perspex prism as shown in the diagram.



Discussion

1. Does the light bend towards or away from the normal as it enters the perspex? (Remember that the normal is a line that can be drawn at right angles to the boundary. It is shown as a dotted line in the diagram. You don't need to draw it — just imagine that it's there.)
2. Imagine a normal at the boundary where the light leaves the perspex to go back into the air. Which way does the light bend as it re-enters the air — towards or away from the normal?
3. Does all of the light travelling through the perspex re-enter the air? If not, what happens to it?
4. Look at the light beam as it enters and leaves the perspex. What do you notice about the direction of the incoming and emerging beam?
5. Turn the prism without moving the ray box so that the light enters the perspex at different angles.
   - **a.** How can you make the incoming light bend less when it enters the perspex?
   - **b.** How can you make the incoming light bend more when it enters the perspex?

Conclusion

How does light behave when it travels through air and through perspex?

8.6.7 Refraction and lenses

Lenses are usually made of glass or plastic. When light passes through them, it slows down as usual and bends. The slowing down is refraction. Due to their special shapes, the light can be guided to a point where it may be projected on a screen.

A common shape of lens is **biconvex** (convex lens) — that means it is curved outwards on both sides. A beam of parallel rays of light travelling through a biconvex lens 'closes in' (converges) towards a point called the focal point, or focus.

Another type of lens is a **diverging lens** (concave lens), which spreads light outwards because of its biconcave shape. A biconcave lens does not have a real focal point. When the parallel light rays emerge from a biconcave lens, they do not converge to a focal point. However, if you trace the rays back to where they are coming from, you find that they do appear to be coming from a single point. That point is called the **virtual focal point**, or virtual focus.

FIGURE 8.55 **a.** Biconvex lenses converge light on a focal point. **b.** Biconcave lenses spread light outwards.

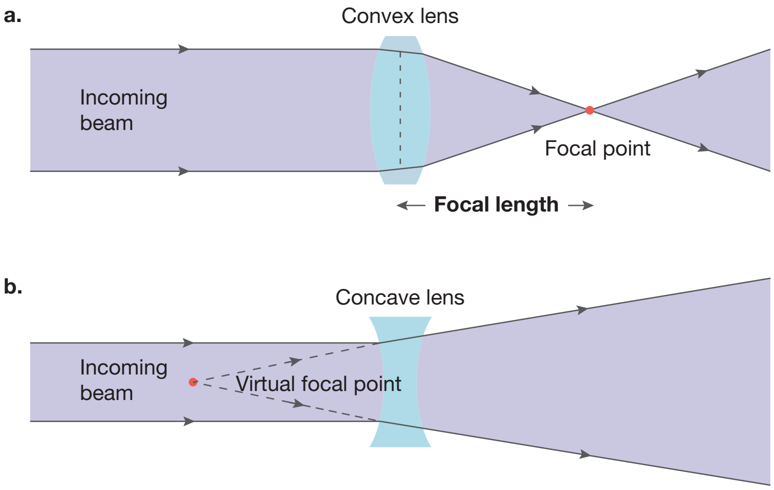
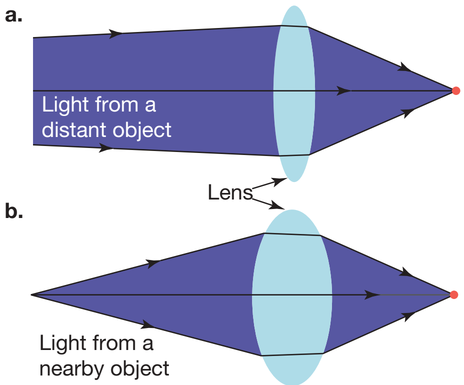


FIGURE 8.56 **a.** The light coming from a nearby object needs to be bent more than the light coming from a distant object. **b.** The lens in your eye becomes thicker when you look at nearby objects.



INVESTIGATION 8.7

Seeing the light

Aim

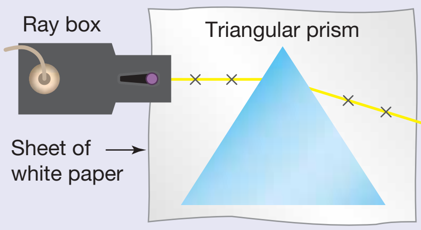
To investigate the reflection of light and its transmission through a prism and lens

Materials

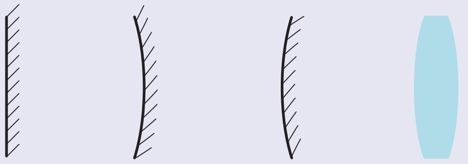
- ray box kit
- power supply
- several sheets of white paper
- ruler and fine pencil

Method

1. Connect the ray box to the power supply.
2. Place a sheet of white paper in front of the ray box. Move the lens backwards and forwards until a beam of light with parallel edges is projected.
3. Use one of the black plastic slides to produce a single thin beam of light that is clearly visible on the white paper.



4. Trace the path of this single beam of light as it meets the lens,
prism or one of the mirrors shown in the diagram provided. The path can be traced by using pairs of very small crosses along the centre of the beam before and after meeting each 'obstacle'. Trace and label the shape of each 'obstacle' before you trace the light paths.
5. Change the slide in the ray box so that you can project several parallel beams towards each of the 'obstacles'.
6. Use a ruler to draw a small diagram showing the path followed by the parallel beams when they meet each of the 'obstacles'.



Results

1. Record the path of the single beam of light.
2. Record the path of the parallel beams of light.

Discussion

1. What happens to a beam of light when it meets a perspex surface:
   a. 'head on'
   b. at an angle?
2. What happens to a beam of light when it meets a plane mirror surface:
   a. 'head on'
   b. at an angle?
3. Describe your observations of the path followed by the three parallel beams when they meet each of the mirrors and the lens.

Conclusion

What can you conclude about the behaviour of light in this investigation?

INVESTIGATION 8.8

Focusing on light

Aim

To investigate the transmission of light through different lenses

Materials

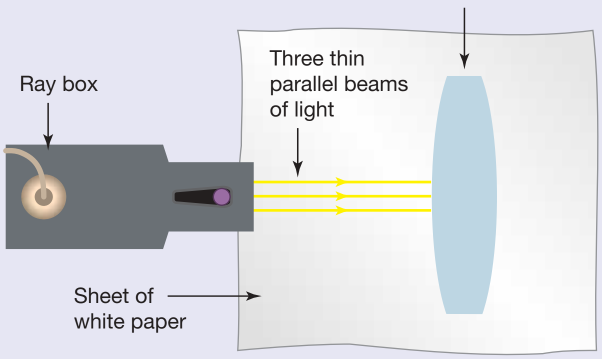
- ray box kit
- sheet of white paper
- 12 V DC power supply
- ruler and fine pencil

Method

1. Connect the ray box to the power supply and place it on a page of your notebook.

Part A: Biconvex lenses

2. Place the thinner of the two biconvex lenses in the kit on the page and trace out its shape. Project three thin parallel beams of white light towards the lens.
3. Trace the paths of the light rays as they enter and emerge from the lens. Remove the lens from the paper so that you can draw the paths of the light rays through the lens.
4. Replace the thin biconvex lens with a thicker one and repeat the previous steps.



Part B: Biconcave lenses

5. Place the thinner of the two biconcave lenses on your notebook page and trace out its shape.
6. Trace the path of each of the three thin light beams as they enter and emerge from the lens. Remove the lens from the page so that you can draw the paths of the light beams through the lens.

Results

Part A: Biconvex lenses

Record the paths of the beams of light through the biconvex lens.

Part B: Biconcave lenses

Record the paths of the beams of light through the biconcave lens.

Discussion

1. State the focal length (distance from the focal point to the centre of the lens) for each lens.
2. Which of the biconvex lenses bends light more — the thin one or the thicker one?
3. Explain why the middle light ray does not bend.
4. How many times does each of the other rays bend before arriving at the focal point?
5. Do the diverging rays come to a focus?
6. Do the diverging rays appear to be coming from the same direction? Use dotted lines on your diagram to check.
7. Predict where the diverging rays will appear to come from if you use a thicker biconcave lens. Check your prediction with the thicker biconcave lens in the ray box kit.

Conclusion

What can you conclude about the behaviour of light through biconvex and biconcave lenses?

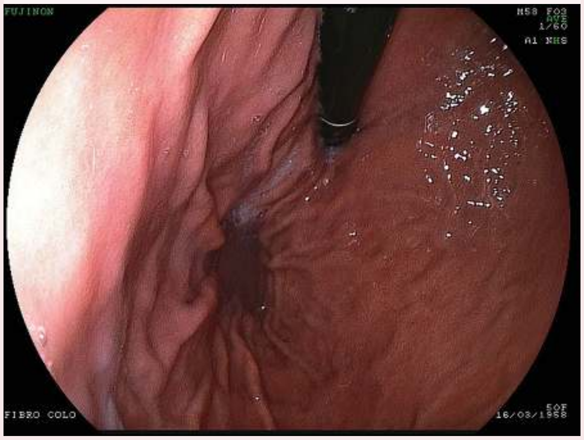
8.6.8 EXTENSION: Piping light

SCIENCE AS A HUMAN ENDEAVOUR: Piping light for use in medicine

The photograph in figure 8.57 shows the inside of a human stomach. It has been photographed through a long, flexible tube called an **endoscope**. Inside the endoscope are two bundles of narrow glass strands called **optical fibres**.

A beam of bright light is directed through one bundle of fibres, illuminating the inside of the stomach. Some of the light is reflected through the other bundle of fibres. A lens at the end of this bundle allows an image to be viewed,
photographed or videotaped.

FIGURE 8.57 Optical fibres allow us to see inside the human body via an endoscope.



Endoscopes can be used to look at many different parts of the body. Different types of endoscopes include:

- gastroscopes, which are used to examine the stomach
and other parts of the digestive system
- arthroscopes, which are used to search for problems in joints like shoulders and knees
- bronchoscopes, which are used to see inside the lungs.

Endoscopes can also be used in laser surgery. Intense laser beams can be directed into the optical fibres. The heat of the laser beams can be used to seal broken blood vessels or destroy abnormal tissue inside the body.

The glass in optical fibres is made so that light is unable to emerge from the glass. As light travels from a substance such as glass into air, it bends away from the normal. As the incident angle gets larger, the light bends more and more. Eventually, the angle becomes so great that the incident light just can't bend any more. This angle is called the **critical angle**. When it is reached, the light does not emerge from the glass — it will just travel along the boundary.

If the light hits the boundary at an angle greater than the critical angle, instead of leaving the glass, it is reflected back into it. This process is called **total internal reflection**. Figure 8.59 shows how total internal reflection occurs in an optical fibre.

FIGURE 8.58 A bundle of optical fibres. The light can be seen through the ends.

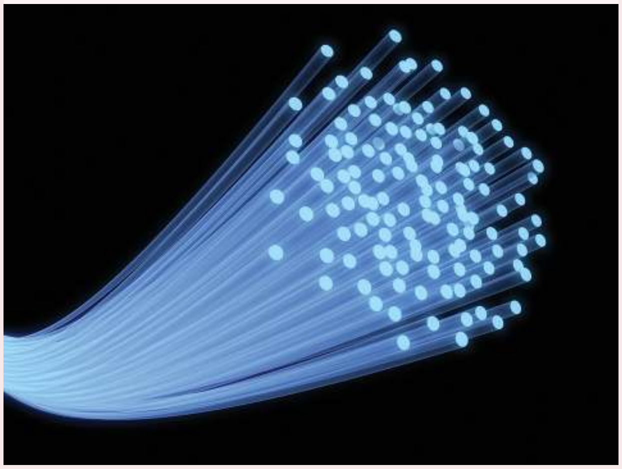
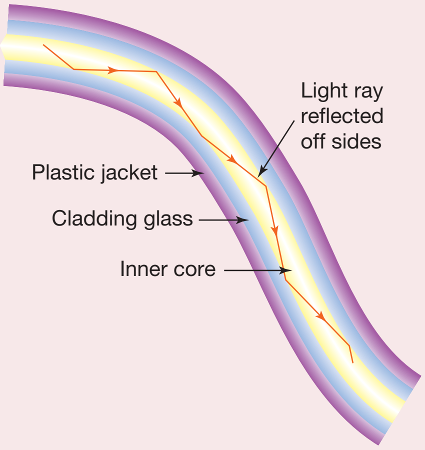


FIGURE 8.59 Total internal reflection in an optical fibre



1. What is the role of optical fibres in an endoscope?
2. Explain the concept of total internal reflection and how it is used in optical fibres.
3. What is the critical angle, and why is it important in the design of optical fibres?
4. List three types of endoscopes and the parts of the body they are used to examine.
5. How has the use of endoscopes improved medical procedures compared to older methods?
6. Describe how laser surgery using an endoscope works and its benefits.
7. How do advances in the understanding of light and optics contribute to the development of new technologies like endoscopes?
8. What other fields besides medicine might benefit from the principles of optical fibres?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

EXTENSION: Why diamonds sparkle

Diamond can sparkle with coloured light, each of its surfaces producing a dazzling display. Diamond is the most optically dense, naturally occurring material on Earth. This means that light entering a diamond through each of its facets (or geometrically cut sides) is refracted by a huge angle, causing light inside the gemstone to bounce back and forth several times before it strikes a facet with an angle straight enough to escape. Because the light has travelled so far, the spectrum of colours that make up light has dispersed (or separated) so significantly that a stunning display of colours is produced.

FIGURE 8.60 A diamond sparkles with many colours because light entering its facets is refracted at a large angle and bounces around inside, separating the spectrum into colours before escaping.

8.6 Activities

learnon

8.6 Quick quiz on	8.6 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 5, 7, 9, 10	3, 4, 6, 12, 13	8, 11, 14, 15

Remember and understand

1. MC You cannot usually see light as it travels through the air. **Identify** what makes it possible to see a beam of light.
   A. When particles in the air scatter the light
   B. When the beam is very bright
   C. When the beam contrasts well with the background
   D. When the light waves have a very long wavelength
2. **Identify** what happens to light when it travels through air and meets:
   a. a transparent surface
   b. a translucent surface
   c. an opaque surface.
3. **Identify** what the angle of reflection will be in each of the following cases.
   a. The angle of incidence is 35°.
   b. The angle between the reflected ray and the mirror is 40°.
   c. The angle between the incident ray and the mirror is 20°.

4. **Identify** in which type of mirror your image can be:
   a. upside down
   b. magnified
   c. the right way up, unmagnified and laterally inverted.
5. Sketch the word LIGHT but laterally inverted.
6. **Identify** whether the following properties of a beam of light would increase, decrease or stay the same when it enters a denser medium (e.g. from air into water).
   a. Wavelength
   b. Speed
   c. Frequency
   d. Angle between the ray and the normal

Apply and analyse

7. The illustration shows a ray of light emerging from still water after it has been reflected from a fish. **State** whether the spear should be aimed in front of or behind the image of the fish. Use a diagram to **explain** why.

8. Are photons particles or waves? **Explain** your answer.
9. **Name** and sketch the shape of a lens that:
   a. converges a beam of light to a single point
   b. makes the rays in a beam of light diverge.
10. MC **Identify** what the focal length of a converging lens is a measure of.
    A. How long the image will be
    B. The distance between the focus (the point to which parallel rays of light converge) and the lens
    C. The distance between the object and the image
    D. The distance you must place the object at to form an image.
11. **Explain** why the focal point of a diverging lens is called a virtual focal point.
12. **Explain** how optical fibres allow light to travel along a bent tube.
13. **Explain** how an endoscope works, listing three medical uses.
14. Can total internal reflection occur when light travels from air into glass? **Explain** your answer.

Evaluate and create

15. SI You are presented with three different transparent materials and you are asked to determine which of them slows light down the most. Plan an experiment stating the independent, dependent and controlled variables that you would use. **State** the equipment that you would use to make any measurements. **Explain** how your readings could determine which substance slowed light down the most.

Answers and sample responses are available in your digital formats.

LESSON 8.7 Static electricity

LEARNING INTENTION

In this lesson you will use the particle model to explain static electricity.

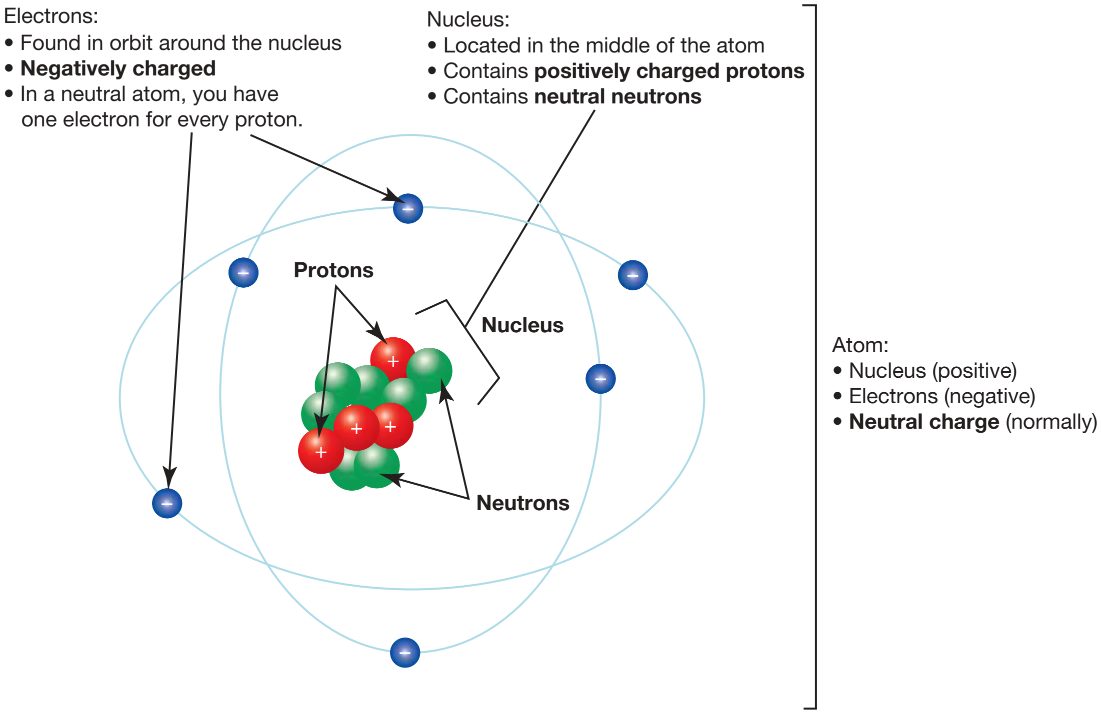
8.7.1 Charge!

When we say that we need to charge our phones, we mean that we have to fill a battery with electrical energy. However, as we will see, electricity doesn't just sit there in a battery. You cannot hold a handful of electricity. We only see electricity doing something when the electrons collide with atoms in the wire and transfer their energy. What causes the motion in the first place is the fact that electrons have a property called **electric charge**.

There are two types of electric charge: positive and negative. If a particle has no charge, or the same amount of positive and negative charge, we say it is neutral.

All matter is made up of atoms. It used to be thought that they were the smallest possible pieces of matter, but we now know that they are made of smaller pieces. Recall that atoms are made of three types of subatomic particles: protons, neutrons and electrons. Protons and neutrons are located in the nucleus of the atom, and electrons are located outside the nucleus.

FIGURE 8.61 A neutral atom contains an equal number of protons (red) and electrons (blue). (Two of the protons are hidden in this diagram.) This diagram represents a carbon atom (six protons and six electrons). The number of neutrons (green) is not always the same as the number of protons.



DISCUSSION

Why is it that sometimes your clothes crackle and you may get a small shock when you remove a jumper over your head?

Typically, protons in the nucleus don't move, so all of the electricity concepts that we will study are due to the movements of electrons.

KEY IDEA

All electricity is due to the movement or position of electrons.

There are two ways of using electrons. In **static electricity**, the electrons build up in one space and are not allowed to move (static means 'not moving'). If we create a pathway for electrons to flow through, we can create **current electricity** — this is how circuits work. Current electricity is really just a type of movement (kinetic) energy.

FIGURE 8.62 **a.** Electrons, which are negatively charged, can be removed from atoms. This produces free electrons and positively charged atoms (ions). **b.** These electrons are able to travel through wires.

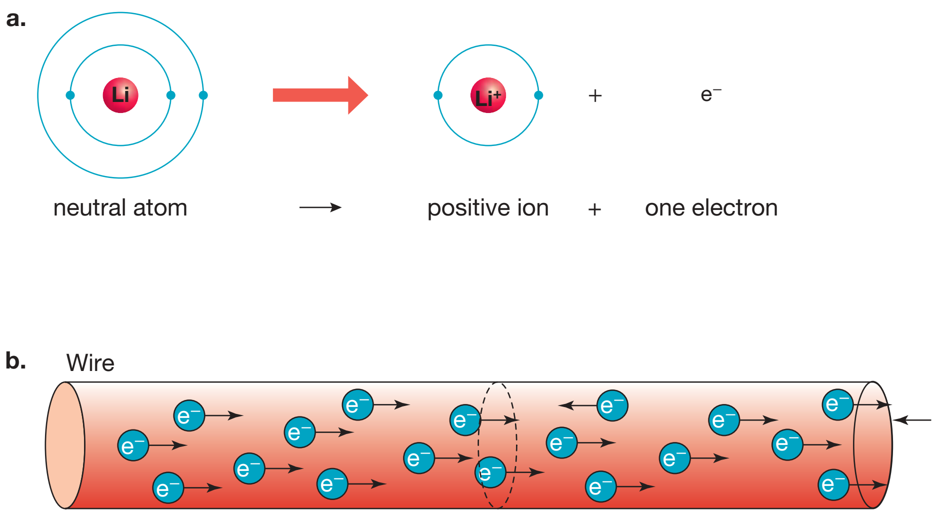


FIGURE 8.63 The cords to earbud headphones carry electricity, not sound. Each cord actually contains two wires. The jack that plugs into the player is composed of four wires, two per earbud.

8.7.2 Electric fields

Perhaps the most important observation in all of electricity is the interaction between charges of the same and opposite signs.

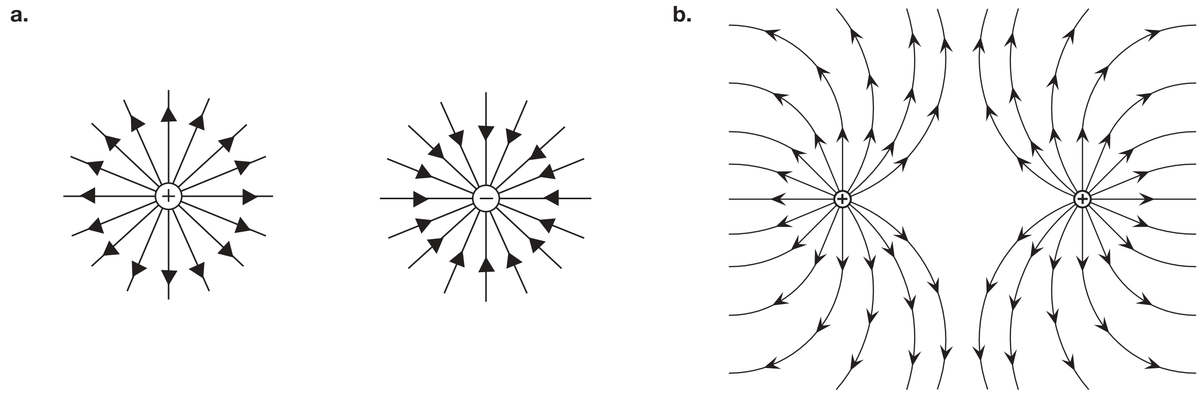
KEY IDEA

Two objects with the same charge will repel, but two objects with different charges will attract.

Just as magnets are surrounded by an invisible magnetic field, all charged objects have an electric field around them. If we bring two different types of charges together, the fields will join, which leads to attraction. If the charges are of the same sign, the fields cannot join and will push each other apart. This is a little bit like magnets, where two north poles would repel but a north and south pole will attract. Be careful, though, not to mix up electricity and magnetism.

It is this idea that causes most of the electrical phenomena that we see.

FIGURE 8.64 **a.** All charged objects have an electric field around them. **b.** Two fields with the same charge will repel each other.



8.7.3 Charging by friction

Materials can be divided into:

- **electrical conductors** — these are usually metals, where the presence of many free electrons allows for easy electron flow
- **electrical insulators** — these can attract or leak charge slightly, but generally do not allow it to flow. Charge can move from one insulator to another when two different insulators are rubbed together.

Some materials can steal electrons from other materials when you rub them together. The object that gains the extra electrons now has more negative charges, so we say it is **negatively charged**. The object that lost the electrons now has more positive charges than negative, so it is **positively charged**. This movement of electrons, and attraction and repulsion between charged objects, is demonstrated by the experiment in figure 8.65. The attraction between opposite charges also explains how lightning works (figure 8.66).

FIGURE 8.65 When a rubber rod is rubbed with a cloth, it gains electrons. When a glass rod is rubbed with a cloth, it loses electrons. We can see the attraction and repulsion between objects when the charged rods are suspended and brought near each other.

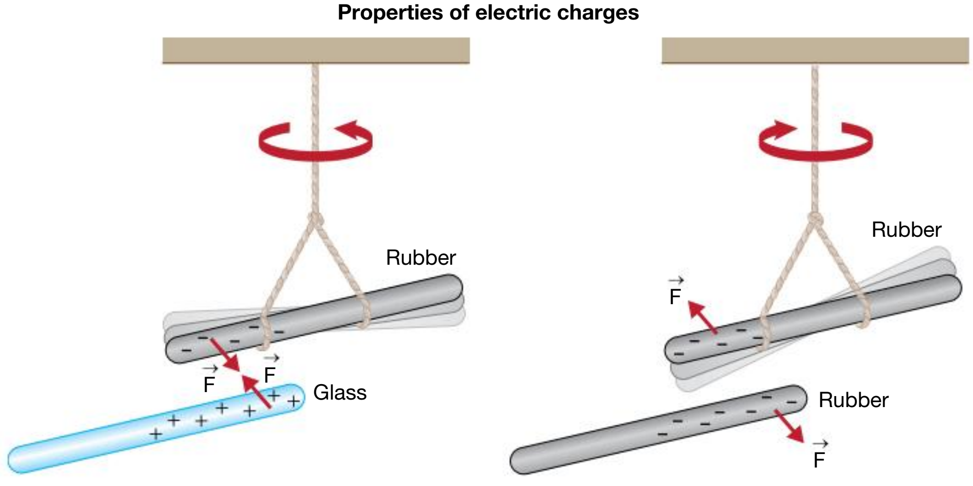
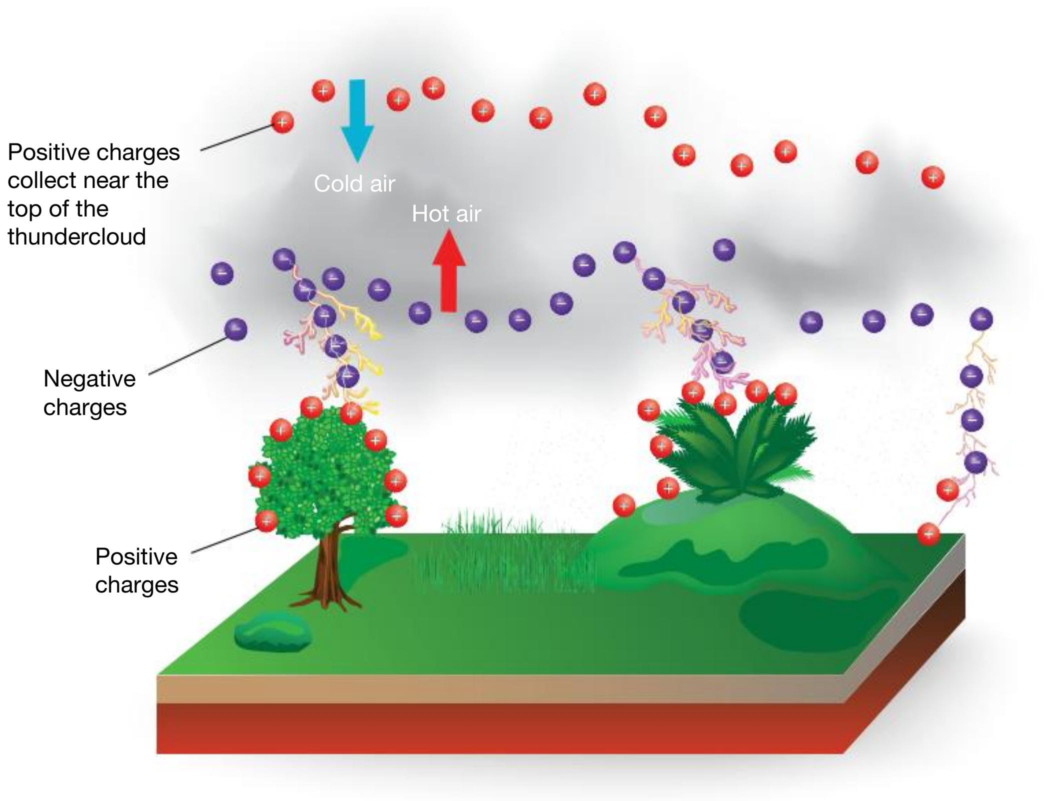


FIGURE 8.66 How lightning works. Attraction between opposite charges causes the particles to move towards one another, creating lightning.

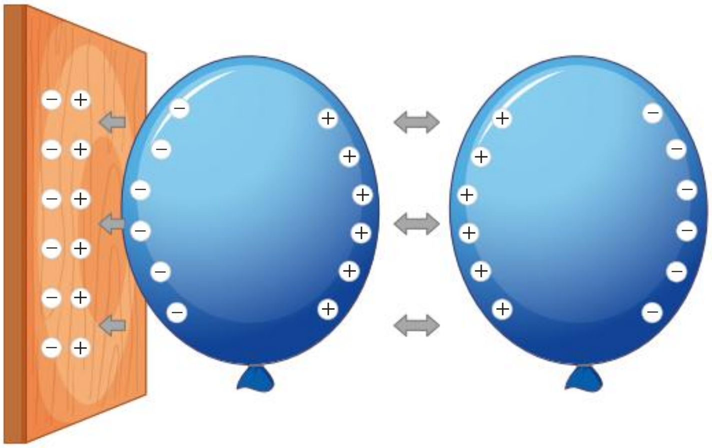


8.7.4 Charging by induction

Charged objects can attract neutral objects. If a charged object is placed near a neutral one, the electric field can repel or attract electrons in the neutral object.

- A positively charged object attracts the electrons to one side and sticks to them.
- A negatively charged object repels the electrons, leaving the region close to the charged object positively charged, so again they can stick (figure 8.67).

FIGURE 8.67 A pair of balloons charged by friction will repel each other if placed with positive charge facing positive charge. If the negative side of a balloon is placed near a wall, electrons in the wall are pushed slightly away. This leaves the surface of the wall slightly positively charged, so the balloon can now stick to the wall.

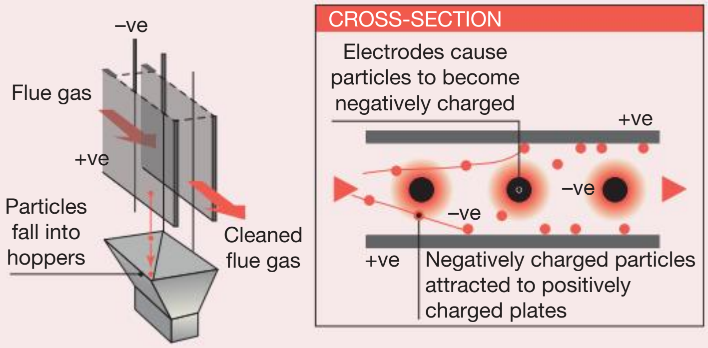


SCIENCE AS A HUMAN ENDEAVOUR: Electrostatic precipitator

Smoke rising from chimneys in power stations used to be a serious pollutant and health hazard. One of the technologies that was developed to clean up our environment is the electrostatic precipitator. Smoke particles in the waste gases pass through a series of negatively charged wires. The smoke particles pick up electrons, becoming negatively charged. They then stick to positively charged metal plates on the inside of the chimney.

The smoke no longer escapes into the atmosphere; instead, it builds up into large chunks of material that can be collected and used as a building material.

FIGURE 8.68 An electrostatic precipitator is a filtration device that removes fine particles, like dust and smoke, from a flowing gas.



1. What is an electrostatic precipitator, and how does it work to reduce particulate emissions?
2. Explain why smoke particles become negatively charged as they pass through the wires of an electrostatic precipitator.
3. What happens to the particles after they stick to the positively charged plates inside the chimney?
4. What are some ways that the collected particulate matter (fly ash) can be reused?
5. How might societal values and environmental regulations influence the adoption of technologies like electrostatic precipitators?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

INVESTIGATION 8.9

Producing different charges

Aim

To investigate how different materials can be charged

Materials

- 2 glass rods
- 2 plastic rods
- wool cloth
- silk cloth
- 2 retort stands or swivel stands

Method

1. Place a glass rod and a plastic rod on separate swivel stands.
2. Put the glass rod next to the plastic rod on the swivel stand and record your observations.
3. Put the glass rod next to the other glass rod on the swivel stand and record your observations.
4. Repeat steps 2 and 3 for the plastic rod.
5. Rub the second glass rod with a silk cloth. Bring it close to the glass rod on the swivel stand and record your observations.
6. Rub the second glass rod with a silk cloth again. Bring it close to the plastic rod on the swivel stand and record your observations.
7. Repeat steps 2 and 3 for the plastic rod and a wool cloth.

Results

1. Copy and complete the following table and give it an appropriate title.

Material	Glass rod on swivel stand	Plastic rod on swivel stand
Glass rod		
Plastic rod		
Glass rod and silk cloth		
Plastic rod and wool cloth		

2. When the glass rod is rubbed with silk, the rod carries a positive charge. Draw a sketch of the charges on both rods when:
   a. the glass rod rubbed with silk cloth is brought next to the glass rod on the swivel stand
   b. the glass rod rubbed with silk cloth is brought next to the plastic rod on the swivel stand
   c. the plastic rod rubbed with wool cloth is brought next to the glass rod on the swivel stand
   d. the plastic rod rubbed with wool cloth is brought next to the plastic rod on the swivel stand.

Discussion

1. Explain your observations when the rods that had not been rubbed were placed next to the rods on the swivel stands.
2. When the glass rod was rubbed with silk cloth, what charges moved?
3. When the plastic rod was rubbed with wool cloth, what charges moved?
4. What are the positive charges and what are the negative charges?
5. When two rods of the same material were brought close to each other, explain what happened in terms of attraction and repulsion.
6. Give an example of electrostatic charge you see in everyday life.

Conclusion

What conclusions can you make about how charges form and move on different objects?

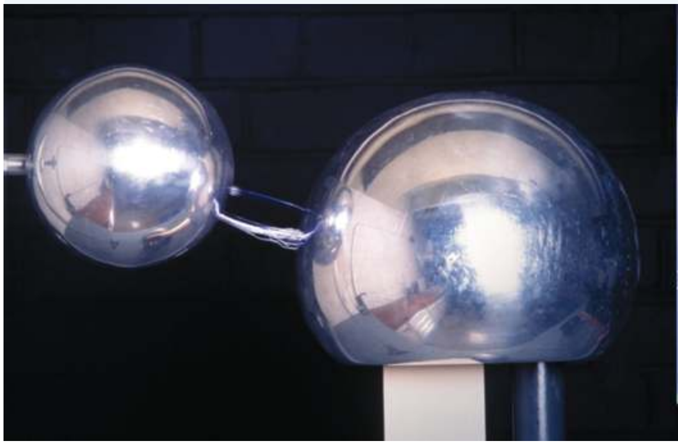
8.7.5 Sparks

Normally, in static electricity, the electrons in a negatively charged object stay in one place — they are literally static. As the electrons all have the same negative charge, the Law of Electrostatics says that they will be repelling each other. If there are enough electrons, the repulsion is big enough to actually push the electrons through the air to a nearby object, or often the ground. This is a spark. The object will be **discharged** or **earthed** if we allow the electrons to flow to the ground.

If the object was originally positively charged, the protons do not move, but if there is enough charge present, electrons from nearby objects or the ground can jump *into* the object. When enough electrons flow in to balance out the positive charge, again we say the object is discharged.

Sometimes when we get out of a car or remove an item of clothing quickly, we may feel a spark. These sparks happen because there is enough force to move electrons quickly across a gap. The **voltage** is a measure of the energy available to push the electrons. The bigger the charge, the higher the voltage. Typically, a spark will have thousands of volts pushing the electrons, but this should do you no harm. The **electric current** is a measure of the amount of charge flowing per second and for such sparks, this is a tiny amount. Lightning is also an electrical discharge, but on a much larger scale, and involves very high currents and voltages. For more information on voltage, current and electrical circuits, see topic 9.

FIGURE 8.69 Static electricity is the build-up of charge on an object. This electrical energy can be transferred from the negatively charged object to the positively charged object, and some energy is transformed into light and sound. This may be **a.** a small amount of energy in a spark, or **b.** a large amount of energy in lightning.



8.7 Activities

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8.7 Quick quiz on	8.7 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 8	3, 5, 6	4, 7, 9

Remember and understand

1. MC **Identify** how we can make a negatively charged plastic rod.
   A. Remove electrons
   B. Remove protons
   C. Add electrons
   D. Add protons

2. MC **Identify** how we can make a positively charged plastic rod.
   A. Remove electrons
   B. Remove protons
   C. Add electrons
   D. Add protons
3. MC A plastic rod is rubbed with a glass rod. The glass rod becomes negatively charged. **Identify** what will happen when the glass rod is held above the plastic rod.
   A. The rods will repel.
   B. The rods will attract.
   C. The rods will exchange charges and neutralise.
   D. Nothing will happen.
4. MC A plastic rod is rubbed with a glass rod. The glass rod becomes negatively charged. **Identify** what will happen when the glass rod is held above some small pieces of paper.
   A. The pieces of paper will repel.
   B. The pieces of paper will attract.
   C. The pieces of paper will exchange charges and neutralise.
   D. Nothing will happen.
5. MC One end of a plastic rod is rubbed with a cloth. That end of the rod becomes negatively charged. **Identify** what the charge at the other end of the rod will be.
   A. Positive
   B. Negative
   C. Neutral
   D. It depends on the type of plastic.

Apply and analyse

6. MC One end of a metal rod becomes negatively charged when it touches a charged wire. **Identify** what the charge at the other end of the rod will be.
   A. Positive
   B. Negative
   C. Neutral
   D. It depends on the type of metal.
7. MC **Identify** which of the following explains why two balloons repel each other after being rubbed on wool.
   A. The balloons acquire a positive charge and like charges repel each other.
   B. The balloons acquire a negative charge and opposite charges attract each other.
   C. The friction between the balloons and the wool generates a magnetic force that repels the balloons.
   D. The balloons become magnetised and repel each other due to their magnetic fields.

Evaluate and create

8. Sketch and label a neutral atom with three electrons.
9. SI Design an experiment to investigate the relationship between the amount of time a charged balloon will stick to a wall and the amount of time charging by friction occurs.
   You should:
   - develop a hypothesis
   - identify your dependent, independent and controlled variables
   - produce a suitable table
   - conduct your experiment (only take five readings)
   - plot a suitable graph of your results
   - evaluate your findings. Discuss whether your hypothesis was correct.

Answers and sample responses are available in your digital formats.

LESSON 8.8 Review

8.8 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
8.2	I can distinguish between heat and temperature.			
	I can define absolute zero.			
	I can describe the key mechanisms of energy transfer in terms of the particle model.			
8.3	I can describe a wave in terms of its nature, frequency and amplitude.			
8.4	I can describe sound as a pressure wave in a medium and calculate its speed.			
8.5	I can describe light as an electromagnetic wave and name the key regions of the spectrum.			
	I can describe the link between energy and frequency of light.			
8.6	I can describe the behaviour of light during reflection and refraction.			
8.7	I can use the particle model to explain static electricity.			

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Post-test	Topic 8 Post-test
eWorkbook	Topic 8 eWorkbook
Digital document	Key terms glossary

8.8 Activities

learnon

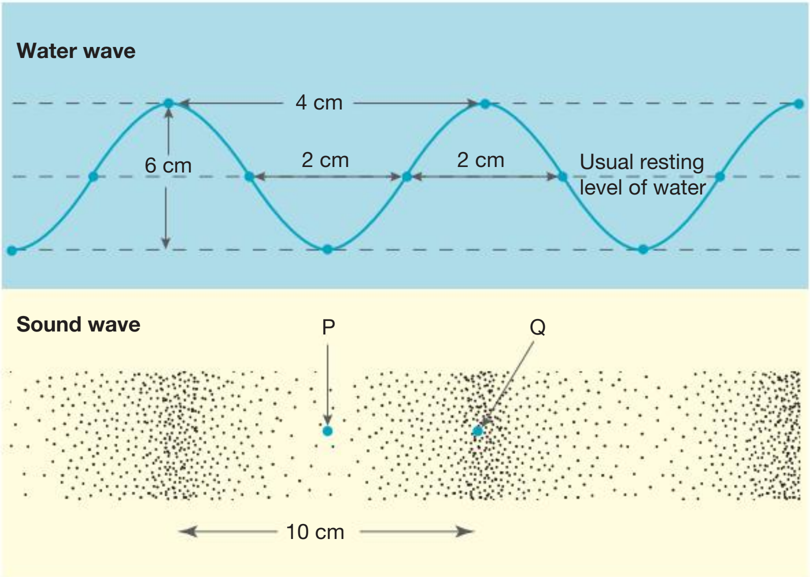
8.8 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 6, 13, 14, 15, 16, 18, 21, 22	2, 5, 7, 12, 17, 20, 23, 24, 25, 26	3, 8, 9, 10, 11, 19, 27

Remember and understand

1. Briefly **describe** how heat is transferred from one region to another by:
   a. conduction
   b. convection
   c. radiation.

2. **Identify** the main method or methods by which heat is transferred to the human body by:
   a. a gas wall furnace
   b. the Sun
   c. holding a hot plate
   d. an open fireplace
   e. walking on hot coals.
3. **Explain** why cooks often cover meat with aluminium foil instead of plastic.
4. **Explain** why solids such as polystyrene, foam and wool do not conduct heat as well as most other solids.
5. **Explain** why heat always transfers from a hotter object to a cooler one. Use this principle to **explain** why a metal chair feels colder than a wooden chair at the same room temperature.
6. **Explain** how reflective materials like foil or shiny space blankets reduce heat loss in cold conditions.
7. **Describe** two features of good insulating materials and explain how they reduce heat transfer by conduction and convection.
8. **Explain** how fibreglass batts are able to reduce the loss of heat through the ceiling by both conduction and convection.
9. **Describe** why coastal areas experience less extreme high and low temperatures than inland regions.
10. **Explain** what causes the movement of continents.
11. **Explain** the following statement in terms of heat transfer: 'Greenhouse gases in Earth's atmosphere trap heat from the Sun'.
12. **Explain** the difference between a transverse wave and a compression wave. **List** two examples of each type.
13. Refer to the water wave and sound wave shown in the figures below to answer the questions that follow.



   a. **Identify** the amplitude of the water wave.
   b. **Identify** the wavelength of the water wave.
   c. **Identify** the wavelength of the sound wave.
   d. **Identify** which of the points — P or Q — is in the centre of a rarefaction.
14. Sound waves cannot travel in space, but light waves can. **Explain** why this is the case, using particle theory and wave models.
15. **List** two everyday applications of sound waves that do not involve hearing, and **explain** how sound energy is transferred in each case.
16. Replace each of the following descriptions with a single word.
   a. Regions of air in which the particles in the air are brought closer together than usual by sound waves
   b. Regions of air in which the particles in the air are moved further apart than usual by sound waves
   c. The effect of sound reflected from a hard surface over and over again
   d. What you see when you look in a mirror — even when you are not directly in front of it
17. When an object vibrates faster, **explain** what happens to the pitch of the sound it produces.

18. Some animals, such as elephants, can hear low-frequency sounds that humans cannot. **Explain** how changing the frequency of a sound affects its wavelength and the material it can travel through.
19. **Explain** which aspect of sound and light can easily be modelled with both particles and waves.
20. a. Complete the following table.

Properties of electromagnetic waves

Electromagnetic wave type	Wavelengths (m)	Properties
Infrared radiation		
Gamma rays		
Ultraviolet radiation		
Light		
X-rays		
Radio		

b. **State** three differences between sound waves and all of the waves listed in the table.
c. **Identify** the two properties that all of the waves listed in the table have in common.
d. **Identify** which type of electromagnetic waves listed in the table microwaves belong to.
e. **Identify** which of the electromagnetic waves listed in the table:
  i. can be produced artificially
  ii. transmits the most energy.

Apply and analyse

21. **Identify** which type of electromagnetic radiation is used in remote control devices.
22. **Identify** what is the major use to society of:
  a. x-rays
  b. ultraviolet radiation
  c. gamma rays.
23. If there was no visible light coming from the Sun, it is obvious that we would not be able to see. But the lack of visible light would cause a much greater problem. **Explain** what that problem is.
24. **Explain** the difference in the meaning of each of the following pairs of words.
  a. Ray and beam
  b. Reflection and scattering

25. When a light ray passes from air to glass and back into air again, **explain** how its speed changes when it:
  a. enters the glass
  b. emerges back into the air.
26. When you stand in clear, shallow water, your legs appear to be bent or shorter than they actually are. **Explain** why this happens, using your understanding of refraction.

Evaluate and create

27. Although electromagnetic radiation has many uses in society, there are also dangers associated with it.
  a. **Explain** the danger that ultraviolet radiation poses to the human body and what measures should be taken to protect against it.
  b. **Suggest** what precautions must be taken by the operators of x-ray equipment in hospitals.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

9 Generating electricity

CONTENT DESCRIPTION

Electricity can be generated as alternating current (AC) using magnets (via turbines turned by wind, water, tides or steam that is generated by the combustion of oil, gas or coal or by nuclear energy) or as direct current (DC) using photovoltaic cells or batteries (VC2S10U16)

Source: Victorian Curriculum F–10 Version 2.0

LESSON SEQUENCE

LESSON 9.1 Overview

9.1.1 Introduction

In this topic, we will dive into the world of electrical circuits and discover how electricity is generated and used. Electricity can be created in two main ways: as alternating current (AC) and direct current (DC). Imagine giant turbines being spun by the force of wind or water, or even by steam from burning fuels like oil, gas, coal or the use of nuclear energy. These turbines work with magnets to produce AC electricity, which is the kind of electricity that powers most of our homes and cities.

FIGURE 9.1 A wind farm near Hamilton, Victoria

On the flip side, DC is another way to generate electricity. Think about solar panels capturing sunlight, or batteries storing energy. These methods create a steady flow of electricity, perfect for powering devices like your phone or laptop. Both AC and DC electricity are essential in our everyday lives, making everything from turning on the lights to charging your gadgets possible. Let's explore how these amazing processes work and why they are so important in the world of electrical circuits!

DISCUSSION

1. Why do some devices use batteries and others need to be plugged in?
2. Why do we have different types of batteries?
3. Why do we have different types of plugs (two or three pins)?
4. Why are some batteries rechargeable and others are not?
5. When did we first start to use electricity?

SCIENCE INQUIRY: Data analysis — electricity in Mali

Electricity is one of the most important forms of energy for modern life. In Australia, most people take electricity for granted — we know when we flick a switch, the lights will come on. We have a reliable electricity source that makes our lives much more comfortable and easier than if we did not have this luxury.

FIGURE 9.2 Mali, shown in the colours of its flag

Not all countries in the world have access to reliable power. Countries or communities need to build the equipment used to generate electrical energy and then transmit it over long distances to houses. As of 2022, the number of people without access to electricity in Africa was around 600 million, indicating that significant challenges persist in expanding reliable power access across the continent.

In this task, we will examine data for the country of Mali. Mali is the eighth-largest country in Africa and has a population of 21.22 million people, which is growing at about 3 per cent per year. In the middle ages, Mali was the centre of an empire, stretching across most of eastern Africa. In the nineteenth century, a couple of hundred years after this empire collapsed, Mali was colonised by the French. Mali gained independence from France in 1960, but for much of the second half of the twentieth century, it suffered devastating famines and political upheaval. The twenty-first century has seen ongoing and serious conflicts within the country, as well as the rise of terrorism. Mali is rich in natural resources, with agriculture, livestock and gold as its main exports.

TABLE 9.1 Electricity access in Mali

Year	People with access to electricity (millions)	People without access to electricity (millions)
1990	0.00	8.50
1992	0.01	8.90
1994	0.10	9.30
1996	0.60	9.50
1998	0.64	9.98
2000	1.08	10.16
2002	1.56	10.39
2004	2.10	10.65
2006	2.26	11.36
2008	3.41	11.14
2010	4.18	11.35
2012	4.23	12.29
2014	5.99	11.56
2016	7.25	11.45
2018	10.15	9.79
2020	10.73	10.49

Your task is to represent these data points in a suitable graph or chart. When you have finished, answer the following questions.

1. Describe what the data shows regarding the electricity infrastructure in Mali. Remember to consider both sets of data.
2. Interpret the data to find the changing percentage of the population with access to electricity. Use this data to evaluate whether things are getting better.
3. Mali has a rapidly growing population but is one of the poorest countries in the world. It is listed as 'Do not travel' by most governments due to its high crime rates. Use your data to make a case for humanitarian aid for Mali. Discuss the benefits that increased access to electricity could bring.

Data and information can be organised, processed and summarised by selecting and constructing representations including tables, graphs, descriptive statistics, models, symbols, formulas and mathematical relationships (VC2S10I04)

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Pre-test	Topic 9 Pre-test
eWorkbook	Topic 9 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 9 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 9.2 Generating power

LEARNING INTENTION

In this lesson you will:

- define power and perform calculations of power
- compare AC and DC power and common sources of each type of power.

9.2.1 Power

Electrical power is measured in watts (W) and is equivalent to joules (J) per second. A 75 W incandescent light globe uses 75 joules of energy per second and would be more costly to run than an 18 W compact fluorescent light, which uses 18 joules per second and provides approximately the same amount of light.

The power rating can be used to determine the electrical energy used by an appliance as follows:

$$\text{Electrical energy use (joules)} = \text{electrical power (watts)} \times \text{time in use (seconds)}$$

For example, using a desktop computer for half an hour would use:

$$\begin{aligned} 120\text{ W} \times 30\text{ min} \times 60\text{ s/min} &= 120\text{ J/s} \times 1800\text{ s} \\ &= 216\,000\text{ joules} \\ &= 216\text{ kilojoules of energy} \end{aligned}$$

TABLE 9.2 Typical power ratings of household appliances

Appliance	Power rating (W)
Fluorescent light	20
Notebook computer	20
Desktop computer	120
Television	200
Toaster	1000
Hair dryer	1500
Electric kettle	1700
Air conditioner (medium size)	5000

An electricity meter located in your home's meter box monitors your energy usage in kilowatt-hours (figure 9.3).

The joule is a very small unit of energy, so electricity suppliers charge us in units called kilowatt-hours (kWh). A kilowatt-hour is the energy used by a 1 kilowatt appliance for an hour. The power use of an appliance depends on the type of energy conversion it carries out. Low-power appliances include fluorescent lights and laptops, and usually convert electrical energy to light and sound energy. High-power appliances such as electric kettles and toasters generally convert electrical energy to heat, and cost more to run.

FIGURE 9.3 Electricity meters measure the number of kilowatt-hours of energy used in homes.

EXTENSION: Meter box readings

Energy companies measure the amount of electrical energy used by a household in kilowatt-hours. Every three months the meter is read so that the energy company knows how much electricity the customer has used. Households are charged a fixed amount for every kilowatt-hour of electricity they use. This customer in figure 9.4 was charged 20.6 cents per kilowatt-hour.

FIGURE 9.4 Sample extract from an electricity bill

Energy used and costs

METER ID	−	THIS READING	=	LAST READING	×	USAGE SPLIT	×	RATE	=	COST
Single energy rate – contract (12/01/25 – 11/04/25)										
		46851.0		45998.0		First 853.0 kWh		853.0*20.600 c		$175.72
Electricity service availability charge								91 days 48.000 c/day		$43.68
*based on 19.1781 kWh/billing day										
Total electricity before GST: 853.0 kWh										$219.40

INVESTIGATION 9.1

Comparing electrical appliances

Aim

To compare the power use and energy conversion in a range of electrical appliances and devices

Materials

- a range of electrical appliances and devices (e.g. radio, hair dryer, blender, laptop, fluorescent light, incandescent light, hot water kettle)

Method

Examine each of the devices, preferably while they are operating.

Results

For each device, record in a suitably designed table the:
- type of energy input
- useful energy output (there may be more than one)
- wasted energy output (there may be more than one)
- operating power in watts (this should be labelled on the device).

Discussion

1. Which appliance/device consumes:
   a. the most power
   b. the least power?
2. Which device do you consider would be the:
   a. most efficient, producing the least wasted energy
   b. least efficient, producing the most wasted energy?
3. Account for the higher operating power of some of the devices in terms of the type of energy transformation that takes place.

Conclusion

Summarise the findings of this investigation in two to three sentences.

9.2.2 Generating electricity

Several years after Danish scientist Hans Ørsted discovered that electric currents produced magnetic fields, British scientist Michael Faraday suggested that perhaps a magnetic field might produce an electric current. In 1831, Faraday succeeded in generating an electric current by moving a coil of wire through a magnetic field. He had made the very first **electric generator**, also known as a **dynamo** (figure 9.5).

Generators work on the principle that a coil of wire moving in a magnetic field creates a current of electricity. This can be demonstrated with a simple hand generator. Current flows in a generator as long as there is relative movement between the magnetic field and the coil. It does not matter if it is the coil that moves while the magnet remains still, or the magnet that moves while the coil remains still.

In a bicycle generator, a magnet spins while the coil of wire remains still. In the generator of a motor car, many coils spin around inside a stationary electromagnet. The coils are turned by the car's engine. The electromagnet is connected to the car battery. The car's generator is used instead of the battery to supply electric current to other parts of the car while the engine is running.

Figure 9.6 shows a car generator. It converts kinetic energy into electrical energy. Each slip ring is connected to one end of each coil of wire. Like the bicycle dynamo, it generates an alternating current (AC).

The method used to generate the electricity in your home or school is not very different from that used by a single hand-operated generator in a bicycle dynamo. Of course, the scale is much larger.

Large-scale generators are turned using a **turbine**. There are many different ways to turn a turbine, which means there are many different methods of generating electricity, including oil, coal and gas power stations, nuclear power stations, and hydroelectric and tidal power stations. Despite the differences in how the turbine is turned, all these power stations use similar generators and use the same process to turn kinetic energy into electrical energy (as shown in figure 9.7).

FIGURE 9.5 A model generator demonstrates that motion between a coil of wire and a magnetic field creates a current in the coil.

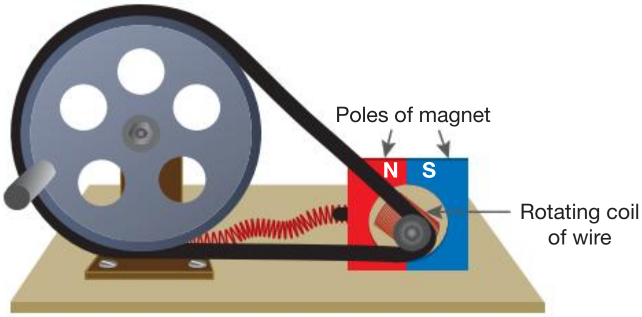


FIGURE 9.6 A typical car generator

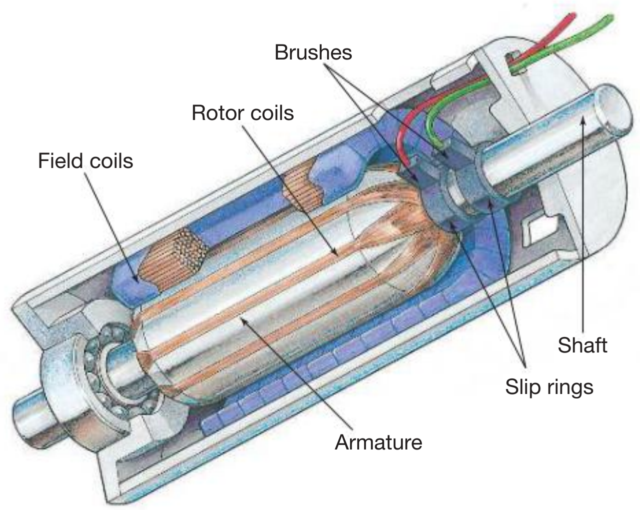


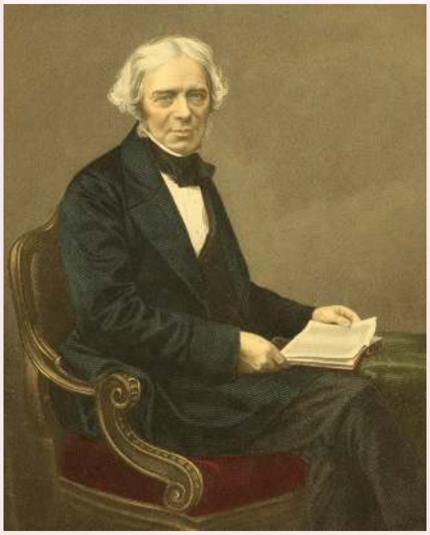
FIGURE 9.7 An industrial steam-turbine generator during construction

SCIENCE AS A HUMAN ENDEAVOUR: The evolution of electricity generation — from Faraday to modern power grids

The discovery of electromagnetic induction by Michael Faraday in 1831 was a pivotal moment in scientific history. His invention of the first electric generator (dynamo) paved the way for modern electrical power generation. Over the past two centuries, technological advancements have refined Faraday's principles into highly efficient systems that power homes, industries and entire cities.

Science and technology are interconnected — scientific discoveries lead to new technologies, which in turn enable further scientific progress. The advancement of generators, for example, has been crucial in the development of renewable energy sources like wind turbines and hydroelectric plants.

FIGURE 9.8 A portrait of Michael Faraday



Key scientific and technological developments in electricity generation

Early generators (1830s–1880s)

- Based on Faraday's principles, hand-cranked dynamos and steam-powered generators were developed.
- These early generators had low efficiency and could only power small devices.

Industrial Revolution and large-scale power plants (1880s–1950s)

- Scientists and engineers, including Nikola Tesla and Thomas Edison, improved upon Faraday's work.
- The invention of the alternator and the development of power grids allowed for mass electricity distribution.
- The rise of coal and hydroelectric power stations increased electricity availability.

Modern power generation and renewable energy (1950s–present)

- Advances in materials, science and electrical engineering improved generator efficiency.
- The development of wind turbines and solar power introduced cleaner energy sources.
- Superconducting materials and smart grids are being researched to reduce energy loss and improve electricity storage.

Investigating the relationship between science and technology in electricity generation

Scenario

Imagine you are a scientist working in renewable energy research. Your goal is to improve wind-turbine generators to make them more efficient and reliable.

Task

- Research how scientific discoveries in electromagnetism have contributed to improvements in modern generators.
- Investigate how technology (e.g. computer modelling, new materials, automation) has helped refine generator designs.
- Consider the impact of government funding and societal needs on energy research.
- Present findings in a report, infographic or short video explaining how science and technology interact in power generation.

1. How did Michael Faraday's scientific discovery contribute to the development of modern power stations?
2. What are some ways technology has improved the efficiency and reliability of electricity generation?
3. How has the push for renewable energy influenced technological advancements in generators?
4. Why is it important for scientists and engineers to work together in solving energy challenges?
5. What future advancements could further improve how electricity is generated and distributed?

Advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)

INVESTIGATION 9.2

Electrical energy from kinetic energy

Aim

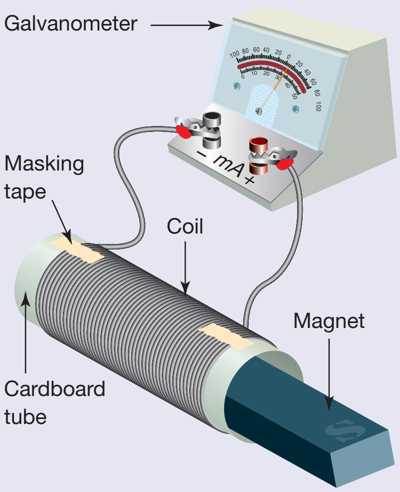
To investigate the generation of electric current by the movement of a magnet inside a coil of wire

Materials

- bar magnet
- length of insulated copper wire
- cardboard tube
- masking tape
- galvanometer (used to detect and measure small electric currents)
- large iron nail

Method

1. Make a solenoid by winding the insulated copper wire evenly around the cardboard tube. Tape the wire down so that it cannot unwind itself. Connect the free ends of the wire to the galvanometer.
2. Place the bar magnet inside the solenoid so that the end you are holding is just inside the cardboard tube.



Results

1. A galvanometer is used to detect and measure small electric currents. What is the reading on the galvanometer while the magnet is inside the solenoid?
2. Describe what happens to the needle of the galvanometer while the magnet is being pulled out.
3. Describe what happens to the needle of the galvanometer while the magnet is being pushed in.
4. Predict which way the needle of the galvanometer will move if the magnet is reversed and pulled out of the solenoid and then pushed into the solenoid.
5. Test your predictions about the movement of the galvanometer needle with the magnet reversed.

Discussion

1. Were your predictions correct?
2. Does a stationary magnetic field inside a solenoid produce an electric current in the solenoid?
3. Does a moving magnetic field inside a solenoid produce an electric current in the solenoid?
4. How is the current affected if the magnet is moved into or out of the solenoid faster?
5. Does pulling the solenoid away from the magnet have the same effect as pulling the magnet away from the solenoid?

Conclusion

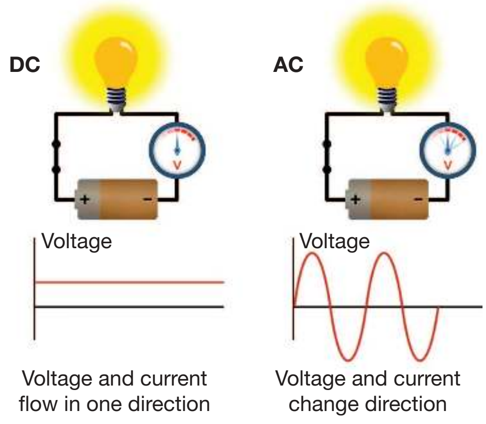
Summarise the findings of this investigation in two to three sentences.

9.2.3 DC or AC?

There are two types of electric current, voltage and power: AC and DC.

DC, or **direct current**, flows in one direction around an electrical circuit. DC voltage has fixed positive and negative terminals in a circuit. AC, or **alternating current**, changes the direction it flows around an electrical circuit. AC current involves electrical charges moving back and forth along the same piece of wire while carrying electrical potential energy around a circuit. AC voltage does not have fixed positive and negative terminals in a circuit — the position of positive and negative terminals regularly alternates.

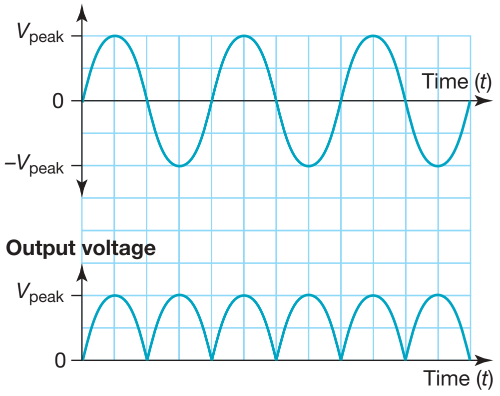
FIGURE 9.9 A DC circuit with a fixed voltage compared to an AC circuit with a voltage that regularly changes direction



The electric current supplied by a cell or battery is DC. It flows in one direction only. The electric current provided to your home by power stations is AC. It changes direction about one hundred times every second. In household lights and appliances, electrical energy is transformed into other forms of energy as electrons move backwards and forwards. All generators create AC current and voltage; however, it is possible to convert this AC current and voltage into DC current and voltage in a number of ways. This allows devices with batteries (DC) to be charged from an AC power point. It also allows people to use DC generators.

AC is supplied by power stations rather than DC because it is easier and cheaper to generate. It is also easier and cheaper to distribute widely over large distances. In Australia, electricity is supplied to homes at a voltage of 230 V.

FIGURE 9.10 The top graph shows an AC voltage. The bottom graph shows the DC voltage that can be created from the top AC signal. Unlike the constant DC voltage from a battery, the bottom DC voltage changes in size. Like the constant DC voltage from a battery, the bottom DC voltage only moves in one direction around an electrical circuit.



EXTENSION: Converting AC to DC

There are a number of ways to convert an AC voltage or current into a DC voltage or current. This includes single-wave rectification, full-wave rectification and changing the design of generators to include a commutator. Investigate these processes and find the similarities and differences between these methods. Are there any other ways of converting AC to DC?

9.2 Activities

learnon

9.2 Quick quiz on	9.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4, 7	5, 6, 8, 9

Remember and understand

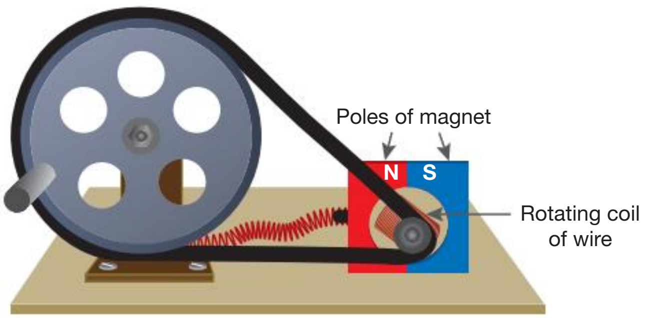
1. **Define** electrical power. **State** the unit used to measure it.
2. MC **Identify** which of the following statements best describes how electricity is generated in large-scale power stations.
   A. Each type of power station uses a completely different generator and process.
   B. All power stations use turbines to generate electricity by converting electrical energy into kinetic energy.
   C. Power stations use various methods to turn turbines, but the generators and the conversion of kinetic energy to electrical energy are generally the same.
   D. Only renewable power stations like hydroelectric and tidal use turbines for generating electricity.
3. **Explain** the main differences between AC and DC power. **Name** one common source for each type of power.

Apply and analyse

4. **Calculate** how much electrical energy (in joules) is transformed by each of the following appliances:
   a. An 18 W light globe in 6 hours
   b. A 2000 W toaster used to toast a slice of bread for 2 minutes
5. a. If a 60 W incandescent light bulb is used for 5 hours per day, **calculate** how much energy it uses per week.
   b. **Calculate** how much energy a 15 W LED bulb (which produces the same amount of light) would use in one week.
6. **Calculate** how much it would cost to operate each of the following appliances if the cost of electrical energy is 21 cents per kilowatt-hour. (Remember, 1 kW = 1000 W.)
   a. A 5000 W air conditioner for 30 minutes
   b. A 1500 W electric blanket for 8 hours
7. If a solar panel system generates 5 kWh of electricity per day and the cost of electricity from the grid is $0.20 per kWh, **calculate** how much money the solar panel system will save in one year (365 days).

Evaluate and create

8. **Identify** the role of each of the labelled components of the generator shown.



9. **Explain** the significance of the magnet in the operation of a simple generator. **Describe** how its role affects the generation of electric current.

Answers and sample responses are available in your digital formats.

LESSON 9.3 DC power sources

LEARNING INTENTION

In this lesson you will describe the process of generating DC electricity using batteries or photovoltaic cells.

9.3.1 Batteries

The great thing about batteries is that they are light and portable. They are predominantly used in devices that require mobility. Think about the inconvenience of having to plug a torch, mobile phone or laptop into a power outlet every time you needed to use them.

Additionally, batteries play a crucial role in many medical devices, serving as a back-up power source in the event of a power outage.

A battery is made up of two or more **cells** connected in series. However, in everyday language, the word battery is used to describe a single cell. The batteries used in a torch are actually single cells. An electric cell consists of two **electrodes** and a substance through which electric charge can flow. When the two electrodes are connected in an electric circuit with a closed switch, a **chemical reaction** takes place inside the cell, releasing electric charge and allowing current to flow.

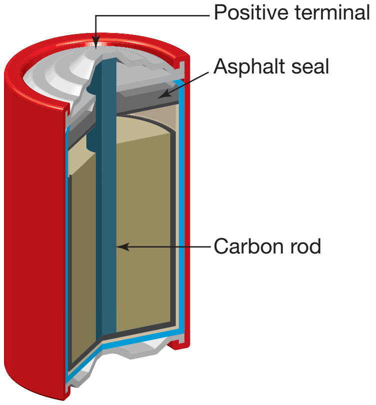
The general-purpose cells used in torches, clocks, smoke detectors and toys are filled with a paste composed of chemicals. The two electrodes are:

- a central rod of carbon, which is attached to the positive terminal
- a zinc case, which is in contact with the negative terminal of the cell.

When a conducting path is provided between the two terminals of the cell, a chemical reaction takes place between the paste and the zinc case. This releases electric charge, allowing an electric current to flow around the circuit. A separating layer stops the chemicals from reacting while the cell is not in use.

These general-purpose cells are called dry cells because the **electrolyte** (the substance inside the cell through which electric charge moves) is not a liquid.

FIGURE 9.11 A general-purpose dry cell



Other types of dry cells work in the same way but use different electrodes or electrolytes.

Alkaline cells contain an electrolyte that allows a greater electric current to flow. They are ideal for torches, remote controls, wireless keyboards and digital cameras.

Mercury cells produce a voltage that is much steadier than other dry cells. Their steady output makes them ideal for hearing aids, calculators, small electronic toys and measuring instruments.

Car batteries consist of six cells connected in series. Each cell has two lead electrodes, one of which is coated with a paste of lead dioxide. The electrodes are surrounded by a sulfuric acid solution. When the battery is in use, a chemical reaction occurs between the electrodes and the sulfuric acid. One of the products of the reaction is lead sulfate. Once the engine is running, the chemical reaction is reversed and the battery recharges. Over time, the lead sulfate builds up on the electrodes and becomes so hard that the reverse reaction cannot take place. The battery cannot be recharged and needs replacing.

Nickel–cadmium cells, such as those used in mobile phones, can also be recharged. A battery charger can be used to reverse the chemical reaction that causes electric current to flow. Other types of rechargeable batteries include lithium-ion and lithium-gel batteries.

FIGURE 9.12 Different types of batteries

EXTENSION: Alessandro Volta

The very first working battery, made by Alessandro Volta more than 200 years ago, was a tall pile of silver and zinc discs with pieces of cloth soaked in salty water between the discs. This structure became known as a voltaic pile.

Research Alessandro Volta, the voltaic pile and current batteries. How do today's batteries compare to the voltaic pile in terms of materials and efficiency?

INVESTIGATION 9.3

A lemon battery

Aim

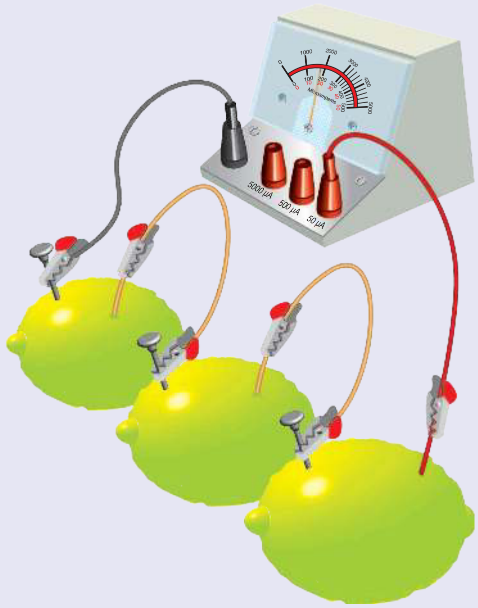
To use lemons to create a battery

Materials

- 3 lemons
- 3 galvanised nails
- 3 × 5 cm lengths of uninsulated copper wire
- microammeter
- 4 connecting leads

Method

1. Squeeze all three lemons to break up some of the pulp inside.
2. Insert a galvanised nail and a piece of copper wire into one of the lemons. The nail and wire should be about 3 cm apart.
3. Use connecting leads to connect the negative terminal of the microammeter to the nail and the positive terminal to the copper wire.



Results

1. Record the electric current.
2. Add a second lemon in series and record the electric current again.
3. Add a third lemon in series and record the electric current.
4. Investigate the effect on the electric current of:
   - pushing the electrodes further into the lemons
   - changing the distance between the nail and the copper wire in the lemon.

Discussion

1. What is the electrolyte in this lemon battery?
2. How did the addition of a second and third lemon in series affect the electric current?
3. How did changing the depth of the electrodes and the distance between them affect the electric current?

Conclusion

Summarise the findings of this investigation in two or three sentences.

9.3.2 Photovoltaic cells

A photovoltaic cell, or solar cell, is a device that converts light energy from the Sun into electrical energy. When light from the Sun strikes the thin semiconductor layer in the photovoltaic cell, electrons are knocked free from their atoms. If the photovoltaic cell is connected to an electrical circuit, the free electrons flow through the circuit, creating electricity that can be used to power devices. Energy can also be stored in batteries for later use; for example, at night when there is little light. The most efficient photovoltaic cells designed for home use convert around 20 per cent of the energy arriving from the Sun into useful energy.

Several photovoltaic cells can be connected together to form a photovoltaic module, more commonly known as a solar panel. Multiple modules can then be wired to form an array. Solar panels installed on residential rooftops are now a common sight.

FIGURE 9.13 Solar arrays are made up of modules, which are made up of cells.

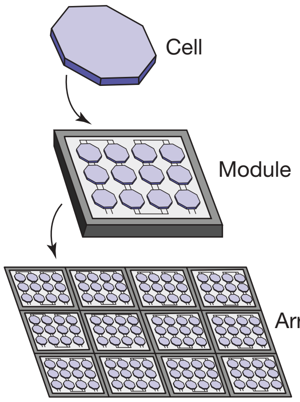


FIGURE 9.14 Solar arrays are often placed on roofs to provide cheap, sustainable energy.

Government priorities and funding have spurred research into enhancing photovoltaic cell performance. Many nations, including Australia, acknowledge the crucial need to transition from traditional fossil-fuel-based electricity production to renewable sources like solar power. While government funding supports only a few research institutions, many others are motivated by the growing public interest and government incentives to create increasingly efficient solar panels. This is an example of how science and government interact, and how society can have a positive impact on scientific research and vice versa.

ACTIVITY: Solar panels

Although solar panels, or photovoltaic cells, have become increasingly popular, there are several challenges associated with their large-scale use. These include storing power for nighttime use, the inconsistency of electricity generation, the environmental impact of manufacturing solar panels, and the costs related to their installation, maintenance and replacement.

Conduct some research on why individuals, communities or industries have chosen to use solar power and how they overcame any challenges.

This could involve:

- learning about the Victorian Solar Homes Program
- researching the Hornsdale Power Reserve in South Australia
- talking to a family who have installed solar panels, or a family who have not
- investigating solar grazing at the Numurkah or Winton Solar Farms in Victoria
- finding out about factories that run entirely off solar power.

Present your research as a digital display to show your class.

SCIENCE INQUIRY: Science, society and solar energy — how research and government influence innovation

The demand for renewable energy is increasing worldwide, with solar power at the forefront of the transition away from fossil fuels. Governments play a key role in funding scientific research to improve photovoltaic cells, which convert sunlight into electricity. In Australia, government priorities and funding are directed at improving the efficiency of solar panels, making them a viable alternative to coal- and gas-powered energy.

At the same time, public interest in renewable energy drives independent research, industry innovation and policy changes. This relationship between science, society and government policy highlights the role of scientific inquiry in addressing global challenges.

FIGURE 9.15 How can solar panel efficiency be improved?

Investigating the efficiency of solar panels

A key question in solar energy research is: How can we improve the efficiency of solar panels to generate more electricity from the same amount of sunlight?

Scientists conduct investigations to test materials, designs and conditions that enhance solar panel performance. These studies involve:

- testing different materials for solar panels
- experimenting with surface coatings to reduce energy loss
- studying the effect of temperature, light intensity and angle on energy output.

Inquiry activity

Critically evaluate scientific claims about solar panels and construct evidence-based arguments.

Scenario

The Australian government funds a university research project that claims it has developed a new type of solar panel that is 25 per cent more efficient than existing models.

Task

Research and evaluate the credibility of this claim by:

- finding reliable sources (scientific papers, government reports, industry data)
- identifying any assumptions or limitations in the study
- checking for conflicting evidence from other research
- considering any ethical or financial influences on the claim
- constructing an argument for or against the claim based on scientific evidence.

1. How do government priorities and funding influence the direction of scientific research?
2. What factors determine whether a scientific claim (e.g. 25 per cent more efficient solar panels) is valid and reliable?
3. Why is it important to consider ethical issues when evaluating scientific research (e.g. environmental impact, funding sources, transparency)?
4. How does public interest in renewable energy impact scientific advancements?
5. What role do secondary sources (e.g. news articles, company reports) play in shaping our understanding of scientific breakthroughs?

Extension: Real-world science and future challenges

1. What emerging technologies are being explored to improve solar panel efficiency?
2. Should governments invest more in solar energy research, or other renewables like wind or hydrogen?
3. How can students contribute to renewable energy solutions in their own communities?

Arguments based on a variety of evidence can be constructed to support conclusions or evaluate claims, including consideration of any ethical issues and cultural protocols associated with accessing, using or citing secondary data or information (VC2S10I07)

INVESTIGATION 9.4

Solar cells

Aim

To investigate the performance of a solar cell under different lighting conditions

Materials

- a solar cell
- a milli-ammeter or milli-voltmeter
- wire leads

Method

Investigate the performance of the solar cell under different light conditions. You may like to try artificial lighting in the classroom, a dim area within the room, bright sunlight and outdoor shade.

Results

Record the current or voltage produced in each condition.

Discussion

1. Under which conditions was the greatest current/voltage produced?
2. Under which conditions was the least current/voltage produced?
3. Bright artificial light creates a similar current and voltage as bright sunlight. Do you agree? Explain why.

Conclusion

What can you conclude about the effect of light on the current/voltage produced by a solar cell?

9.3 Activities

learnon

9.3 Quick quiz on	9.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 3	4, 5, 7	6, 8, 9

Remember and understand

1. MC **Identify** the difference between a cell and a battery.
   A. A cell is made of many batteries.
   B. A battery and a cell both work without power.
   C. A battery is made of two or more cells.
   D. A cell and a battery are the same thing.
2. **Explain** what takes place inside a cell to cause an electric current to flow.
3. **Explain** what substances the electrodes of a general-purpose dry cell are made of.
4. **Compare** alkaline cells to general-purpose dry cells. How are alkaline cells different?
5. **Describe** the energy transfers and transformations happening inside a photovoltaic cell.

Apply and analyse

6. **List** all the devices you can think of that use batteries. Try to classify these devices according to the type of battery they use.
7. **Describe** the process inside a photovoltaic cell that turns light energy into electrical energy.

Evaluate and create

8. **Summarise** some of the issues connected to using solar panels as a source of household electricity.
9. Design an experiment to compare the efficiency of a battery and a photovoltaic cell in generating DC electricity. **Explain** the factors you would consider in your comparison and how your findings could influence real-world energy choices.

Answers and sample responses are available in your digital formats.

LESSON 9.4 AC power sources

LEARNING INTENTION

In this lesson you will:
- describe the process of generating AC electricity using a generator
- explain how different electricity generation methods incorporate a generator.

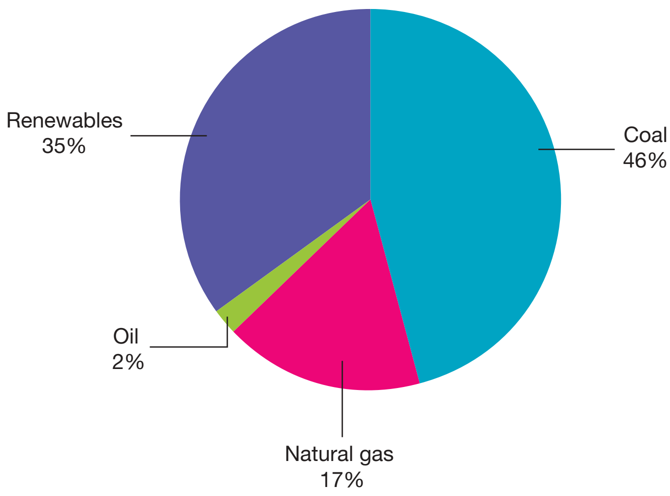
9.4.1 Oil, coal and gas power

In coal-fired power stations, electrical energy is transformed from the chemical energy stored in coal. Similarly, in oil and gas power stations, electrical energy is transformed from the chemical energy stored in the oil or gas. Oil, coal and gas are collectively known as fossil fuels as they are the remains of long-dead plants and microorganisms. In all fossil-fuelled power stations the energy production process is as follows:
- Chemical energy in the fuel is released as heat and light energy by combustion (burning).
- Heat energy is transferred to water, which produces steam.
- Steam is under pressure and the temperature is up to 400 °C. It hits a turbine (fan-like blades) at high velocity.
- Heat energy of the steam is converted to kinetic energy of the turbine.
- The turbine is connected to the coils in a generator. The coils rotate rapidly inside huge electromagnets.
- The motion of the coils in the magnetic field produces a large voltage.
- When the generator is connected to a load, a large electric current flows.

In 2023, just over 57 per cent of Victoria's electrical energy was generated by coal-fired or gas-fired power stations, a decline from 66 per cent in 2022. These fossil fuels remain examples of non-renewable energy resources. Meanwhile, renewable energy continues to expand, providing 38 per cent of Victoria's electricity. Despite this shift, Victoria still relies heavily on coal due to its affordability and the abundant reserves in East Gippsland, which are easily accessed and located near the state's central population hubs. As a result, much of Victoria's electricity is generated and consumed in these areas.

Across Australia, fossil fuels account for 65 per cent of total electricity generation, with renewables making up 35 per cent, reflecting a steady increase in renewable energy adoption (see figure 9.16).

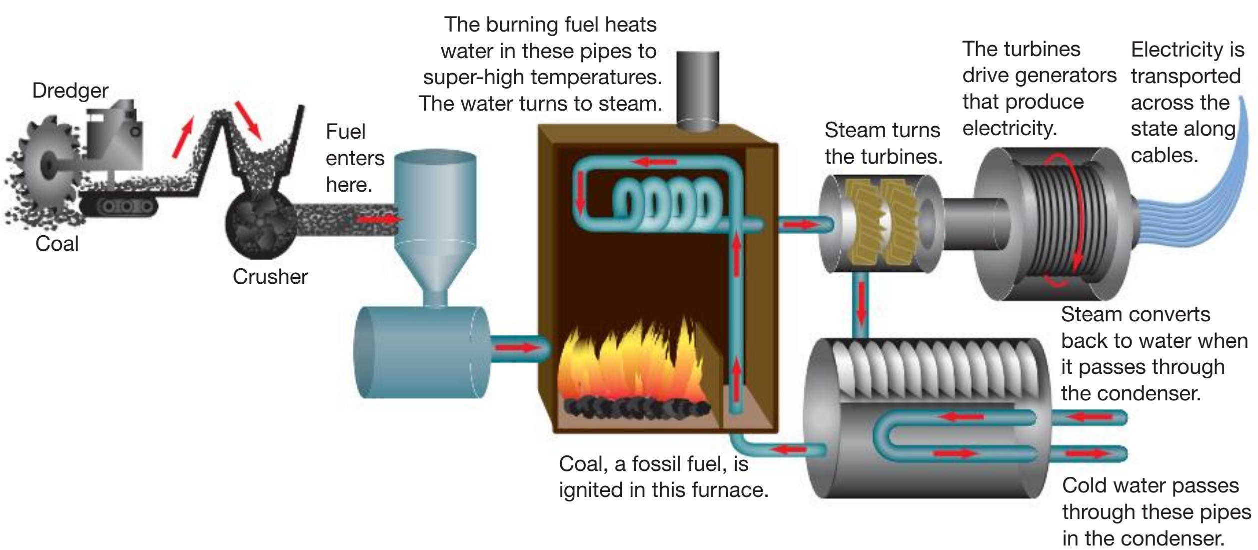
FIGURE 9.16 Energy sources used in electricity generation in Australia in 2023. Fossil fuels including coal, gas and oil now account for approximately 65 per cent.



Our dependence on coal and gas to generate electricity brings with it certain responsibilities — for government, industry, power companies and individuals. The first step is to be aware of the problems caused by using fossil fuels and the alternative methods of generating electricity.

One of the products of the combustion of fossil fuels in power stations is carbon dioxide. Increased levels of carbon dioxide in the atmosphere is contributing to global warming, which could have significant consequences for the climate and the biosphere in the years ahead. In addition, some of the chemicals in the coal burnt in power stations produce gases like sulfur dioxide and various nitrogen oxides, causing air pollution. These gases may also dissolve in water vapour in the atmosphere, creating acid rain. Acid rain speeds up the weathering of rocks, eats into building materials, and threatens plants and other living things that depend on these plants.

FIGURE 9.17 The chemical energy contained in fossil fuels such as coal is used to generate electricity in power stations.



However, there is another form of pollution that is not so obvious. During electricity generation, heat energy is transferred to the surroundings, increasing the temperature of the air and waterways. This increase in the temperature of the environment is known as thermal pollution. Thermal pollution of lakes is a serious problem as the increased temperature (even one or two degrees Celsius) decreases the amount of oxygen dissolved in the water, threatening organisms that live in the water and within the ecosystem.

The demand for electrical energy is increasing, both in Australia and worldwide, and so the supply of fossil fuels such as coal, natural gas and oil used in power stations is gradually diminishing. Table 9.3 shows how long these resources might last at current rates of use.

TABLE 9.3 Reserves of fossil fuels

Fossil fuel	Known reserves based on current rates of production and use (years)	
	Australasia	Global
Coal	53	112
Oil	14	54
Natural gas	35	64

The air, water and thermal pollution caused by burning fossil fuels to generate electricity is not acceptable to many people. Therefore, even though the cost of electricity production using fossil fuels is low by comparison with newer non-renewable technologies, many governments throughout the world are supporting research and the development of alternative methods for electricity generation.

9.4.2 Wind turbines

Wind turbines use the power of moving air to make a generator work and generate AC electricity. Wind turbines are rarely found individually; normally, multiple wind turbines are found close together in a wind farm. Each individual turbine contains its own generator. The electricity coming from the individual turbines is combined to produce the electrical output of a wind farm.

The turbines in a wind farm are constructed to face in slightly different directions so that wind from any direction will make a turbine turn, ensuring electricity can be generated any time there is wind.

Wind farms are normally found on top of hills or cliffs, or around the coast. These locations experience more wind than others, such as the bottom of a valley. This means wind farms are very visible, so are often criticised for destroying a view.

Wind farms use a lot of land to make sure the turbines do not touch or hit each other. The land underneath wind turbines can be used for farming, recreation or other uses, as long as the owners of the wind farm can access the turbines when needed.

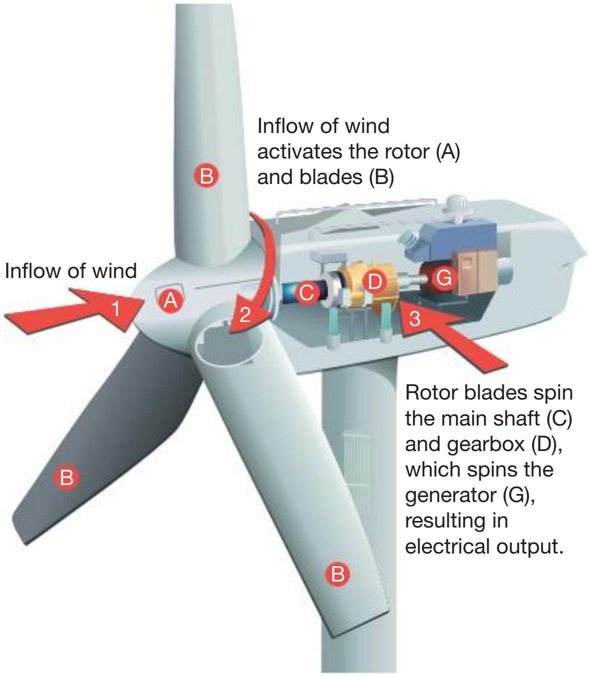
Wind farms dotted with wind turbines can be found in many countries throughout the world, including Australia. As of 2023, Australia has over 300 wind farm projects that are either operational, under construction or proposed. The installed wind capacity is approximately 13.3 gigawatts (GW) as of September 2024.

In comparison, Australia's largest coal-fired power station, Eraring Power Station in New South Wales, has a capacity of approximately 2800 megawatts (MW). It is noteworthy that the New South Wales government has secured an agreement with Origin Energy to operate the Eraring Power Station until August 2027, extending its operational life to ensure energy reliability during the transition to a renewable energy source.

Several wind energy projects have been commissioned in Australia, with the objective of powering nearly 2.2 million Australian homes annually in the coming years.

FIGURE 9.18 A row of wind turbines in Albany, Western Australia

FIGURE 9.19 How a wind turbine works



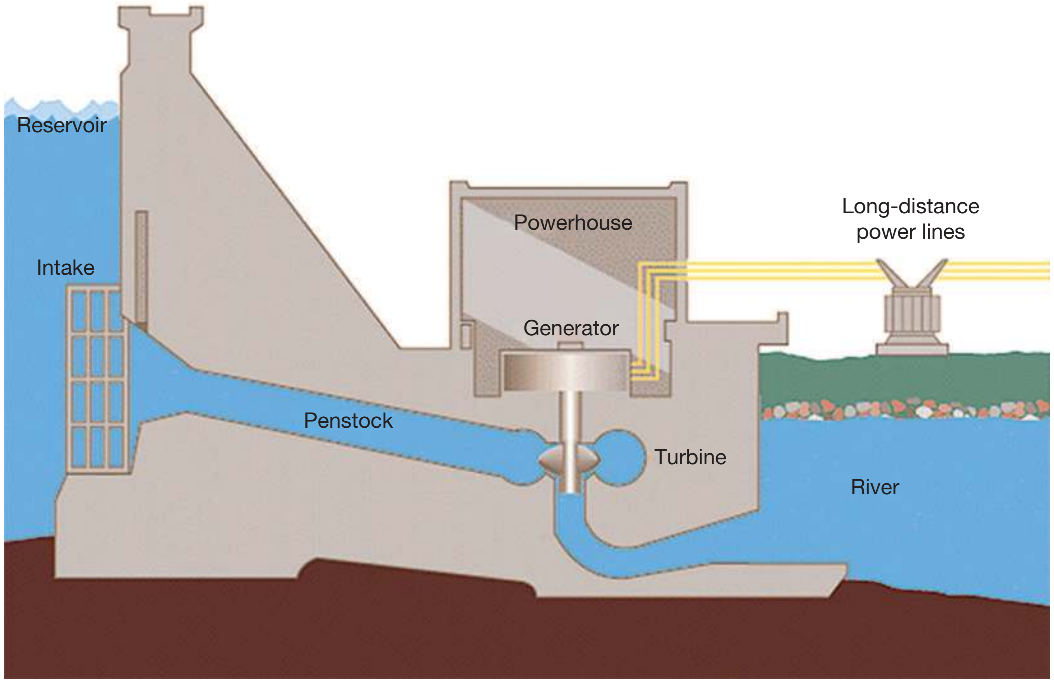
9.4.3 Hydropower

Hydropower uses the energy of moving water to turn turbines attached to generators in a hydroelectric plant. This method of generating electricity is one of the oldest in existence. Water wheels turned by fast-moving rivers were connected to some of the first electricity generators. Water wheels could only produce a small amount of power and could only be used on reliable and quickly moving rivers, so their use was very limited. More recently, large dams have been built to provide a constant supply of water and to control the movement of the water turning the turbines. This allows more electricity to be generated using a more reliable method.

FIGURE 9.20 The Tumut Hydroelectric Power Station (part of the Snowy Mountains Scheme), New South Wales

A small proportion of Australia's electricity is generated by hydroelectric power plants, a renewable source of energy. As water stored in a dam at high elevation falls through pipes, it gains kinetic energy. This kinetic energy is used to turn turbines that generate electricity. This does not involve combustion of a fossil fuel and so does not generate greenhouse gases. A disadvantage of hydroelectricity is that it involves damming river systems and thus alters ecosystems. Hydroelectric power plants also require a large amount of concrete during their construction, which results in an initial contribution to carbon dioxide emissions.

FIGURE 9.21 Turbines in a hydroelectric power plant are driven by the kinetic energy of water.



SCIENCE AS A HUMAN ENDEAVOUR: Hydropower — balancing renewable energy and environmental impact

Hydropower has been used for centuries to harness the energy of moving water. Early water wheels provided mechanical power for grain mills and other machinery, but their ability to generate electricity was limited. With advancements in engineering and science, large hydroelectric dams were developed, allowing for a constant supply of electricity by controlling the flow of water. Today, hydroelectric power is a major contributor to renewable energy production worldwide.

However, while hydropower is a clean and renewable energy source, it has significant environmental and social impacts. Large dams can alter river ecosystems, displace communities and affect wildlife. This raises an important socio-scientific debate: Should society continue to expand hydroelectric power, or should we seek alternative renewable energy sources?

FIGURE 9.22 The Gordon River Dam is a major hydroelectric dam located in Southwest National Park, Tasmania.

The science and technology of hydropower

Early water wheels and small-scale hydropower

- Used in ancient civilisations to power mills and machinery
- Limited by the availability of fast-moving rivers

Large-scale hydroelectric dams

- Store large amounts of water behind a dam to regulate electricity generation
- Provide consistent and controllable energy supply
- Generate large amounts of electricity compared to early water wheels

Modern advances in hydropower

- Pumped-storage hydropower allows energy to be stored and released when needed.
- Tidal and wave energy are emerging technologies that use ocean movement to generate electricity.
- Run-of-river hydro plants generate power without large dams, reducing environmental impact.

Evaluating the benefits and challenges of hydropower

Scenario

You are an environmental scientist working for the Australian government. Your job is to assess whether Australia should build a new hydroelectric dam to supply electricity to a growing city.

Task

- Research the benefits of hydroelectric power (e.g. renewable energy, reliable electricity supply, flood control).
- Investigate the challenges and drawbacks (e.g. habitat destruction, impact on aquatic life, displacement of communities).
- Compare hydropower to other renewable energy sources like solar and wind.
- Present your findings in a scientific report, persuasive essay or debate on whether hydroelectric dams should be expanded.

1. How has scientific knowledge improved the efficiency of hydropower generation?
2. What are the environmental and social impacts of hydroelectric dams?
3. How does government funding and public opinion influence the development of hydropower projects?
4. Should society continue to build large dams, or should we focus on newer technologies like tidal energy?
5. What ethical considerations should scientists and engineers keep in mind when designing hydropower projects?

The use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)

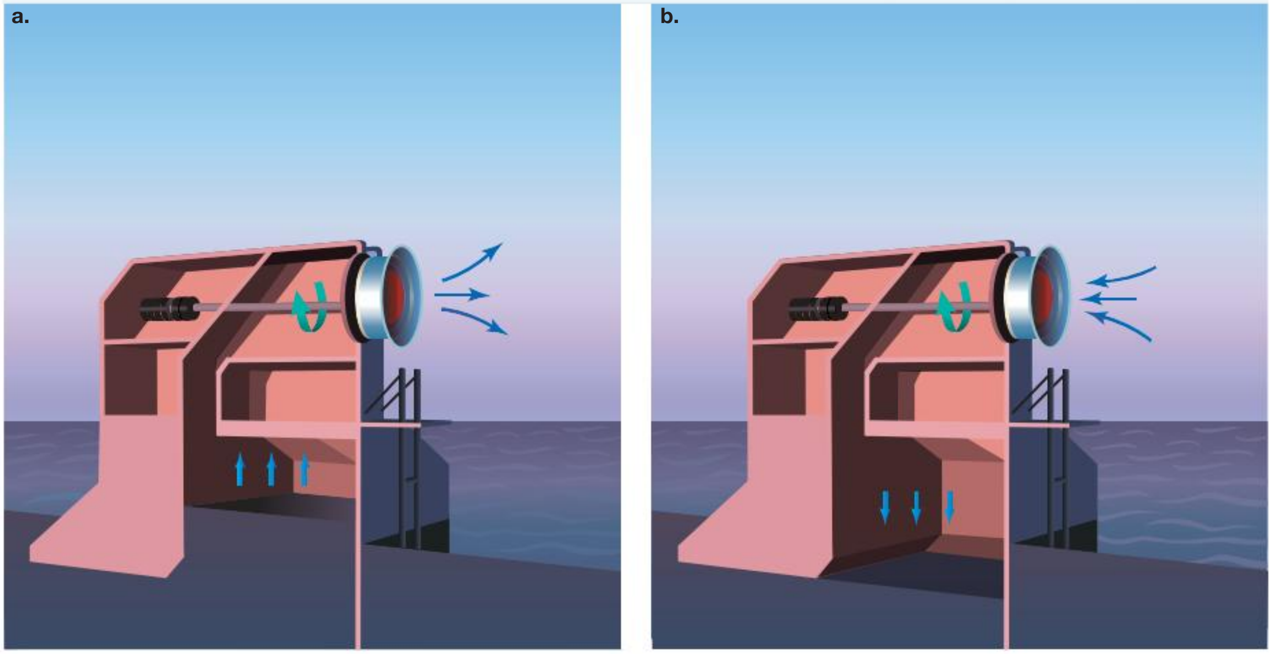
9.4.4 Tidal power

Electricity can be generated using a range of ocean energy sources, including tides, waves, marine currents, thermal layering and salt gradients. Only two of these sources are being investigated for development in Australia — tides and waves.

Tidal power stations harness energy from the rise and fall of tides and are currently being used in France, Russia and China. Turbines with reversible blades are placed at the entrance to a bay in areas with extremely high and low tides. Water moving in and out of the bay turns the turbines to generate electricity. A tidal range of at least 5 m is considered necessary for large-scale installations. Several areas were identified as suitable in the Kimberley region on the northwest coast of Western Australia. No suitable locations have been found in Victoria. In the future, it might be possible to build tidal power stations which do not need such extreme tidal ranges to work.

Wave energy systems do not make use of waves as such, but rather the swell that occurs in deeper water or can be captured by coastal installations. Wave energy is being used to generate electricity in Norway, for example. Wave energy has previously been trialled in South Australia, but is no longer active at that location. A new wave energy trial is now underway off the coast of Western Australia. CSIRO studies show that waves off Tasmania's west coast have three times as much energy as those in Norway.

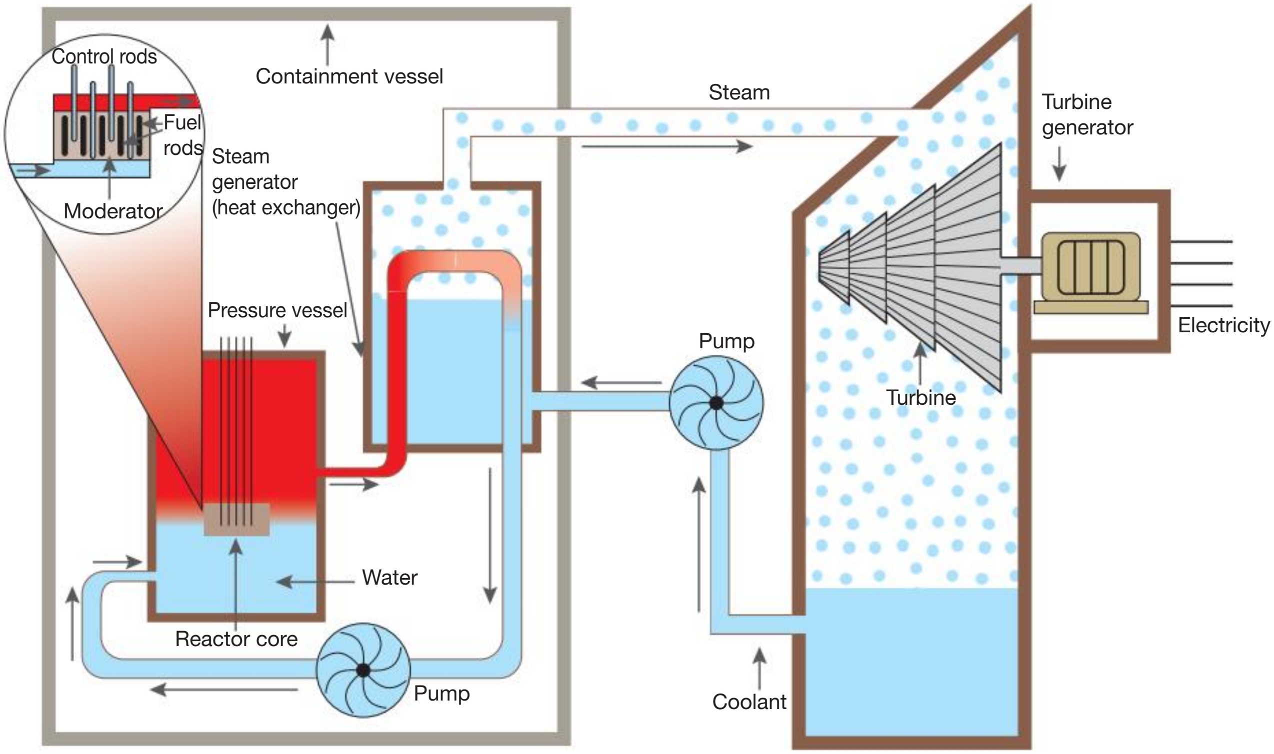
FIGURE 9.23 Electricity generation using wave energy was developed and constructed in Port Macdonnell off the coast of South Australia. In this system, as waves **a.** rose and **b.** fell within a water column, it acted like a piston, driving a column of air ahead of it and through the turbine. The plant generated 1000 kilowatts of electrical power and was the first of its kind in the world.



9.4.5 Nuclear power

Nuclear power stations use energy released from the nuclear fission of radioisotopes such as uranium to drive turbines that generate electricity in the same way that fossil fuel power plants operate. Like fossil fuels, uranium is a non-renewable resource, but because nuclear power plants do not rely on the combustion of fossil fuels to generate electricity, greenhouse gases are not emitted. The critics of nuclear power object to this alternative because the nuclear waste produced must be stored for many years and because of the risk of nuclear accidents.

FIGURE 9.24 In a nuclear power plant, fuel rods — generally composed of uranium oxide — are placed within the reactor core. The rods are bombarded with neutrons to initiate a fission reaction that liberates huge quantities of heat energy and further neutrons. A moderator within the core, usually water or graphite, slows the neutrons released from fission so that they cause more fission. Control rods, made of neutron-absorbing material such as boron, are inserted or withdrawn from the core to control the rate of reaction. A liquid or gas is circulated through the core to transfer the heat produced to the steam generator, from which high-pressure steam is used to drive a turbine and generate electricity.



While Australia is yet to utilise this technology for generating electricity, there are approximately 439 nuclear reactors operating in around 30 countries that account for around 9 per cent of the world's electricity production. Nuclear power accounts for a large proportion of the electricity supply in many parts of Europe, Asia and the United States. Regional contributions are as follows:

- In 2023, nuclear energy accounted for around 23–24 per cent of total electricity generation in Europe.
- Several countries in Asia are actively expanding their nuclear power capabilities to meet increasing energy demands. China, for instance, has 58 nuclear power reactors in operation and an additional 28 under construction.
- The United States remains the largest producer of nuclear power, with nuclear energy providing about 19 per cent of its electricity.

It is also important to note that while Australia does not currently utilise nuclear power for electricity generation, there is ongoing debate about its potential role in the country's energy future.

9.4 Activities

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9.4 Quick quiz on	9.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 4, 5	2, 7, 8	3, 6, 9

Remember and understand

1. MC **Identify** the difference between renewable and non-renewable energy resources.
   A. Renewable resources can be replenished, while non-renewable resources cannot.
   B. Renewable resources are more expensive than non-renewable resources.
   C. Renewable resources are less reliable than non-renewable resources.
   D. Renewable resources release more greenhouse gases than non-renewable resources.
2. MC **Identify** the main problem with generating electricity from fossil fuels.
   A. They release greenhouse gases into the atmosphere.
   B. They are expensive.
   C. They are difficult to find.
   D. They are difficult to transport.
3. **Describe** the role of each of the following in a nuclear reactor.
   a. Moderator
   b. Control rods

Apply and analyse

4. **State** whether each of the following energy sources is renewable or non-renewable.
   a. Nuclear
   b. Hydro
   c. Coal
   d. Wind
   e. Solar
5. MC **Identify** the main advantage of using nuclear power for electricity generation.
   A. High efficiency
   B. Low greenhouse gas emissions
   C. Abundant fuel supply
   D. All of the above
6. **Explain** how solar power works to generate electricity.
7. Briefly **describe** the process of burning fossil fuels to generate electricity.

Evaluate and create

8. **Identify** the advantages and disadvantages of using wind as an energy resource. Considering these factors, **evaluate** how viable wind energy is as a sustainable solution for the future.
9. **Discuss** one environmental benefit of using renewable energy sources for electricity generation. How significant is the environmental impact? **Justify** your response.

Answers and sample responses are available in your digital formats.

LESSON 9.5 Review

9.5 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
9.2	I can define power and perform calculations of power.			
	I can compare AC and DC power and common sources of each type of power.			
9.3	I can describe the process of generating DC electricity using batteries or photovoltaic cells.			
	I can explain how seeds are dispersed and germinate.			
9.4	I can describe the process of generating AC electricity using a generator.			
	I can explain how different electricity generation methods incorporate a generator.			

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Post-test	Topic 9 Post-test
eWorkbook	Topic 9 eWorkbook
Digital document	Key terms glossary

9.5 Activities

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9.5 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 5, 7	2, 4, 8, 10	6, 9, 11, 12, 13, 14

Remember and understand

1. **Identify** the type of current provided by a battery.
2. **Explain** the difference between a cell and a battery.
3. **Outline** the steps involved in using a generator to generate electricity.
4. **Explain** why there are many different types of batteries.

5. Label the magnet, coil of wire and the place where the electricity exits in the following image of a generator.

Apply and analyse

6. **Compare** the DC current produced by a photovoltaic cell and the DC current produced by a DC generator.
7. **Explain** how wind turbines generate electricity.
8. **Describe** the difference between coal and oil power stations.
9. **Explain** how tidal power is used to generate electricity.
10. New research is making solar panels more efficient. **Explain** why this is important.
11. **Describe** the process by which batteries produce electricity.
12. **Compare** the generation of electricity using tidal power with the generation of electricity using wind power.

Evaluate and create

13. **Construct** a Venn diagram comparing the production of AC and DC power.
14. **Explain** how a wind turbine is rotated and **evaluate** the efficiency of the process.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

10 Energy efficiency

CONTENT DESCRIPTION

The Law of Conservation of Energy can be analysed in systems, including Earth systems, by assessing the efficiency of energy inputs, outputs, transfers and transformations (VC2S10U15)

Source: Victorian Curriculum F–10 Version 2.0

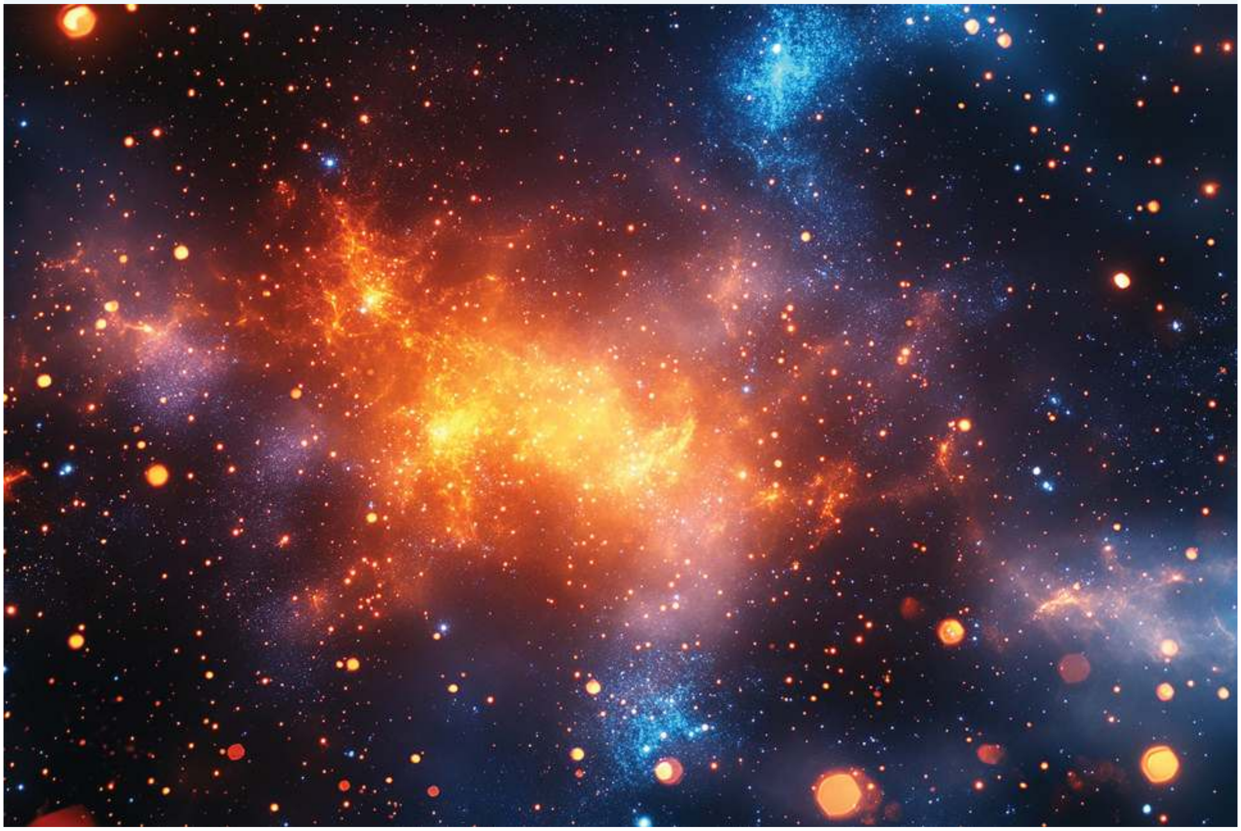
LESSON SEQUENCE

LESSON 10.1 Overview

10.1.1 Introduction

Energy is important to every aspect of our lives, but there is a limited amount of energy available. All the energy we use must come from another object or be transformed from another type of energy. The energy we use to move and think comes from the food we eat. When we move and think, we transform energy or transfer energy to other objects to continue the energy chain. We can trace this energy chain back to the Big Bang, which scientists believe was the starting point of the universe we live in. We can also predict the path of the energy chain into the future until the universe stops existing.

FIGURE 10.1 A representation of stars and galaxies in the early universe. All the energy in the universe, including all the energy we use in our everyday lives, has been in the universe since the Big Bang.



DISCUSSION

1. Where does the energy in a battery come from?
2. Does an apple give all its energy to us when we eat it?
3. What do we mean when we say 'I don't have much energy today'?
4. How many different forms of energy exist?
5. Can all forms of energy be transformed into all other forms of energy?
6. What is the most common form of energy in the universe?
7. What is 'dark energy'?

SCIENCE INQUIRY: Perpetual motion machines

What is a perpetual motion machine?

A perpetual motion machine (PMM) is an imaginary machine that people believe could keep moving forever without stopping and without needing any extra energy.

For example, imagine a wheel that keeps spinning without needing a push — this would be a PMM.

It sounds like a great idea, but scientists have shown that such a machine is impossible. In the real world, all moving objects eventually slow down and stop unless they receive energy from an outside source.

FIGURE 10.2 A clock pendulum will eventually stop swinging without extra energy being provided.

Why is a PMM impossible?

There are three major reasons why a PMM cannot keep running forever.

1. Energy cannot come from nowhere.
   - Every machine needs energy to move. For example, a car needs fuel, and a bicycle needs you to pedal.
   - A PMM would have to create its own energy to keep going, but energy cannot appear from nowhere.
   - In real life, machines always lose energy to heat, sound or friction, so they must take in more energy to keep moving.
2. Friction slows things down.
   - Imagine pushing a toy car on the floor. It does not keep rolling forever — it slows down and stops because of friction.
   - Friction happens when two surfaces rub against each other. It turns some of the energy into heat, so the object loses energy and stops moving.
   - Even in space, where there is no air, friction inside moving parts (like gears) would eventually slow things down.
3. Air resistance stops motion.
   - When an object moves through the air, air pushes against it and slows it down.
   - For example, a parachute slows a skydiver because of air resistance.
   - Even machines that seem to move for a long time (like a windmill or a pendulum) eventually stop because of air resistance unless they get extra energy from the wind or another source.

Real-world examples of possible PMMs

- Pendulums and clocks — a pendulum swings back and forth, but eventually it stops moving unless it is given extra energy (like winding up a clock).
- Fidget spinners — a fidget spinner keeps spinning for a while but eventually stops due to friction and air resistance.
- Rolling a ball — no matter how hard you push a ball, it will slow down and stop unless something keeps pushing it.

1. What happens to a moving object when no extra energy is added?
2. Why does friction make objects stop moving?
3. How does air resistance affect the movement of objects?
4. Why do scientists say a true PMM is impossible?
5. Can you think of any real-life examples where machines need constant energy to keep working?

Constructing arguments based on evidence to support conclusions or evaluate claims (VC2S10I07)

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Pre-test	Topic 10 Pre-test
eWorkbook	Topic 10 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 10 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 10.2 The Law of Conservation of Energy

LEARNING INTENTION

In this lesson you will:
- describe the Law of Conservation of Energy
- define energy efficiency
- calculate the energy efficiency of energy transfers and transformations.

10.2.1 The Law of Conservation of Energy

Energy cannot be created or destroyed. We cannot make new energy, and we cannot destroy energy once we have finished using it. This is the **Law of Conservation of Energy**. Another way of stating the Law of Conservation of Energy is that the amount of energy in the universe is fixed and constant. There is the same amount of energy in the universe now as when the Big Bang happened, and there will continue to be the same amount of energy in the universe until the universe ends (if it ever does).

Energy can be transferred from one object to another or it can be transformed into different types of energy. This is how energy moves from one object to another and can perform different jobs. Energy never appears from nowhere or disappears — it always comes from somewhere and goes somewhere. The chemical potential energy stored in a mobile phone battery has come from the electrical energy used to the charge the phone, and will transform into light energy — including the radio waves used to send information through the phone network and using wi-fi — sound energy, heat energy, and kinetic energy when the phone vibrates. The Law of Conservation of Energy says that these transfers and transformations have always happened and will keep happening.

FIGURE 10.3 There are multiple energy transfers and transformations occurring in your mobile phone.

DISCUSSION

Where did the chemical potential energy in your body right now come from? Think about the last thing you ate — where did the energy in that come from? How far back can you trace the energy transfers and transformations?

SCIENCE AS A HUMAN ENDEAVOUR: Energy conservation and scientific progress

The Law of Conservation of Energy is one of the most important principles in science. It states that energy cannot be created or destroyed — only transferred or transformed. This means that the total amount of energy in the universe has always stayed the same. Scientists and engineers use this principle to develop new technologies, improve energy efficiency and understand how natural processes work.

How the Law of Conservation of Energy has led to scientific breakthroughs

Scientists have used this law to make major discoveries, such as:

- *understanding the Big Bang*. The energy from the birth of the universe is still present today, transformed into light, heat and motion.
- *nuclear energy*. Inside atoms, energy can be released and transformed into heat and electricity, which powers homes and cities.
- *space exploration*. Spacecraft, like the *Voyager* probes, use carefully planned energy transfers. By using the gravity of planets to speed up (called *gravitational assists*), they can travel for decades without using much fuel.

Energy efficiency and technological innovation

The Law of Conservation of Energy has also helped scientists create more energy-efficient technologies to reduce waste. Examples include:

- *electric vehicles (EVs).* EVs are designed to maximise energy transfers, converting more electrical energy into movement instead of wasting it as heat.
- *renewable energy sources*. Solar panels transform light energy into electricity, and wind turbines convert kinetic energy from the wind into power.
- *battery technology*. Scientists continue to develop better batteries that store and release energy more efficiently, so less energy is wasted as heat.

By understanding and applying energy conservation, scientists and engineers can design more sustainable and efficient ways to use energy in the future.

1. Define the Law of Conservation of Energy in your own words.
2. Identify two real-world examples of energy transfers and transformations that you see in everyday life.
3. Explain how energy is transformed when you charge and use a mobile phone. Where does the energy go?

Scientific knowledge, including models and theories, can change because of new evidence (VC2S8H01)

EXTENSION: The Sun

The Sun is often considered as the source of all energy on Earth. Do you think this is true? Where does the Sun's energy come from? Is there an ultimate source of all energy?

10.2.2 Energy efficiency

Energy efficiency means using less energy to do the same amount of work. The **efficiency** of a car, light bulb, gas heater, power station, solar cell or any other energy converter is a measure of its ability to provide useful energy.

KEY IDEA

Efficiency is usually expressed as a percentage, and can be calculated using the following formula:

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

The efficiency of every device that uses fossil fuels is very important for the environment and life on Earth. Scientists and automotive engineers are constantly working on methods of reducing fuel consumption by:

- increasing the efficiency of burning petrol and other fossil fuels such as diesel by reducing the amount of energy wasted as heat
- changing the external design of cars to reduce the amount of energy needed to overcome air resistance
- searching for alternative fuels such as ethanol that can be produced from sugar cane and grain crops.

Sankey diagrams

According to the Law of Conservation of Energy, energy can neither be created nor destroyed, but it can be transferred and converted from one form to another. This energy conversion can be represented by a Sankey diagram. Sankey diagrams are used to show the flow of energy by identifying energy stores, energy transfers and wasted energy. They provide information about energy quantitative input, useful and wasted energy.

FIGURE 10.4 Features of a Sankey diagram

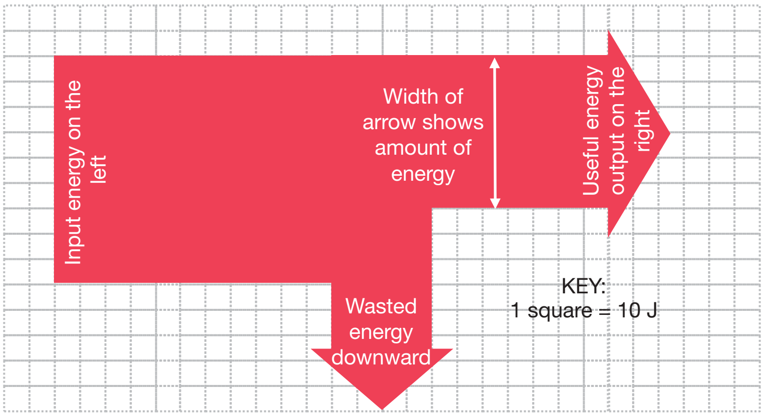
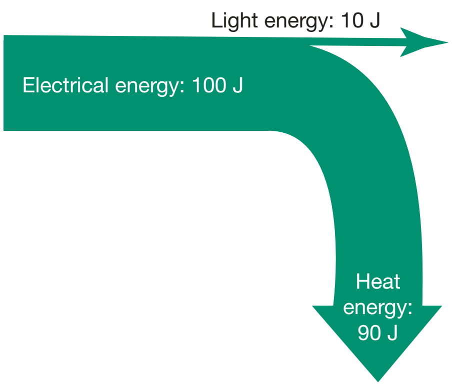


FIGURE 10.5 Energy output of an incandescent light globe



For the light bulb shown in the Sankey diagram in figure 10.5, the efficiency could be calculated as:

$$\begin{aligned}\%\text{ efficiency} &= \frac{\text{useful energy output} \times 100}{\text{total energy input}} \\ &= \frac{10 \times 100}{100} \\ &= 10\%\end{aligned}$$

INVESTIGATION 10.1

Light globe efficiency

Aim

To compare the efficiency of an incandescent light with a compact fluorescent light (CFL)

Materials

- cardboard box
- data logger
- temperature sensor
- light sensor (optional)
- portable lamp
- an incandescent light and CFL of equivalent light output, as follows:

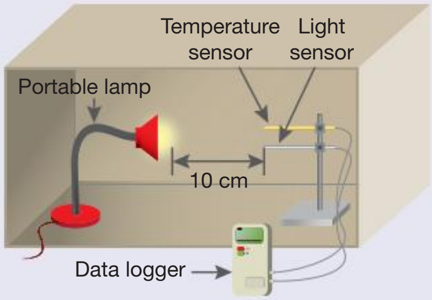
Incandescent light	CFL
40 watts	9–13 watts
60 watts	13–15 watts
75 watts	18–25 watts
100 watts	23–30 watts

Method

1. Insert the incandescent globe into the portable lamp.

CAUTION: Ensure that the lamp is not connected to the power outlet while light globes are inserted or removed.

2. Connect the temperature sensor and light sensor (if available) to the data logger.
3. Position two sensors 10 cm away from the lamp within the cardboard box and record the temperature and light intensity each minute over a 10-minute period.
4. Repeat the experiment with a CFL.



Results

Record your results in an appropriate table.

Discussion

1. Compare the temperature change due to the incandescent light and the CFL.
2. Compare the light intensity of the incandescent light and the CFL.
3. Which light globe is the most energy efficient? Explain in terms of the data collected.
4. Calculate the:
   a. energy use for each globe in kWh if each was run for 8 hours
   b. annual cost of running each lamp for 8 hours per day, assuming a tariff of 21 c per kWh.

Conclusion

Summarise the findings of this investigation in two to three sentences.

INVESTIGATION 10.2

Investigating energy efficiency

Aim

To calculate the energy efficiency of an electrical appliance

Materials

- electric kettle
- 100 mL measuring cylinder
- water
- data logger and temperature probe
- stopwatch

Method

1. Use the measuring cylinder to measure and pour 500 mL of water into the electric kettle.
2. Place the tip of the temperature probe into the kettle and record the initial temperature of the water.
3. Remove the temperature probe, then switch on the kettle and heat the water for 60 seconds.
4. Insert the temperature probe again to record the new water temperature.
5. Calculate the temperature rise over the 60-second period and record your data.
6. Refer to the label on the kettle to identify and record the power use of the kettle.

Results

Copy and complete the following table. Remember to give your table an appropriate title.

Liquid	Volume of water (mL)	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)	Time (s)	Power use of kettle (W)
Water						

Discussion

1. Calculate the input of electrical energy to the kettle over the 60-second period as follows:

   Electrical energy input (J) = power (watts) × operating time (s)

2. Calculate the output of heat energy gained by the water in the kettle as follows:

   Heat energy output (J) = volume of water (mL) × 4.2 × temperature rise (°C)

3. Calculate the efficiency of the kettle as follows:

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

4. Explain why the efficiency of the kettle is well below 100 per cent in terms of transformation of electrical energy and the transfer of heat energy generated.

Conclusion

Summarise the findings of this investigation in two to three sentences.

10.2 Activities

learnon

10.2 Quick quiz on	10.2 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 4	2, 5, 9	6, 7, 8

Remember and understand

1. MC **Identify** what energy efficiency means.
   A. Using less energy to perform the same task
   B. Using more energy to perform the same task
   C. Using the same amount of energy to perform a different task
   D. Using less water to perform the same task
2. **State** the Law of Conservation of Energy.
3. MC **Identify** how you can improve energy efficiency at home.
   A. By using energy-efficient appliances
   B. By leaving windows and doors open when heating or cooling your home
   C. By taking long showers
   D. By using incandescent light bulbs
4. MC **Identify** which of the following is an example of an energy-efficient archery technique.
   A. Pulling the bowstring back with maximum force
   B. Using heavy arrows to maximise kinetic energy
   C. Incorporating proper body alignment and posture
   D. Increasing the draw weight of the bow for stronger shots

Apply and analyse

5. An apple contains 400 J of energy. After eating it, a person runs for a few minutes and uses 320 J of energy.
   a. **Determine** how much energy from the apple was converted into non-useful forms.
   b. **Identify** the most likely non-useful form of energy.
   c. **Calculate** the efficiency of this process.
6. A high-efficiency light globe can operate at 94 per cent efficiency. A low-efficiency light globe only operates at 38 per cent efficiency. Both light globes receive 900 J of energy while turned on.
   a. **Calculate** the amount of useful energy that the high-efficiency light globe produces.
   b. **Calculate** the amount of non-useful energy that the low-efficiency light globe produces.
   c. Which light globe would you choose to use in a reptile habitat? **Justify** your answer.

Evaluate and create

7. **Explain** why non-useful forms of energy are often called 'lost' energy.
8. Scientists are trying to detect the amount of energy in the universe and believe that some energy is 'missing'. They have called this 'dark energy' as they are unable to detect it. **Suggest** why scientists believe dark energy exists.
9. Choose an everyday activity or situation and **analyse** the energy transfers and transformations happening. Draw energy flow and Sankey diagrams to show how the Law of Conservation of Energy applies to the activity or situation.

Answers and sample responses are available in your digital formats.

LESSON 10.3 Complex energy systems

LEARNING INTENTION

In this lesson you will:
- explore how energy transfers and transformations are never 100 per cent efficient
- examine how everyday situations involve multiple energy transfers and transformations, each reducing the amount of useful energy available at the end.

10.3.1 Energy in complex systems

Complex systems are made up of many different parts interacting with each other. No energy transfer or transformation is perfectly efficient — some energy is always lost, usually as heat, sound or friction. The more energy transfers and transformations that take place, the greater the energy losses, reducing the overall efficiency of the system.

FIGURE 10.6 Electric cars maximise energy efficiency.

For example, a car engine is a complex system with multiple energy transfers and transformations. In a petrol-powered car, the chemical energy stored in fuel is converted into thermal energy through combustion, then into mechanical energy to move the car. At each stage, some energy is lost as heat, sound or friction, making petrol-powered cars relatively inefficient.

Electric cars, on the other hand, have fewer energy transfers and transformations compared to petrol-powered vehicles, making them more energy efficient. Instead of relying on combustion, electric cars use energy stored in batteries to directly power an electric motor, reducing the number of energy conversions and the amount of energy lost.

Examples of energy inefficiency in everyday life include:
- *household appliances*. Refrigerators, washing machines and ovens all convert electrical energy into useful work, but some energy is lost as heat or noise.
- *lighting*. Incandescent bulbs lose a lot of energy as heat, while LED lights are more efficient because they convert most of the electrical energy into light.
- *public transport*. Trains and trams that use electricity from renewable sources can be more efficient than cars that rely on fossil fuels.

10.3.2 Designing more efficient systems

While it is impossible to create a system that is 100 per cent efficient, scientists and engineers work to minimise energy losses and improve energy efficiency in transportation, industry and homes. Some strategies include:
- *reducing friction*. Using lubricants in machines reduces energy loss due to friction.
- *improving insulation.* Homes and buildings with good insulation lose less heat, reducing the need for extra heating.
- *using regenerative braking*. Electric and hybrid cars can capture energy that would otherwise be lost when braking and reuse it to power the vehicle.
- *developing energy-efficient engines*. Modern engines and power plants are designed to convert more of the input energy into useful work.

These strategies are used to develop more efficient energy systems and reduce reliance on fossil fuels.

SCIENCE INQUIRY: Investigating energy efficiency in complex systems

Energy transfers and transformations occur constantly in everyday life, but they are never 100 per cent efficient. Scientists and engineers aim to measure, test and improve efficiency by investigating how much useful energy remains after each transformation and identifying ways to reduce energy losses.

One way scientists investigate energy efficiency is by conducting controlled experiments that measure energy input and output in real-world systems. These experiments often involve:

- measuring energy losses — tracking heat, sound or friction that reduces efficiency
- comparing different systems — testing how much energy is lost in different designs, such as electric versus petrol-powered cars
- using models and simulations — running digital simulations to predict how changes in materials, design or energy sources can improve efficiency.

For example, engineers use thermal imaging cameras to detect heat loss in homes and factories, helping to improve insulation and reduce wasted energy. They also design experiments to test the effectiveness of regenerative braking systems in electric vehicles, measuring how much energy can be recovered instead of lost as heat.

To design more efficient systems, scientists follow a process of testing, evaluating and refining their ideas:

1. Hypothesising — predicting which design changes will lead to greater efficiency
2. Experimenting — measuring energy inputs and outputs in different conditions
3. Analysing data — identifying trends, patterns and sources of energy loss
4. Applying findings — using results to develop new energy-saving technologies

Understanding where and how energy is lost helps scientists and engineers make evidence-based decisions to improve energy efficiency in transport, buildings and power generation.

1. Define what it means for an energy transfer to be inefficient.
2. Describe one method scientists use to measure energy efficiency in a real-world system.
3. Compare two examples of energy transfer devices, and explain which one is more efficient and why.
4. Analyse how regenerative braking in electric cars improves energy efficiency.
5. Evaluate an everyday system (e.g. a home appliance or a transport system) and suggest ways to improve its energy efficiency.

Investigable questions, reasoned predictions and hypotheses can be developed in guiding investigations to identify patterns, test relationships and analyse and evaluate scientific models (VC2S8I01)

10.3.3 Future developments in energy efficiency

Improving energy efficiency is a major focus for scientists, engineers and policymakers. Many researchers are working on new energy-efficient technologies to reduce energy waste and lower greenhouse gas emissions. Some key areas of development include:

- *renewable energy sources*. Solar, wind and hydroelectric power are being developed to replace fossil fuels.
- *energy storage solutions*. High-efficiency, fast-charging batteries are essential for electric vehicles and renewable energy storage.
- *smart grids*. Advanced systems help manage energy distribution more efficiently, reducing losses.

Governments and private organisations fund research into energy-efficient transport and communication technologies, recognising the need for more sustainable solutions.

FIGURE 10.7 Powering a sustainable future — wind turbines and solar panels utilise wind and sunlight to produce clean energy.

Energy transfers and transformations are never 100 per cent efficient, meaning that some energy is always lost as heat, sound or friction. The more complex a system is, the greater the energy losses. Scientists and engineers are working to develop more energy-efficient systems by reducing energy losses, using renewable energy sources and improving energy storage technologies. Understanding and improving energy efficiency is critical for building a sustainable future.

DISCUSSION

1. What are some ways we can reduce energy losses in transportation and industry?
2. How can emerging technologies improve energy efficiency in everyday life?
3. What are the challenges of switching to more energy-efficient systems?

ACTIVITY: Energy research in Australia

Research the sources of funding for the CSIRO (Commonwealth Scientific and Industrial Research Organisation).

1. Why does the CSIRO focus on researching energy-efficient technologies?
2. What impact does their research have on transportation, electricity generation and communication systems?

10.3 Activities

learnon

10.3 Quick quiz on	10.3 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 5	3, 7, 8	4, 6, 9

Remember and understand

1. **Define** the term *energy-efficient system* and **explain** why no system can be 100 per cent efficient.
2. **List** two examples of complex systems that involve multiple energy transfers and transformations.
3. **Identify** one reason why energy losses occur in complex systems.
4. **Explain** why scientists are motivated to discover more energy-efficient technologies and processes.

Apply and analyse

5. **Explain** why complex systems tend to have lower energy efficiency compared to simpler systems.
6. SI **Compare** the efficiency of a process with 10 energy transfers to one with 20 energy transfers using real-world data. What patterns or trends can you identify in energy loss, and how do they influence system design?
7. **Explain** why electric cars are more energy efficient than petrol-powered cars. Use examples of energy transfers and transformations to support your answer.

Evaluate and create

8. SI **Evaluate** the impact of solar-powered devices on mobile phone use in remote regions of Africa or India. What factors have contributed to their rapid adoption, and how have they influenced communication, economic growth and daily life?
9. **Compare** the effect of improving energy efficiency in public transport systems (e.g. buses and trains) to the effect of improving the energy efficiency of cars. Which would have a greater impact on overall energy consumption and why?

Answers and sample responses are available in your digital formats.

LESSON 10.4 Improving energy efficiency

LEARNING INTENTION

In this lesson you will:
- describe ways to improve energy efficiency in a range of different situations
- evaluate the usefulness of different systems based on their energy efficiency.

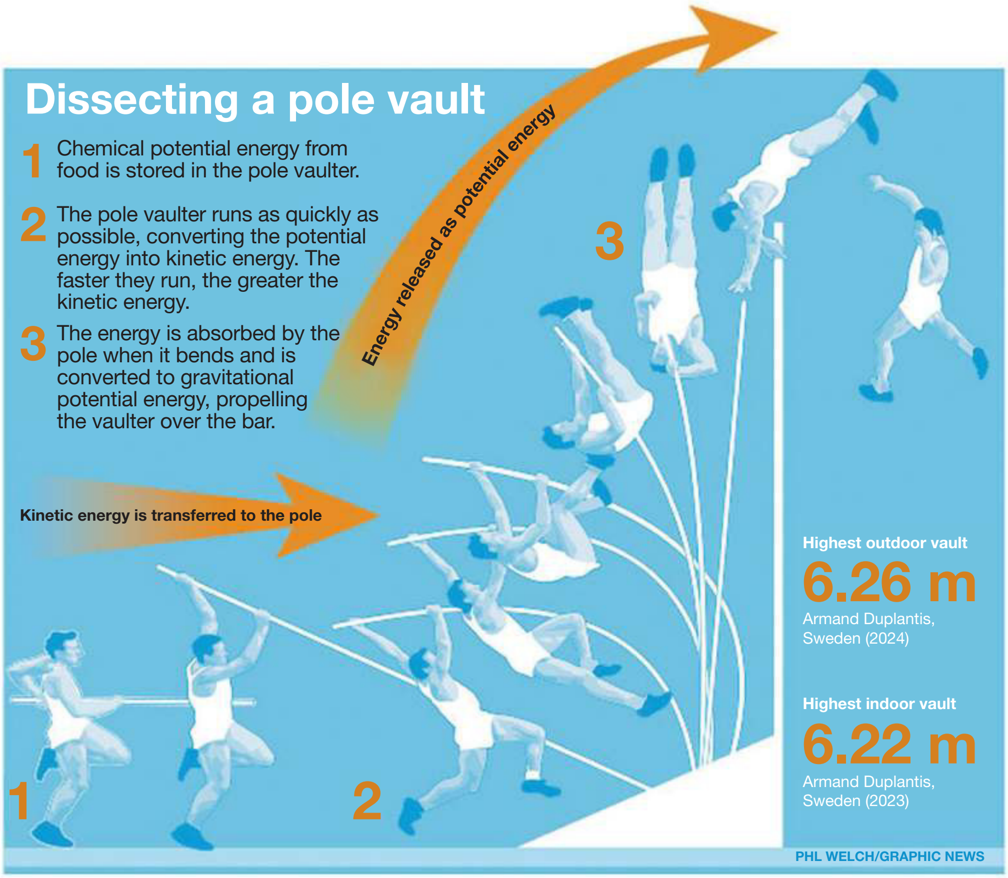
10.4.1 Energy efficiency in sport

Energy efficiency in sport refers to how much energy is used while moving at a given speed; for example, while running or swimming. Increased efficiency means that less energy is required to sustain the athlete at a particular speed. Athletes undertake training sessions to maximise energy transformation. Such transformations convert chemical potential energy into heat and kinetic energy.

The pole vault

The pole vault is an example of how athletes use conversion of energy to rise to increased heights. The activity of pole vaulting involves multiple energy conversions, as shown in figure 10.8. The athlete transforms stored chemical energy into kinetic energy while running, which then shifts to elastic potential energy as the pole bends. As it straightens, the athlete gains kinetic and gravitational energy, reaching maximum gravitational potential energy at the peak before converting it back into kinetic energy on descent. Energy efficiency plays a key role in athletic performance.

FIGURE 10.8 Energy conversion in pole vaulting



Energy efficiency is crucial for successful performance in many sports. Examples of efficient energy transfer and transformations in pole vaulting include the following:

- Athletes must optimise their speed, stride length and rhythm to generate sufficient kinetic energy for the jump. Proper running mechanics and a well-timed take-off maximise the transfer of energy into the pole.
- A stiffer pole can store more elastic potential energy, which can be effectively converted into kinetic energy to propel the athlete upwards.
- The bending action of the pole during the vault is a key element in energy transfer. As the pole bends, it stores potential energy. The athlete must utilise this stored energy by transitioning smoothly from the take-off to the swing phase, transferring the energy into upward momentum.
- Efficient body positioning and technique during the vault allow the athlete to convert potential energy into kinetic energy effectively. Properly extending the body and utilising the pole's recoil energy through proper pole drop and grip techniques can maximise the energy transfer and propel the athlete over the bar.

ACTIVITY: Men's pole vault world records

Investigate the progression of the men's pole vault world record height since 1890.

1. Create a table of pole vault world records. You might choose to investigate the world record over a shorter time frame, or choose to note the record every five or ten years.
2. Using your table, create an appropriate graph to show the progression of the men's pole vault world record.
3. Describe key features of your graphs by linking them back to your original data. Are there any flat areas in your graph? Are there places where the graph goes up sharply? Does the graph go down? What do these parts of your graph tell you about the men's pole vault world record?
4. Link any key features of your graph to historical events or scientific breakthroughs. Explain how these events affected the men's pole vault world record.

Archery

Archery is another sport involving multiple energy conversions, and therefore a need for energy-efficient conversions.

When the athlete pulls back on the bow string, the bow string is stretched. Chemical potential energy in the athlete's muscles is converted to elastic potential energy stored in the bow string. When the bow string stretches, the limbs of the bow also bend to store elastic potential energy. When the string is released, the elastic potential energy of the bow string is transformed into kinetic energy and transferred to the arrow.

The arrow also has gravitational potential energy from being released above ground height. As the arrow flies through the air, some of its kinetic energy is transformed into gravitational potential energy, and back again, as the arrow gains and loses height. When the arrow hits the target, the arrow's remaining kinetic and gravitational potential energy are transferred to the target as kinetic energy.

FIGURE 10.9 When an athlete pulls back on the string of a bow, they convert their chemical potential energy into elastic potential energy. This energy is then given to the arrow so the arrow has kinetic energy to move towards the target.

Efficient transfers and transformations of energy are essential in archery, and contribute to successful performances through the following:

- Large amounts of elastic potential energy can be stored in the bow string. Choosing a material for the bow string that can store large amounts of elastic potential energy, and that can be stretched to its greatest extent by the archer, ensures the maximum energy efficiency the archer is giving to the bow.

- Stiffer limbs in the bow can store even more elastic potential energy before it is transformed into the kinetic energy given to the arrow.
- The larger the initial kinetic energy of the arrow, the straighter and faster the arrow will travel and therefore have a higher probability of hitting the middle of the target.
- Correct body position and technique, along with strength, are needed to pull the bow string directly back from the limb. Pulling in any other direction, even by a small amount, will reduce the amount of kinetic energy received by the arrow to travel forward towards the target.
- Choosing an appropriate angle to fire the arrow at is important to ensure the arrow reaches the target but does not transform too much gravitational potential energy into kinetic energy to minimise energy losses.

DISCUSSION

Bows and arrows have been used by humans to hunt for many thousands of years. How do you think their construction has changed over this time? How has the availability of different materials changed the effectiveness of using a bow and arrow?

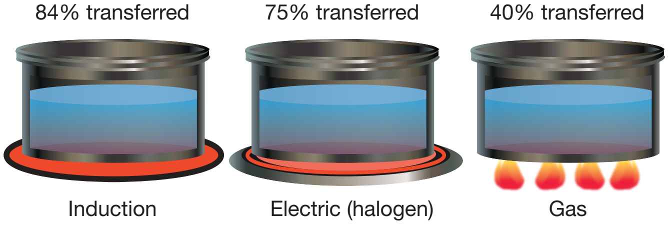
10.4.2 Energy efficiency in cooking

In recent years, there have been technological advances in energy-efficient cooking appliances. Traditional cooking uses a gas or electric hotplate. Induction cooking is a recently developed technology that transfers energy from the cooktop to the saucepan more efficiently than any other cooking appliance. In gas cooking, only 40 per cent of the heat supplied by the gas flame is transferred directly to heat the contents of a saucepan. The rest of the heat energy is wasted as light or heat to the surrounding air. Modern electric hotplates are more efficient, with 70 per cent of the heat energy transferred to heat involved in cooking.

Induction cooking, however, can achieve close to 85 per cent energy efficiency. Electricity supplied to metal coils within an induction cooktop creates an oscillating magnetic field that directly heats any saucepan placed on it, as long as it is made of a magnetic metal, such as stainless steel. With induction cooking, energy is supplied directly to the saucepan by the magnetic field; therefore, the cooktop itself does not get hot, and so almost all of the source energy is transferred to the saucepan.

FIGURE 10.10 When using an induction cooktop, only the saucepan gets hot, resulting in less wasted heat and greater energy efficiency.

FIGURE 10.11 A comparison of the energy efficiencies of various cooktop technologies



10.4.3 Efficiency of ground ovens

Some Aboriginal and Torres Strait Islander Peoples' traditional cooking methods involve roasting food on hot coals, baking in ashes and steaming in ground ovens. Earth ovens or ground ovens are commonly used, involving the use of heated stones or burnt clay lumps placed inside a hole in the ground to cook food. Ground ovens can also be used for medicinal practices, such as creating a steam bath with eucalyptus leaves and other medicinal plants to relieve coughs, colds, nasal congestion and even dysentery.

How ground ovens work

Ground ovens are constructed by digging a hole in the ground, carefully sized to fit the amount of food being cooked. Stones are placed at the bottom of the hole and a fire is built on top of them. The fire heats the stones until they are hot enough to retain heat for extended periods.

Once the stones reach the desired temperature, the fire is extinguished and food is layered inside the oven, often wrapped in bark to protect the food. Herbs and a variety of plants can also be added for flavour. The layering process alternates between food and hot stones, ensuring even heat distribution. Finally, the oven is covered with dirt or leaves to trap the heat, allowing the food to cook slowly. Once the food is cooked, the dirt is removed and the food is retrieved and separated from the stones.

Why ground ovens are energy efficient

Although ground ovens take longer to cook food compared to modern ovens, they are highly energy efficient for several reasons:

- *Minimal heat loss*. Ground ovens are sized to fit the food being cooked, preventing unnecessary heat loss. In contrast, modern ovens often heat large empty spaces, thereby wasting energy.
- *Natural insulation*. The soil and earth surrounding the oven act as insulation, preventing heat from escaping. Modern ovens lose heat through the oven door, which can be felt when touched.
- *Heat retention by stones*. The stones used in ground ovens absorb and retain heat energy, releasing it slowly over time. This ensures continuous cooking at a steady temperature without requiring additional fuel.
- *Efficient heat distribution*. The layering method ensures that all heat from the stones is used efficiently to cook food. If all the hot stones were placed only at the bottom, a significant amount of heat would be lost to the Earth instead of being used to cook the food.

10.4.4 Energy from the Sun

Although sunlight appears to travel directly to Earth's surface, it actually undergoes multiple energy transfers and transformations before reaching us.

The Sun emits light energy across the entire electromagnetic spectrum, including:

- radio waves
- microwaves
- infrared radiation
- visible light
- ultraviolet (UV) radiation
- x-rays
- gamma rays.

However, by the time this energy reaches Earth, we mostly receive visible light and infrared radiation, with small amounts of ultraviolet radiation. The rest of the light energy is absorbed, reflected or transformed before it reaches the surface.

FIGURE 10.12 The Sun emits light energy.

How the Earth's atmosphere affects solar energy

The atmosphere absorbs, reflects or transforms different types of solar radiation.

TABLE 10.1 Different types of solar radiation

Type of solar radiation	What happens in the atmosphere?	Effect on Earth
Radio waves and microwaves	Mostly absorbed or reflected	Some energy is transformed into kinetic and chemical energy. Scientists use these waves to study the Sun and space.
Infrared radiation and visible light	Mostly passes through	These are essential for warming Earth and enabling life. They are transformed into heat energy when absorbed by the land, water and atmosphere.
Ultraviolet (UV) radiation	Partially absorbed by the ozone layer	Some UV radiation reaches Earth's surface, aiding photosynthesis and vitamin D production, but too much can be harmful.
X-rays and gamma rays	Almost entirely absorbed by oxygen and nitrogen	These are transformed into kinetic and chemical potential energy. These rays would be dangerous if they reached Earth's surface.

SCIENCE AS A HUMAN ENDEAVOUR: Understanding solar energy and sustainable technologies

Solar energy is a renewable energy source and its use is constantly improving due to advances in both science and technology. The ability to harness energy from the Sun has developed significantly over time, transforming industries, shaping global energy policies and influencing how we reduce our reliance on fossil fuels.

FIGURE 10.13 Advances in technology are improving solar panel efficiency.

Advancements in scientific understanding of solar radiation, materials science and energy conversion have led to technological innovations, such as:

- *photovoltaic (PV) solar panels*. These panels use silicon-based materials used to convert sunlight directly into electricity through the photoelectric effect. Advances in nanotechnology and quantum mechanics are improving their efficiency.
- *solar thermal technology*. Some solar power plants use mirrors to concentrate sunlight and generate steam, which drives turbines to produce electricity.
- *solar batteries*. The development of more efficient and affordable batteries has made it possible to store solar energy for later use, solving the problem of energy supply at night or during cloudy days.

Without scientific research, these technologies would not have been developed, and without technological advancements, we would not be able to apply solar energy in practical ways.

Solar energy and sustainability

The development of solar technology is driven by the need for sustainable energy solutions. Scientists continue to research ways to improve solar efficiency while reducing environmental impacts associated with manufacturing solar panels. Future technologies may include:

- *perovskite solar cells*. These are a promising alternative to traditional silicon-based cells that are more flexible and cheaper to produce.
- *solar fuels*. Scientists are working on methods to use sunlight to split water molecules, producing clean hydrogen fuel.
- *bio-solar cells*. Researchers are exploring how living organisms, such as algae, can generate energy from sunlight.

These technologies are part of the broader shift towards clean energy solutions and are an example of how scientific knowledge leads to technological advancements that benefit both society and the environment.

1. Define solar energy and explain how it is used to generate electricity.
2. What is the role of photovoltaic cells in converting solar energy into electricity?
3. Explain how science and technology work together to improve solar energy efficiency.
4. Compare solar energy with fossil fuel energy in terms of sustainability and environmental impact.
5. Discuss how improvements in solar batteries help overcome one of the main challenges of solar energy.

Multidisciplinary endeavours to advance scientific knowledge make use of people's different perspectives and worldviews (VC2S8H02)

10.4.5 Energy efficiency in electricity generation

Different power plants have different levels of efficiency when it comes to generating electricity. When we burn fuel to generate electricity, a significant amount of the *input* energy is lost, mainly in the form of heat.

Typically, fossil fuel plants operate with an efficiency range of approximately 32 to 40 per cent. This means that around 60 to 68 per cent of the energy is wasted as heat.

- Coal-fired power plants have an efficiency that can range from 32 to 42 per cent. This depends on the temperature and pressure of the steam used in the plant.
- Natural gas-fired power plants have an efficiency of 32 to 38 per cent when they operate in a simple cycle mode. However, when they operate in a combined cycle mode using advanced technology, they can achieve an efficiency of 60 per cent.

Typical nuclear power plants achieve efficiencies of around 33 to 37 per cent, which is similar to the efficiencies of fossil-fuel power plants. However, higher temperatures and newer designs have the potential to achieve efficiencies exceeding 45 per cent.

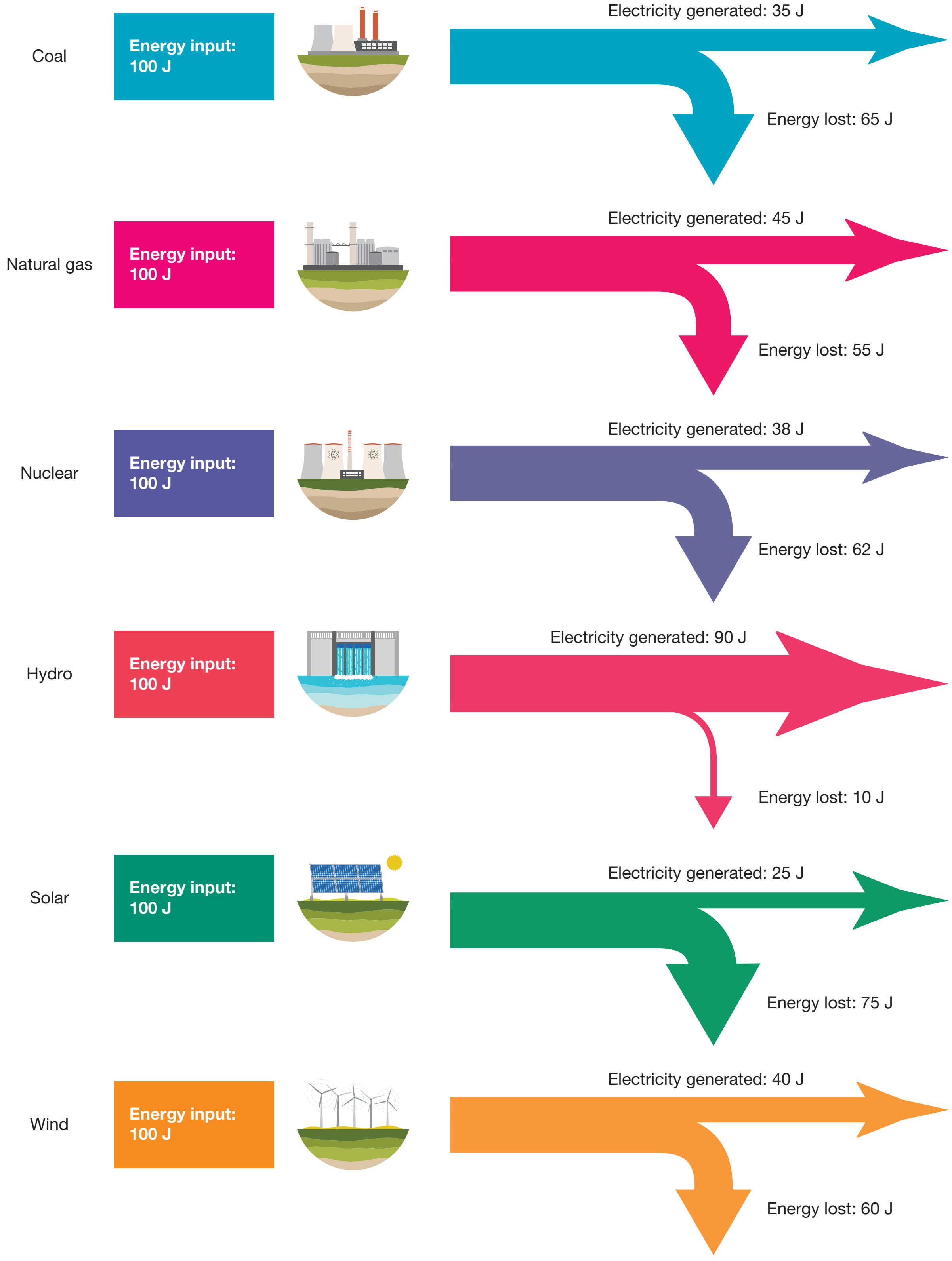
When considering renewable energies, there is no energy 'wasted' from the input and burning of fossil fuels and so are often measured, instead, by energy *output*.

Hydro, solar and wind are all efficient forms of electricity generation, although their efficiencies can vary.

- Hydroelectric turbines, which harness the energy of flowing water, are known for their efficiency and have been widely used for electricity generation. A typical efficiency for hydro is 90 per cent or more. This means that a large percentage of the energy available in the water can be successfully converted into electrical power.
- Solar power, specifically photovoltaic systems, have seen significant improvements in efficiency over the years. The efficiency of solar panels refers to how well they can convert sunlight into electricity. Currently, commercial solar panels have an average efficiency of around 15 to 22 per cent. More advanced solar technologies have the potential to achieve even higher efficiencies, reaching up to 40 per cent or more in some cases. Ongoing research and development aim to further improve solar panel efficiency. However, there are still energy losses, as not all the energy from the Sun hitting a solar panel is transformed into electricity.
- Wind turbines harness the energy of the wind to generate electricity. The efficiency of wind turbines depends on factors such as wind speed and turbine design. On average, modern wind turbines have an overall conversion efficiency ranging from 30 to 45 per cent. Similarly, not all the wind energy interacting with a wind turbine is converted into electrical energy.

While these renewable energy sources have high efficiencies in terms of energy conversion, it is worth noting that their actual electricity generation is influenced by factors like availability of sunlight, wind speed and water flow. Therefore, their output can vary depending on the specific location and environmental conditions.

FIGURE 10.14 Comparison of electricity generation in terms of energy input, loss and output



DISCUSSION

The efficiency of wind turbines is about the same as the efficiency of a coal- or gas-fired power station. Despite having the same efficiency, wind turbines are considered to be a better source of electricity. Discuss other factors that are important when making decisions about energy use, and why looking only at energy efficiency does not provide enough information for good decision-making processes around energy.

10.4 Activities

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10.4 Quick quiz on	10.4 Exercise

LEVEL 1	LEVEL 2	LEVEL 3
1, 2, 5, 9	3, 6, 7	4, 8, 10

Remember and understand

1. **List** two ways a pole vault athlete can be more energy efficient.
2. **List** three different types of light energy from the Sun.
3. **Describe** the construction of a ground oven.
4. **Identify** three different methods of generating electricity.

Apply and analyse

5. **Describe** the role of a bow string in improving energy efficiency in archery.
6. SI **Analyse** why not all light energy emitted by the Sun reaches the surface of Earth. What patterns in atmospheric interactions contribute to energy absorption, reflection or scattering?
7. **Explain** why using more energy-efficient methods of generating electricity is important.
8. **Explain** why a ground oven takes a long time to cook food.

Evaluate and create

9. SI **Evaluate** the claim that the most efficient bow for a beginner archer differs from that of an experienced archer. What assumptions, sources of error and factors influence this difference?
10. **Explain** the importance of the ozone layer to life on Earth.

Answers and sample responses are available in your digital formats.

LESSON 10.5 Review

10.5 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	Green	Yellow	Red
10.2	I can describe the Law of Conservation of Energy.			
	I can define energy efficiency.			
	I can calculate the energy efficiency of energy transfers and transformations.			
10.3	I can understand that energy transfers and transformations are never 100 per cent efficient.			
	I have examined how everyday situations involve multiple energy transfers and transformations, each reducing the amount of useful energy available at the end.			
10.4	I can describe ways to improve energy efficiency in a range of different situations.			
	I can evaluate the usefulness of different systems based on their energy efficiency.			

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Post-test	Topic 10 Post-test
eWorkbook	Topic 10 eWorkbook
Digital document	Key terms glossary

10.5 Activities

learnon

10.5 Review questions

LEVEL 1	LEVEL 2	LEVEL 3
1, 3, 6	2, 5, 7, 10	4, 8, 9, 11, 12

Remember and understand

1. **State** the Law of Conservation of Energy.
2. **Define** the term *energy efficiency*.
3. **State** the equation used to calculate energy efficiency.

4. **Calculate** the efficiency of the following processes.
   a. 500 J of input energy resulted in 280 J of useful output energy.
   b. 934 J of energy was put into a system, and 327 J of useful light, 365 J of useful sound and 20 J of useful kinetic energy were produced.
   c. A system received 87 J of energy and produced 51 J of non-useful heat energy.
   d. A laptop uses 75 000 J of energy every hour. The laptop produces 24 000 J of light energy, 14 000 J of sound energy and 22 000 J of kinetic energy, and stores 10 000 J of chemical potential energy in the battery.

Apply and analyse

5. SI **Analyse** real-world examples of energy transfers. Why are they never 100 per cent efficient, and what patterns in energy loss can be observed across different systems?
6. SI **Compare** the energy efficiency of simple and complex systems using data from real-world examples. What trends or relationships can you identify, and how do they impact system design?
7. **Describe** one reason why perpetual motion machines are impossible to create.
8. **Discuss** the importance of researching ways to improve energy efficiency.
9. **Compare** the efficiency of using solar power and wind power to generate electricity.
10. **Explain** why light energy from the Sun does not always reach the surface of Earth.

Evaluate and create

11. **Evaluate** the challenges involved in making cooking more energy efficient, focusing on at least two key issues to address.
12. SI **Explain** how enhancing an athlete's technique improves performance by optimising energy transfer. Present your findings using scientific vocabulary and an appropriate representation, such as a diagram or model.

Answers and sample responses are available in your digital formats.

on To test your understanding and knowledge of this topic, go to your learnON title at www.jacplus.com.au and complete the **post-test**.

11 Psychology

LESSON SEQUENCE

online only

12 Forensics

LESSON SEQUENCE

online only

GLOSSARY

absolute zero the lowest temperature that is theoretically possible, at which the movement of particles stops; it is zero on the Kelvin scale, equivalent to −273.15 °C
absorbed refers to when energy hitting an object is transferred to it; this will causes the atoms in the object to vibrate more and the temperature to rise
accurate refers to how close an experimental measurement is to a known value
acid a chemical that reacts with a base to produce a salt and water; edible acids taste sour
acid rain rainwater, snow or fog that contains dissolved chemicals, such as sulfur dioxide, that make it acidic
active immunity immunity achieved by your body making antibodies to a specific antigen
adrenal glands a pair of glands situated near the kidneys that release adrenaline and other stress hormones
adrenaline a hormone secreted in response to stressful stimuli, which readies your body for the fight-or-flight response
aim a statement outlining the purpose of an investigation
alkalis bases that dissolve in water
allotropes different forms of the same element; diamond and graphite are allotropes that contain carbon
alpha particles positively charged nuclei of helium atoms, consisting of two protons and two neutrons
alternating current electrical current that changes direction along a wire a number of times per second
alveoli tiny air sacs in the lungs at the ends of the narrowest tubes; oxygen moves from alveoli into the surrounding blood vessels, in exchange for carbon dioxide; singular = alveolus
amplitude the maximum distance that a particle moves away from its undisturbed position
angiosperms plants that have flowers and produce seeds enclosed within a carpel
angle of incidence the angle between an incident ray on a surface and the line perpendicular to the surface at the point of incidence, called the normal
angle of reflection the angle measured from the reflected ray to the normal
anther the male part of a flower that makes pollen
antibiotic a substance derived from a microorganism and used to kill bacteria in the body
antibodies proteins that are produced by B lymphocytes as a result of the presence of a foreign substance in the body and that act to neutralise or remove that substance
antigen a molecule that triggers an immune response
antiseptic a mild disinfectant used on body tissue to kill microbes
aorta a large artery through which oxygenated blood is pumped at high pressure from the left ventricle of the heart to the body
aqueous solutions mixtures in which substances are dissolved in water
arteries hollow tubes (vessels) with thick walls that carry blood pumped from the heart to other body parts
arterioles vessels that transport oxygenated blood from the arteries to the capillaries
asexual reproduction a type of reproduction that does not require the fusion of sex cells (gametes)
Asian influenza a strain of influenza caused by the H2N2 subtype of influenza virus, which spread across parts of the world in 1956–58
atmosphere the layer of gases (such as nitrogen, oxygen, methane and carbon dioxide) around Earth
atomic number the number of protons in the nucleus of an atom of a particular element
auditory nerve a large nerve that sends signals to the brain from the hearing receptors in the cochlea
autonomic nervous system a part of the peripheral nervous system that controls involuntary movement, such as breathing or heartbeat
avian influenza a strain of influenza caused by the H5N1 subtype of influenza virus that is highly contagious in birds and has caused over 300 fatalities in humans since 2003
axon a long structure within a neuron through which the nervous impulse travels from the dendrite and the cell body

B lymphocytes part of the third line of defence, these lymphocytes may be triggered by antigens to differentiate into plasma cells that produce and release specific antibodies against the antigen; also known as B cells, as they are made in the bone marrow, where they also mature
bactericidal describes an antiseptic that kills bacteria
bacteriostatic describes an antiseptic that stops bacteria from growing or dividing but does not kill them
base a chemical substance that will react with an acid to produce a salt and water; edible bases taste bitter
beam a wide stream of light rays, all moving in the same direction
beta particles charged particles (positive or negative) with the same size and mass as electrons
bibliography a list of references and sources at the end of a scientific report
biconvex describes a convex lens with both sides curved outwards
binary fission a reproduction method in which an organism (usually a single cell) divides into two new organisms
biodiversity the total variety of living things on Earth
biomimicry the act of copying and adapting processes that occur in nature
biosphere the layer in which all living organisms (biota) exist, containing the atmosphere, lithosphere and hydrosphere
biota the living things within a region or geological period
Black Death *see* bubonic plague
brain stem the part of the brain connected to the spinal cord, responsible for breathing, heartbeat and digestion
breech a birth in which the baby is born feet or bottom first
bronchi narrow tubes through which air passes from the trachea to the smaller bronchioles and alveoli in the respiratory system; singular = bronchus
bronchioles small, branching tubes in the lungs leading from the two larger bronchi to the alveoli
bubonic plague an infectious, epidemic disease caused by the *Yersinia pestis* bacteria and carried by fleas from rats; also known as the Black Death
budding the formation of a new organism from an outgrowth (bud) of the parent
caesarean an operation to remove a baby by cutting the mother's abdomen
calibrate to check or adjust a measuring instrument to ensure accurate measurements
capillaries numerous tiny blood vessels that are only a single cell thick to allow exchange of materials to and from body cells; every cell of the body is supplied with blood through capillaries
carbon capture a method used to collect carbon dioxide and store it
carbon dioxide a colourless gas (CO_2) made up of one carbon and two oxygen atoms; essential for photosynthesis and is a waste product of cellular respiration; a potent greenhouse gas, principally emitted during the combustion of fossil fuels
carbon footprint a measure of the amount of greenhouse gases (mainly carbon dioxide) that are released into the atmosphere
carbon neutral refers to when the carbon dioxide that is put back into the atmosphere is the same amount that was taken out of the atmosphere
cell the smallest unit of life that can exist independently, and the building block of all living organisms; a single battery
cell body the part of a neuron that contains the nucleus
cellular immune response immunity involving T lymphocytes (assisted by phagocytes) that actively destroy damaged cells or cells detected as non-self, such as those triggering an immune response
cellular pathogen a pathogen that is made up of cells, such as a tapeworm, fungus or bacterium
cellular respiration a series of chemical reactions in which the chemical energy in molecules such as glucose is transferred into ATP molecules, which is a form of energy that the cells can use
central nervous system the part of the nervous system composed of the brain and spinal cord
cerebellum the part of the brain that controls balance and muscle action
cerebral cortex the outer, deeply folded surface of the cerebrum
cerebral hemispheres the left and right halves of the brain
cerebrum the largest part of the brain, responsible for higher-order thinking, controlling speech, conscious thought and voluntary actions

chemical reaction a chemical change in which one or more new chemical substances are produced
chemoreceptors special cells within a sense organ that are sensitive to particular chemicals
circulatory system consists of the heart, blood and blood vessels, which are responsible for circulating oxygen and nutrients to body cells, and carbon dioxide and other wastes away from them
clone an identical copy
cloning the process used to produce genetically identical organisms
closed system a system in which energy, but not matter, can be transferred to and from its surroundings
cochlea the snail-shaped part of the inner ear in which receptors are stimulated
combustion a chemical reaction in which a fuel reacts rapidly with oxygen to produce heat energy, carbon dioxide and water
compression a region in which particles are closer than when not disturbed by a wave; a squeezing force
compression wave *see* longitudinal wave
concave curved inwards
conception the successful embedding of a fertilised egg in the uterine wall
conduction the transfer of heat through collisions between particles
cones photoreceptors located in the retina that respond to red, green or blue light
contraception the prevention of fertilisation of an egg or the prevention of a fertilised egg from becoming embedded in the uterine wall
contraceptives devices or substances that prevent fertilisation of an egg or prevent a fertilised egg from becoming embedded in the uterine wall
control an experimental set-up in which the independent variable is not applied; used to ensure that the result is due to the variable and nothing else
control centre a structure of the body that receives and processes information from receptors about a physiological factor, such as temperature or pH
controlled variables the conditions that must be kept constant throughout an experiment
convection the transfer of heat through the flow of particles
convection current the movement of particles in a liquid or gas resulting from a temperature or density difference
convex curved outwards
cornea the curved, clear outer covering of your eye
corpus callosum a bridge of nerve fibres through which the two cerebral hemispheres communicate
corpus luteum an endocrine structure that is involved in the production of progesterone
corrosive describes a chemical that wears away the surface of substances, especially metals
cosmic radiation naturally occurring background radiation from outer space, mostly in the form of high-energy protons
cotyledons special leaves of the embryo plant inside a seed that provide food for the developing seedling
critical angle refers to when the incident angle becomes so great that the incident light cannot bend any more
cross-pollination the transfer of pollen from the stamens of one flower to the stigma of a flower of another plant of the same species
crude oil liquid formed from the remains of marine plants and animals that died millions of years ago — a fossil fuel; many other fuel products are obtained from crude oil
cryopreservation refers to when cryoprotectant chemicals and cooling are used to safely freeze biological material such as human embryos
cultural burning a traditional fire management technique used by Aboriginal and Torres Strait Islander peoples to burn vegetation in a controlled manner; it helps reduce fuel loads, promotes the growth of certain plant species and supports ecosystem health
current electricity the flow of electrons through a region
cytosol the fluid found inside cells that makes up the cytoplasm
decay to transform into a more stable particle
decomposers small organisms that break down dead and decaying matter
deforestation the process of clearing trees to convert the land for other uses
dendrite a structure that relays information towards the cell body of a neuron

deoxygenated blood blood from which some oxygen has been removed
dependent variable the variable that is being affected by the independent variable — that is, the variable that is being measured
detritivores organisms that feed on decomposing organic matter
diatomic molecule a substance containing only two atoms
direct current a flow of electricity that moves in one direction only, like the power from a battery
discharged refers to when excess charge is removed from an object, either by removing the charged particles or adding an equal amount of charge of the opposite sign
disease any change that impairs the function of an organism in some way and causes it harm
disinfectant a chemical used to kill bacteria on surfaces and non-living objects
disperse to scatter over a wide area
diverging lens a lens that bends rays so that they spread out; diverging lenses are thinner in the middle than at the edges
DNA (deoxyribonucleic acid) a substance found in all living things that contains genetic information
dopamine a neurotransmitter involved in producing positive moods and feelings
dynamo a type of generator that produces direct current (DC) electricity, often used in bicycles to power lights
ear canal the tube that leads from the outside of the ear to the eardrum
eardrum a thin piece of stretched skin inside the ear that vibrates when sound waves reach it
earthed refers to when excess charge is taken away from an object, by connecting it to the ground
echo a sound caused by the reflection of sound waves
echolocation the use of sound to locate objects by detecting echoes
ectoparasite a parasite that lives outside the body of its host organism
effector an organ that responds to a stimulus to initiate a response
efficiency in energy terms, the fraction of energy supplied to a device as useful energy
egg the female reproductive cell in animals and plants; an ovum
electric charge a physical property of matter that causes it to experience a force when near other electrically charged matter; electrical charge can be positive or negative
electric current a measure of the number of electrons flowing through a circuit every second
electric generator a machine that converts movement (mechanical energy) into electricity
electrical conductors materials through which electricity flows easily
electrical insulators materials that do not allow electricity to flow easily
electrode a conductor (such as a metal strip) that lets electricity flow into or out of a substance, often used in batteries
electrolyte a liquid or substance that helps electricity move between electrodes, commonly found in batteries
electromagnetic waves electromagnetic energy that is transmitted as moving electric and magnetic fields; there are many different types of electromagnetic energy, such as light, microwaves and radio waves
electrons extremely light (1800 times lighter than protons and neutrons) negatively charged particles inside an atom; electrons orbit the nucleus of an atom in specific, defined regions called shells or orbitals
element a pure chemical species consisting of atoms of a single type
embryo a group of cells formed from the zygote that develop into the different body organs
empathy the capacity to recognise and, to some extent, share feelings that are being experienced by other people
endocrine glands organs that produce hormones, which are released into the bloodstream
endocrine system the body system composed of different glands that secrete signalling molecules (hormones) that travel in the blood for internal communication and regulation, and to maintain homeostasis
endoparasite a parasite that lives inside the body of its host organism
endoscope a long, flexible tube with one optical fibre to carry light to an area inside the body and another optical fibre to carry light from the body to a lens; the image formed by the lens is examined or recorded
endosperm the food supply for the embryo plant in a seed
enhanced greenhouse effect the additional heating of the atmosphere due to the presence of increased amounts of carbon dioxide, methane and other gases produced by human activity
epidemic a disease affecting a large number of people in a particular area in a relatively short period of time

equation a statement describing a chemical reaction, with the reactants on the left and the products on the right, separated by an arrow
erythrocytes red blood cells
ethics the system of moral principles on the basis of which people, communities and nations make decisions about what is right or wrong
external fertilisation a method of sexual reproduction in which the eggs are released by the female into water and fertilised by sperm released nearby
external radiotherapy a cancer treatment in which radiation is directed from an external machine to the site of the cancer
extrapolation the use of a graph to determine unmeasured data values beyond the range of measured data values
fair test a test in which only one variable is changed and all other variables are kept constant when attempting to answer a scientific question
fallopian tube a tube connecting each ovary to the uterus, and through which an egg travels
fertilisation fusion of the male sex cell or gamete (sperm) and the female sex cell or gamete (ovum)
fetus the unborn young of an animal that has developed a distinct head, arms and legs
fields regions around an object in which each point is affected by a force of some type
firestick farming *see* cultural burning
fission splitting of the nuclei of large atoms into two smaller atoms and several neutrons, releasing radiation and heat energy
flower the reproductive part of angiosperms containing petals, stamens and carpels; they are often colourful to attract pollinating insects
focal point the focus for a beam of light rays
follicles structures found in the ovary that each contain a single immature ovum (egg)
follicle-stimulating hormone (FSH) regulates the development, growth and reproductive processes of the body
forebrain consists of the cerebrum, cerebral cortex, thalamus and hypothalamus
fossil fuel a fuel formed from the remains of ancient organisms that is non-renewable and unsustainable (for example, coal, oil and natural gas); it can be burned to produce heat
frequency the number of vibrations in one second, or the number of wavelengths passing in one second
fruit a ripened ovary of a flower, enclosing seeds
fuel a substance that is burned in order to release energy, usually in the form of heat
fuel rods rods that form the fuel source of a nuclear reactor; contain the fissile nuclides needed to produce a nuclear chain reaction
gametes reproductive cells (sperm or ova) containing half the genetic information of normal cells
gamma rays high-energy electromagnetic radiation produced from some radioactive decay during nuclear reactions; the radiation has no mass and travels at the speed of light
gene a coded set of instructions within DNA that determines the characteristics of an organism
genetic modification the technique of modifying the genetic structure of organisms, making it possible to design organisms that have certain characteristics
geosequestration storage of liquid carbon dioxide well below Earth's surface
germination the first sign of growth from the seed of a plant
global warming an increase in the surface temperature above Earth
glucagon a hormone, produced by the pancreas, which increases blood glucose levels
glucose a six-carbon sugar (monosaccharide) that acts as a primary energy supply for many organisms
gonads the reproductive organs in which gametes are produced; the testes and ovaries
greenhouse a building containing glass walls and a glass ceiling
greenhouse effect a natural effect of Earth's atmosphere trapping heat from the Sun, mainly by carbon dioxide, resulting in warmer temperatures
greenhouse gases gases found in the atmosphere that contribute to the greenhouse effect, trapping the Sun's heat
gut flora bacteria and other organisms that live inside the intestines and help digest food
haemoglobin the red pigment in red blood cells that carries oxygen

half-life the time taken for half the radioactive atoms in a sample to decay — that is, change into atoms of a different element

hazardous substance a chemical that has an effect on human health; this effect may be immediate, such as poisoning, or long-term, such as cancer

heart a muscular organ that pumps deoxygenated blood to the lungs to be oxygenated and then pumps the oxygenated blood to the body

heat the total energy of a substance due to the movement of all of its particles

heat sink a device that transfers the heat generated by an electronic or a mechanical component to a coolant, often the air or a liquid, where it can be taken away from the component

herd immunity protection against an infectious disease; describes a high proportion of the population being immune to a disease, via vaccination, reducing the spread of the disease and protecting individuals who are not immune

hermaphrodite an organism that has both male and female reproductive organs

hindbrain a continuation of the spinal cord

hippocampus a part of the brain with a key role in consolidating learning, comparing new information with previous experience, and converting information from working memory to long-term storage

homeostasis the maintenance by an organism of a constant internal environment (for example, blood glucose level, pH, body temperature)

hormone a signalling molecule that is produced in specialised cells and travels in blood to act on target cells to cause a specific response

host the organism that a parasite lives on or in to gain nourishment

humoral immune response immunity involving antibodies (which are specific to a particular antigen) that are produced and secreted by B lymphocytes that have differentiated into plasma cells

hydrocarbons compounds containing only hydrogen and carbon atoms

hydroelectricity a type of renewable energy that uses water overflowing from a dam to generate electricity

hydrosphere includes all the water above, on and under Earth's surface, such as the oceans, seas, lakes and rivers

hyperglycaemia refers to when blood glucose levels are above the normal range

hyperthermia refers to when body temperature rises above the normal range

hypoglycaemia refers to when blood glucose levels are below the normal range

hypothalamus a part of the brain involved in maintaining homeostasis in the body

hypothermia refers to when body temperature drops below the normal range

immune system a network of interacting body systems that protects against disease by identifying and destroying pathogens and infected, malignant or broken-down cells

immunisation administering an antigen, such as in a vaccine, with the aim of producing an enhanced immune response against the antigen in a future exposure

immunity resistance to a particular disease-causing pathogen

immunology the branch of science that deals with immunity from disease

incident ray the initial ray of light that approaches a surface (such as a mirror or lens) before any reflection or refraction occurs

independent variable the variable that a scientist changes to observe its effect on another variable

inert not reactive

infectious disease a disease that is contagious (can be spread from one organism to another) and is caused by a pathogen

inflammation a reaction of the body to an infection, commonly characterised by heat, redness, swelling and pain

infrared a type of energy wave that is part of the electromagnetic spectrum

infrared radiation invisible radiation emitted by all warm objects; you feel infrared radiation as heat

insect-pollinated flowers flowers that receive pollen carried on the body parts of insects from other flowers

insulator a material that has a very high resistance, allowing very little current to flow through it

insulin a hormone that reduces blood glucose levels

intermediate host the organism that a parasite lives in or on in its larval stage; also known as a secondary host

internal fertilisation a method of sexual reproduction in which the egg remains in the female and is fertilised by sperm inserted into the female
internal radiotherapy a cancer treatment also known as brachytherapy; radioisotopes are placed inside the body at, or near, the site of a cancer
interneuron a nerve cell that conducts a nerve impulse within the central nervous system, providing a link between sensory and motor neurons
interpolation the use of a graph to determine unmeasured data values within the range of measured data values
ionising radiation a type of radiation that has enough energy to remove tightly bound electrons from atoms, creating charged particles (ions)
iris the coloured part of the eye that opens and closes the pupil to control the amount of light that enters the eye
isotopes atoms of the same element that differ in the number of neutrons in the nucleus
IVF (in vitro fertilisation) a fertility treatment that involves fertilisation between eggs and sperm and the culture of embryos in a laboratory
kerosene fuel used in jet aircraft
kinetic energy energy due to the motion of an object
labour the process of delivering the baby, placenta and umbilical cord from the uterus
Large Hadron Collider (LHC) a machine that can smash together particles travelling at close to the speed of light in order to find out what they are made of
lateral inversion reversed sideways
Law of Conservation of Energy a law that states that energy cannot be created or destroyed
Law of Conservation of Mass a law that states that in a chemical reaction, the total mass of the reactants is the same as the total mass of the products
Law of Reflection a law that states the angle of incidence must equal the angle of reflection
left atrium the upper-left section of the heart where oxygenated blood from the lungs enters the heart
left ventricle the lower-left section of the heart, which pumps oxygenated blood to all parts of the body
lens a transparent curved object that bends light towards or away from a point called the focus; the eye has a jelly-like lens
limestone a sedimentary rock formed from the remains of sea organisms; it consists mainly of calcium carbonate (calcite)
lithosphere the outermost layer of Earth; includes the crust and uppermost part of the mantle
longitudinal wave a wave involving the vibration of particles in the same direction as energy transfer; also known as a compression wave
luminous describes an object that releases its own light
lungs the organ for breathing air; gas exchange occurs in the lungs
luteinising hormone (LH) a hormone produced by the anterior pituitary gland that initiates ovulation, the production of progesterone and corpus luteum development in females, and is involved in the stimulation of production of testosterone in testes in males
lymphatic system the body system containing the lymph vessels, lymph nodes, lymph and white blood cells that is involved in draining fluid from the tissues and helping defend the body against invasion by disease-causing agents
lymphocytes small, mononuclear white blood cells present in large numbers in lymphoid tissues, and circulating in blood and lymph
marble a metamorphic rock formed as a result of great heat or pressure on limestone
mass number the total number of protons and neutrons in the nucleus of a particular atom
matrix a visual thinking tool that organises, analyses and compares through the use of a grid
mechanical waves waves carried by the vibration of particles of matter
mechanoreceptors special cells within the skin, inner ear and skeletal muscles that are sensitive to touch, pressure and motion
medium a material through which a wave moves
medulla oblongata a part of the brain developed from the posterior portion of the hindbrain; also known as the medulla

memory cells cells that may be formed from lymphocytes after infection with a pathogen — they 'remember' each specific pathogen encountered and are able to mount a strong and rapid response if that pathogen is detected again
menstrual cycle a series of hormonal changes in females measured from the beginning of one period to the beginning of the next period
menstruation the monthly discharge of blood and other materials from the uterus lining through the vagina (also known as a period)
microbiome the community of microorganisms (such as bacteria, fungi and viruses) living together in a particular habitat
microwave an electromagnetic wave of very high frequency
midbrain a part of the brain involved in motor control, regulating alertness and body reflexes
middle ear the section of the ear between your eardrum and the inner ear, containing the ossicles
mineral a naturally occurring, inorganic and solid substance with a defined chemical formula and an ordered arrangement of atoms
mirror neurons a group of neurons that activate when you perform an action and when you see or hear others performing the same action
model a simplified description, often a mathematical one, of a process
molecule a group of atoms bonded together covalently
motor neuron a nerve cell that conducts a nerve impulse from the central nervous system to an effector, such as a muscle or gland, so that it may respond to a stimulus
motor neuron disease a medical condition that progressively destroys motor neurons, resulting in progressive paralysis but leaving the brain and sense organs unaffected
moulds types of microscopic fungi found growing on the surface of foods
multiple fission a reproduction method in which a single-celled organism divides into more than two cells
mutation damage to DNA in cells, which can be passed on to offspring through sperm and eggs
myelin a fatty, white substance that encases the axons of neurons
nanoplastics tiny plastic particles similar in size to a red blood cell
native elements elements found uncombined in Earth's crust
nectaries the parts of a flower, located at the base of the petals, that secrete nectar
negative feedback a homeostatic mechanism that returns a stimulus back within its normal range
negatively charged having more electrons than protons (more negative charges than positive charges)
nerve a bundle of neurons
nervous system the body system in which messages are sent as electrical impulses (along neurons) and chemical signals (neurotransmitters across synapses)
neural prostheses technological devices that can replace a motor, sensory or cognitive structure
neuron another name for a nerve cell, which is a specialised cell for transmitting a nerve impulse
neurotransmitters signalling molecules released from the axon terminals into the synapse between nerve cells (neurons)
neutralisation a reaction between an acid and a base; a salt and water (a neutral liquid) are the products of this type of reaction
neutrons tiny particles in the nucleus of an atom; they have no electric charge (they are neutral)
non-cellular pathogen a pathogen that is not made up of cells, such as a virus, prion or viroid
non-infectious disease a disease that cannot be spread from one organism to another
non-ionising radiation a type of radiation that does not have enough energy to remove tightly bound electrons from atoms
non-luminous describes objects that release no visible light of their own
noradrenaline a common neurotransmitter involved in arousal states; also called norepinephrine
normal a line drawn perpendicular to a surface at the point where a light ray meets it
nuclear radiation radiation from the nucleus of an atom, consisting of alpha or beta particles, or gamma rays
nuclear reactors power plants in which the radioactive properties of uranium are used to generate electricity
nucleus a roundish structure inside a cell that acts as the control centre for the cell; the central part of an atom, made up of protons and neutrons; plural = nuclei

nuclide a type of atom characterised by the number of protons and the number of neutrons in its nucleus
obligate intracellular parasite a parasite that needs to infect a host cell before it can reproduce
octane a hydrocarbon with eight carbon atoms (C_8H_{18}); it is the major component of petrol
odourants chemicals that are added to odourless gases to give them a detectable odour
oestrogen a hormone secreted from the ovaries and the placenta with a variety of effects, such as inducing puberty changes and thickening of the uterine lining
offspring the young born of a living organism
olfactory nerve the nerve that sends signals to the brain from the chemoreceptors in the nose
opaque describes a substance that does not allow any light to pass through it
open system a system in which both energy and matter can be transferred to and from its surroundings
optic nerve a large nerve that sends signals to the brain from the sight receptors in the retina
optical fibres narrow strands made of two concentric glass layers so that the light is internally reflected along the fibres
optically stimulated luminescence (OSL) a technique used to determine the age of sediments by measuring the amount of stored energy in quartz and other minerals
ore a mineral from which a valuable metal can be removed for profit
organelle a small structure in a cell with a special function
organism a living thing, such as an animal or plant, that grows, changes and needs food, water and air to survive
organs structures composed of tissue that perform specific functions
ossicles a set of three tiny bones that send vibrations from the eardrum to the inner ear
ovary the female gonad; produces the female gametes (egg cells; ova)
ovulation the release of an ovum from a mature follicle in the ovary into the fallopian tube
ovule the receptacle within an ovary that contains egg cells
ovum the female gamete or sex cell produced in the ovaries; also known as an egg cell (plural = ova)
oxidation a chemical reaction involving the loss of electrons by a substance
oxygen an atom that forms molecules (O_2) of tasteless and colourless gas; it is essential for cellular respiration for most organisms and is a product of photosynthesis
oxygenated blood blood that is rich in oxygen
pain receptors special cells located throughout the body (except for the brain) that send nerve signals to the brain and spinal cord in the presence of damaged or potentially damaged cells
pandemic a disease occurring throughout an entire country or continent, or worldwide
papilla bumps on your tongue that are thought to contain tastebuds
paralysis loss of the ability to move
parasite an organism that obtains resources from another organism (host) that it lives in or on, and can cause harm to
parthenogenesis the development of new individuals from unfertilised eggs
passive immunity immunity achieved by your body receiving antibodies from an outside source, such as from your mother's milk or through vaccination
pathogen a disease-producing organism
penicillin a powerful antibiotic substance found in moulds of the genus *Penicillium* that kills many disease-causing bacteria
peripheral nervous system the part of the nervous system containing nerves that connect to the central nervous system
petals the coloured parts of a flower that attract insects
pH scale the scale from 1 (acidic) to 14 (basic) that measures how acidic or basic a substance is
phage a type of virus that infects and kills bacteria
phagocyte a white blood cell that ingests and destroys foreign particles, bacteria and other cells
phagocytosis the ingestion of solid particles by a cell
pheromones chemicals that are important in communication between members of the opposite sex
photon a particle such as a quantum of light or electromagnetism
photoreceptors special cells located in the eyes that are stimulated by light

photosynthesis the process by which phototrophic organisms (such as plants) use light energy, carbon dioxide and water to make glucose and oxygen
phototrophic describes an organism that obtains energy from sunlight via photosynthesis
pie chart a diagram that uses sectors of a circle to compare the sizes of parts making up a whole quantity
pineal gland a gland that produces the hormone melatonin, which can make you feel drowsy
pitch refers to how our hearing interprets frequency; high-frequency vibrations are perceived as high pitch, low-frequency waves are perceived as low pitch
pituitary gland a small gland at the base of the brain that releases hormones
placenta an organ formed in the mother's uterus in pregnancy, through which the baby receives food and oxygen from the mother's blood and the baby's wastes are removed
plagues contagious diseases that spread rapidly through a population and result in high mortality (death rates)
plasma cell a differentiated B lymphocyte that produces antibodies specific to the invader's antigens
plumule a small bud at the tip of the embryo plant in a seed
poliomyelitis a highly infectious disease caused by the *Picornaviridae* virus that can have consequences including complete recovery, limb and chest muscle paralysis, or death
pollen a fine powder containing pollen grains (the male sex cells of a plant)
pollen grain the male gamete of a flower
pollen tube a long tube growing from a pollen grain through the style to the ovule
pollination the transfer of pollen from the stamen (the male part) of a flower to the stigma (the female part) of a flower
pons the part of the brainstem that links the medulla oblongata to the thalamus
positive feedback a process in which the output of a system amplifies or reinforces the initial change, leading to greater change
positively charged having more protons than electrons (more positive charges than negative charges)
positron a particle emitted during positron emission tomography (PET) scans that is like an electron but with a positive charge
precise refers to how close multiple measurements of the same investigation are to each other
primary host the organism that a parasite lives in or on in its adult stage
prion an abnormal and infectious protein that converts normal proteins into prion proteins
producers organisms that create their own food, forming the base of the food chain and providing energy for all other organisms
products the chemical substances that result from a chemical reaction
progesterone a hormone produced in the ovaries that inhibits ovulation and prepares the lining of the uterus for pregnancy
protons tiny particles found in the nucleus of an atom; they have a positive electrical charge and the same mass as a neutron
puberty the life stage when the sex glands become active and bodily changes occur to enable reproduction
pulmonary artery the vessel through which deoxygenated blood, carrying wastes from respiration, travels from the heart to the lungs
pulmonary vein the vessel through which oxygenated blood travels from the lungs to the heart
pupil a hole through which light enters the eye
qualitative data (or categorical data) data expressed in words
quantitative data (or numerical data) data that can be precisely measured and have values that are expressed in numbers
quarantine strict isolation of sick people from others for a period of time (originally 40 days) in order to prevent the spread of disease
radar a technology that uses radio waves to detect the presence, location, speed and direction of objects by analysing the reflected signals
radiant heat heat that is transferred from one place to another by radiation
radiation a method of heat transfer that does not require particles to transfer heat from one place to another; the transfer of energy that comes from a source and travels through space, in the form of light, heat, particles or waves

radiation sickness immediate symptoms of exposure to damaging nuclear radiation
radicle the beginnings of a root making up part of a plant embryo inside a seed
radio waves low-energy electromagnetic waves with a much lower frequency and longer wavelength than visible light
radiocarbon dating a method of determining the age of a fossil using the remaining amount of unchanged radioactive carbon
radiography the process of taking an image produced by x-rays, gamma rays or similar radiation
radioisotope a radioactive form of an isotope
radiometric dating a method of determining the ages of rocks and fossils based on the rate of decay or half-life of particular isotopes
rarefaction a region in which particles are further apart than when not disturbed by a wave
rays narrow beams of light
reactants the original substances present in a chemical reaction
receiving antenna a metal structure in which electrons are made to vibrate by radio waves or microwaves in the atmosphere
receptor a cell or organ designed to detect a stimulus
recipient the person or couple receiving embryos or gametes from another person as a form of fertility treatment
red blood cells cells in the blood that transport oxygen to all other living cells in the body
reduction the gain of electrons to a substance; it can also refer to the removal of oxygen from a substance
reflected ray the ray that leaves the surface of a mirror
reflection bouncing off the surface of a substance
reflex arc a quick response to a stimulus that does not involve the brain (for example, a knee jerk); the message travels from receptor to sensory neuron to interneuron in the spinal cord, then directly via the motor neuron to the effector
refraction the bending of light when passing from one medium into another
refractive index the measure of the bending of light when it is passed through a material
remote sensing uses satellites to study Earth's surface by detecting invisible energy, like heat, to measure temperature changes and track events like global warming and bushfires
respiration the process where glucose is broken down in the presence of oxygen to produce carbon dioxide, water and a form of energy that cells can use; also cellular respiration
respiratory system the lungs and associated structures that are responsible for getting oxygen into an organism and carbon dioxide out
response an action taken by an effector to alter and return a variance in an environment to normal
reticular formation a network of neurons that controls the amount of information that flows into and out of the brain
retina the curved surface at the back of the eye
right atrium the upper-right section of the heart, where deoxygenated blood from the body enters
right ventricle the lower-right section of the heart, which pumps deoxygenated blood to the lungs
RNA (ribonucleic acid) a complex compound that functions in cellular protein synthesis and replaces DNA as a carrier of genetic codes
rods photoreceptors located in the retina that respond to low levels of light and allow you to see in black and white in dim light
sanitation the process of cleaning something to make it safe by killing germs like bacteria or viruses; UV light can be used to sanitise food, water, air and surfaces by stopping these germs from spreading
scattering light sent in many directions by small particles within a substance
scientific method a systematic and logical process of investigation to test hypotheses and answer questions based on data or experimental observations
sea breeze the breeze that occurs when differences in air pressure cause air particles to flow from the ocean towards the land
seed the product of a fertilised ovule
seed coat the protective layer around a seed
seedling a young plant produced from the embryo in a seed after germination

self-pollination the transfer of pollen from the flower's own stamen to its stigma
semen ejaculate from the male reproductive organs made up of sperm and secretions essential for its viability
sense organ a specialised structure that detects stimuli (such as light, sound, touch, taste and smell) in your environment
sensory neuron a nerve cell found in sensory organs that conducts a nerve impulse from a receptor to the central nervous system
serotonin a common neurotransmitter involved in producing states of relaxation and regulating sleep and moods
sexual intercourse the act of inserting sperm into a female; also called copulation or mating
somatic nervous system a part of the peripheral nervous system that controls voluntary movement, such as walking
sonar the use of reflected sound waves to locate objects under water (sound navigation and ranging)
Spanish influenza a strain of influenza caused by the H1N1 subtype of influenza virus, which spread across the world in 1918–1920
sperm the male reproductive cell; it consists of a head, a middle section and a tail used to swim towards the egg
spore a reproductive cell capable of developing into a new individual without fusion with another reproductive cell
stable describes a nucleus that does not change spontaneously; the protons and neutrons in the nucleus are held together strongly
static electricity a build-up of charge in one place
sterile refers to a person unable to produce gametes
stigma the female part of a flower, located at the top of the carpel, that catches the pollen during pollination
stimuli any changes in the environment that an organism can detect
stimulus–response model a system in which a change (stimulus) is detected by receptors leading to a response, which acts to alter and return the variance to normal
style the supporting part of a flower that holds the stigma
subatomic particles particles within an atom — electrons, protons and neutrons
supercritical a substance kept at a temperature and pressure above its critical point
surface protein a protein molecule occurring on the surface of a virus
swine flu a strain of influenza caused by the H1N1 subtype of influenza virus, containing a combination of genes from the swine, human and avian flu viruses
symbol a simplified representation of an element consisting of one or two letters
synapse the gap between adjoining neurons where neurotransmitters travel
system a collection of tissues and organs that work together to perform a specific function in the body
T lymphocytes part of the third line of defence, these lymphocytes fight the pathogens at a cellular level; some T lymphocytes may also attack damaged, infected or cancerous cells; also known as T cells as, though they are made in the bone marrow, they mature in the thymus
target cells cells that contain receptors on their surface that are complementary to a specific hormone
tastebuds nerve endings located in your tongue that allow you to experience taste
temperature the average kinetic energy of the particles in a substance
testable able to be supported or proven false through the use of observations and investigation
testes the organs in a male that produce sperm and sex hormones
testosterone male sex hormone
thalamus a part of the brain through which all sensory information from the outside (except smell) passes before going to other parts of the brain for further processing
thermoreceptors special cells located in your skin, part of your brain and body core that are sensitive to temperature
thermoregulation the control of body temperature
tissue a group of cells of similar structure that perform a specific function
total internal reflection the complete reflection of a light beam that may occur when the angle between a boundary and a beam of light is small
trachea the narrow tube from the mouth to the lungs through which air moves

translucent describes a substance that allows light to come through imperfectly, as in frosted glass
transmissible spongiform encephalopathy (TSE) a degenerative neurological disease caused by prions
transmitted refers to when energy is passed on from one place to another through space or a non-opaque substance
transmitting antenna a metal structure in which vibrating electrons cause radio waves to travel through the air
transparent describes a substance that allows most light to pass through it; objects can be seen clearly through transparent substances
transverse wave a wave involving the vibration of particles perpendicular to the direction of energy transfer
turbine a device with blades that spins when hit by water, wind or steam, helping to generate electricity
ultrasound sound with frequencies too high for humans to hear
ultraviolet (UV) radiation a form of short-wave radiation that comes from the Sun; invisible radiation similar to light but with a slightly higher frequency and more energy
unstable describes an atom in which the neutrons and protons in the nucleus are not held together strongly
uterus the site of embryo implantation; supports the developing fetus from implantation to birth; is about the size of a pear if not pregnant
vaccination the administering of a vaccine to stimulate the immune system of an individual to develop immunity to a disease
valid describes an experiment that truly investigates what it sets out to investigate (via an appropriate method, controlling variables and so on)
variable any factor that can be changed, kept constant (controlled) or measured during an experiment
variolation deliberate infection of a person with smallpox (*Variola*) in a controlled manner so as to minimise the severity of the infection and also to induce immunity against further infection
vasoconstriction the narrowing of blood vessels, primarily caused by the tightening (constriction) of smooth muscle cells in the vessel walls
vasodilation the widening of blood vessels, caused by the relaxation of smooth muscle cells in the vessel walls
vector an organism that carries a pathogen between other organisms without being affected by the disease the pathogen causes
vegetative propagation the reproduction of plants using parts other than sex cells
veins blood vessels that carry blood back to the heart; they have valves and thinner walls than arteries
vena cava the large vein leading into the top-right chamber of the heart
venules small veins
vesicle a small, fluid-filled, membrane-bound sac in a cell
vibrations repeated, fast, back-and-forth movements
virgin birth a birth that does not involve the joining of an egg and sperm
viroid a non-cellular pathogen comprised solely of a short circular RNA without a protein coat
virtual focal point a common point from which rays appear to have come before passing through a concave lens
virus a very simple microorganism that infects cells and may cause disease
visible light a very small part of the electromagnetic spectrum to which our eyes are sensitive
voltage the amount of energy that is pushing electrons around a circuit, per coulomb of charge that flows between two points
wave the transmitter of energy without the movement of particles from place to place; the vibration of particles or energy fields is involved
wavelength the distance between two neighbouring crests or troughs of a wave; this is the distance between two particles vibrating in step
wave-particle duality a model that treats all objects as having both wave-like and particle-like properties; the property observed depends on the observation method chosen
white blood cells living cells that fight bacteria and viruses
wind-pollinated flowers flowers that receive pollen carried by the wind from another flower
x-rays high-energy electromagnetic waves that can be transmitted through solids and provide information about their structure
zona pellucida a layer that surrounds the ovum and embryo for the first week of development
zygote a cell formed by the fusion of two gametes

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