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Interactive Textbook Included



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Cambridge science for the NSW Syllabus Second Edition

STAGE 4

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Answers are available in the Online Teaching Suite. Teachers can enable or disable answers in their students' accounts.

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How to use this resource

Elements in the print book

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

Explore!

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

Quick check

These provide quick checks for recalling facts and understanding content. Cognitive verbs appear in bold. These questions can be completed in the Interactive Textbook or downloaded as Word documents.

Section questions

Question sets at the ends of sections are categorised under five headings: Remembering, Understanding, Applying, Analysing and Evaluating. Cognitive verbs appear in bold. These questions can be completed in the Interactive Textbook or downloaded as Word documents.



DEPTH STUDY IDEA
Inspiration for depth studies are signposted throughout the content.



INVESTIGATION
Opportunities for primary or secondary source investigations are signposted throughout the content.

Learning goals

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

Did you know?

These are short facts that contain interesting, relevant information.

Advances in science

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

Hands-on activities

Try this

Classroom or at-home activities help explore concepts that are currently being covered.

Practical skills/Investigation

These activities focus on developing Working Scientifically skills, including using laboratory equipment. Practical skills activities can be conducted within one lesson, while Investigations are longer and cover more areas of the experimental design. These activities are also available as Word document downloads in the Interactive Textbook.

Worked example

Worked examples are provided for topics that require calculations, or to reinforce important skills.

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End-of-chapter features

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
3.1	explain forces as either direct/contact or indirect/non-contact and conduct a practical investigation on the effects of a range of direct and indirect forces.	2
3.1	use force diagrams to model balanced and unbalanced forces and analyse them to make predictions.	4, 19
3.1	examine the relationship between force and energy.	12
3.1	describe the electrostatic and gravitational forces between objects.	8, 14
3.1	use forces to describe the motion of objects in orbit.	5, 13
3.1	define weight force using $F = mg$ and use it to solve for F, m and g.	1
3.2	describe magnetic attraction and repulsion in relation to polarity.	11
3.2	conduct a practical investigation to test how magnetic force varies with distance.	3
3.2	observe and map the magnetic fields of magnets.	7
3.2	conduct a practical investigation to make electromagnets and compare their strength.	15
3.3	investigate how levers and pulleys and inclined planes are used to change the magnitude of force needed when performing a task.	6, 16
3.3	identify examples of simple machines.	9
3.3	explore the role of simple machines, from now and in the past, as used in everyday life.	10

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

Chapter review question sets are categorised under five headings: Remembering, Understanding, Applying, Analysing and Evaluating. These questions can be completed in the Interactive Textbook or downloaded as Word documents.

Data questions

Earth's Moon and the planets in our solar system have different forces of gravity on their surface than Earth because they have different masses. The graph below plots the surface gravity of different planets relative to that of Earth.

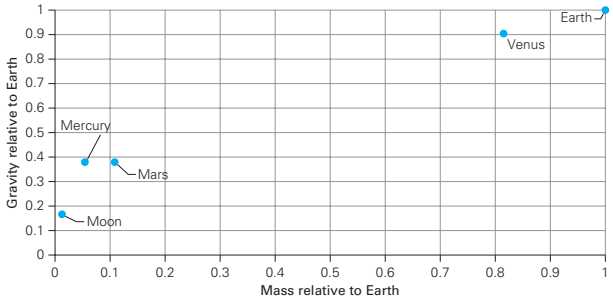
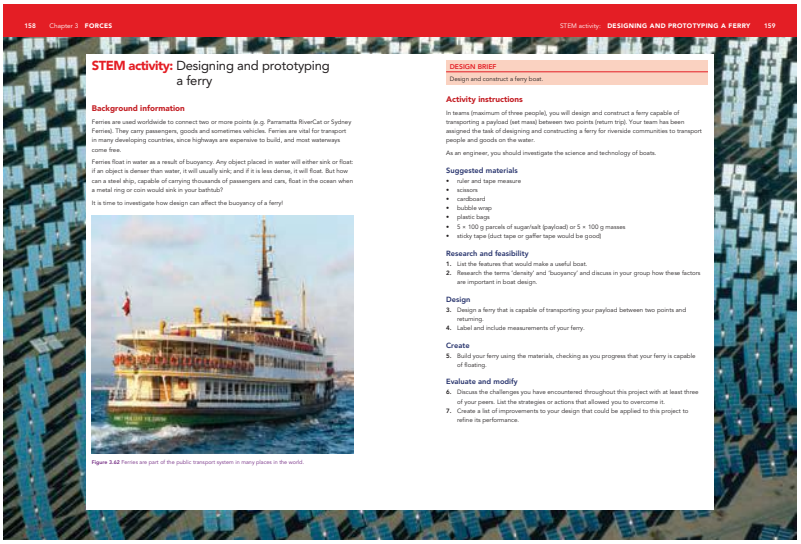


Figure 3.61 Gravity on the Moon and planets relative to that of Earth given their relative masses

Data questions help students apply their understanding, as well as analyse and interpret different forms of data linked to the chapter content. These questions can be completed in the Interactive Textbook or downloaded as Word documents.


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STEM activity: Designing and prototyping a ferry

Background information

Ferries are used worldwide to connect two or more points (e.g. Parramatta RiverCat or Sydney Ferries). They carry passengers, goods and sometimes vehicles. Ferries are vital for transport in many developing countries, since highways are expensive to build, and most waterways come free.

Ferries float in water as a result of buoyancy. Any object placed in water will either sink or float: if an object is denser than water, it will usually sink; and if it is less dense, it will float. But how can a steel ship, capable of carrying thousands of passengers and cars, float in the ocean when a metal ring or coin would sink in your bathtub?

It is time to investigate how design can affect the buoyancy of a ferry!

Figure 3.62 Ferries are part of the public transport system in many places in the world.

DESIGN BRIEF

Design and construct a ferry boat.

Activity instructions

In teams (maximum of three people), you will design and construct a ferry capable of transporting a payload (set mass) between two points (return trip). Your team has been assigned the task of designing and constructing a ferry for riverside communities to transport people and goods on the water.

As an engineer, you should investigate the science and technology of boats.

Suggested materials

- ruler and tape measure
- scissors
- cardboard
- bubble wrap
- plastic bags
- 5 × 100 g parcels of sugar/salt (payload) or 5 × 100 g masses
- sticky tape (duct tape or gaffer tape would be good)

Research and feasibility

1. List the features that would make a useful boat.
2. Research the terms 'density' and 'buoyancy' and discuss in your group how these factors are important in boat design.

Design

3. Design a ferry that is capable of transporting your payload between two points and returning.
4. Label and include measurements of your ferry.

Create

5. Build your ferry using the materials, checking as you progress that your ferry is capable of floating.

Evaluate and modify

6. Discuss the challenges you have encountered throughout this project with at least three of your peers. List the strategies or actions that allowed you to overcome it.
7. Create a list of improvements to your design that could be applied to this project to refine its performance.

STEM activities encourage students to collaboratively come up with designs and build solutions to real-world problems and challenges.

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Links to the Interactive Textbook (ITB)

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

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

These icons indicate documents, worksheets, activities or question sets can be downloaded from the Interactive Textbook.

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

SCORCHER
Competitive questions can be found in the Interactive Textbook for every chapter review.

These icons indicate questions can be completed in workspaces in the Interactive Textbook.

Overview of the Interactive Textbook

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

Definitions pop up for key terms in the text.

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

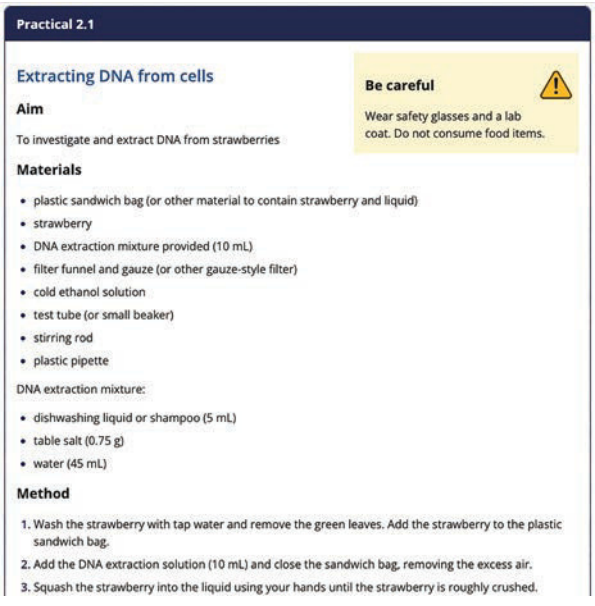
Worksheets are provided as downloadable PDFs, with editable Word documents and answers available in the Online Teaching Suite.

Videos summarise, clarify or extend student knowledge.

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

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

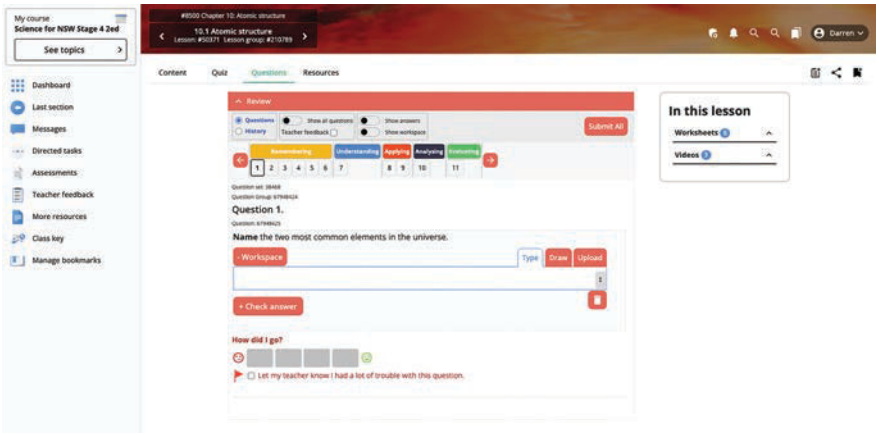




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Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

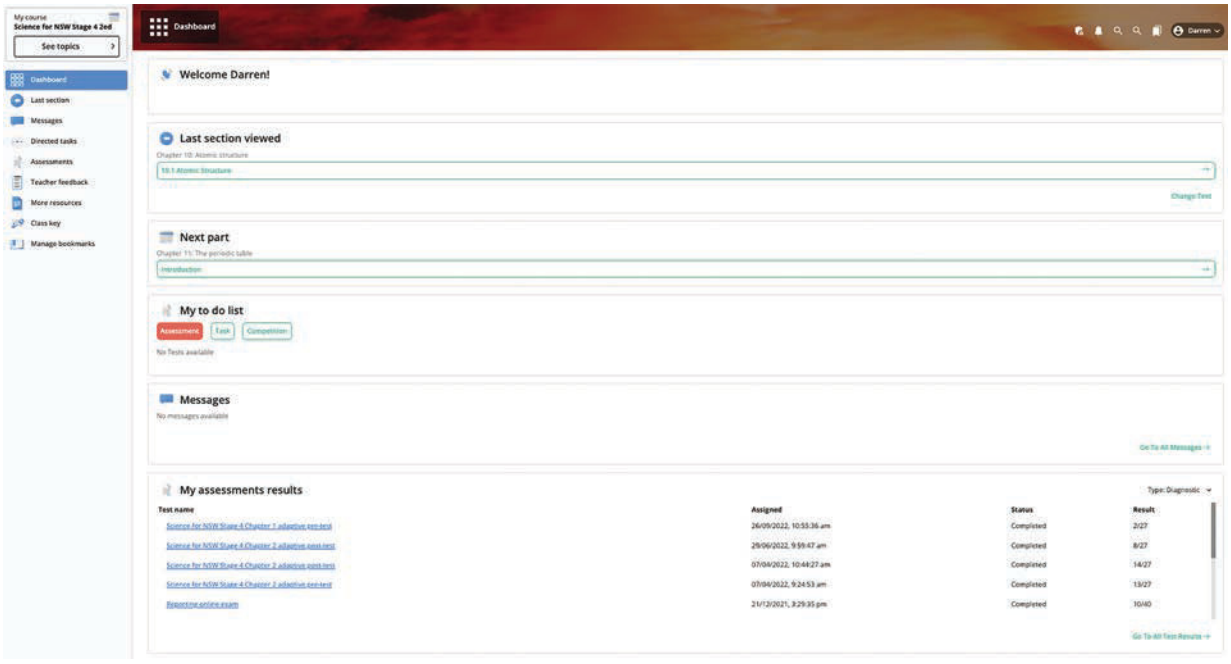
Self-assessment tools enable students to check answers, mark their own work and rate their confidence level in their work. Student accounts can be linked to the learning management system used by the teacher in the Online Teaching Suite.



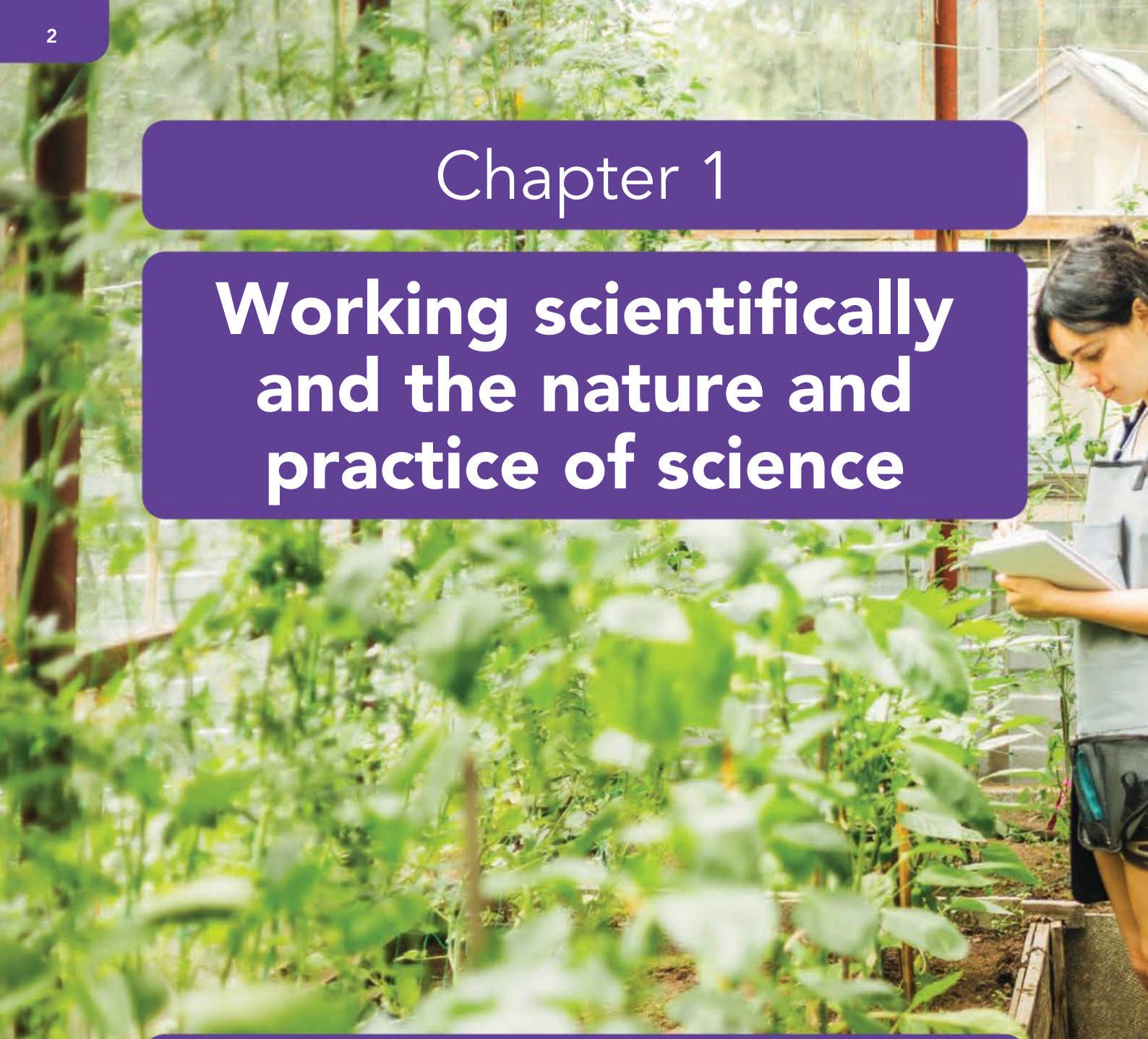
Overview of the Online Teaching Suite (OTS)

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

- the **Edjin learning management** system with class and student analytics and reports, and communication tools
- teacher's view of **students' working and self-assessment**
- **chapter tests** and **worksheets** as PDFs and as editable Word documents with answers
- editable **syllabus grids** and **teaching programs**
- **teacher notes** (including suggested responses if relevant) for Practical skills, Investigations, Try this, Explore! and STEM activities
- **adaptive tools**, including ready-made pre- and post-tests and intuitive reporting.



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Chapter 1

Working scientifically and the nature and practice of science

Chapter introduction

Note: This chapter is designed to be used either for dedicated skills lessons at the start of the course, or used throughout the year when the skills are relevant to the science content, integrated with Chapters 2–14.

Every time you have been curious or observed something in our world or universe, you have started using a scientific method. Science is asking questions about the world around you and seeking to find answers in a systematic way. In this chapter, you will learn more about the nature and practice of science, what a scientist does, who they work with, and the rules and principles that govern their work. It is important that all scientists have a set of similar processes and working scientifically skills that they follow to make sure their findings are valid. You will learn skills for working scientifically – how to carry out research and analyse sources of data, how to record and process your own experimental data, and how to communicate your scientific findings to the world. At the end of the chapter you should check off what you have learned, or note what you still need to learn, against a list of requirements for this course in *Section 1.7 Practice of science*.

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Chapter map



Glossary terms

accuracy
axes
bar/column graph
bias
biology
causal relationship
causation
chemistry
claim
concave
condition
continuous data
controlled variable
convex
correlated
Cultural Lore
data
dependent variable
discrete data
experiment
extrapolation
fair test
geology
holistic
hypothesis
independent variable
inference
interdisciplinary
interpolation
investigable question
knowledge
line graph
mean
meniscus
observe
origin
outlier
parallax error
physics
precision
prediction
qualitative
quantitative
random error
range
relationship (between variables)
reliability
reproducible
research question
systematic error
transdisciplinary
the Dreaming
trend
trendline/line of best fit
trial
variable

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1.1 Nature of science

WORKSHEET
Nature of science

Learning outcomes

At the end of this section, I will be able to:

1. explain the purpose of science in building understanding of the world and universe.
2. describe the different branches of science, and its interconnected nature.
3. explain why science is collaborative, building on the work of others.
4. identify that science is based on experiments, observations and predictions.

The purpose of science

knowledge
the understanding of information

data
information in the form of facts or statistics gathered to answer a question or for further analysis

experiment
a controlled situation where data is gathered to answer a question

The word for 'science' comes from the Latin word for '**knowledge**', *scientia*. Science is not only a collection of knowledge that we have already gathered but also the process of gaining new knowledge. The purpose of science is to ask and answer questions, solve problems and create new technologies.

Scientists are curious and ask questions about the universe, how things work, why they work and what happens if you change things. By collecting and analysing information about the world around us, scientists can suggest answers to each question asked. This is the purpose of science.

Scientists often use experiments to collect **data** in a controlled way. Data is the term used to group together anything observed during an **experiment**. The data generated from observations and experiments allows scientists to draw conclusions, make recommendations and create models that explain the world around us.

Branches of science

Science covers a vast range of topics about the universe, which is why it is divided into different branches, also called disciplines or fields. The scientists in these fields could be carrying out very diverse studies, as shown in Figure 1.1.



Figure 1.1 Scientists at work in the field: **(a)** biologists in the field observing organisms in their natural environment; **(b)** a chemist collecting water samples from a lake; **(c)** a physicist watching the night sky through a telescope; **(d)** a geologist taking samples of rocks.

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- **Biology** is the scientific study of living organisms and their interactions with each other and their environment. It encompasses a wide range of topics, including genetics, ecology, evolution and physiology.
- **Chemistry** is the scientific study of the composition, properties and reactions of matter. It involves the study of atoms and molecules, and their interactions with each other, as well as the laws and principles that govern chemical reactions.
- **Physics** is the scientific study of matter and energy, and their interactions with each other. Physics seeks to understand the fundamental laws of the universe and to explain the behaviour of the natural world, from the smallest particles to the largest structures in the universe.
- **Geology**, or earth science, is the study of the natural processes that shape Earth, as well as the materials (such as rocks and minerals) of which it is made. It includes the physical and chemical properties of these materials and the effects that organisms have on them. Geology is said to be **interdisciplinary** since it combines knowledge from physics, chemistry and biology.

Just as Earth is a part of the universe, so geology is a part of space science, along with many other fields including oceanography and meteorology. Fields used to study Earth can be applied to other planets and objects. Then there are fields that apply to the universe as a whole, such as astronomy and cosmology. Such fields are also interdisciplinary.

Some fields that include science address very broad issues that also have engineering, social and economic aspects. The term **transdisciplinary** is used for such issues. Examples include environmental management and climate change.

biology
the scientific study of living organisms and their interactions with each other and their environment

chemistry
the scientific study of the composition, properties and behaviour of matter

physics
the scientific study of matter and energy, and their interactions with each other

geology
the study of rocks and minerals and the natural processes that shape Earth

interdisciplinary
including more than one scientific branch or discipline

transdisciplinary
merging scientific and non-scientific disciplines such as social science and economics, and non-academic fields such as management, to address a broad issue

Aboriginal and Torres Strait Islander knowledge and science

Aboriginal and Torres Strait Islander Peoples have a deep connection to Country, and a **holistic** world view in which humans are part of an interdependent ecosystem. Caring for Country is both a responsibility and an honour for Aboriginal and Torres Strait Islander Peoples, and they draw upon their ancestral knowledge, **Cultural Lores** and customs in maintaining ecosystems and utilising resources sustainably. Stories from **the Dreaming** describe how Creator Spirits emerged, shaped the landscapes and established the laws of existence through their actions and ceremonies. These stories are passed down through generations as part of oral traditions, preserving cultural knowledge and spiritual connections to Country. There is a huge diversity of Indigenous languages across the nation, yet many stories across these languages share common themes and serve as powerful tools for recording and communicating knowledge.

holistic
considering the whole thing rather than just the parts individually

Cultural Lore
the stories, customs, beliefs and spirituality of Aboriginal and Torres Strait Islander people, which are passed down through generations and act as a guide for everyday life

the Dreaming
the spiritual framework of Aboriginal and Torres Strait Islander cultures that explains the creation and interconnectedness of all things, existing beyond time and guiding relationships with land, community and culture

NOTE

Students should approach terms such as the Dreaming with reverence, recognising them as living knowledge systems and cultural truths, rather than mythological or historical concepts.

Aboriginal and Torres Strait Islander people have been asking scientific questions and making observations on the Australian continent for thousands of years, demonstrating a profound and enduring understanding of Country and Place. Aboriginal and Torres Strait Islander Peoples have deep understandings of:

- the unique seasonal cycles that occur in many parts of Australia, including Victoria
- moon phases, and the effect of the moon on the tides
- the use and preparation of native Australian plants for food and medicine
- local ecosystems and how they are affected by invasive species
- land and water resource management to protect biodiversity
- the cultural significance of Country/Place, which informs protocols used by scientists to respectfully conduct experiments on traditional lands.

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Some examples will be presented throughout this resource.

There are a number of principles that students and scientists should follow when researching Indigenous Knowledge and cultural practices or carrying out scientific research with Indigenous people. These comprise:

- respect for Indigenous Knowledge and culture
- investigating examples from local Indigenous communities and not generalising them to wider regional or national groups
- attributing Indigenous Knowledge to the community that owns it and acknowledging individuals, and seeking consent from knowledge holders
- respect for the cultural significance of Country/Place
- sharing knowledge, which means giving something back to the community which has provided knowledge
- using reliable published sources that have been created by or with Indigenous people.



DOCUMENT Guide to studying Aboriginal and Torres Strait Islander Peoples' perspectives in science

These points are expanded on in the *Guide to studying Aboriginal and Torres Strait Islander Peoples perspectives in science* provided in the Interactive Textbook and teacher resources. Sources are also provided for reliable examples which can be found online.

If you would like to connect with your local Indigenous community, contact either the Local Aboriginal Land Council (LALC) or the Local Aboriginal Education Consultative Group (AECG).

Explore! 1.1

Aboriginal and Torres Strait Islander Peoples' heritage sites and artefacts

Many different Aboriginal and Torres Strait Islander Peoples have thousands of years of Knowledge of Country/Place in New South Wales, and there are some policies in place to protect and communicate this Knowledge.

Use the internet to research the following questions.

1. What is the 'Caring for Country' strategy?
2. Are there any laws to protect Aboriginal Peoples' heritage sites and artefacts in New South Wales?

Quick check 1.1

1. **Write** a definition of 'science'.
2. **State** the name given to information gathered in science.
3. **Name** the controlled situation used in science to gather data.
4. **Identify** the field of science that would study:
   a. an endangered animal
   b. the distribution and origin of rocks
   c. the composition of a new drug.

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Science is collaborative

Asking questions, being curious and observing the world around you are key elements of science. However, conducting a scientific investigation to answer such questions requires a systematic approach that scientists use in their experimental work. Often, many different scientists come together to collaborate and share their expertise to answer questions that they might have in common.

For example, the New South Wales Government might want to collect data on the bleaching of coral in the Lord Howe Island Marine Park. Here is one example of how different scientists might work together.



Figure 1.2 Lord Howe Island

A marine biologist could review related knowledge of how corals feed, grow and reproduce, and provide a summary of background scientific research. The scientist might ask the **research question** 'what factors are causing the coral to bleach?' They might bring in a physicist to consider whether changes in temperature, amount of sunlight or other physical factors could be the cause. Then a chemist might be asked to consider whether acidity or chemical pollution might be a factor. Then, this group of scientists can create a possible **hypothesis** about the cause of the coral bleaching.

They could design an experiment to test the hypothesis. They could gather data about the temperature or acidity readings of the ocean.

An environmental scientist could join the team to **observe** the experimental procedure, and gather, analyse and evaluate the data.

The results could then be communicated back to the New South Wales Government or written in a scientific journal.

Sometimes, researchers begin their work due to someone making a **claim**, which is sometimes a statement that has little evidence but may be worthy of study. Researchers can evaluate a claim by collecting further evidence through procedures like the above. What a scientific team effort!

research question
a question that can be answered practically through scientific investigation or through research

hypothesis
a proposed explanation or an educated guess that can be tested through further investigation and experimentation

observe
use senses and tools to gather information/data

claim
a statement or assertion that something is true or factual, which may require further investigation or evaluation to determine its validity

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The scientific method

The skills of working scientifically are part of what is more generally called 'the scientific method'. There is no single version of the method, but all Western science is based on its principles. Figure 1.3 summarises the skills of working scientifically which will be covered in this chapter. The skills are numbered 1 to 8 in the figure and in the skills headings in the rest of the chapter.

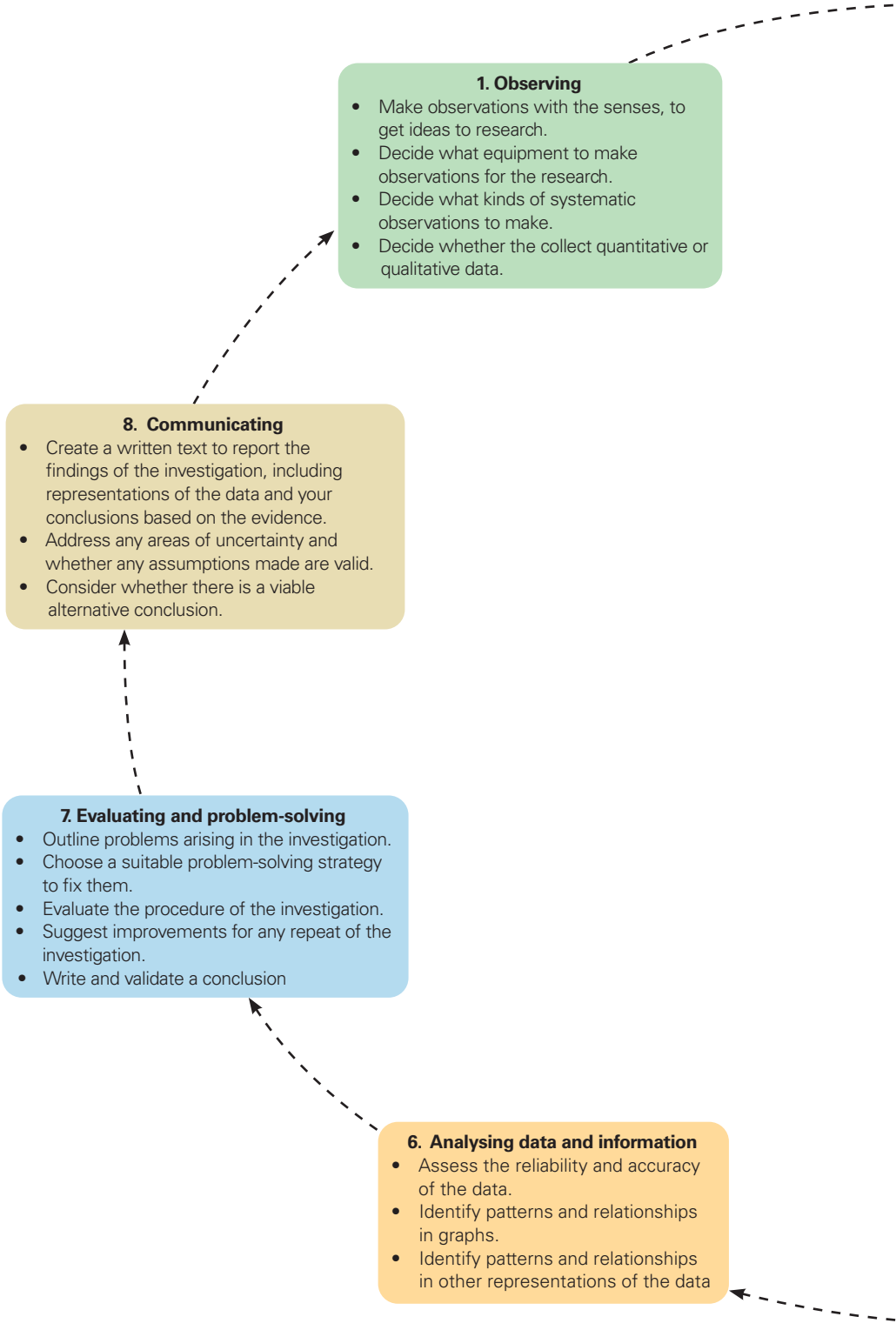
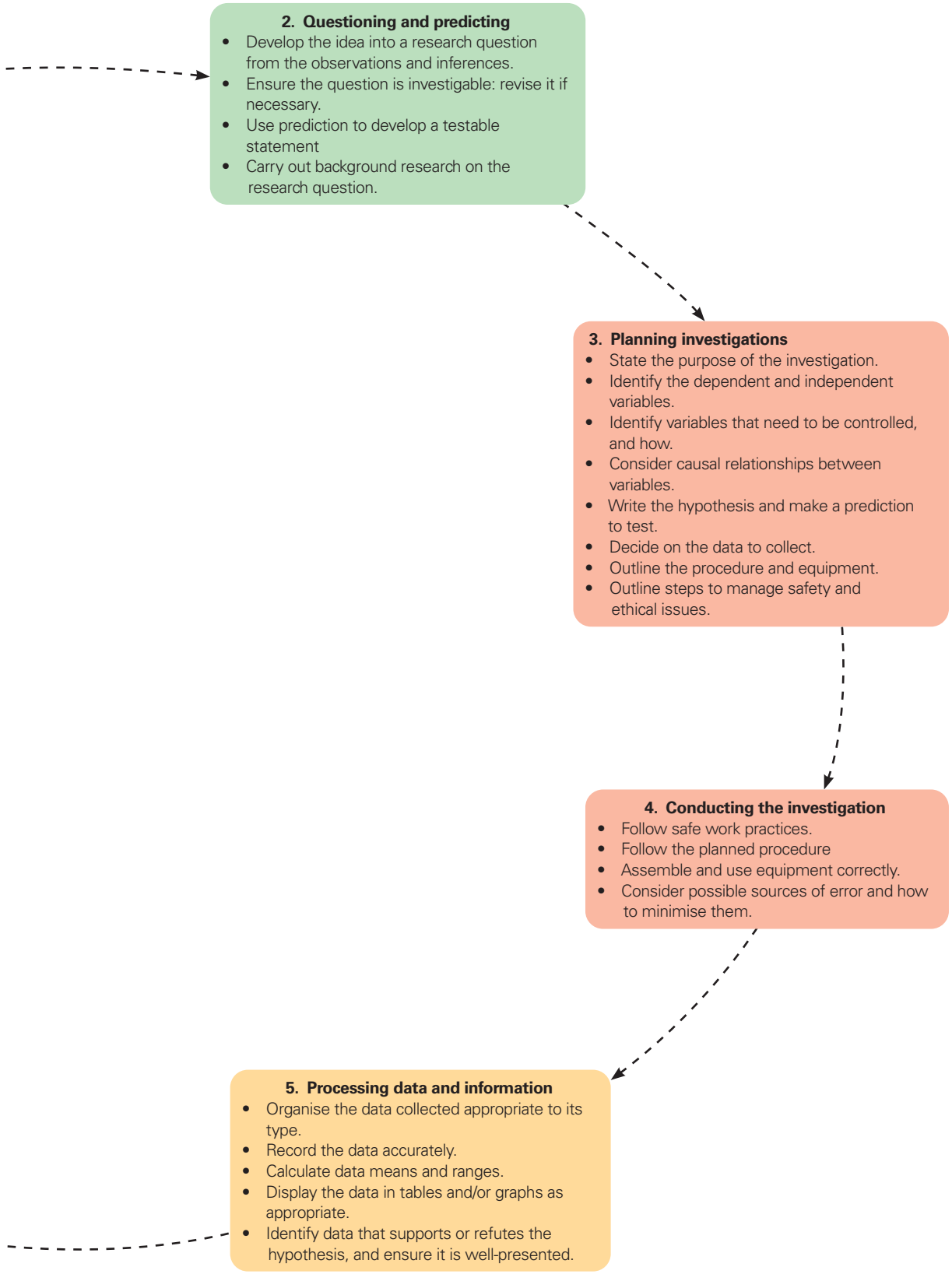


Figure 1.3 The skills of working scientifically arranged in the sequence of how they would typically be used in a scientific investigation.

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Go online to access the interactive section review and more!

Section 1.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 1.1 questions

Remembering

1. **State** a question that a biologist might ask.
2. **Explain** the difference with examples of what interdisciplinary and transdisciplinary mean.
3. **Outline** how scientists collect data.

Understanding

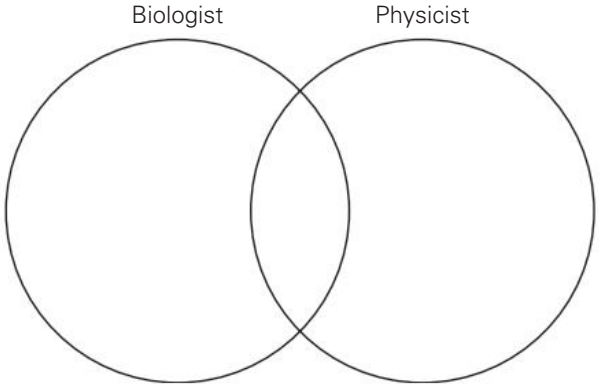
4. **Explain** how science has affected your day so far.
5. **Describe** three things that scientists do and why they do them.

Applying

6. **Describe** an example of how a biologist, chemist and physicist might collaborate on a research project.
7. **Propose** the field of science that would study asteroids.

Analysing

8. **Construct** a flow chart that illustrates the sequence of experimenting, predicting and observing in the scientific method, and add what happens at the end of this sequence.
9. **Compare**, using a Venn diagram, the work of a biologist to that of a physicist.



Evaluating

10. Some fields of science can overlap. **Suggest** what fields of science a biochemical engineer might study.



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1.2 Skills: Observing, questioning and predicting

Learning outcomes

At the end of this section, I will be able to:

1. make relevant observations appropriate to answer a scientific question.
2. identify questions and problems that can be investigated scientifically.
3. make predictions based on scientific knowledge and observations.
4. use a wide range of reliable secondary sources and correct referencing.

Working scientifically skills

The skills introduced in the rest of this chapter occur throughout the resource. You will practise these skills each time you conduct practicals and investigations.

1. Observing

A scientific investigation and its method generally starts with an observation. We observe the world and gather information using our senses: sight, hearing, smell, taste and touch.

Observations made with the senses

Observations made with the senses are only statements about the information gathered. For example:

- The grass is green.
- The flame is hot.
- The flower has a strong smell.

The senses can sometimes give conflicting or unreliable information. For instance, what one person perceives as a strong smell may be faint to someone else, or the colour of an object might appear differently depending on the lighting.



WORKSHEET Comparing observations using senses and measuring equipment

Try this 1.1

Measuring temperature with the senses

You will need a thermometer and three bowls. Fill one bowl with water from the cold tap and one from the hot tap, making sure it is not too hot to put your hand in. Fill the third bowl with lukewarm water (about two-thirds cold water and one-third warm). Place one hand in the cold water and one in the warm water for about a minute. Then place both hands in the lukewarm water

1. What do you feel its temperature to be? Compare the result from both hands.
2. Now use a thermometer to record the temperature of all three bowls of water. Write a conclusion comparing the observations made with the sense of touch to those made with the thermometer. Do yours agree with others in class?
3. Make a list of other disadvantages of using the senses for observations.

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Observations made with scientific equipment

Scientific instruments have been developed to overcome the disadvantages of observations with the senses.

WORKSHEET Laboratory equipment

Choosing equipment

When conducting an experiment in the laboratory, the equipment used needs not only to ensure safety of the experimenter, but also to perform a specific task with precision. Some laboratory glassware, for instance, is used to measure specific quantities of substances, while others hold substances. You will need to know the names of the common equipment found in the laboratory as well as how to draw them for communication in laboratory reports.

In the right column of Table 1.1, you will see the two-dimensional (2D) drawings that show the dimensions of length or height and width. These are called scientific drawings, and you use them when you draw the set-up for an experiment. Use the following rules when creating a scientific drawing:

- Use a sharp lead pencil.
- Use a ruler to draw a straight line (use freehand only for curves).
- Only draw in two dimensions.

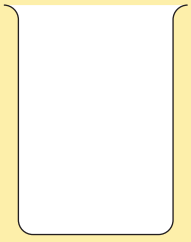
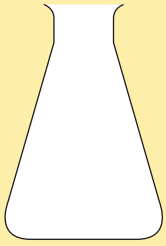
Equipment	What it is used for	How it looks	How it is drawn
Beaker	A common piece of equipment found in most labs. It comes in many sizes and is generally used for holding, mixing and heating liquids.		
Conical flask	This is similar to a beaker, but its shape is different to reduce the likelihood of liquid spilling. It can be used to swirl liquids and prevent hot liquids from boiling over.		
Test tubes	These are used for holding small amounts of substances. As they do not have a flat bottom, a test-tube rack is used to hold them.		
Measuring cylinder	This is used to accurately measure volumes of liquids. It must not be used to mix or heat liquids.		

Table 1.1 Some common lab equipment

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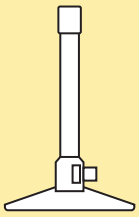
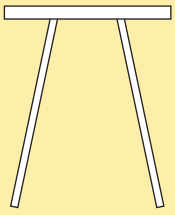
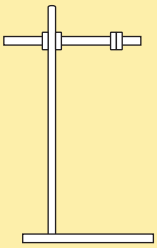
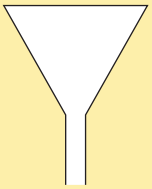
Equipment	What it is used for	How it looks	How it is drawn
Bunsen burner	This is a common device used to add a controlled amount of heat to an object.		
Tripod	This is used to hold an object above a Bunsen burner flame while it is being heated. A wire gauze mat usually sits on top of the tripod.		
Bosshead clamp and stand	A retort stand and bosshead clamp are used to hold objects in place while testing.		
Funnel	This can be used to make it easier to transfer liquids into containers with narrow openings, or to separate substances in filtration.		
Evaporating dish	This is used to heat up and evaporate small amounts of liquid.		

Table 1.1 *(continued)*

Systematic observations

Systematic refers to following a structured, organised method or process. This is a key feature of the scientific method, meaning **systematic observations** are data collected through this approach. Examples include:

systematic observations observations collected and recorded using scientific methods

- recording temperature changes in an experiment at regular intervals
- using consistent, clearly defined criteria to make qualitative observations with the senses
- conducting controlled experiments to ensure reliable results.

In this course you should:

- demonstrate that you can use scientific equipment to make observations
- make relevant observations and measure quantities that are appropriate to answer a question that has been posed.

To practice doing this, *Investigation 1.1 Vitamin C in fruit juices* has been provided in Section 1.3.

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Qualitative and quantitative data

Generally, we can classify data observed in an experiment into two categories: **qualitative** and **quantitative** observations, as described in Table 1.2.

	Data type	
	Qualitative observations	**Quantitative observations**
Definition	Qualitative observations are descriptive and usually come from our senses, such as what we see, hear, smell, taste and feel, and are often used to describe the physical characteristics or properties of something being tested. They refer to a type, which might be represented by a name, letter or number code. For instance, the swimmers may be called Ali and Tom, or A and B, or Lane 1 and Lane 2, etc.	Quantitative observations are numerical values or counts that are expressed as numbers and are often measured with tools such as thermometers, measuring cylinders or (in this example) stopwatches.
Example	Ask who is a better swimmer or ask observers to rate their swimming style on a scale of Poor / Fair / Excellent.	Record the times of the swimmers in seconds using a stopwatch.
Accuracy	This description could be very detailed, but each person who watched the race might give a slightly different description, and so qualitative descriptions are harder to compare. They are subjective (open to interpretation or opinion).	This may be a more reliable piece of data as a number is objective (not open to interpretation or opinion). It can be easily compared to other observations – for example, the next time they race each other, even if a different person is collecting the data. Repeated measurements are also helpful to see if there are outliers.

Table 1.2 Comparing the properties of qualitative and quantitative observations, using swimmers as an example

qualitative
a form of data that is a descriptive measurement

quantitative
a form of data that is a numerical measurement

inference
to link an observation with past knowledge and assign meaning to the observation

Quick check 1.2

1. **Describe** an example of how an observation made with the senses could give unreliable information.
2. **Describe** or draw the following pieces of laboratory equipment and state what they are used for in a science laboratory.
   - **a.** A measuring cylinder
   - **b.** A conical flask
   - **c.** A funnel
3. **Explain** what is meant by a systematic observation, giving an example.
4. **Compare** the accuracy of qualitative observations with quantitative observations using an example of who is the fastest swimmer in a race.

2. Questioning and predicting

Asking research questions

Once an observation has been made, an **inference** can be drawn. In the following examples, an observation is stated, followed by an inference.

Observation	Inference
Chloe has a longer long jump than Siloé.	Chloe is taller than Siloé.
Leon has an upset stomach.	Leon ate some off food.

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These inferences provide a possible explanation to what was observed, but does that mean the inference is true? Not necessarily. But an inference allows a scientist to start to formulate a research question, to identify whether there is evidence to support the inference. For example:

- Does height affect how far someone can jump in long jump?
- Does eating off food cause an upset stomach?

From inferences, research questions are created. A question to research can be about anything, such as: 'Why do people prefer red food over green food?' or 'Does listening to music help students focus in class?'

investigable question
a research question that can be answered through completing an experiment

Both are **investigable questions** that can lead to a possible scientific experiment. Investigable questions are questions that lend themselves to the collection of data through scientific investigation. For a question to be investigable, it needs to meet the criteria outlined in Table 1.3.

Criteria	Description
Specific	The question needs to be clear and unambiguous. It should be well defined so that it can be investigated systematically.
Testable	The question should be testable through experimental procedures. It should be possible to collect data or information that can be used to answer the question.
Relevant	The question should be relevant to the field of study. It should address an important issue or problem and have the potential to contribute to existing knowledge.
Feasible	It should be possible to collect the necessary data or information, and conduct the investigation using the available resources, time and budget.
Novel	Ideally, the question should not have been investigated before or should have a different approach or perspective from previous investigations.

Table 1.3 The criteria for a question to be considered investigable

Consider the question 'Does a person's height affect how far someone can jump in long jump?'.

The question is investigable because we can test the effect of height on long jump length. The question is practical as you would have enough time and the necessary materials to successfully answer the question.

Some questions cannot be tested. Those that can't be tested are called non-investigable and are based around ideas. They are often open-ended and encourage thoughtful discussion and exploration of various perspectives. Try and identify the investigable questions in Figure 1.4.

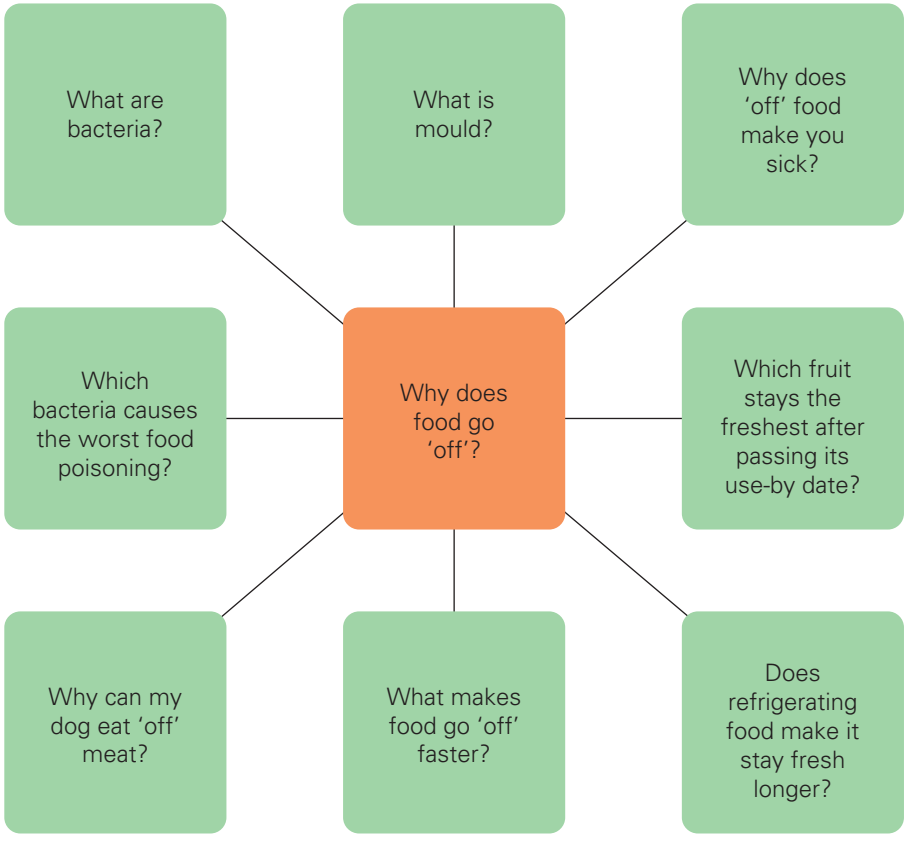


Figure 1.4 Which of these questions are investigable?

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Predicting

prediction
a statement of a testable expected outcome based on observation or scientific knowledge

Prediction is used to develop a research question through a testable statement that an action or situation will have an expected outcome. Suppose you want to formulate a research question about exercise and heart and breathing rates. You think of a general prediction: 'If someone exercises, their heart and breathing rate increases'. This comes from something you observe or some scientific knowledge you've read. Inference is usually involved as well. For example, you might have inferred from observation that exercise increases the need for oxygen. Now you can modify the research question into one that asks about whether the intensity of a particular exercise affects the rate of breathing and heart rate. Making a prediction which is specific and methodical is associated with identifying variables and writing a hypothesis. As this is an essential part of planning an investigation, this will be covered in the next section.

Quick check 1.3

1. **State** three observations you might make at the beach.
2. **Define** the term 'inference'.
3. Ibrahim observed that his wet washing dried quicker in direct sunlight compared to when it was hung in the shade. **State** an inference and a prediction that Ibrahim might make based on this observation.
4. **State** the kind of observation that is gathered using measurement tools.
5. **Describe** the possible strengths of using qualitative data.
6. A certain research question is specific, relevant and novel, but you can't work out how to test it. **Explain** whether it is investigable.
7. **Create** a research question that you would like to investigate if you had the means. Comment on whether it meets the criteria for being 'investigable'.

Background research on existing scientific knowledge

Many research questions might have already been answered by other scientists! It is worthwhile to complete background research prior to designing an experiment as your research question might change when considering research that has already been done.

A web-based search of your question might turn up an overwhelming amount of information. But if you follow the steps below, you can refine your search.

Step 1: Identify key words

A simple technique you can use to break down a research question is reading with a pen. See *Try this 1.2* for ways to do this.

Try this 1.2

Reading with a pen

While reading about your research question, keep a pen handy.

Underline key words or phrases.

Circle words or phrases you don't understand.

? Put this next to something that raises a question.

! Put this next to something that surprises you.

Write important thoughts in the margin or around the question.

For example:

How does palm oil farming in Indonesia affect young people? living in Australia?

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Step 2: Develop specific testable research questions to answer

Questions you could investigate from the inquiry question shown in *Try this 1.2* are:

1. What is palm oil?
2. What is palm oil used for?
3. Who farms palm oil?
4. Where is Indonesia?
5. Why is palm oil farmed in Indonesia?
6. What is the age range of the 'young people'?
7. How can farming in another country affect Australia?
8. What are the effects of palm oil farming?

Make sure the question is investigable and that you would have enough time and the necessary materials to successfully test the answer to the question.

Step 3: Search for sources of information

Often when we have a question, other people have asked the same question and have conducted some form of research to find answers.

The internet is an effective resource for shared global information, but there are also some skills required to use it effectively.

Using the internet

The internet has so much information that it can sometimes be difficult to know whether the information you are reading is correct and without **bias**. It is important to always consider whether the information presented online from a text, image or video is provided as an opinion or whether it is based on fact. For example, if you are finding some background information on the use of petroleum oil in the world, you might find vastly different points of view in a web-based search from an oil company and a renewable energy company.

bias
when a source of information is influenced by personal opinion or judgement

Searching

When searching for information, there are techniques you can use to help refine your search. For example, if you were researching the question 'What are the effects of palm oil farming?' you might use the techniques listed in Table 1.4. You can also search for different types of information using the common file types in Table 1.5.

Search technique	How?	Example
Finding exact matches for grouped words	Use quotation marks to group search words together.	"palm oil farming"
Search for exact matches in titles or headings	Type: intitle:"search word"	intitle:"farming palm oil"
Search for a file type (see Table 1.5 on the following page)	Type: filetype:abbreviation for file type "search word"	filetype:pdf"palm oil"
Try different spellings	Sometimes words are spelled differently on US websites, so try spelling search words the American way.	*colour* (on Australian and UK websites) is spelled color on US websites
Try a variety of sources	Google is not designed to bring the most scientific pages to the front of your search, so try other search engines and databases.	Google Scholar Library search engines World Book Databases to which your school subscribes

Table 1.4 Search techniques

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File type	Use
pptx, pages, key, pez	Presentations
jpeg, psd, png, tiff	Images
pdf, doc, pub	Documents

Table 1.5 Common file types and their uses

Referencing

Once we have searched and found enough information relating to a topic that is being studied, it is important to make notes on where that information came from. This is so the sources can be fact checked at a later date or used by readers for more in-depth study. We do this by creating a reference list. There are many types of reference list formats, but all of them will contain:

- a title
- an author
- the date of publication.

One of the most common reference formats is the Harvard Reference System. If you used the Harvard format to reference this textbook, it would look like this:

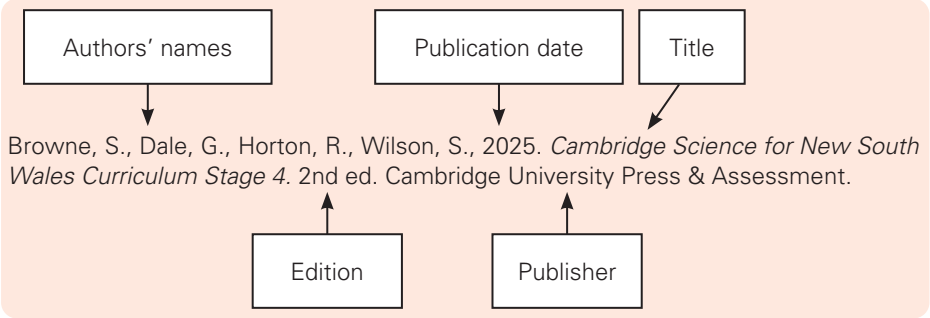


Figure 1.5 Harvard reference system

It is important to make sure that you use the correct format for your school and place your references in an alphabetical list at the end of any research assignment.



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Section 1.2 review

Online quiz

Section questions

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Section 1.2 questions

Remembering

1. **Define** prediction.
2. **Recall** how an observation is different to an inference.
3. **Define** qualitative data and quantitative data.

Understanding

4. **Explain** why an investigable question must be specific.

Applying

5. Classify the following pieces of data as qualitative or quantitative.
   a. Josh scored 74% on the test. Kirra scored 95% on the test.
   b. Students mixed two chemicals and recorded what they saw. Aaron wrote down, 'The mixture went blue. 'Hannah wrote down, 'The mixture went a dark greenish blue. The test tube felt warm to the touch. Small bubbles appeared.'
   c. A scientist recorded the number of times a dingo ate in a 24-hour period.
6. Look around you. **Record** one observation and make one inference from this observation.
7. A tennis ball is dropped from various heights, and a student measures the time taken for the ball to hit the ground. **State** an appropriate prediction for this experiment.

Analysing

8. **Connect** hypotheses, predictions and investigable questions.

Evaluating

9. **Develop** an investigable question to explore how salinity affects plant growth.



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1.3 Skills: Planning and conducting investigations

Learning outcomes

At the end of this section, I will be able to:

1. plan an investigation including safe methods, use of equipment and consideration of ethical issues.
2. identify the independent, dependent and controlled variable(s) and the type of data that needs to be collected.
3. employ safe work practices using appropriate equipment and resources.
4. conduct an investigation using the planned investigative method, including the measurement and control of variables.

fair test
an experiment where all variables are kept constant except for the independent variable being tested

variable
a factor or condition that can be controlled, changed or measured in an experiment

independent variable
the variable that is deliberately changed during an experiment

dependent variable
the variable that is measured during an experiment (as it responds to the independent variable)

qualitative
a form of data that is a descriptive measurement

controlled variable
a variable in an experiment that is kept constant so that it does not affect the observations of the independent variable

3. Planning investigations

Planning should start with the purpose of the investigation. This is determined by the research question. In *Worked example 1.1* on page 22, the purpose is to link intensity of exercise with rates of breathing and heartbeat.

Identify the variables

Once the research question has been determined, a scientist can begin to design the experiment to answer the question. For an experiment to be a considered a **fair test**, only one thing in the experiment should be changed and one thing measured. The things that are changed and measured are called **variables**.

For example, in our research question 'Does a person's height affect how far someone can jump in long jump?':

- the height of the person is changed. This is the **independent variable**.
- the distance of their jump is measured. This is the **dependent variable**.

In an experiment, we want to know if a change in the independent variables causes a change in the dependent variable. To show that the height of a person influences the distance of a long jump, all other variables must be kept the same. These might include using the same long jump pit and the same tape measure, as well as completing the jump in the same weather conditions. These are the **controlled variables**. Failing to control other variables makes it difficult to determine the effect of the independent variable on the dependent variable.

In a laboratory, you may have to make some assumptions about some variables that you would find very hard to control. You should assume that factors such as ambient temperature, the properties of materials used and the purity of substances are all constant.

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Relationship between variables

Much scientific research involves looking for the **relationship** between two or more variables. This is the way in which they are linked or associated. The relationship that is looked for the most is a **causal relationship**, so a scientist can say, for instance, of the variables *x* and *y*, that *x* causes *y*. You may recognise that here *x* is the independent variable and *y* is the dependent variable. For example, the amount of sunlight (independent variable) causes a plant to grow bigger (dependent variable).

Sometimes the relationship is a correlation: Two variables change together, but one does not necessarily cause the other to change.

For example, it was noticed in a certain city that when ice cream sales rose, street crime also rose. It was suggested the ice cream caused crime! Research showed that in fact both of these variables were dependent variables of weather – particularly temperature. On hot days, people went out for ice crime, so there were more people on the streets, and thieves had more opportunities to commit crimes. So, ice cream sales and crime were **correlated**, and did not have a causal relationship.

The importance of relationships between variables is that they help in:

- forming hypotheses
- designing experiments to test cause and effect
- making accurate predictions
- developing explanations of natural phenomena.

relationship (between variables) the link or association between two or more variables

causal relationship a relationship between two variables in which changing one causes the other to change

correlated (of variables) two or more variables that change at the same time but without one causing the other (this relationship is called a correlation), usually because another (possibly unknown) variable is the cause; sometimes further research can turn a correlation into a causal relationship when the cause is discovered

The variables, hypothesis and prediction

After identifying the variables, we can write a specific hypothesis. It is an educated guess that is written before conducting an experiment.

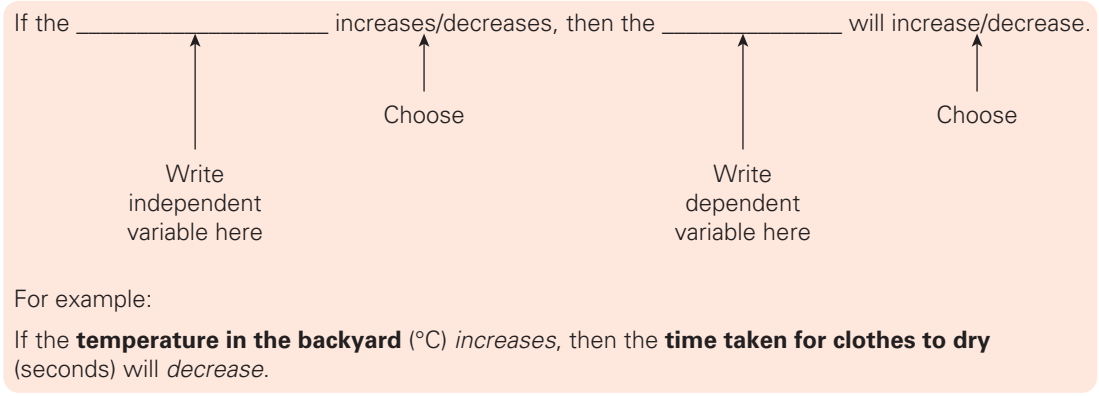


Figure 1.6 An example of setting out a hypothesis for the effect of backyard temperature on how long clothes take to dry

WORKSHEET Identifying variables and hypotheses

Points to remember when writing a hypothesis:

- A hypothesis is an educated guess about the outcome of the experiment.
- The hypothesis must be written as a statement that can be tested (it is capable of being accepted or rejected).
- It should consider how the independent variable will affect the dependent variable. The hypothesis is an 'if … then …' statement. See Figure 1.6.
- Do not use 'I think …', and do not give a reason for your hypothesis.

A prediction from a hypothesis is a statement that describes what is expected to happen if the hypothesis is true. It is typically based on the hypothesis and is used to guide the design of an experiment or the collection of data. The prediction is now a statement about what will happen in a particular situation, based on the hypothesis being tested.

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Worked example 1.1

Developing reasoned predictions, hypotheses and investigable questions

Raj wants to research the effect of exercise on the human body. He knows that after he exercises at the gym, his heart rate and breathing rate increase.

Raj hypothesises that as the intensity of exercise increases, heart rate and breathing rate will also increase.

Based on this hypothesis, Raj predicts that participants who engage in high-intensity exercise will have higher heart rates and breathing rates than participants who engage in low-intensity exercise or in no exercise at all.

This hypothesis and prediction can be tested through empirical research, such as measuring heart rate and breathing rate before, during and after different levels of exercise intensity, and comparing the results between participants of different fitness levels.

This leads Raj to develop the investigable question 'How does the intensity of exercise affect heart rate and breathing rate?'

In pairs, generate some other investigable questions about the relationships between human body systems and everyday events.



Figure 1.7 One investigable question that you might ask is: How does the height of a box jump affect my chance of injury?

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Type of data that needs to be collected

In planning your investigation, consider the type of data you need to collect. Refer back to the items on data from the senses or scientific equipment, and quantitative and qualitative data. This will also affect what method and equipment is needed and how the data will be treated later.

Outline the method and equipment needed

When an experimental procedure is designed, it is written as a step-wise method. These steps should be numbered and detail exactly what should be done in the experiment, including any materials and how much of each material was used. A method should be **reproducible**. So, keep this is mind when writing your own method! When you write your scientific report, you will rewrite your experimental procedure in the past tense for the 'Method' section of your report.

The method should also clearly detail how you are changing the independent variable, measuring the dependent variable and controlling various other variables.

When you are writing an experimental procedure, think about how you would write the instructions for making a cake: the baker needs to know exactly how much flour, sugar, eggs and butter to add, in which order to add them, how to mix them, how long to cook the cake and at what temperature to cook it, otherwise the cake could be a disaster.

Also consider how many **trials** you will undertake. A reliable experiment should have at least three trials so that you can see if the experimental method is producing an **outlier**. This might indicate that it needs improvement.

It is important to detail how many different **conditions** will be used for the independent variable in the method. For example, suppose the research question is 'Does temperature affect how long it takes a substance to melt?' Then the method could time how long equal amounts of the substance take to melt in the fridge, at room temperature, in direct sunlight and in a flame. This uses four different levels of 'temperature', which is the independent variable. This experiment is therefore said to have four experimental conditions.

reproducible
able to be reproduced or copied

trial
a run-through of an experimental method that is usually repeated several times, to obtain data that can be averaged, to reduce any effect of variables not being completely controlled

outlier
an extreme data value that is very different from the other data and could be the result of a faulty procedure

condition
the different levels of the independent variable

Points to remember when writing a method:

1. Write the numbered steps in order.
2. Include specific names and sizes of equipment used and quantities measured.
3. Outline what will be changed in the experiment and how it is changed (independent variable).
4. Outline what results will be measured (dependent variable) and how this will be done.
5. Include the number of trials that will be carried out.
6. Write in the third person (do not use you/I/we).

Investigation 1.1 on the following page is an example that you can do.

Quick check 1.4

1. **Describe** an investigation that you have carried out or would like to carry out, and include the independent variable, the dependent variable, the hypothesis and a prediction.
2. **Construct** a method for making a cup of tea. Give your method to a classmate for them to review while you review theirs. Provide feedback to your classmate on their method. Is it fully reproducible?

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INVESTIGATION

VIDEO
Vitamin C in fruit juices

Investigation 1.1

Vitamin C in fruit juices

Do not taste or drink any of the fruit juices.

Be careful
Ensure appropriate signage is displayed during and after hotplate usage.

Aim
To develop observations and inferences based on a simple task.

Research question
Do citrus fruits contain a higher concentration of vitamin C than other types of fruit?

Materials
- soluble starch (or freshly prepared 1% starch solution)
- 250 mL beakers × 3
- test tube rack
- test tubes (× 1–3 per juice sample)
- sticky labels and marker
- pipette
- stirring rod
- hotplate
- iodine solution
- water
- about 80 mL each of various fruit juices (at least two citrus and two non-citrus)

Planning
1. You need to provide some background information about the investigation. Complete some research and write a brief paragraph to explain the importance of vitamin C in a balanced diet.
2. Identify the independent variable in this investigation.
3. Identify the dependent variable in this investigation.
4. Identify the controlled variables in this investigation.

Procedure
1. Add 1 g of starch about a beaker.
2. Measure out 100 mL of water and add a small amount to the starch, enough to make a paste-like consistency.
3. Add the remaining water to a 250 mL beaker and bring to the boil on the hotplate. Add the starch paste, stir well and turn off the hotplate. This is your starch solution.
4. Add 75 mL of distilled water and 10 drops of starch solution to another beaker.
5. Add a few drops of iodine to this solution until it turns a dark blue-black. This is your vitamin C indicator.
6. Add 5 mL of the indicator solution to a test tube and label it with the juice being tested and the trial number.
7. Add the first sample of fruit juice, drop by drop, to the indicator solution. Make sure the drops fall directly into the solution, instead of running down the side of the test tube.The more vitamin C present in the juice, the fewer the number of drops required to turn the indicator solution colourless. Count and record the number of drops it takes to remove the blue colour. Keep the test tube in the rack.
8. Repeat steps **6** and **7** with a new test tube for the next juice or trial. Continue until all juices have been tested.
9. If time permits, carry out three trials for each type of juice. Record your results in the table.
10. Now make inferences to explain your observations based on your prior knowledge or experience.

continued …

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Results

Table showing how many fruit juice drops were required to cause a colour change

Juice	Number of drops taken to cause a colour change			
	Trial 1	Trial 2	Trial 3	Average

Data analysis

Plot a column or bar graph of the number of drops versus the type of fruit juice.

Discussion

1. Describe any **trends** in your results. Is there any pattern between the type of fruit (e.g. citrus versus non-citrus) and the number of drops needed for a colour change? Or is there another pattern present, such as the colour of the fruit?
2. Another variation is to add the same volume of juice to each test tube and compare. Using your results from the drop-wise experiment, predict what you think the results of that experiment would be.
3. Consider your method and suggest any improvements that you could make if you were to do it again.

trend
a pattern in data that shows the general direction/shape of the relationship between the independent and dependent variables

Conclusion

1. Make a claim about the concentration of vitamin C.

Outline steps to manage safety

Safety has to be planned and built into the method as well as carried out when conducting the investigation.

Scientists can work 'in the field' that is, out in the natural environment – but many scientists may also work in a laboratory. Here, they may conduct experiments that can be hazardous to humans. Thus, it is important that you know the safety basics and the tools that you will be using when you step into a scientific laboratory this year! Laboratory safety rules are in place to protect experimenters from hazards such as cuts from broken glassware, burns from fire and exposure to dangerous chemicals. Referring to Figure 1.9 on the next page, spot the differences between the students who are ignoring the rules (top image) and those following the rules (bottom image). The class in the top image are making dangerous mistakes – discuss what they may be.



Figure 1.8 It is important to always wear appropriate personal protective equipment when working in a lab environment.

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Figure 1.9 Good lab safety is essential.

4. Conducting investigations

Safe work practices

The starting point for conducting a practical investigation in science is safety.

Good lab safety means you:

- always wear safety glasses over your eyes (not on top of your head) when you are handling chemicals or glassware. Chemicals and broken glass can be damaging to your eyes.
- always wear a lab coat that can protect your school uniform from stains and your skin from harmful chemicals.

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- always wear gloves if your teacher gives them to you. These will protect your hands from harmful substances. Always wash your hands after you have removed your gloves to be extra safe. Sometimes, safety glasses, lab coats and gloves are grouped together and called personal protective equipment (PPE).
- always wear enclosed footwear to make sure that nothing can fall onto your feet.
- use a safety mat/heatproof mat whenever you are using a Bunsen burner or chemicals to prevent damage to the bench and other equipment.
- always follow your teacher's instructions.
- never eat or drink in the laboratory to avoid accidental ingestion of harmful chemicals or pathogens.
- never run in the laboratory to reduce the risk of spills, breakages or other hazardous situations that could harm you or others.

It is important that you follow your school's laboratory safety rules to keep yourself safe. But you should also stay focused on identifying hazards as they appear. For example, you might notice a slippery floor due to spilled water, or some broken glassware on the floor that hasn't been cleared. Hazards should be repoted to your teacher immediately so that they can be managed and the risks minimised.

Hazard symbols

If you are using a hazardous chemical in the laboratory, it will have a hazard symbol on the container. These are shown in Table 1.6. The hazard symbol provides details on what type of risk the exposure to the chemical may cause to humans. These risks range from irritating the skin to exploding!

Name of hazard	Symbol	Meaning	Examples
Corrosive	 **Corrosion**	This chemical causes skin corrosion/burns or eye damage on contact, or is corrosive to metals.	Sodium hydroxide Hydrochloric acid
Health hazard Also used to show substances that are hazardous to the ozone layer	 **Exclamation mark**	This chemical will cause immediate skin, eye or respiratory tract irritations.	Many acids and alkaline substances
Flammable	 **Flame**	This chemical will catch fire easily.	Ethanol Hexane

Table 1.6 Chemical hazard symbols

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Name of hazard	Symbol	Meaning	Examples
Hazardous to the environment	 **Environment**	This chemical will cause damage to living things in the environment, especially in soil, waterways or the atmosphere.	Copper sulfate
Explosive	 **Exploding bomb**	This chemical is at risk of exploding, even without exposure to air.	Potassium Lithium
Oxidising	 **Flame over circle**	This chemical contains or acts like oxygen, which causes other substances to burn or react more.	Potassium permanganate Nitric acid
Acute toxicity	 **Skull and crossbones**	This substance will cause severe illness or death if it enters the body.	Mercury Lead
Serious health hazard	 **Health hazard**	This chemical can cause serious long-term health hazards such as damage to organs, cancer or genetic defects if it is swallowed or enters airways.	Turpentine Petrol
Gas under pressure	 **Gas cylinder**	These gases are stored under pressure and may leak, causing fire, poisoning, corrosion, suffocation or 'ice burns'.	Ammonia Liquid nitrogen

Table 1.6 *(continued)*

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Risk assessments

Scientists use the information that hazard symbols provide when they are carrying out a risk assessment before conducting their experiment. Risk assessments show the hazard, the risk that the hazard poses and a way of managing those hazards. An example is shown in Table 1.7.

Type of hazard	Risk	Assess	Control
Glass 	There are many pieces of glass equipment in the lab.	Glass can get hot, form sharp edges that can cut if broken and can also be heavy.	• Always place glassware in the centre of the bench on a flat surface. • Allow to cool before handling. • Inform your teacher of breakages and avoid any broken glass.
Biological 	Biological material, such as organs for dissection, bacterial cultures, microbes or plants, are studied in the lab.	Any living or dead specimen could contain microorganisms that can make you sick.	• Make sure you wash your hands thoroughly. • Wear gloves when your teacher tells you to. • Dispose of all biological material in the correct way.
Chemical 	You will use many chemicals in experiments.	Some of these can be toxic, corrosive or irritate your skin.	• Make sure you always wear gloves and safety glasses and wash your hands. • Never get any chemicals in your mouth or eyes.

Table 1.7 Risk assessment table

The Bunsen burner

Often in the laboratory, you will be required to heat materials in glassware such as a beaker. This can be achieved using a hot water bath or a microwave, but a Bunsen burner is normally used. Although not all Bunsen burners look the same, they all have the same parts, as shown in Figure 1.10.

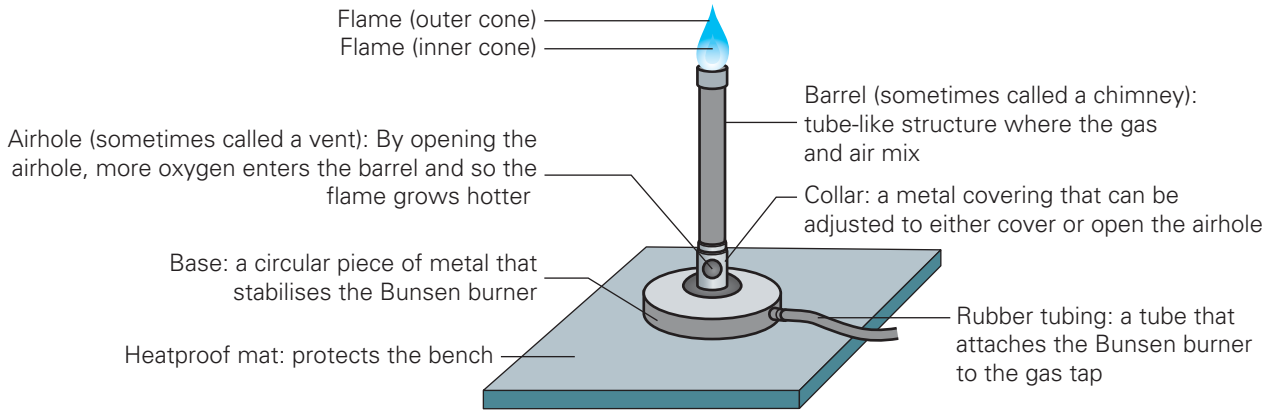


Figure 1.10 A Bunsen burner

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Be careful

Remember these important safety points when using a Bunsen burner:

- Tie long hair back and secure loose clothing such as school ties.
- Roll up sleeves if they are too long.
- Never leave the Bunsen burner unattended.
- Turn the Bunsen burner to a yellow safety flame when not heating.
- Place the Bunsen burner on a heatproof mat.
- Wait for all equipment to be cool before handling.



The temperature and intensity of the Bunsen burner flame can be controlled by changing the size of the airhole. This is adjusted by turning the collar. On lighting the Bunsen burner with a match, the airhole should be completely closed. This limits the amount of oxygen that can mix with the gas, and it produces a less hot 'safety flame'.

You will know that you have a safety flame as it burns with a yellow colour. When you are ready to increase the intensity of the flame, open the collar gradually to allow more oxygen to mix with the burning gas. This will produce a 'blue flame' that is considerably hotter than the safety flame. Remember, when you are not heating something, always use a safety flame.

Figure 1.11 The Bunsen burner blue flame is produced when the airhole is fully open. It allows oxygen from the air to mix with the gas in the barrel, producing a hotter flame.

VIDEO
Using a Bunsen burner

Practical skills 1.1

Using a Bunsen burner

Be careful

Ensure that you follow measures to ensure general fire safety.

Aim

To practise the safe procedure for lighting a Bunsen burner.

Materials

- Bunsen burner
- matches
- heatproof mat

Planning

Read through the method and carry out a risk assessment. List the risks associated with this activity and suggest ways to control or minimise their impact.

1. Explain why the airhole is closed before turning on the Bunsen burner.
2. Explain why the match is struck away from the body.

continued …

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Procedure

1. Check that the rubber tubing is intact, with no damage.
2. Attach the Bunsen burner rubber tubing to a gas tap.
3. Ensure the Bunsen burner hole is closed to give a safety flame.
4. Strike a match away from your body.
5. Turn on the gas.
6. Bring the match up towards the tip of the barrel mouth to light the flame.
7. Shake out the match and place it on the heatproof mat.
8. When heating anything, twist the collar to open the airhole and produce a blue flame.
9. When the Bunsen burner is not being used for heating, twist the collar to close the airhole and produce a safety flame.
10. At the end of the Bunsen burner practical, ensure the gas is turned off. Allow the Bunsen burner to cool down before packing it away.

Practical skills 1.2

Heating water

Be careful

Ensure general fire safety instructions are followed. Ensure appropriate personal protective equipment is used when handling hot equipment.

Aim

To identify and use the appropriate equipment for heating water.

Materials

- 250 mL beaker
- boiling tube (large test tube)
- evaporating dish
- stopwatch
- Bunsen burner
- tripod
- gauze mat
- heatproof mat
- test-tube tongs
- 250 mL measuring cylinder

Planning

Read through the method and carry out a risk assessment. List the risks associated with this activity and suggest ways to control or minimise their impact.

Procedure

The diagrams in Figure 1.12 show how to set up your equipment for each test.

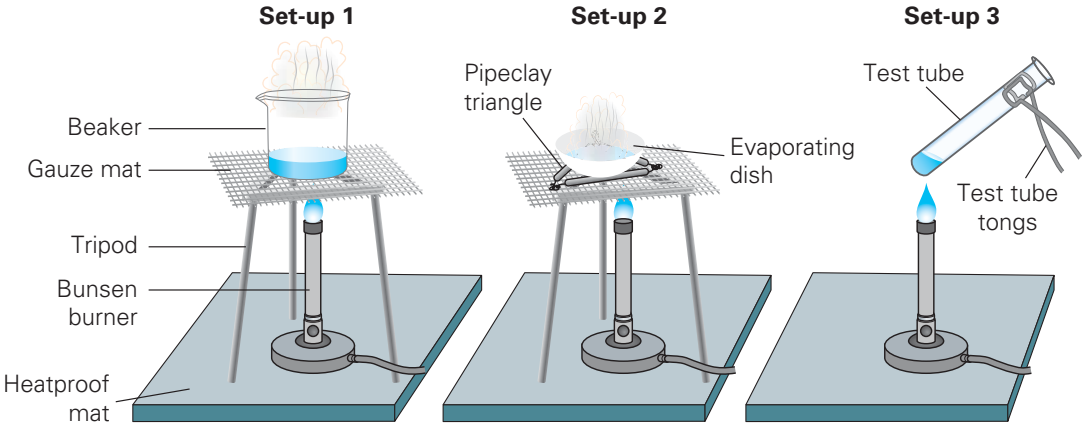


Figure 1.12 Experimental set-ups

continued …

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Set-up 1

1. Add 30 mL of water to a beaker.
2. Place the beaker on the gauze mat over the tripod.
3. Light the Bunsen burner and measure the time taken for the water to reach boiling point.

Set-up 2

4. Fill an evaporating dish with water (not too close to the top to prevent it spilling) and pour it into the measuring cylinder. Record the volume of water it can hold.
5. Repeat steps **1–3**, adding 30 mL of water to the evaporating dish.

Set-up 3

6. Fill a test tube with water and pour it into the measuring cylinder. Record the volume of water it can hold.
7. Repeat steps **1–3**, adding 30 mL of water to the test tube.
8. Hold the test tube over a blue flame using test-tube tongs. Point the test tube opening away from yourself and anyone else and move it in a circular motion above the flame until the water boils. Record the time it takes for the water to boil.
9. Wait until the water has cooled and measure the amount of water left in the beaker, evaporating dish and test tube.

Results

Table showing how long it takes water in different containers to reach boiling point

Container	Maximum volume of equipment (mL)	Volume of water left after boiling point was reached (mL)	Time taken to reach boiling point (s)
Beaker			
Evaporating dish			
Test tube			

Discussion

1. Describe any trends in your results.
2. Identify the best piece of equipment for holding and heating a small sample of liquid (hint: consider the time taken to reach boiling point and how much water was left after reaching boiling point).
3. Identify the best piece of equipment for evaporating some of the water.
4. Identify any challenges you faced and how you overcame them.

Quick check 1.5

1. **State** the first thing you should do if you see a hazard in the science lab.
2. **Recall** the name of the safety equipment that will protect your eyes.
3. **Sketch** a hazard symbol that would be found on a bottle of propanone, which is highly flammable.
4. **List** six safety points to observe when using a Bunsen burner.

Ethics in investigations

Ethics means knowing right from wrong, and choosing right. In science this includes being honest about results, treating people and animals with care, and protecting the environment. For example, if your experiments' results don't support your hypothesis, it is not ethical to change the results. Note that in schools, research on vertebrate animals is generally not allowed (except for observations in the field that do not disturb the animals), because of the strict ethical requirements.

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Explore! 1.2

Ethics in research

As well as being practical, when research questions involve experimenting on humans or other organisms, ethics must be considered. Consider the research question 'Why does "off" food make you sick?' Consider doing this experiment. Would you be allowed to purposely cause someone harm by feeding them off food?

Use the Internet to research some other ethical considerations that must be made when conducting experiments.



Figure 1.13 Feeding someone food that is 'off' wouldn't be an ethical experiment.

Using equipment

Measuring tools

When scientists use tools to collect data, it's important to select and use equipment that is appropriate to the investigation so that the results are accurate.

Accuracy is the closeness of a measurement to the true value, and there are many pieces of equipment available to help increase this. The choice will depend on what you want to measure. For example, you should select a thermometer that can measure within the range of temperatures expected, or select a measuring cylinder with an appropriate capacity for the volume of liquid needed in the experiment.

WORKSHEET Taking measurements

accuracy how close a measurement is to the true value

precision how close measurements are to each other

Length

You can use rulers to measure the length of a straight object. You can also use measuring tape for a non-straight object or even a trundle wheel for large distances. It is important to use the most precise tool and unit when measuring. For example, if you are measuring the size of a snail, you would use a ruler and millimetres. If you are measuring the size of a person, you would use a measuring tape and centimetres, and if you are measuring the length of the school grounds, you would use a trundle wheel and metres. The ruler has smaller markings and greater **precision** than the trundle wheel. Some professions use a laser distance-measuring tool. This tool uses a laser to make even more precise distance measurements. Digital tools tend to generate more precise data.

WORKSHEET Comparing analogue and digital measuring tools

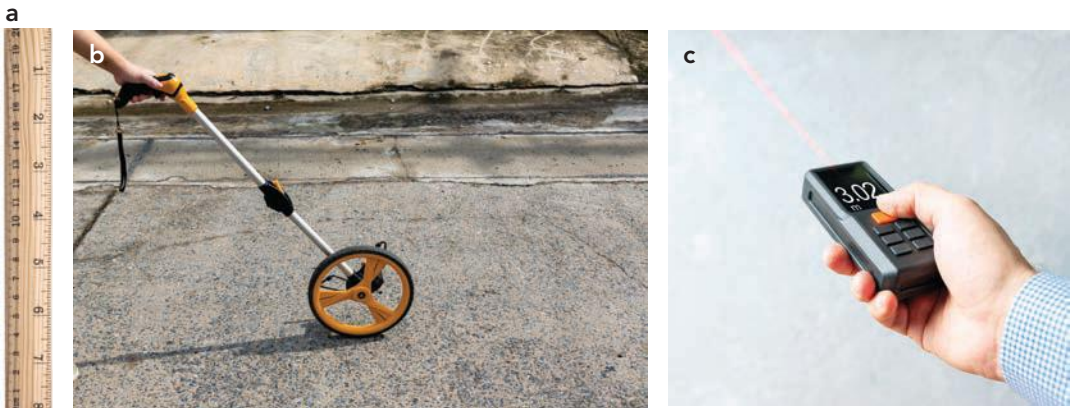


Figure 1.14 (a) A 20 cm ruler, **(b)** a trundle wheel and **(c)** a laser distance measure for precise distances. Generally, to measure the length of an object, you use the units millimetre (mm), centimetre (cm), metre (m) or kilometre (km).

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Volume

In mathematics, volume is commonly measured in units of cubic centimetres (cm^3) or cubic metres (m^3). However, in a laboratory, it is usually the volume of a liquid that needs to be measured, and so units of millilitres (mL) and litres (L) are used.

Volumes can be measured using a measuring cylinder, but if precise measurements need to be made, a special piece of equipment called the pipette can be used.



Figure 1.15 (a) A measuring cylinder and **(b)** a scientist using a glass pipette for dispensing a volume of liquid

Temperature

Temperature in a laboratory is usually measured using a thermometer in units of degrees Celsius (°C). For more precise measurements, a digital thermometer probe can be used. Sometimes, scientists may use digital tools such as sensors that can record environmental data periodically.

Time

Scientists use stopwatches for precisely recording time values. Stopwatches are great for measuring time in seconds (s), minutes (min) or hours (h), but they can also be used for experiments lasting days.

Mass

Electronic scales precisely measure mass in the laboratory. The units of milligrams (mg), grams (g) and kilograms (kg) are used to measure mass. Larger masses can be measured in tonnes (1 tonne = 1000 kg). Force meters may also have a reading available for mass, and this type of equipment will be discussed later in this text.

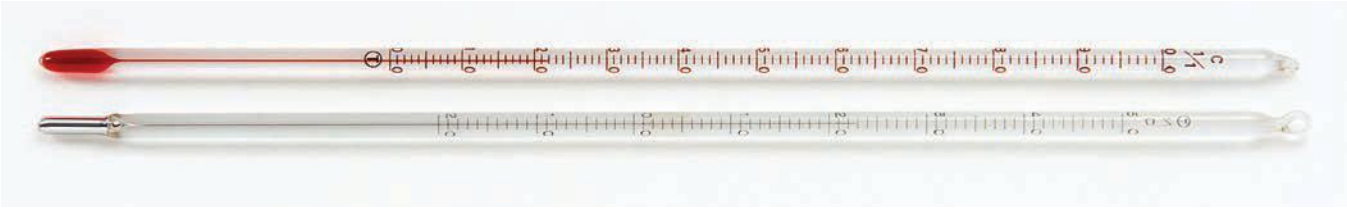


Figure 1.16 The liquid in the glass thermometer shown uses the measurement unit Celsius (°C). The thermometer with a red-coloured liquid is modern and uses alcohol, while the thermometer with the grey-coloured liquid is mercury. Why might have mercury thermometers have been phased out of production?

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Digital tools

Digital tools have revolutionised the way scientific data is collected, managed and analysed, and devices such as data loggers (see Figure 1.17) can make data collection more efficient for larger sample sizes. Digital tools such as online surveys, mobile apps and wearable devices can be used to collect large amounts of data quickly and accurately.

One advantage of digital tools for data collection is that they can reduce the potential for human bias and random error. For example, online surveys can be programmed to skip irrelevant questions, ensuring that respondents only answer questions that apply to them. Wearable devices can capture physiological data automatically (see Figure 1.18), reducing the risk of measurement errors that can occur with traditional data collection methods, as all participants provide data in the same way.

Digital tools can also help data management and analysis, particularly for larger sample sizes. Digital tools can automate data entry, reducing the time and resources required for these tasks, and facilitate complex data analysis, allowing researchers to analyse large amounts of data quickly and efficiently.



Figure 1.17 Many weather-monitoring systems employ data loggers.



Figure 1.18 Digital tools can ensure that physiological data is recorded accurately.

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Practical skills 1.3

Taking readings with measuring equipment

Aim

To practice taking readings using specific pieces of equipment.

Materials

Station 1

- spring balances: 100 g, 500 g, 1 kg, 5 kg
- 100 g masses

Station 2

- 3 sugar cubes
- electronic balance

Station 3

- 2 ice cubes
- 50 mL water
- beaker
- thermometer

Station 4

- stopwatch

Station 5

- ruler
- A4 sheet of paper

Procedure

In groups of three, rotate through the stations, taking individual readings and filling out the results table. Alternatively, you could work alone and collect results from two other people.

Station 1

1. Place the mass onto each spring balance and measure the mass in grams.
2. Copy and complete the table shown in the results section.

Station 2

1. Measure the mass of one sugar cube using the electronic balance.
2. Keep the sugar cube on the electronic balance and zero the balance.
3. Add two more sugar cubes and record the mass.

Station 3

1. Place 50 mL of water into a 250 mL beaker.
2. Use the thermometer to measure the initial temperature.
3. Add two ice cubes, wait for 30 seconds and then measure the temperature.
4. Record the results in your table.

Station 4

1. Attempt to stop the stopwatch at exactly 2 seconds.
2. Record the results from three attempts.

continued ...

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Station 5

1. Measure the diagonal length of the A4 sheet of paper.
2. Measure the width of the A4 sheet of paper.
3. Measure the length of the A4 sheet of paper.
4. Record the results from three attempts.

Results

Station	Person 1 reading	Person 2 reading	Person 3 reading	Mean
1: 100 g balance (g)				
1: 500 g balance (g)				
1: 1 kg balance (g)				
1: 5 kg balance (g)				
2: initial (one cube) (g)				
2: (zero)				
2: (two cubes added) (g)				
3: (°C) initial				
3: (°C) final				
4: first try (s)				
4: second try (s)				
4: third try (s)				
5: diagonal (mm)				
5: width (mm)				
5: length (mm)				

Discussion

1. Station 1: Decide when each of the spring balances would need to be used in an experiment.
2. Station 2: Explain why it is important to zero the electronic balance before each use.
3. Station 3: Propose a reason why it is important to think about time when measuring temperature.
4. Station 4: Explain why it is important to do multiple trials and average the results.
5. Station 5: Discuss why millimetres were used for units to measure the paper, rather than metres.
6. If there were differences in the temperatures recorded by different people at station 3, suggest possible reasons for the differences.

Minimising error

Errors refer to the differences between the values we observe and the true values. They can result in inaccurate or even false results. **Random errors** are unpredictable and often caused by the experimenter, such as not timing something correctly. These are sometimes referred to as 'human error', but this term should be avoided. **Systematic errors** are consistent and may be caused by faulty equipment or flawed methodology. For example, a scale that consistently reads 20 grams higher than the actual mass of an object introduces a systematic error. This error is consistent, meaning that every time the scale is used, it will show readings 20 grams higher than the true mass, regardless of the object being weighed.

random error
an error that is caused by factors that cannot be easily controlled by the experimenter

systematic error
an error that causes measurements to differ from the true result by a consistent amount, often due to faulty or uncalibrated equipment

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Meniscus

When measuring liquid volumes in measuring cylinders or pipettes, it is common for the liquid to curve at the position where the volume is read. This curve is called the **meniscus**, and it is when the liquid interacts with the sides of the glassware to make either a **concave** or a **convex** shape (see Figure 1.19). In your experiments, you will come across both types of meniscus, and it is important to know where to take a reading of volume to be accurate and precise. For a concave meniscus, take the reading from the bottom of the meniscus, and for a convex meniscus, take the reading from the top.

meniscus the surface of a liquid in a container

concave a surface that curves inwards

convex a surface that curves outwards

parallax error an error caused by not reading liquid measurements at eye level, which leads to measurements being too high or too low

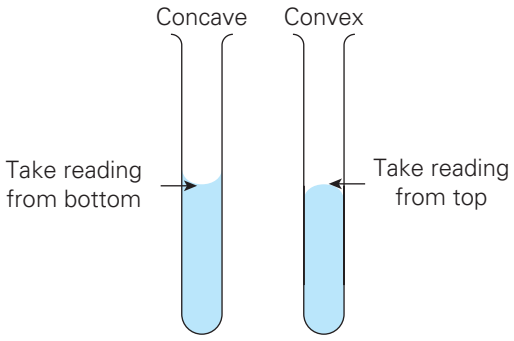


Figure 1.19 Reading a meniscus

Parallax error

When making a measurement from the meniscus of a liquid, you can also encounter an error known as **parallax error**. This occurs when you are making a reading of volume from a meniscus without being at eye level with the meniscus. Your line of sight should be parallel to the position at which you are taking the reading. If it is not, the data recorded may be inaccurate.

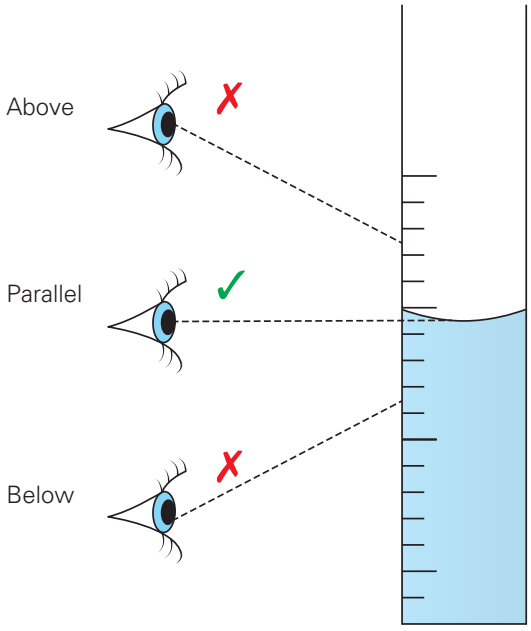


Figure 1.20 How a parallax error can occur

Quick check 1.6

1. **Define** the term 'meniscus'.
2. **Explain** why measurements are taken from either the top or the bottom of the meniscus.
3. **Explain** how a concave meniscus forms.
4. **Describe** how you would minimise parallax error.

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Section 1.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Go online to access the interactive section review and more!

Section 1.3 questions

Remembering

1. **Name** the kind of relationship between variables A and B if an increase in B causes an increase in A.
2. **List** three pieces of personal protective equipment you might use in the lab.
3. **Define** accuracy and precision in the context of scientific measurements.
4. **Name** three types of digital tools that can be used for data collection in scientific research.

Understanding

5. **Outline** the steps involved in safely lighting a Bunsen burner.
6. **Describe** some features of a reproducible investigation.
7. **Describe** the difference between random errors and systematic errors in scientific experiments.

Applying

8. **Organise** the lab equipment featured in this chapter into categories: containers, heating equipment, measuring tools and others.
9. **Identify** the most appropriate equipment for measuring the mass of a small sample of powder in a laboratory.
10. **Write** a hypothesis of what will happen if a glass of ice is removed from a refrigerator and placed on the kitchen bench for an hour on a hot day.

Analysing

11. **Compare** the uses of a conical flask and a beaker.
12. A scientist undertook the following experiment.
    1: Observed that a pot plant seems to grow better the closer it is to a window.
    2: Conducted an experiment where a flowering plant was placed in the window and a cactus was placed in a dark room. The flowering plant was watered and the cactus was not. The flowering plant was also given fertiliser but the cactus was not.
    3: Collected the data and concluded that plants grow better when they are exposed to more sunlight.
    a. **Identify** the error in the scientist's method.
    b. **Describe** the effect this has on the findings.
13. **Analyse** how the presence of a systematic error in your measuring equipment impacts the results of an experiment over time.

Evaluating

14. **Discuss** why risk assessments are a necessary part of completing any experimental work.
15. **Propose** what a meniscus would look like if the molecules of a liquid inside a container were equally attracted to themselves and the container.
16. **Discuss** the advantages and disadvantages of using digital tools versus traditional tools for collecting scientific data.

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1.4 Skills: Processing, presenting and analysing data

Learning outcomes

At the end of this section, I will be able to:

1. process and organise data and information and present it appropriately.
2. calculate mean and range and convert between units.
3. analyse data and information as to their reliability and compare them to other sources.
4. identify patterns and relationships in graphs, tables and spreadsheets.

5. Processing data and information

This section applies to data that you have created in an investigation and information including data that you have obtained from secondary sources. These sources may be texts, diagrams, flow charts, tables, databases, graphs and multimedia resources. You need to consider the purpose of the information and how you are going to use it in order to decide which representation will be suitable for it.

Data from an experiment

When data from an experiment is collected, it is important to represent it in such a way that it can be easily analysed. The analysis of the data will help you answer your research question and provide evidence to support or not support your hypothesis. Data is usually first recorded in an organised table and then represented in a graph. The appropriate data representation to use depends on the type of data (quantitative or qualitative) that was collected.

continuous data quantitative data points that have a value within a range; this type of data is usually measured

discrete data quantitative data points that have whole numbers; this type of data is usually counted

Quantitative data is data that is numerical in nature and can be categorised as either **continuous** or **discrete**. Continuous data includes all numerical values within a range, while discrete data only considers integer-number (whole-number) values. Qualitative data is data that is worded, descriptive or categorical in nature, such as red or blue, and dog or cat.

Table 1.8 lists the differences between continuous and discrete quantitative data as well as the appropriate graph type to represent the data.

	Continuous data	Discrete data
Features	Usually measured	Usually counted
	Takes any value within a range, e.g. might have decimal places	Usually takes whole-number values
Examples	*Human height* If you measured the height (in metres) of every person in the classroom, the data might look like: 1.75, 1.77, 1.80, 1.83, 1.99 … *Other examples:* time, weight, temperature (measured with a thermometer or temperature probe)	*Number of plants* If you counted the number of plant seedlings that grew in an experiment, the data might look like: 1, 0, 5, 8, 17 … It is impossible to have 1.39 plants. You can only have whole numbers of plants. *Other examples:* number of siblings, number of crystals formed after a chemical reaction
Usual graph	Line graph	Bar graph

Table 1.8 The differences between continuous and discrete quantitative data

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Recording data with precision

When presenting any numerical values, it is important to determine the appropriate level of precision. This may involve rounding values to a certain number of decimal places, depending on the significance of the data and the level of accuracy obtained during the experiment. There should be consistency in the number of decimal places used when recording data. However, it is essential to avoid excessive rounding that may result in the loss of important information.

Positive and negative signs are particularly important when dealing with standard units that involve both positive and negative values. For example, when measuring temperature changes, including the appropriate positive or negative sign indicates whether the temperature has increased or decreased relative to a reference point.

In cases where very large or very small numbers are encountered, scientific notation can be utilised to represent the data concisely. This involves expressing numbers as a coefficient multiplied by a power of 10.

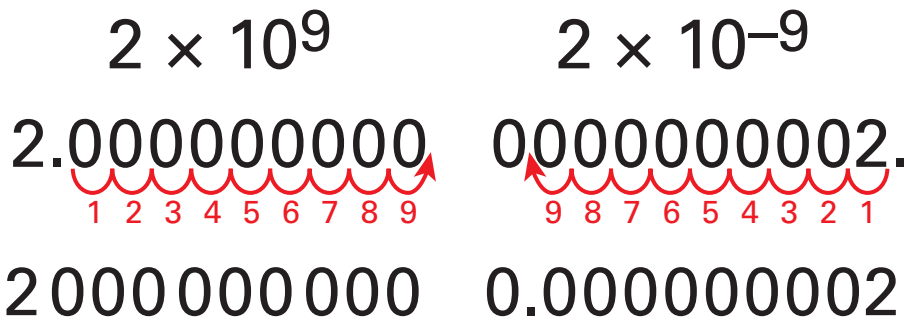


Figure 1.21 Scientific notation helps simplify the presentation of very large or small numbers, making it easier to compare values.

Converting between units of measurement

Converting between units is essential for maintaining consistency and accuracy in scientific and everyday contexts. The metric system used in science is based on powers of ten, making conversions straightforward. For volume, common units include litres (L) and millilitres (mL), with the conversion factor being 1 litre equals 1000 millilitres.

For instance, to convert 2.5 litres to millilitres, multiply 2.5 by 1000 to get 2500 millilitres.

When converting mass, the primary units are kilograms (kg) and grams (g). Here, 1 kilogram equals 1000 grams.

To convert 3.75 kilograms to grams, multiply 3.75 by 1000 to get 3750 grams.



Figure 1.22 This time could be recorded as 3 minutes and 26 seconds, but to make analysis easier, it should be converted to 206 seconds.

In the lab, time conversions will involve seconds, minutes and hours. Measuring time with a stopwatch is typically easier in minutes, but scientific calculations often require time in seconds. To convert minutes to seconds, use the conversion factor 1 minute equals 60 seconds.

For example, to convert 8 minutes to seconds, multiply 8 by 60 to get 480 seconds. Similarly, converting hours to minutes involves multiplying by 60, as 1 hour equals 60 minutes.

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Calculating the mean and range

mean
the average of a set of data, calculated by adding up all the values in the set and dividing by the total number of values

range
the difference between the largest and smallest values in a set

Calculating the **mean** and **range** can be simple ways to gather more information on a dataset. For example, your teacher might calculate the mean of test scores to understand how well the class is performing compared to other classes. The mean provides an average score, giving a sense of the overall performance level.

However, the results must be analysed carefully. While the mean tells you the average, it does not give any information about the spread or variability of the data points. To understand the spread, you also need to consider the range, which is the difference between the highest and lowest scores. The range provides insight into how varied the test scores are, indicating whether students' performance is consistent or widely dispersed.

For instance, if the mean score is 75 but the range is 40 (with scores ranging from 55 to 95), it shows a wide variation in students' performance. In contrast, a smaller range would indicate more consistency among students' scores. Therefore, both the mean and the range are important for understanding the data.

Worked example 1.2

Calculating the mean and range

A pool owner takes five temperatures in a pool: one from each corner and one from the middle of the pool. The temperatures were 17°C, 15°C, 13°C, 16°C and 15°C. Calculate the mean and the range of the temperatures of the pool.

Equation	Solution	Explanation
$\text{mean} = \frac{\text{sum of all data values}}{\text{number of all data values}}$	17°C + 14°C + 14°C + 16°C + 14°C = 75°C $\text{Mean} = \frac{75°C}{5} = 15°C$	The sum of the measurements is 75°C. Divide the sum by the number of measurements, which in this case is five.
range = highest number – lowest number	17°C – 14°C = 3°C	The highest number is 17. The lowest number is 14.

Try this 1.3

Collecting smartphone data

As a class, collect data about the number of hours each student spends on their smartphone per week. Look for the 'Screen Time' or 'Digital Wellbeing' feature. It might be located under the 'Usage' or 'Battery' section. Depending on your device and operating system, you may find a weekly summary or a detailed breakdown of your smartphone usage. You can now collate data from the class to create a summary of this data. Consider the different ways you might want to analyse the data, perhaps based on gender or age or type of phone.

Quick check 1.7

Consider the following dataset: 22, 23, 23, 24, 25, 26, 27, 29, 31
For the data, **calculate** the:

1. mean
2. range

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Displaying data in tables

It is a good idea to construct a table before the experiment begins, so you can record the data as you go.

All tables have:

- a title that describes what is in the table (not 'Results table')
- lines drawn with a ruler
- column headings showing the unit that is measured.

Data for all trials should be included in the table, as well as means, differences or changes (if appropriate to the experiment). Units should only appear in the column headings.

Example of how to set up a table

An example of a table of data is shown in Figure 1.23. The title of this table is 'How the mass of sodium bicarbonate added to vinegar affects the height of bubbles produced over time'.

The values in a table should all be written to the same number of decimal places.

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

Table: How the mass of sodium bicarbonate added to vinegar affects the height of bubbles produced over time

Mass of bicarbonate (g)	Height of bubbles (mm)			
	Trial 1	Trial 2	Trial 3	Mean
1.0	89	91	90	90
2.0	105	104	106	105
3.0	139	141	140	140
4.0	162	165	159	162

The **dependent variable** is placed in the top row, and results for each trial are shown.

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

Figure 1.23 How to set up a table of data

✔

Time (s)	Volume of liquid (mL)
1.0	89.1
2.0	105.2
3.0	139.0
4.0	162.5

✘

Time (s)	Volume of liquid (mL)
1.0	89.1
2.0	105.2
3.0	139
4.0	162.5

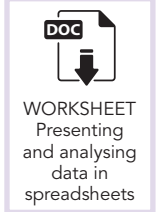
Figure 1.24 Data values in a column should all have the same number of decimal places.

In Figure 1.24, the table on the left is correct, but the table on the right is wrong because the third value, 139, is not given to the same number of decimal places as the other data.

When collecting data, you should consider the spread of your repeated measurements. If there is wide variation in your data after you repeat a measurement several times, it may be due to random error. This would be considered lower-quality data. Once you have recorded your data in a table, it is good practice to write a short sentence summarising what the table shows.

For example, from the table in Figure 1.24, you could say, 'The results provide evidence that, as time (s) increases, the volume of liquid (mL) also increases'. Note that units should always be included.

Spreadsheets provide a useful alternative to a table; statistical measures can be calculated automatically, and digital graphs can be generated.



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Quick check 1.8

1. **Identify** the mistake in each of the following tables.

a

Time (s)	Temperature
0	40°C
60	50°C
120	60°C
180	70°C

b

Distance (km)	Time (s)
1	66.6
2	140.00
3	293.45
4	603.32

2 **Construct** a table to show the following data. Include an appropriate title.
Max is making toffee. He is using a thermometer to measure the temperature of the sugar. At 5 minutes, he finds that the temperature of the sugar is 100°C. At 10 minutes it is 108°C, at 15 minutes it is 115°C and at 20 minutes it has reached 122°C.

3 Anna measures how long it takes a bottle of water to freeze when the freezer is set at different temperatures. She records her results in the table below.
Identify the mistake in the table.

Time to freeze (h)	Freezer temperature (°C)
6	–2
4	–4
3	–6
2	–8

Practical skills 1.4

Testing paper planes

Aim

To test how the size of a paper aeroplane affects the distance it can travel by recording data from multiple trials.

Materials

- A4 paper
- scissors
- measuring tape

Procedure

1. Define the following for your experiment: independent variable, dependent variable and controlled variables. Create a table of results for your experiment.
2. Construct a hypothesis for your experiment. Predict how the independent variable will affect the dependent variable.
3. Follow the steps shown in Figure 1.25 to produce a paper aeroplane.
4. Cut up the paper so you have A4, A5, A6 and A7 sized rectangles to make different-sized paper aeroplanes. Planes made from bigger pieces of paper will have a bigger mass and a bigger wing span.
5. Throw the first aeroplane and measure the distance it travels until it hits the ground.
6. Record your measurement in the results table.
7. Throw this plane two more times, recording your result each time.
8. Repeat steps **5–7** for each of the four different planes.

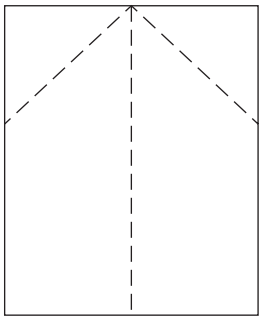
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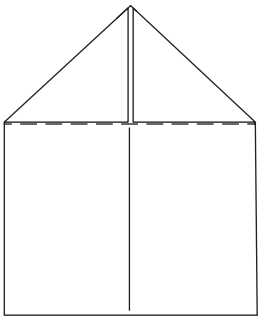
9. Calculate the mean for each set of results.

Fold along the dotted lines.

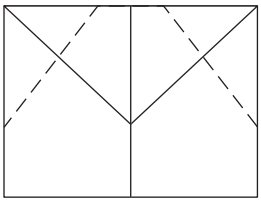
1



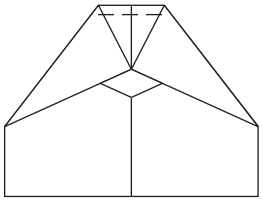
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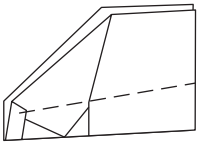
3



4



5



6

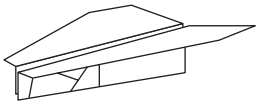


Figure 1.25 How to make the paper aeroplane

Results

Write a short summary of what your data shows.

Discussion

1. Now that you have completed the experiment, identify other variables that you should have controlled that may have affected your results.
2. Identify one variable that you were not able to control, that could have affected your results (one potential source of error).
3. Suggest two other independent variables that you could change, other than the size of the aeroplane.
4. Explain the reason for conducting multiple trials and calculating the mean of your results.

Displaying data in graphs

Now that you have data from your experiment in a results table, you can display the data in a graph to easily show any possible patterns, trends or relationships that your experiment has uncovered. Graphs can also allow you to easily identify any outliers results in your data.



WORKSHEET
Displaying data

Line graphs

A scatter plot is a way of displaying how one quantitative variable changes in response to another quantitative variable, by plotting points. When the points are connected, it is called a **line graph**. Line graphs are generally used with continuous data, as they show how the data points continue on from one another. The lines at the side and bottom of a graph are called the **axes**. When you transfer data from a table, place the independent variable on the horizontal axis (the x-axis) and the dependent variable on the vertical axis (the y-axis).

line graph
a type of graph used to display continuous data

axes
the horizontal and vertical lines used to frame a graph

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trendline/line of best fit
a line drawn to show an average of plotted points

interpolation
using existing data (such as a line of best fit) within the original dataset to make a reliable prediction

extrapolation
using existing data (such as a line of best fit) outside the original dataset to make a prediction

After plotting your data as points, you may notice a pattern or trend, such as the points lying more or less in a straight line or curve. To highlight this pattern, you can use a curve or line of best fit. While connecting every data point may suggest that there are no errors in the data, a **trendline** approximates the relationship between the two variables more accurately. Additionally, you can use the line of best fit to predict missing measurements. However, if you make predictions within the original dataset, this is called **interpolation**, and it may be reliable in certain circumstances, but caution is advised. **Extrapolation**, or making predictions outside the original dataset, is less reliable and should be approached with care.

When drawing a line of best fit, make sure that there are an equal number of points on one side of the line as on the other. You do not need to join each data point with the line. The line of best fit is like an 'average' that runs smoothly through the middle of the set of data points and makes the trend obvious.

A line of best fit:

- is continuous, with no gaps.
- can be straight, curved or any other shape that averages the data points. Do not try to draw a straight line of best fit over data that is clearly curved.
- should not be forced through a (0, 0) origin if one is used on the graph.
- should not be drawn beyond the range of the data points. It can, however, be linked back to the axes with a dotted or dashed line, as shown in Figure 1.26.
- should not consider any outlier data points when averaging the data points.

Figure 1.26 is a scatter plot with a line of best fit, drawn in red. Note how the line runs through the 'middle' of the data, like an average. The dotted regions are where the line has been continued past the original dataset. If you use the line in these regions (for example, to predict the reaction time for 0.1 mol L^{-1} acid), then it is extrapolation and is less reliable.

The line of best fit is not always a straight line. The graph in Figure 1.27 shows how 100 mL of water cools over 100 minutes. As you can see, a straight line would not fit the dots very well. In this case, the line of best fit, with an equal number of points either side, is a curved line.

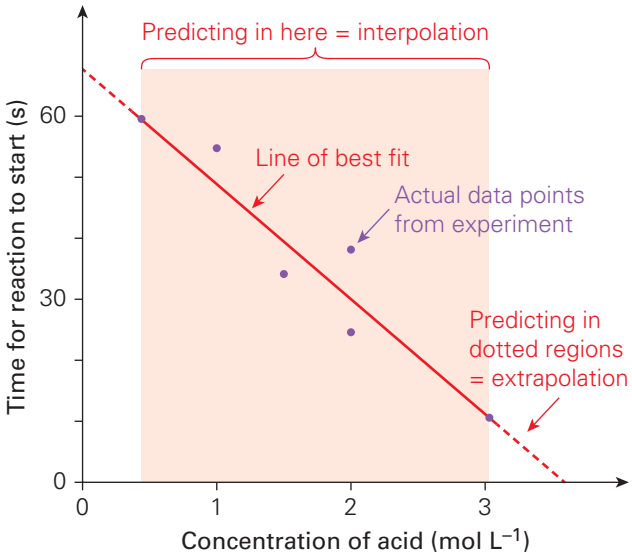


Figure 1.26 The effect of acid concentration on the time taken for a reaction to start

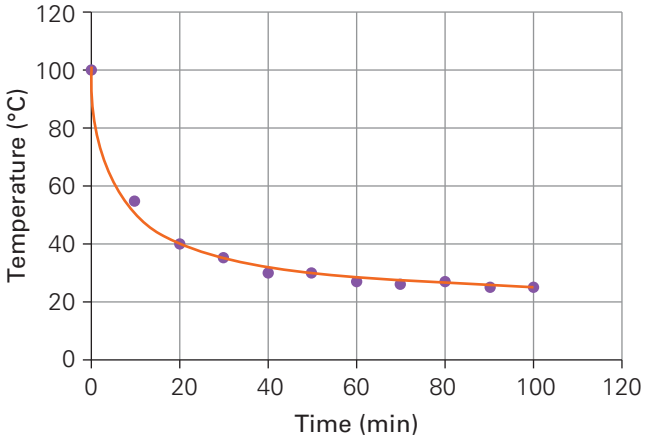


Figure 1.27 The effect of time on the temperature of 100 mL of water

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Bar graphs and column graphs

Bar graphs and **column graphs** are a way of displaying how a quantitative, discrete dependent variable (e.g. heart rate) changes in response to a qualitative independent variable (e.g. species).

bar/column graph a type of graph used to display the frequency of a qualitative variable (category)

Bar graphs and column graphs are similar; often one is chosen over the other simply due to how the information is best displayed. In column graphs, categories are listed along the horizontal axis and numbers along the vertical axis, while on bar graphs it is the other way around.

Bar and column graphs have spaces between the bars – the bars do not touch (see Figure 1.28).

Table B Heart rates of different mammals

Animal	Heart rate (beats/min)
Camel	35
Horse	41
Human	70
Rabbit	210
Mouse	670
Rat	750

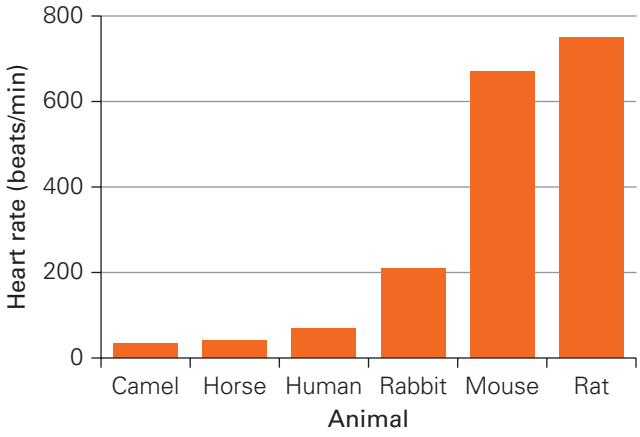


Figure B.1 Heart rates of different animals

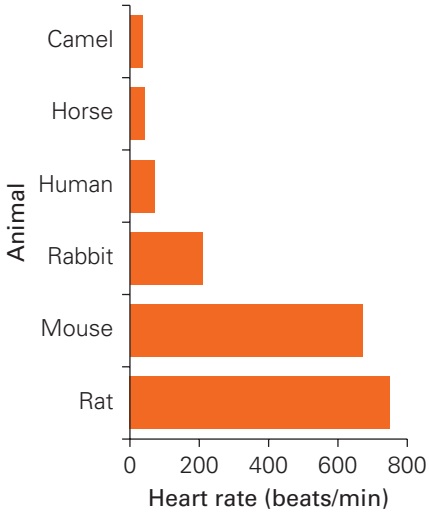


Figure B.2 Heart rates of different animals

Figure 1.28 A data table, column graph and bar graph showing heart rates of different mammals

Guidelines for drawing graphs

- Always use a sharp, dark pencil.
- Usually, the independent variable goes on the horizontal axis and the dependent variable on the vertical axis. However, sometimes you may be asked to disregard this rule.
- Axes should be labelled with the quantity being measured and the units. The units should be in brackets after the quantity name – for example, time (s) or volume (L).
- Use the full width of the graph paper (if drawing on paper) and choose a scale that spreads the data points out over most of the grid. If you are measuring quantities where zero does not mean 'no quantity' (for example, temperature), then you do not have to start the axes at zero. If the range of values does not go to zero (for example, 85–115), then don't start the axes at zero. In this example, you could start the axis at 80 and continue the numbers to 120. If the quantities on both axes go to zero, then the point where the axes meet, (0, 0), is called the **origin**.
- The scale needs to increase evenly, preferably with each grid square used to represent multiples of 1, 2, 5 or 10. Do not have breaks in the scale – for example, you can't show zero to 20 in intervals of five and then skip straight to 60.
- Data points are typically represented with a dot or an 'X'. If you are plotting multiple sets of data on the same graph, use different-coloured points for each dataset and add a legend.
- Circle any outlier results and label them as 'outlier'. These data points are those that are clearly different and are likely a result of an error or mistake in recording that data point. Note: you cannot simply remove the point! Scientists must communicate all data, including outlier results.
- Write a clear and concise title for the graph, incorporating the independent variable and dependent variable. This should sit below the graph. When the data comes from a secondary source, this should be referenced. Add labels and keys where necessary.

origin the point (0, 0), where the horizontal axis and vertical axis intercept when both axes start from zero

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Quick check 1.9

1. **Propose** which kind of graph should be used to display the following kinds of data:
   a. one quantitative variable changes in response to another quantitative variable
   b. a quantitative discrete dependent variable (for example, mass of seeds) changes in response to a qualitative independent variable (for example, variety of plant).
2. **Compare** interpolation and extrapolation.

6. Analysing data and information

Assessing reliability

reliability the consistency and repeatability of a measurement, experiment or test under the same conditions

The first step in analysing the data is to assess its **reliability** to determine if it is accurate and realistic. Table 1.9 compares reliability and accuracy.

	Reliability	Accuracy
What does it tell you?	The extent to which the results can be reproduced when the research is repeated under the same conditions	How close a measurement is to the correct value
How is it assessed?	By checking the consistency of results across time, across different observers and across parts of the test itself	Are the measurements close to a standard measurement?
How do they relate?	A reliable measurement is not always valid; the results might be reproducible, but they're not necessarily correct.	A measurement can be accurate but not precise.

Table 1.9 Comparing reliability and accuracy

If the data comes from a well-designed experiment we conducted, with fully functioning measuring tools and only one or two outliers, we can be confident it is reliable. It's important to compare our data with observations from other sources, especially from classmates who followed the same method. We should also consult secondary sources, such as published scientific research, for further validation. If there are any issues with the data, refer to the next section for guidance.



Identifying patterns and relationships in graphs

Graphs are visual representations of numerical data, making it easier to identify patterns. The data is typically gathered from an experiment to test a hypothesis, and this is what should be looked for in the graph.

We refer to patterns in graphs as trends. The graphs that follow show some common trends you might observe and describe. In Figure 1.29, the data show a steady increase. You would describe this by saying, 'As the age of the child (in years) increases, the size of clothing also increases'.

In Figure 1.30, the data show a rapid increase in customers that reaches a plateau (flat line) and then remains constant. You would describe this by saying, 'Initially, during approximately the first 60 months, as the number of months increases, the number of customers per month increases rapidly from 0 to 2000. Then, for the next 100 months, the number of customers per month remains constant at around 2000'.

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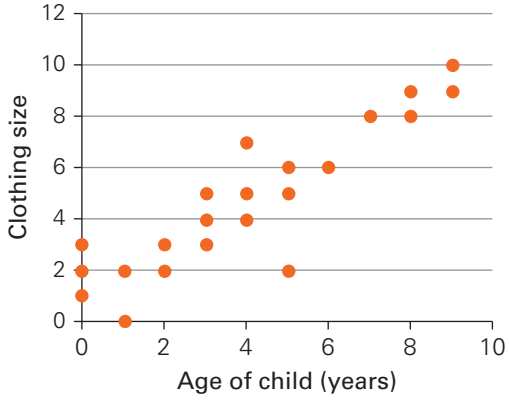


Figure 1.29 The effect of child age on clothing size

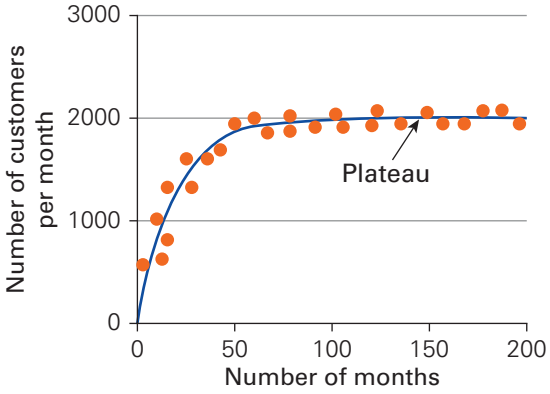


Figure 1.30 The total number of customers per month over 200 months

The data in Figure 1.31 show an exponential increase. You would describe this by saying, 'For the first 10 hours, the number of bacteria increases slowly from 10 000 to 30 000. After 10 hours, the number of bacteria increases more rapidly'.

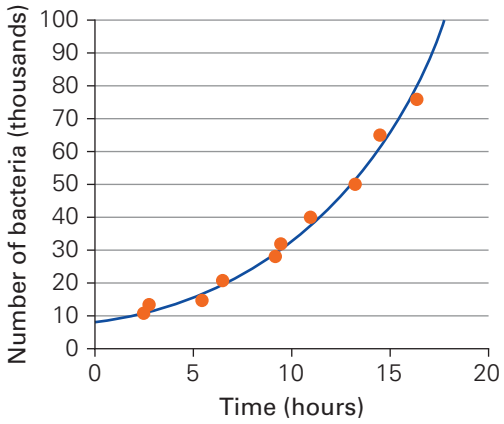


Figure 1.31 The effect of time on the number of bacteria

In Figure 1.32, the data do not show a clear pattern. There are seemingly random fluctuations over time. You should still highlight that the data points appear to be scattered or randomly distributed without a clear pattern or correlation.

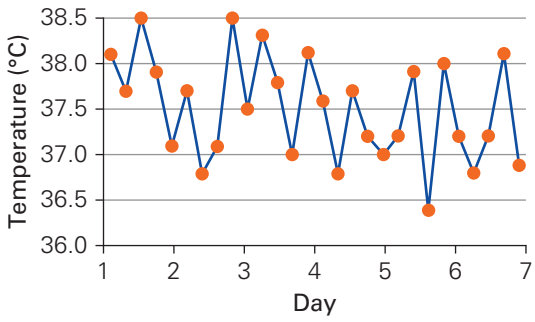


Figure 1.32 Temperature fluctuations over a seven-day period

It is important to note that identifying a trend in data points does not prove that one variable had caused another variable to change because there's always a possibility that the trend arose by chance. The data analysed might provide evidence; however, the results and method must be evaluated before making any conclusions or claims of **causation**!

causation the relationship between two variables where a change in one directly results in a change in the other

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Identifying patterns in other representations of data

Although tables and spreadsheets don't display patterns visually, they are useful for calculating summary statistics, such as the mean (average). Often, a clear difference in the mean result between a treatment or action and a control group is enough to support a hypothesis suggesting that the treatment leads to a quantitative improvement. However, if you suspect a pattern in the data, a graph is usually the best way to highlight it, with tables and spreadsheets serving as a step towards creating a graph.

In biology, research often involves observing organisms or their structures and processes. In these cases, the data may be descriptive rather than numerical. Images, videos and diagrams may be the most effective way to present this data. Diagrams should follow scientific conventions, including clear labels, titles, keys and notes on the conditions under which the observations were made.

Other ways of identifying relationships in the data

Inferences can often be made from observations or information gathered during the research, and these may lead to being able to identify a relationship between variables. In Section 1.2 it was mentioned that an inference may lead to a research question, and inferences may also lead to modifying the research question or method.

Scientific understanding drawn from data collected or secondary sources may also suggest a relationship that can be seen in the data.

The main purpose of analysing collected data is to check if it supports or refutes the testable statement being investigated (the hypothesis), and this is addressed in the next section.

Advances in science 1.1

Data science

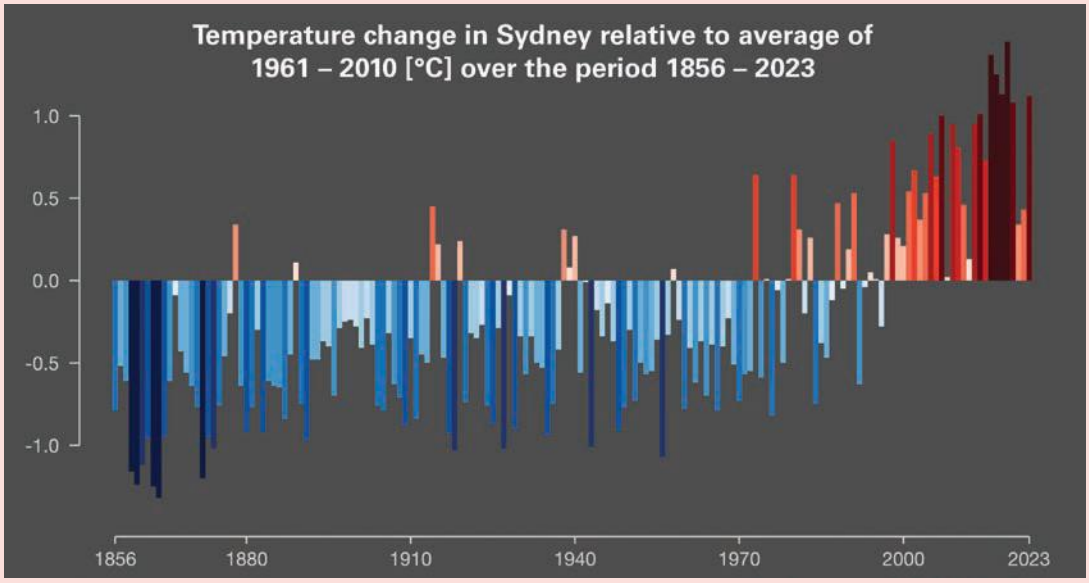


Figure 1.33 This graph shows the annual change in average temperature as coloured bars, with the larger changes displayed as deeper colours.

Data science is a fast-growing field that combines different areas of study to make sense of data. It uses statistics, scientific methods, processes, algorithms and systems to gain insights from data. Data scientists look at large sets of data and use mathematics, computer science and specific knowledge about a topic to analyse and interpret it.

continued …

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They apply statistical models and artificial intelligence techniques to discover patterns and trends that aren't easy to see at first glance. These insights help make informed decisions, predict future trends and solve problems in various fields like business, healthcare and technology. By bringing together information from different sources, data science helps us understand complex issues better and find new and innovative solutions. Figure 1.33 shows fluctuations in temperature, with some years above or below the 1961–2010 average. However, the trend shows an overall increase in temperature in recent decades, indicating warming. By integrating historical observations with modern climate data, scientists can make projections about future temperature changes and assess the impact of human activities on Sydney's climate.

Section 1.4 review

Online quiz

Section questions

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Section 1.4 questions

Remembering

1. **Define** continuous data and provide an example.
2. **Define** discrete data and provide an example.
3. **State** which type of graph should be used when data are collected as continuous data.
4. **Recall** the term that is used to refer to patterns in graphs.

Understanding

5. **Explain** why it is important to use the same number of decimal places when recording data in a table.
6. **Describe** where the independent and dependent variables should be placed on a graph.
7. **Describe** the difference between interpolation and extrapolation.
8. **Illustrate** a graph that shows an exponential trend.
9. **Explain** why data should be assessed for reliability.
10. **Describe** some advantages of using a spreadsheet to record numerical data.

Applying

11. **Construct** a table to record data from an experiment where the temperature of water is measured every minute for 10 minutes.
12. **Create** a line graph to display the data from the following set.

Time (minutes)	0	1	2	3	4	5
Temperature (°C)	22	24	25	26	27	28

13. **Convert** four minutes and 16 seconds to seconds.
14. Consider a graph depicting the change in the height of plants over time. You note that the height of the plants increases steadily over time. **Describe** this trend.
15. **Describe** the trend you would expect to see in a graph depicting the temperature of water cooling over time.

Analysing

16. Given the data [5, 8, 12, 7, 10], **calculate** the mean and range, and discuss what these values indicate about the dataset.

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17. Identify the general trend in the graph shown in Figure 1.34.

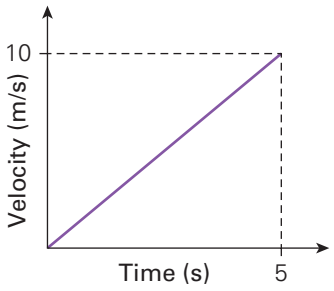


Figure 1.34 Change in velocity over time

Evaluating

18. Evaluate the significance of including outliers in your data analysis. How should they be handled?

19. Rose had a bag of lollies of different colours. She found that, when she offered them to friends, she was always left with purple lollies. She decided to conduct an experiment to test people's favourite lolly colours. She shared a bag that had 20 of each colour and recorded what was left at the end. From this she worked out how many of each colour had been eaten. The results are shown in the table.

Lolly colour	Number of lollies eaten
Purple	4
Green	13
Yellow	18
Red	20

a. Decide on the type of graph that should be used to represent this data.
b. Decide which column in the table should be used as the dependent variable.
c. Propose the independent variable in this experiment.

20. Decide why it is important to describe patterns in data accurately.



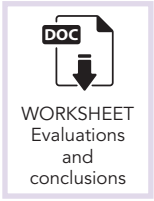
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1.5 Skills: Evaluating, problem solving and concluding

Learning outcomes

At the end of this section, I will be able to:

1. identify data which supports or refutes a testable statement or hypothesis.
2. use scientific understanding to identify relationships and draw conclusions.
3. identify problems in the method used to investigate a question and devise possible solutions.
4. identify cause-and-effect relationships and use them to explain phenomena.



Note that this section covers some content points listed under *Analysing data and information in the syllabus*.

7. Evaluating and problem-solving

This is the section of the report where you would outline any problems you faced during the experiment and offer suggestions for improvements or extensions to the method. This includes possible errors or mistakes encountered in experimentation.

Any suggested improvements should include the following information:

- a brief description of the problem encountered
- a description of how the problem affected the results
- a description of how you could improve the experimental method (e.g. use different equipment or change the order of the steps)
- an explanation of how this would improve the reliability and accuracy. Table 1.9 details the differences between these two things.

Here is an example of how to approach an evaluation.

Some students investigated the effect of salt on the boiling point of water. They used a thermometer to measure the temperature at the boiling point after salt had been added.

Step 1: Describe a problem that was encountered. The thermometer did not allow accurate readings because it is difficult to judge exactly when the water starts boiling – it is not when the first bubbles are seen. The boiling point should be taken as when the temperature stays the same for a period of time, even though more heat is added. Secondly, depending on the type of thermometer and the size of the gradations, it may be difficult to see the small changes in boiling point on a thermometer.

Step 2: Describe how the problem affected the results. It was unclear whether the temperature was staying the same, so the students had to make a judgement about when the boiling point had been reached. This judgement could vary from person to person.

Step 3: Explain how it could be improved. Using a temperature probe, a data logger or an electronic thermometer could allow more accurate measurements.

Step 4: Explain how this would improve accuracy and reliability. The data collected would be digital and more accurate, as there would be fewer measurement uncertainties and less chance of introducing random error. A digital output would show more clearly what the temperature was when it stopped changing.

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Figure 1.35 Using a pH meter instead of pH paper allows for more accurate and precise pH measurements.

To finalise your evaluation, consider the following:

- Did you identify all the variables that needed to be controlled? For example, was the concentration of salt the same each time (same mass of salt added to same volume of water)?
- Were all controlled variables controlled in the experiment?
- Were there any errors that were unavoidable in the experiment?

Next time the experiment takes place, it may be appropriate to modify the method. Any modifications should aim to improve the reliability and accuracy of the results. For instance, if the original method involved measuring the pH of a solution using pH paper, a modification could be made to use a pH meter instead. This change would be made because pH paper measurements may introduce errors due to inconsistencies in colour interpretation.

Another reason for modifying the method could be to address potential sources of error. For example, if the original method required a specific incubation time for a reaction, but it was found that the reaction did not proceed as expected within that time frame, the incubation time could be extended to allow for complete reaction. This modification is based on the recognition of an error in the original method and the need to ensure accurate data collection.





Figure 1.36 The effect of walks on the number of socks chewed

Write a conclusion

A conclusion is a short paragraph in a scientific report and should always include three key ideas:

- the claim of causation that can be made from the experiment regarding the independent and dependent variables
- the evidence from your data that supports this claim (specific data should be stated)
- an explanation of whether the data supports or does not support the hypothesis.

It is important that when scientists have evaluated their data, they are very careful in describing claims of causal relationships. Remember, a trend in data doesn't necessarily mean that there is causation.

The conclusion may be that there is some evidence of a trend or relationship, but it is not conclusive and further research is needed on a modified question or hypothesis.

Here is an example of an experiment along with the conclusion that was made:

Ollie conducted an experiment to see if taking her dog Teddy for more walks reduces the number of socks Teddy destroys.

Ollie's hypothesis was 'If Teddy takes more walks per day, then Teddy will chew a smaller number of socks'.

Ollie put her collected data into a graph and produced a line of best fit, shown in Figure 1.36.

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From analysis of the trend in the graph, Ollie developed the following conclusion: 'This experiment provided evidence that there is a possible causal relationship between the number of walks Teddy has per day and the number of socks he chews. The data shows that as the number of walks per day increased (from 2 to 6), there was a decreasing trend in the number of socks chewed (from 5 to 0). The evidence from this experiment supports the hypothesis that if Teddy takes more walks per day, then Teddy will chew a smaller number of socks'.

Validating a conclusion

Comparing results with other groups or secondary sources is a valuable practice to assess the consistency of your findings. If there are discrepancies or conflicting results, the potential reasons behind them can be analysed, such as differences in methods, sample size or experimental conditions. Such conflicts may lead to further investigation or discussion to understand the underlying factors causing the variations. Sometimes, this comparison may produce additional questions that need to be explored to verify the validity of those claims.

Remember, when validating any conclusion, it is important to look for facts or ideas that have been taken for granted to be true. Discussing these assumptions with others helps determine if they are reasonable and supported by evidence. This process helps in developing a stronger understanding of the topic and promotes a more thorough examination of the evidence.

Try this 1.4

Writing a conclusion

Gen conducted an experiment to see if the distance from a window would affect the growth of her potted plants.

Gen's hypothesis was 'As distance from the window increases, the growth of the plants will decrease'.

Gen measured her plants before the experiment, placed them at different distances from the window and measured them two months later. She then graphed her results and obtained a line of best fit.

1. Develop a conclusion based on Gen's results.
2. Suggest three controlled variables that Gen would have used to make this a fair test.
3. Propose two possible causes for the increase in plant height for the plant that was placed 6 m from the window.

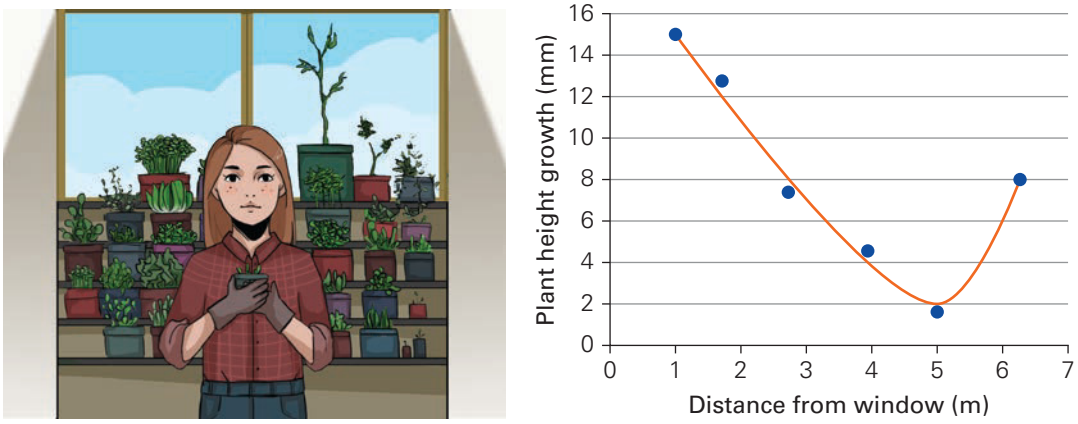


Figure 1.37 How the distance from a window affects plant height growth

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Worked example 1.3



Suppose that you were watching a race, and you noticed that the racer named Trent beat the one named Lewis. This was an observation of the world around you. If you were interested in why that happened, you might carry out further research by using the following procedure.

Practical report section	Example	Explanation
Research question	Do more training hours improve race performance?	The question needs to able to be investigated scientifically and answered safely. The question has an independent and a dependent variable, which are easily measured.
Background information	Runners who train for more than four hours a week reduce their race time by an average of ten minutes. Runners who add three days of strength training to their weekly program increase their leg strength and improve their race performance.	This is your background information. You need to use the internet and books to find scientific information that provides information about what you're studying. Make sure you use reputable websites and give a reference link for anything you use. The sentences shown are an example of what could be included.
Hypothesis	An increase in training hours will increase race performance and decrease the time taken to finish a 10 km race.	This is where the research question is changed into a hypothesis that can be tested.

continued ...

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<table>
<tr><th>Practical report section</th><th>Example</th><th>Explanation</th></tr>
<tr><td>Procedure</td><td>Variables
Independent variable: number of training hours
Dependent variable: time taken to finish a 10 km race
Controlled variables: participants are the same age, have the same athletic abilities and receive the same amount of training. The same race distance is used for all participants.
Risk assessment
All runners must wear suitable footwear during the race.
Method
1. Gather a group of 18 12-year-old males who will participate in the study.
2. Provide each participant with a logbook to note down their training time and the type of training they did.
3. Instruct the participants to record their training time and type for a certain period of time leading up to the race.
4. On race day, record the time taken for each participant to finish the race.
5. Collect and analyse the data recorded in the logbooks and race results.</td><td>This is where you design your investigation. You need to consider the variables (i.e. what you will change and what you will measure), a risk assessment and a method.
The number of training hours is the independent variable because it is the variable that we change to see what effect it has on the dependent variable.
The time taken to finish a 10 km race is what we predict will change as a result of the change in training hours. This makes time taken to finish a 10 km race the dependent variable.</td></tr>
<tr><td>Results</td><td><table><tr><th>Number of training hours (hours)</th><th>Time taken to finish a 10 km race (minutes)</th></tr><tr><td>4</td><td>102</td></tr><tr><td>7</td><td>92</td></tr><tr><td>10</td><td>86</td></tr><tr><td>15</td><td>80</td></tr><tr><td>21</td><td>72</td></tr><tr><td>32</td><td>59</td></tr></table>Table: Relationship between training hours and race completion time
 
Figure: Training hours versus. race completion time</td><td>You need to present your results in tables and graphs.</td></tr>
</table>

continued ...

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Practical report section	Example	Explanation
Analysis	As the number of training hours increases, the time taken to finish the race decreases. For example, when athletes trained for four hours, it took them 102 minutes to finish a race, whereas when athletes trained for 32 hours, it took them 59 minutes to finish the race.	You need to look at your data and identify any trends, patterns or relationships. Include data to justify the trend you have identified.
Evaluation	The investigation only considered 18 male runners completing one 10 km race. Although the participants were all 12 years old, they were all different heights and had different diets. Their training also varied. Some completed only running training, whereas others also swam or did strength training. To improve the investigation, a bigger number of participants is required. Each participant should eat the same diet and complete the same type of training. The investigation could be extended by also considering female runners, or looking at different race distances.	This section is where you consider any issues with your method and suggest potential improvements for any future investigation. If the data is inconclusive, it could mean that there are more variables that need to be controlled.
Conclusion	In conclusion, the results show that more training hours improve race performance. This is shown by the data: runners who only trained for four hours completed their race in an average of 102 minutes, whereas the runners who trained for 32 hours finished their race in an average of 59 minutes. The hypothesis of 'an increase in training hours will increase race performance' is accepted. The data could also be used to improve race performance in teenage boys.	You need to answer your research question, justifying it with data that you collected. This will allow you to accept or reject your hypothesis.



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Section 1.5 review

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Section 1.5 questions

Remembering

1. **Name** the part of a scientific report that states whether the hypothesis was supported.
2. **Name** the part of a scientific report where you can talk about problems you faced and changes you would make.

Understanding

3. **Explain** why it is important to evaluate the method and results before making any conclusions about causation.
4. **Explain** how a problem with the equipment can affect the results of an experiment.
5. Imagine the data in Figure 1.32 is the mean body temperature of dogs on a medication and the hypothesis is 'When taking this medication, dogs will have a steady body temperature of 37.5°C'. **Write** a conclusion for the study from the graph.

Applying

6. **Describe** a problem you might encounter when measuring the pH of a solution using pH paper.
7. **Identify** an improvement to the method of measuring pH in the previous question and explain how this would improve accuracy and reliability.

Analysing

8. **Compare** the use of a thermometer and a temperature probe in terms of measurement accuracy and reliability.

Evaluating

9. **Discuss** why it is essential to identify and address potential sources of error when modifying an experimental method.



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1.6 Skills: Science communication

WORKSHEET Conducting research

Learning outcomes

At the end of this section, I will be able to:

1. present results and conclusions in a range of communication types appropriate to audience and purpose.
2. write up scientific reports on investigations and analysis of secondary sources.

Every day, scientists must communicate with a wide range of people. They might write papers and proposals, give talks or educate others. Sometimes they communicate with other scientists, but often, they communicate with members of the public.

To be successful, scientists must learn how to communicate well. A scientist who can explain things clearly helps people understand their message. This skill can help them get jobs or research grants. They can also write better papers that inspire or teach others.

When scientists communicate well with the public, it helps people support science and understand why it matters. It also helps everyone make better decisions, from the government to communities to individuals. Good communication makes science open to everyone, improving diversity and inclusivity.

8. Communicating

Scientists communicate their findings in different ways to reach various audiences. One way is giving talks, where they present their findings in person to other scientists or interested groups. Posters are another way to show research and often contain diagrams, graphs and images. Diagrams and animations help explain complex processes or phenomena. Reports, both scientific and practical, are a common way for scientists to share their findings. News articles and infographics can be used to present scientific information in a more accessible way. For example, a scientist may talk about the effects of climate change at a scientific conference, show a poster at a local community event, publish a report in a scientific journal or share an infographic on social media to reach a wider audience.



Figure 1.38 You should consider your audience when choosing how to present information.

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Science miscommunication

Even scientists can have problems understanding one another when scientific papers are written in very research-specific language. But when dealing with the public, poor, biased or incorrect communication about science can have a serious impact on progress in many areas of society.

Science miscommunication most commonly takes place on the internet, and it is important to remember that not all information found online is trustworthy. When searching for information, you should look for a credible or reliable source.

Using primary data

When using primary data, you should assess the validity and reproducibility of the methods used. Reproducibility refers to whether the research produces consistent results when repeated by other researchers. Any gaps or weaknesses in the conclusions drawn from the data may be due to problems with the validity or reproducibility of the methods used.

Assumptions made in research methods can also affect the validity of the conclusion. For example, if a researcher assumes that the study population is representative of the general population, but it is not, this could lead to biased or inaccurate conclusions. Similarly, if a researcher assumes that a particular method of data collection is the most accurate or appropriate, but it is not, this could also affect the validity of the conclusion.

It is also essential to identify any facts taken for granted in the research and evaluate their reasonableness. For example, if a study assumes that a particular medicine is safe and effective, but there is limited evidence to support this claim, this could lead to flawed conclusions.

It is important to evaluate whether assumptions are reasonable and consider areas of uncertainty when determining if there is enough evidence to support the conclusion or if there is a viable alternative conclusion.

Using secondary data

Secondary data refers to data that has been collected by someone else for a different purpose, but which may be relevant to your investigation question or claim. This can include data from published studies, government reports and other sources.



Figure 1.39 In the late 1990s, British doctor Andrew Wakefield claimed that the MMR (measles, mumps and rubella) vaccine was linked to autism and bowel disease. Wakefield's study was later found to be fraudulent, but it led to a decline In MMR vaccination rates in the UK and other countries. This resulted in outbreaks of measles and other diseases, causing serious harm and even death in some cases. Wakefield was eventually found guilty of professional misconduct and the study was withdrawn.



Figure 1.40 A 2010 article published in the journal *Behavioural and Brain Sciences* claims that Individuals studied in a significant portion of psychology literature are WEIRD – Western, Educated, Industrialised, Rich and Democratic – but this group is 'among the least representative populations one could find for generalising about humans'.

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A key consideration when examining secondary data is ensuring that it does not contain personal information that could potentially harm individuals. This is particularly important when dealing with sensitive data, such as medical records, criminal records and financial information. Before using any secondary data, review it carefully and ensure that any identifying information has been removed or anonymised. You should cite secondary data correctly. This involves identifying the original source of the data and providing a clear and accurate reference to it in any reports or publications. Failing to cite sources correctly can lead to accusations of plagiarism or academic misconduct and can damage the credibility of your research. When sources are cited correctly, readers can locate and verify the information that has been cited.

When you find secondary data that you want to use, you can use the CRAAP test to check whether you should use that information. The CRAAP test considers the currency, relevance, authority, accuracy and purpose of the information. When you use the CRAAP test, you give each of these factors a score of 0, 1, 2 or 3. You then add up all the scores. You should aim to use sources that have total scores of at least 13. Table 1.10 explains how to apply the CRAAP test.

	Description	Score			
		0	1	2	3
C	**Currency:** How old the information is • When was the information published or posted? • When was the last time the information was updated? • Is any of the information out of date or does it use old terms? • Do the links work?	No date is given.	The information is over three years old; no date of revision or update is given.	The information has been created or updated within the last three years.	The information was created less than two years ago. Sources referenced are current.
R	**Relevance:** How well the information matches what you are researching • Does the information answer your question or link to the topic? • Who is the information aimed at? • Is the information worded at an appropriate level for you to understand?	There is no relevance to the topic I'm researching.	It has a small amount of information about the topic I'm researching.	It has a large amount of information about the topic I'm researching.	It can fully help me understand the topic I'm researching.
A	**Authority:** The writer of the information • Who is the author/publisher/source/sponsor? • Have the authors stated why they are experts? (Dr/Professor/experience) • What are the author's qualifications in the topic? • Is contact information provided, such as a publisher or email address? • Does the URL reveal anything about the author or the source? • Is the information linked to a biased organisation?	No author is identified.	The author is identified, but no credentials are given.	The author is named, and their contact details are given. The publisher is identified.	The author and publisher are identified and respected, and all contact details and credentials are listed.

Table 1.10 The CRAAP test

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	Description	Score			
		0	1	2	3
A	**Accuracy:** How correct or truthful the content is • Where does the information come from? • Is the information supported by evidence? • Has the information been reviewed or refereed by an expert? • Can you verify any of the information by checking another source? • Is the writing free of emotion? • Are there spelling, grammar or other errors in the writing?	There are no links to sources or a citation list. Information is difficult to understand, contains errors and may be incomplete.	There are no links to sources or a citation list. Information contains spelling and grammar errors.	There are links to sources or a citation list. Information is easy to understand and contains only minor spelling issues.	There are links to sources or a citation list. Information is corroborated with other sources. It contains no errors, is written well and in a concise way.
P	**Purpose:** The reason the information exists • What is the purpose of the information? • Do the authors make their intentions or purpose clear? • Is the information fact, opinion or propaganda? • Is the information biased? • Does the writer's point of view appear objective and neutral?	The purpose is biased, and therefore is personal. There may be too much advertising.	The purpose is to persuade or sell something to a reader.	It offers some factual information, but there may be some advertising.	The purpose is to present factual information in a balanced way.

Table 1.10 *(continued)*

Quick check 1.10

1. **Define** validity.
2. **Describe** how validity in secondary sources can be evaluated.

Try this 1.5

Using the CRAAP test

The aim of this activity is to research an inquiry question and use the CRAAP test to assess the usefulness of the resources you find.

1. Define 'adaptation'.
2. Outline one reason why it is important for animals to have adaptations.
3. Copy and complete the following table.

Australian animal characteristics	Animal 1	Animal 2
Common name		
Scientific name		
Where the animal is found in Australia		
Description of the animal's habitat		
Description of the animal's adaptation		
Type of adaption (behavioural, physiological, structural)		
Outline of how the adaptation allows the animal to survive in its habitat		

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4. Compile a sources list.
   a. List the search terms you used for searches (at least three terms).
   b. Name and score three of your sources.
   c. Identify the best source of information you have accessed.
   d. Compare the best source to the worst source.



DEPTH STUDY IDEA
How are natural disaster risks communicated?

Did you know? 1.1

One-in-100-year events

The 2022 Lismore floods were labelled a 'one-in-100-year' event, but what does it mean when a natural disaster is described as a 'one-in-50-year' or 'one-in-100-year' event? Many people might think it means that another flood would not happen for 99 years, but this is incorrect.

In fact, a one-in-100-year event simply means that the event has a 1% or one in a 100 chance of happening in any single year. While this may be easily understood by scientists and mathematicians, it can be misleading for members of the public. People may think that once they have lived through one natural disaster, they need not worry because the next one will not happen for another 99 years. But from a mathematical perspective, the probability of experiencing a similar event is the same every year. This fact could be more effectively communicated if the public were told there was a 1% chance of flooding every year.



Acknowledging and communicating Aboriginal and Torres Strait Islander Peoples' Knowledges

Aboriginal and Torres Strait Islander Peoples' Knowledges are grounded in a deep understanding of the natural world and have been developed over thousands of years through careful observation and experimentation. Western science uses rigorous methods of observation, experimentation and analysis to develop an understanding of the natural world.

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Acknowledging and identifying the relationship between Aboriginal and Torres Strait Islander Peoples' Knowledges and Western science promotes a more inclusive and collaborative approach to knowledge production. This is known as working 'both ways' or combining traditional Knowledge with Western scientific methods. When working 'both ways', it is important to recognise the value and contributions of both approaches.

When communicating Aboriginal and Torres Strait Islander Peoples' Knowledges, it is important to be culturally responsive and respectful, maintain cultural protocols, and avoid any offensive narratives, language or images. Generally, it is wise to seek permission from the relevant Aboriginal and Torres Strait Islander communities, avoid stereotypes and use appropriate language. This includes being aware of the differences between different nations and languages and using the correct terminology when discussing specific cultural practices or beliefs.

Explore! 1.3

INVESTIGATION

Traditional knowledge

Aboriginal and Torres Strait Islander Peoples have a rich history of medicinal knowledge and practices that have been developed and refined over thousands of years. Their understanding of the human body and physiology, and the environment continues to contribute significantly to the advancement of modern medicine.

The Wiradjuri People of central New South Wales have a history of treating respiratory illnesses by constructing steam pits heated by fire, lined with eucalyptus leaves and overlaid with possum rugs. This practice triggered Western scientists to further investigate the medicinal qualities of *Eucalyptus*, and they relied on Aboriginal Peoples' knowledge about how to formulate the plant for effective use. Modern research has shown that eucalyptus oil has antiviral and antibacterial qualities, and it is now manufactured for commercial use in the same way that the Wiradjuri People have been using it for thousands of years.



Figure 1.41 Some Aboriginal and Torres Strait Islander Peoples use eucalyptus oil to treat respiratory infections.

As two other examples:

- The use of emu oil as a topical anti-inflammatory has been adapted from Aboriginal knowledge.
- The Kakadu plum, which has the highest concentration of vitamin C of any fruit in the world, has been used to treat the disease scurvy. Its antioxidant properties have also been studied for their potential in cancer treatment. Aboriginal people now harvest and share the fruit for medicinal uses to the world.

Research some other plants that different groups of Aboriginal and Torres Strait Islander Peoples use as medicine. Explore whether their use has been adapted by Western science. Kangaroo apple and banksia flowers are a good place to start.

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Go online to access the interactive section review and more!

Section 1.6 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 1.6 questions

Remembering

1. The CRAAP test assesses the quality of a piece of information. **State** what the letters stand for.
2. **Describe** the process of working 'both ways'.

Understanding

3. **Explain** the domains a CRAAP test assesses by copying and completing the table.

Domain	What is being assessed?
Currency	
	Does the information address your research question? Is it written for the right audience?
Authority	Who is the author, and are they appropriately qualified?
Accuracy	
	Is the information fact or opinion? Are the author's intentions clear? Is the information free from bias?

Applying

4. You are reading a story on the internet, and some evidence has been cited to support the claim being made in the headline. This is different to what you read on another website the day before. **Describe** how you would evaluate this conflicting evidence to decide what was true.

Analysing

5. **Contrast** primary data and secondary data.

Evaluating

6. **Discuss** why people may post incorrect stories or comments about science on the internet. You should consider people who post such things deliberately and those who may not realise their posts are incorrect.



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1.7 Practice of science

The practice of science focusses on applying the Working Scientifically skills and processes (Sections 1.2–1.6) to certain contexts and aspects of science.

This section differs from others in not having questions or activities of its own. Instead, it lists course requirements for the practice of science in a table that links to where in the book the requirements are covered. The also provides a way to monitor whether you have met the requirements.

Course requirements

For each requirement in the checklist on the next page, a cross-reference is provided to practicals, activities or other items where the requirements can be met. Some of these may link to online material in the Interactive Textbook and teacher resources. Your teacher may also give you a different activity to meet a particular course requirement.

You can copy or download the table from the online resources, and then use the space provided to check off your progress in meeting them, and insert notes about what you did and in particular whether your activities were different from the cross-referenced ones.



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Practice of science checklist		
Course requirement and cross-reference	**✓**	**Notes on activity**
1. Measuring devices: range, sensitivity and accuracy Compare analogue and digital measuring devices. Cross-references: page 33–35 *7 Using equipment* and *Worksheet: Comparing analogue and digital measuring tools*; page 36 *Practical skills 1.3 Taking readings with measuring equipment*		
2. Accuracy and reliability of the senses Compare to observations made with measuring equipment. Cross-references: page 14 *Qualitative and quantitative data* and *Activity: Comparing observations using senses and measuring equipment*; pages 253 and 254 *Investigation 6.1 Investigating diffusion*		
3. Observations, inferences and testable predictions Using observations to make inferences and testable predictions. Cross-references: page 11–19 *Section 1.2 Skills: Observing, questioning and predicting*; page 477 *Investigation 11.1 Predicting properties of elements*		
4. Systematic observations and controlled experiments Explore different approaches used in science. Cross-references – Systematic observations: page 13 *Systematic observations*; page 272 *Practical skills 6.5 Calculating density*; page 421 *Investigation 9.3 Analysing biodiversity at your school* Controlled experiment: page 20 *Identifying variables*; page 24 *Investigation 1.1 Vitamin C in fruit juices*; page 366 *Investigation 8.1 Investigating the impact of salt on liver function*; page 552 *Investigation 13.1 Investigating chemical change*		
5. Changing the independent variable to cause a change in the dependent variable Conduct an investigation to observe this causal relationship. Cross-references: page 20 *Identifying variables*; page 44 *Practical skills 1.4 Testing paper planes*; page 113 *Practical skills 3.1 Stretching springs*; page 119 *Practical skills 3.3 Surfaces and friction;* and others		
6. Investigations with observations over time Use scientific tools and instruments to make observations over time. Cross-references: page 265 *Investigation 6.2 Changes of state of water*; page 274 *Investigation 6.3 The effect of state of matter and salinity on water density*; page 392 *Investigation 9.1 Investigating ecosystems;* and others		
7. Trends, patterns and relationships Identify these features in tables and graphs, and draw conclusions. Cross-references: page 20 *Relationship between variables*; page 31 *Practical skills 1.2 Heating water*; page 43 *Displaying data in tables*; page 45 *Displaying data in graphs*; page 570 *Investigation 13.2 Investigating factors that affect the rate of photosynthesis;* and others		

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Chapter review

Chapter checklist



Success criteria I am now able to…		**Linked questions**
1.1	explain the purpose of science in building understanding of the world and universe.	1
1.1	describe the different branches of science and its interconnected nature.	2
1.1	explain why science is collaborative, building on the work of others.	5
1.1	identify that science is based on a method that includes experiments, observations and predictions.	6
1.2	make relevant observations appropriate to answer a scientific question.	8
1.2	identify questions and problems that can be investigated scientifically.	7
1.2	make predictions based on scientific knowledge and observations.	9
1.3	plan an investigation including safe methods, use of equipment and consideration of ethical issues.	3
1.3	identify the independent, dependent and controlled variable(s) and the type of data that needs to be collected.	10
1.3	employ safe work practices using appropriate equipment and resources.	4
1.3	conduct an investigation using the planned investigative method, including the measurement and control of variables.	17
1.3	use a wide range of reliable secondary sources and correct referencing.	11
1.4	process and organise data and information and present it appropriately.	15
1.4	calculate mean and range and convert between units.	12
1.4	analyse data and information as to their reliability and compare them to other sources.	18
1.4	identify patterns and relationships in graphs, tables and spreadsheets. e.g. Identify the pattern in this data:	19a
1.5	identify data which supports or refutes a testable statement or hypothesis.	19b
1.5	use scientific understanding to identify relationships and draw conclusions.	13
1.5	identify problems in the method used to investigate a question and devise possible solutions.	14
1.5	identify cause-and-effect relationships and use them to explain phenomena.	20

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1.6	present results and conclusions in a range of communication types appropriate to audience and purpose.	15
1.6	write up scientific reports on investigations and analysis of secondary sources.	16

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Explain** what data means in the context of science.
2. **Recall** the term used for a testable statement of the outcome of a scientific experiment.
3. In an investigation in the laboratory using a Bunsen burner, **describe** the safety precautions that should be taken.



4. **Describe** three general safe work practices for a school laboratory.

Understanding

5. **Explain** why interdisciplinary collaboration is important in science.
6. **Describe** the role of experiments, observations and predictions in the scientific method.
7. **Explain** whether the question 'What is the most beautiful work of art?' is one that can be answered scientifically.



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Applying

8. **Describe** what kind of observation is required to answer the question of whether magnesium or zinc is the more reactive metal.
9. **Predict** whether a lander with a mass of 100 kg will weigh more on Mars (Mars's gravity is 38% of Earth's gravity) or Earth's Moon (the Moon's gravity is 16.5% of Earth's gravity).



10. In an experiment to test how amount of light affects the growth of a plant, **identify** the independent, dependent and controlled variable(s) and the type of data that needs to be collected.



11. Find and **state** a reliable source for data on the mean atmospheric concentration of carbon dioxide over the past 100 years.
12. **Calculate** the mean and range of the masses of these 12 koalas:
    8.1, 5.1, 14.7, 11.1, 8.8, 5.3, 14.5, 6.9, 8.0, 9.5, 13.8, 13.7
13. **Describe** the relationship between a mass and a force acting upon it.
14. **Identify** problems in and devise possible solutions for the use of equipment in this method: Students investigating time of reaction to a loud noise use a stopwatch to measure the time interval between the sound and the subject moving.
15. **Propose** the best type of communication to inform visitors to a forest on the number of koalas in the forest each year over the past 20 years.



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16. **Describe** the headings that should be used in a report on a physics experiment to find the melting point of a solid.

Analysing

17. **Describe** the steps in the method of a planned investigation you have carried out.
18. **Analyse** how the mean and range of the masses of koalas given in question 12 compares to a reliable secondary source for koalas in the wild that you can find (give the reference).
19. **Analyse** this data and answer the questions below.

Time (hours)	0	1	2	3	4
Number of bacterial cells	100	200	400	800	1600

    a. **Identify** the pattern in this data.
    b. **Decide** whether the data support or refute the statement 'Bacterial cells reproduce every hour by binary fission' (which means each cell divides in two).

20. **Identify** a cause-and-effect relationship from the following observation and use it to **explain** the phenomenon: An unknown crystalline solid is observed to dissolve faster as water temperature increases.

Evaluating

21. **Propose** reasons why some people dislike science or distrust science and what could be done to overcome their opposition to it.
22. **Explain** possible reasons why explanations for phenomena change in science, and what was once accepted is replaced.

Data questions

You can measure 100 mL of water in a measuring cylinder by filling the glassware to the 100 mL line and making sure that the water level is read correctly from the bottom of the meniscus. Some Year 7 students measured out 100 mL of water in a measuring cylinder and weighed the amount of water on an electronic balance. They repeated this experiment 10 times, and the results are shown in Table 1.11.

Measuring cylinder	Mass of water (g)
1	100.0
2	96.5
3	100.0
4	100.0
5	99.7
6	100.8
7	100.3
8	99.9
9	99.7
10	104.2

Table 1.11 Mass of 100 mL of water measured in a measuring cylinder and weighed on an electronic balance

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1. 1 mL of water has a mass of 1 g. Use this information to **determine** what should be the accurate value for the mass of 100 mL of water.
2. **Identify** two results which are considered furthest away from the accurate value.
3. Use the data in Table 1.11 to **describe** the differences in the collected results.
4. **Deduce** whether the differences in results identified in Question **3** could be from the measuring cylinder or the electronic balance or both.
5. **Infer** why there might be considerable differences in the collected data.
6. If the students were to repeat this experiment 10 more times, **predict** whether the results would change.

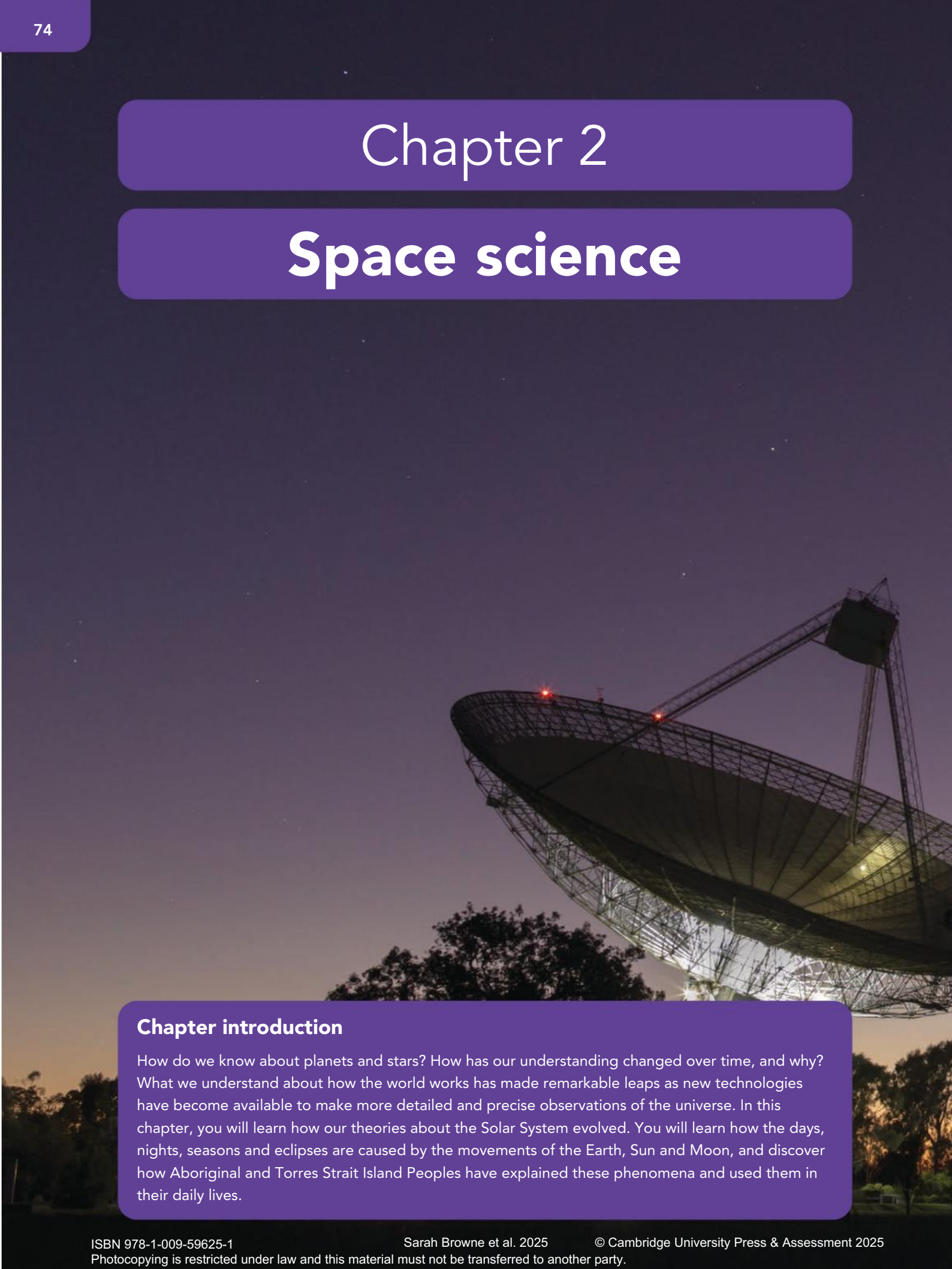


Figure 1.42 A measuring cylinder

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Chapter 2

Space science



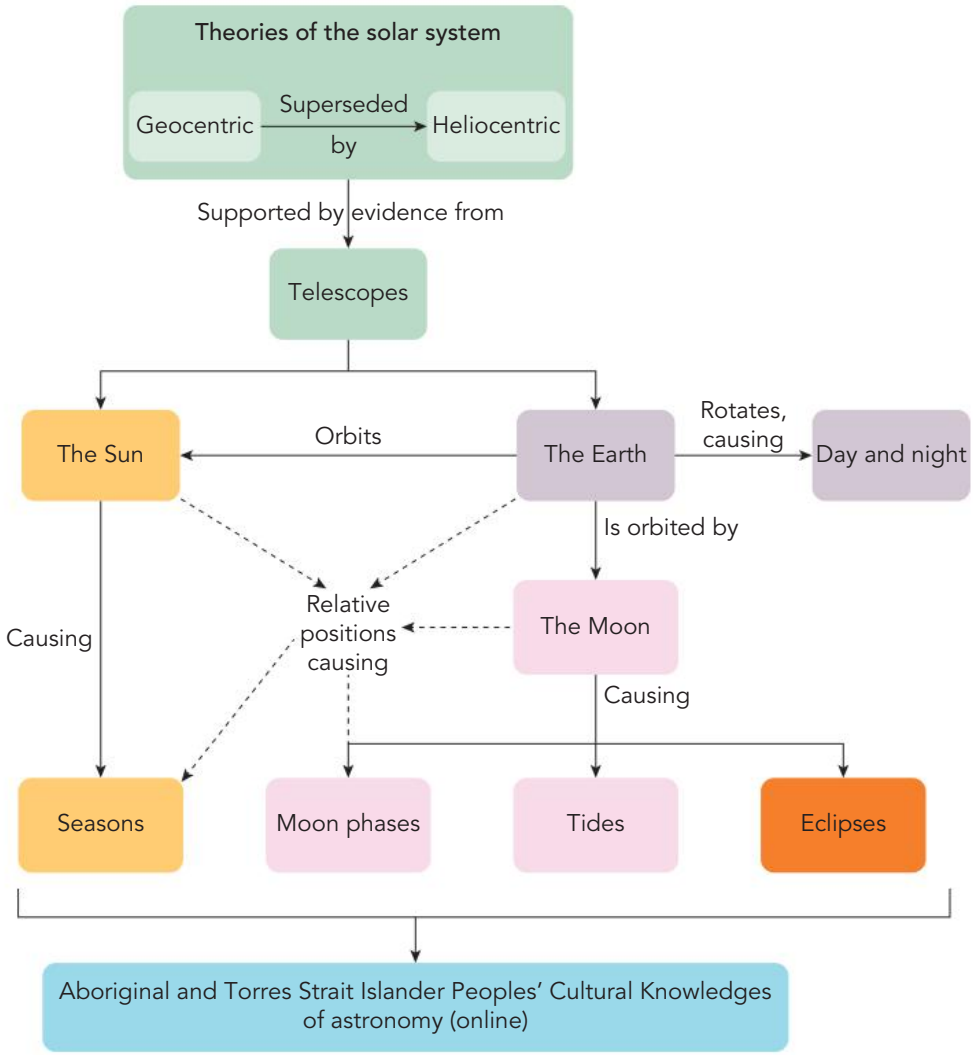
Chapter introduction

How do we know about planets and stars? How has our understanding changed over time, and why? What we understand about how the world works has made remarkable leaps as new technologies have become available to make more detailed and precise observations of the universe. In this chapter, you will learn how our theories about the Solar System evolved. You will learn how the days, nights, seasons and eclipses are caused by the movements of the Earth, Sun and Moon, and discover how Aboriginal and Torres Strait Island Peoples have explained these phenomena and used them in their daily lives.

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Chapter map

2.1
2.2
2.3
2.4
2.5
2.6



Glossary terms

annular eclipse
apogee
blood moon
equator
geocentric model
gravitational field
heliocentric model
leap year
lunar eclipse
Northern Hemisphere
orbit
orbital period
partial eclipse
penumbra
perigee
phase of the Moon
revolution
solar eclipse
Southern Hemisphere
synchronous rotation
syzygy
telescope
total eclipse
umbra
waning
waxing

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2.1 Our place in space

WORKSHEET
Models of the solar system

Learning outcomes

At the end of this section, I will be able to:

1. compare historical and current solar system models to show how models are modified or rejected due to new scientific evidence.

Historical models of the solar system



Figure 2.1 A 1692 engraving depicting several important astronomers. From left to right: Galileo Galilei, Johannes Hevelius, Aristotle, Tycho Brahe, Nicolaus Copernicus and Claudius Ptolemy.

People have always been fascinated with the night sky. Before there was power for light and entertainment, people rested after dark, looked up at the stars and wondered about the universe. They noticed patterns between stars formed constellations, which were different in every culture, and eventually led to astrology. Because consistent repeatable evidence cannot support it and therefore has no scientific basis, astrology is not a science. It is considered a 'pseudoscience'. However, patterns of how the stars changed position night after night were consistent regardless of which culture was observing them. Interpreting these patterns led to our understanding of the solar system.

Aristotle's geocentric model

The most prominent Greek scientist Aristotle outlined his **geocentric model** around 350 BCE, with the Earth stationary at the centre, and the Sun and the rest of the universe orbiting around it. The evidence for the model was that we can't feel the Earth rotate or orbit; it seems fixed in space, and it *looks* as if the Sun, Moon and stars move across the sky.

Aristarchus's heliocentric model

The problem that models have to explain is the strange motion of the planets. They look like stars but don't move regularly across the sky like stars. They move at different rates and they *wander*, sometimes moving backwards on successive nights. ('Planet' comes from the Greek word for wanderer). To explain this evidence, Aristarchus of Samos, who lived from around 310 BCE to 230 BCE, developed the first known **heliocentric model** of the solar system; that is, all planets, including the Earth, rotated around the Sun. *Helios* is a Greek word meaning Sun. His theory was rejected by many philosophers and astronomers at the time as it conflicted with their firmly held belief in Aristotle's model.

heliocentric model a model with the Sun as the centre of the solar system

geocentric model a model where the Earth was the centre of the universe

Ptolemy's geocentric model

VIDEO
the shape of our solar system

While Aristarchus was ignored, Aristotle's model was developed further in a book *The Mathematical Collection* by Ptolemy (Figure 2.2). Ptolemy was an astronomer, geographer and mathematician who lived in 90–168 CE and who followed Aristotle's ideology. To explain planetary motion, he used the idea of planets revolving on 'epicycles', which are circular paths that then revolve around the Earth (Figure 2.3). All astronomers of Ptolemy's time used this geocentric model, and it continued to be the preferred explanation of how the solar system works for more than a thousand years.

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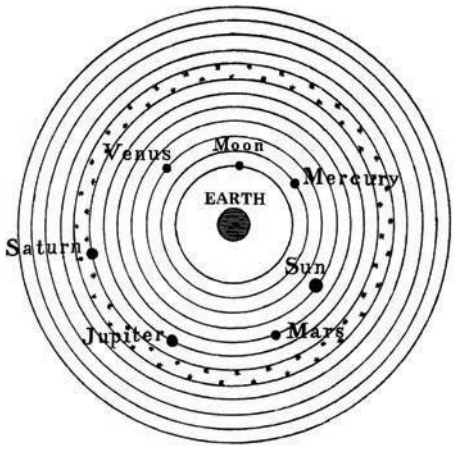


Figure 2.2 Historical artwork of the Earth-centred (geocentric) model of the solar system by Ptolemy

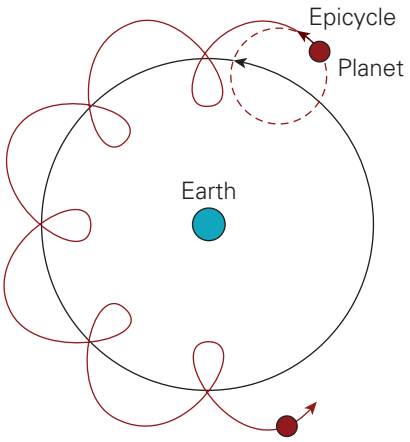


Figure 2.3 Attempted explanation by Ptolemy of wandering planetary motion: viewed from Earth on successive nights, a planet that revolves around an imaginary epicycle that itself revolves around the Earth would wander across the sky and regularly move backwards, as observed.

Copernicus's heliocentric model and Galileo's telescope

It was not until the year 1543, approximately 1400 years after Ptolemy (and 1800 years after Aristarchus!) that Nicolaus Copernicus published his heliocentric model, borrowing from the work of Aristarchus. The model stated that, in fact, it is the Earth that revolves around the Sun (Figure 2.4). Copernicus adopted a heliocentric view because it better explained the apparent wandering of the planets and the motions of the heavens mathematically. As it didn't need epicycles or other complications, it was much simpler than Ptolemy's model!

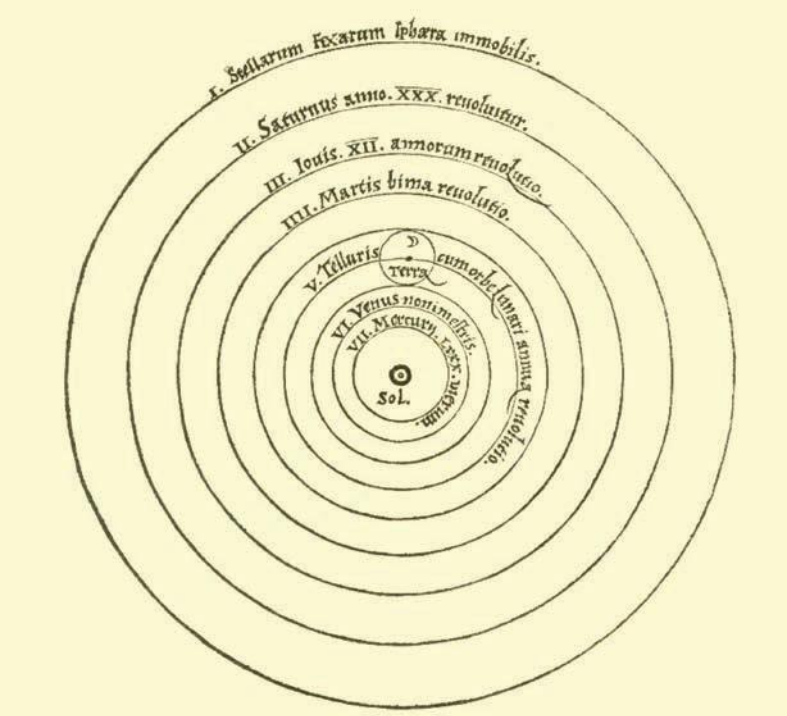


Figure 2.4 The diagram of Copernicus's heliocentric system, in Latin, as it appears in his book *De Revolutionibus orbium coelestium, On the revolutions of the heavenly bodies*, in 1543. 'Sol' is the Sun and 'Terra' is Earth.

There was insufficient evidence to support Ptolemy or Copernicus until 1610, when Galileo Galilei, an Italian astronomer, first looked at the heavens with a **telescope** and made observations challenging the geocentric model. A telescope was a significant advancement in technology that allowed detailed observations that you could not make with the naked eye. With the telescope, Galileo observed four moons in orbit around Jupiter. If Aristotle and Ptolemy were right about all things orbiting the Earth, then these moons could not exist. Galileo also observed that Venus waxed and waned like the Moon, which proved that the planet orbits the Sun. In 1687, Isaac Newton, a physicist and mathematician who had been working on the force due to gravity, published his book *Philosophiæ Naturalis Principia Mathematica*, which finally produced convincing proof that supported the heliocentric model.

telescope an optical instrument for making distant objects appear nearer and larger

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Advances in science 2.1

Different cultures and their contribution to current understanding of the solar system

Babylonian astronomy

The Babylonians were one of the first civilisations to record the movement of the Moon, Sun, planets and stars. Daily recordings were taken and used over the years to predict the positions of celestial bodies and the onset of seasons.

Greek astronomy

Over 2000 years ago, Greek scholar Eratosthenes calculated the circumference of the Earth and the tilt on its axis of 23°. Compared to today's measurements, Eratosthenes calculations were comparatively accurate. Both were great achievements considering the technology he had available. Pythagoras is another famous Greek scholar who, among other achievements, provided evidence that the Earth was spherical in shape and that movement of the planets, Sun, Moon and stars could be predicted.

Indian astronomy

Indian astronomer Aryabhatiya (476–550 CE) believed that the solar system was geocentric. However, he did summarise that the Earth rotates on its axis, and that we can observe the Moon and other planets because they reflect light from the Sun.

Mayan astronomy

The Mayans studied the motion of the Moon, planets, Sun and stars by using shadow-casting devices they invented. They recorded their observations and used them to develop the Mayan calendar to track the passage of time.

Egyptian astronomy

Ancient Egyptians used their observations of celestial bodies such as the Sun, Moon and stars to predict seasons. This allowed them to prepare for the flooding of the Nile River (in the wet season). The Egyptians also used their study of the heavenly bodies to create a calendar. Their calendar was similar to ours in that it had 12 months, but one week consisted of 10 days, so there were only three weeks in a month.

Advances in science 2.2

Technological advances: Telescopes

The telescope has had a serious influence on our understanding of the universe and our place within it. There have been several technological advances in telescope design over the centuries. The first telescopes were created in the early 1600s in the Netherlands. A significant advancement in telescope design was an invention by Newton who discovered a way to make powerful telescopes by replacing the lenses with mirrors. Over time, bigger telescopes with smoother lenses were made that could see more detail. Observatories were built to house these giant telescopes on top of mountains to minimise the distorting effect of the atmosphere. The Siding Springs Observatory in Coonabarabran is the largest telescope in Australia. The area is one of Australia's three dark sky parks, where night light pollution is minimised. The International Dark Sky Places (IDSP) program protects dark sites through responsible lighting policies and public education.

continued …

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A further technological advancement allows information to be obtained by attaching a spectrometer to a telescope. This device allows astronomers to analyse the colours in the light from a star. The colour of a star indicates its temperature, and by looking at the temperature and sizes of many stars, astronomers realised that stars do not stay the same but evolve over time. Using this information, astronomers estimate that our Sun is about 4.6 billion years old and is expected to continue shining for a further 4.6 billion years.

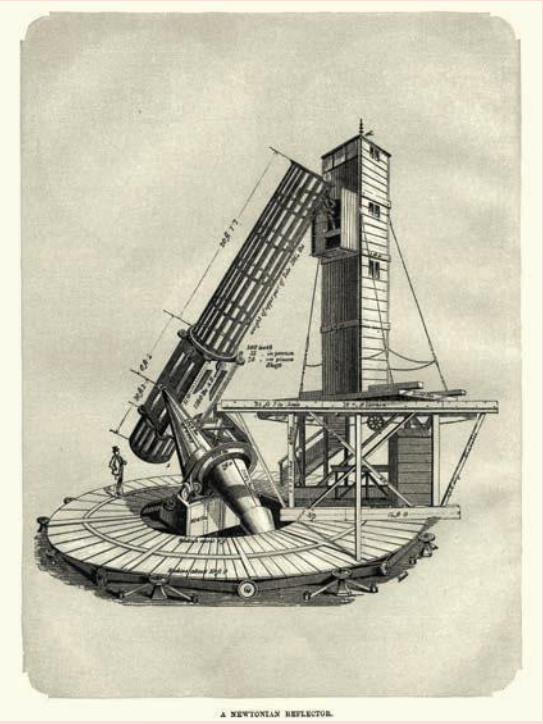


Figure 2.5 A sketch of a Newtonian telescope, 1870, a type of reflecting telescope that used two mirrors



Figure 2.6 The telescope at Siding Springs Observatory in central NSW

The Hubble Space Telescope

Edwin Hubble's contribution to understanding our place in space was recognised when a telescope launched into space was named after him. The Hubble Space Telescope takes images that are free from any distortion from the atmosphere and, by using long exposure times, the images it takes are often both stunning and beautiful.

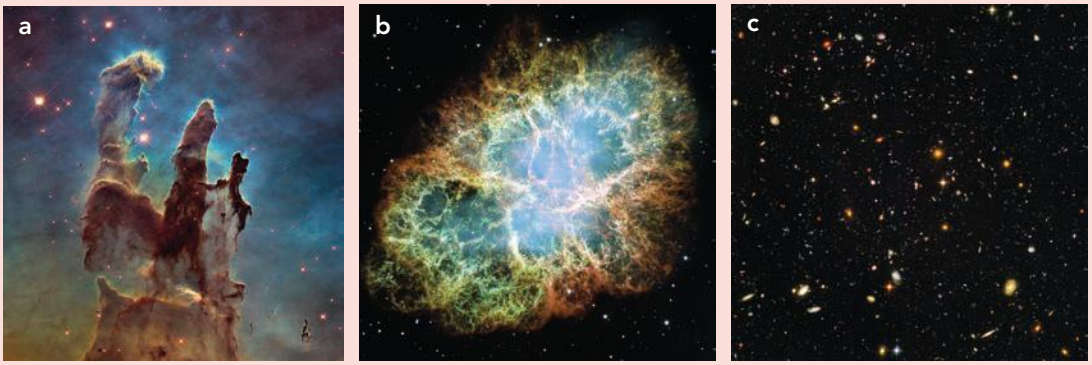


Figure 2.7 Images taken by the Hubble Space Telescope: **(a)** The Pillars of Creation, a star-forming region in our galaxy, **(b)** The Crab Nebula, the remains of a star that exploded in 1054 CE, and **(c)** The Hubble Space Telescope shows that even the darkest patch of sky is found to be full of galaxies.

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The James Webb Space Telescope



Figure 2.8 The James Webb Space Telescope

The largest telescope in space was launched in 2021. It is equipped with very high-resolution and high-sensitivity instruments due to its large gold mirrors. This allows it to see objects that are much more distant or dim than the Hubble Space Telescope.

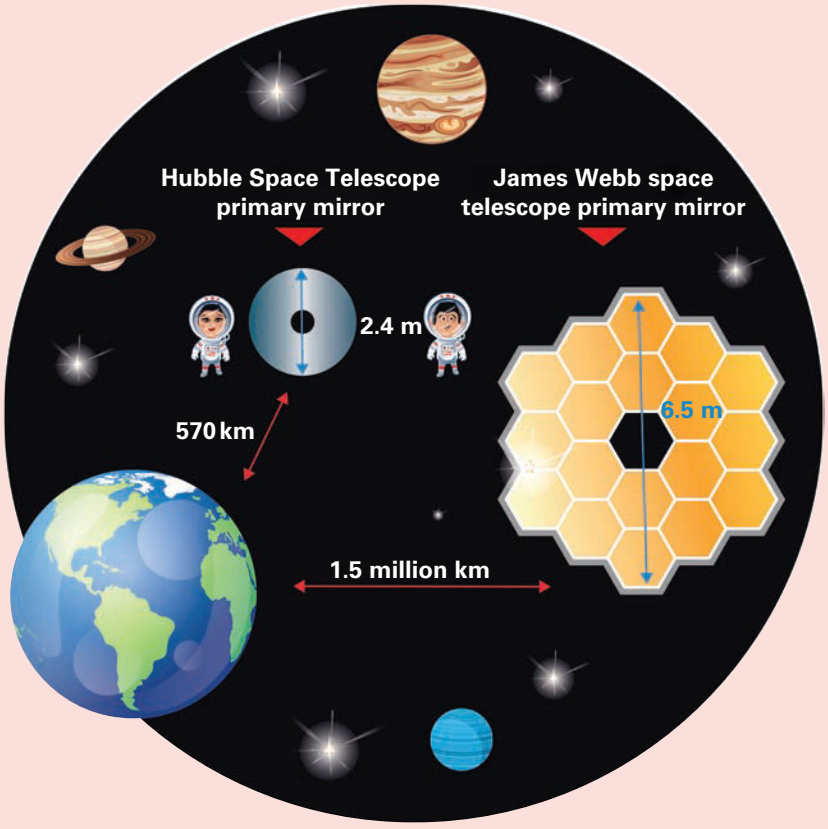


Figure 2.9 Comparison between the mirror used to 'see' in the Hubble Space Telescope and the James Webb Space Telescope (Note that sizes for the Earth and planets, and distances from Earth are not to scale.)

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The current model of the solar system

The current model of the solar system is heliocentric. Earth is one of eight planets that orbit the Sun. All the planets except Mercury and Venus have moons. Jupiter, which is the biggest planet, has at least 95 moons. The solar system is the name given to the Sun and all its orbiting planets and other natural objects including dust, particles and gas. The invention of the telescope gave us much more information about the solar system. With the introduction of the telescope, scientists discovered that Jupiter had moons and Saturn had rings. Scientists were able to look further into the solar system and the planets, Uranus (1781) and Neptune (1846) were discovered.

Earth's Sun is just one star in a galaxy of billions called the Milky Way.



Figure 2.10 The solar system includes Earth. All the planets except Uranus and Neptune can be seen without a telescope.

Try this 2.1

Scale model of the solar system

Planet	Distance from the Sun (km)	Scale distance from the Sun (cm)	Model diameter (mm)	Material
Sun (is a star)	0	0	139	polystyrene ball
Mercury	58 000 000	3.9	0.5	sawdust
Venus	108 000 000	7.9	1.2	seed
Earth	150 000 000	10	1.3	seed
Mars	228 000 000	15.2	0.7	sugar
Jupiter	778 000 000	52.0	14.3	large ball bearing
Saturn	1 430 000 000	95.4	12.0	marble
Uranus	2 870 000 000	192	5.2	medium ball bearing
Neptune	4 500 000 000	301	4.8	small ball bearing

Method

1. Collect all the materials listed in the table above and a metre ruler.
2. Place the Sun on the ground outside. This is 0 cm.
3. Measure out a length equal to the the distance from the Sun to Mercury from the table.
4. Place the nametag Mercury and the bit of sawdust at the point you measured.
5. Continue until you have positioned all your 'planets'.

Questions

1. What is the largest planet in the solar system?
2. What is the smallest planet in the solar system?
3. Which planet is closest to Earth?
4. Which part of our solar system is not represented in the model?
5. What other things in space are not shown in the model?
6. Why do you think it is good to use models in science?
7. Assess the use of this model by describing its strengths and limitations.

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INVESTIGATION

Explore! 2.1

Pluto, planet or not?

Pluto, discovered in 1930, used to be considered a planet. About a third of Pluto is covered in water in the form of water ice.

- Conduct some research to investigate other features of Pluto.
- In 2006, Pluto was reclassified as a dwarf planet. Conduct some research to investigate why this was the case. State the criteria that disqualified Pluto from being a planet.

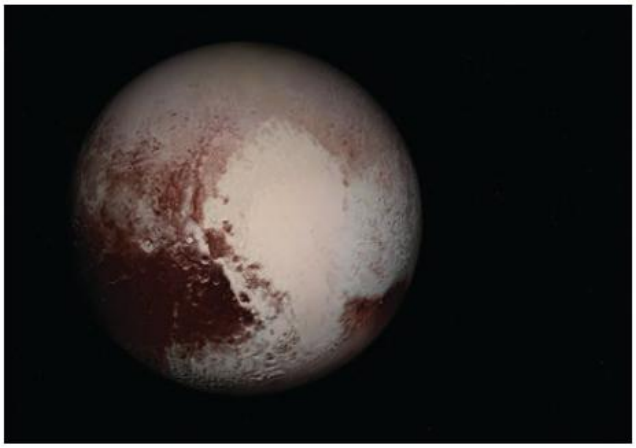


Figure 2.11 Dwarf planet Pluto

Go online to access the interactive section review and more!

Section 2.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.1 questions

Remembering

1. **Outline** what the solar system is made up of.
2. **Identify** whether astrology is a science.

Understanding

3. **Explain** what evidence supported Aristotle's and Ptolemy's model of the solar system.
4. **Explain** what evidence was used by Aristarchus to develop his model of the solar system.
5. **Describe** the sorts of discoveries that can be made with telescopes.
6. **Describe** ways that two different cultures have contributed to the understanding and exploration of our solar system.

Applying

7. **Explain** using the heliocentric model why planets appear to 'wander', and specifically to move backwards sometimes on successive nights.

Analysing

8. **Explain** one piece of evidence or other reason why Copernicus's model replaced Ptolemy's model.
9. **Compare** and **contrast** the geocentric and heliocentric models.

Evaluating

10. **Describe** how telescopes have changed our understanding of the universe. How might the understanding of the universe be different if the telescope had not been invented?
11. **Evaluate** how well the current scientific model of the solar system is supported by evidence.

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2.2 Our rotating Earth

Learning outcomes

At the end of this section, I will be able to:

1. describe the effect of Earth's rotation relative to the Sun on creating day and night, on daylength and on temperature.
2. state the rotation time for Earth.

WORKSHEET
Day and night

VIDEO
Timelapse of stars in the sky

Day and night

The Earth rotates once every 24 hours about its axis. Sunlight shines on one side, while the other side is in darkness. The side of the Earth facing towards the Sun experiences day and the side facing away experiences night. The Sun appears to move across the sky because the Earth is rotating. The same effect applies to the stars at night (Figure 2.12).

At midday (noon) the Sun is overhead. At that location, its rays travel the shortest path through the atmosphere to the surface, and more solar energy reaches the surface in a concentrated area. As a result, this is when the Sun's light and heat is strongest at the surface. This means that the hottest time of day happens shortly afterwards – it takes a little time for the atmosphere and surface to warm up to the maximum temperature. However, hot or cold winds can mask this effect at times.

Just before sunset and just after sunrise, the Sun's rays travel a longer path at an angle through the atmosphere, meaning that less solar energy reaches the surface and spreads over a larger area. The amount of heat and light reaching the surface is less, so it is usually cooler.

At night, the part of the Earth not facing the Sun does not receive any heat from the Sun, so it is cooler. But it takes time to cool because the Earth has an atmosphere, which acts like a blanket – without an atmosphere the temperature during the day would reach 110 degrees Celsius and −190 degrees Celsius at night!

The apparent movement of the Moon as seen from the Earth is a special case as it is the only visible natural object in the sky that orbits around the Earth. Its apparent motion is a complicated combination of the rotation of the the Earth and its orbit around the Earth. This is covered in Section 2.4.



Figure 2.12 Long-exposure photography reveals the apparent motion of the stars caused by the Earth's rotation.

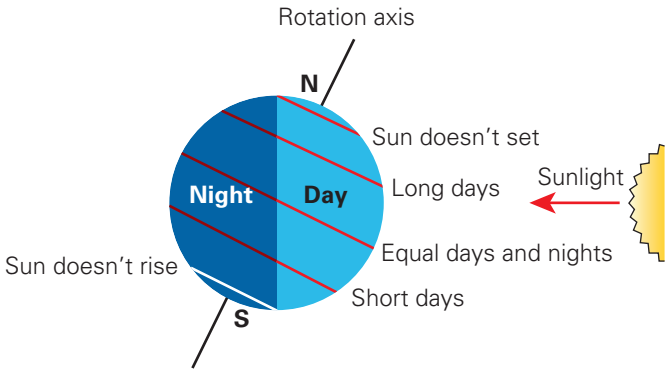


Figure 2.13 The rotation of the Earth, and its position relative to the Sun (not to scale), explains day and night, and their length at different locations. The tilt of the axis of rotation explains why locations further north or south have different daylengths and therefore experience different temperatures. In the position shown, the Southern Hemisphere has shorter days and less heat from the Sun, so it is winter there.

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Try this 2.2

Modelling rotation of the Earth with tilted axis

This activity requires a torch or lamp to aim a beam of light, representing the Sun, at a globe in a darkened room.

1. Set up the equipment as shown in Figure 2.14. Note the position of Australia.
2. Rotate the globe to model day and night in Australia. Note the comparative lengths of day and night.
3. Compare to a location on the equator, and again to one in the Northern Hemisphere. Write down where day length is short or long or the same as night length.
4. Change the position of the globe's base so it tilts away from the Sun, and repeat. What differences do you see?

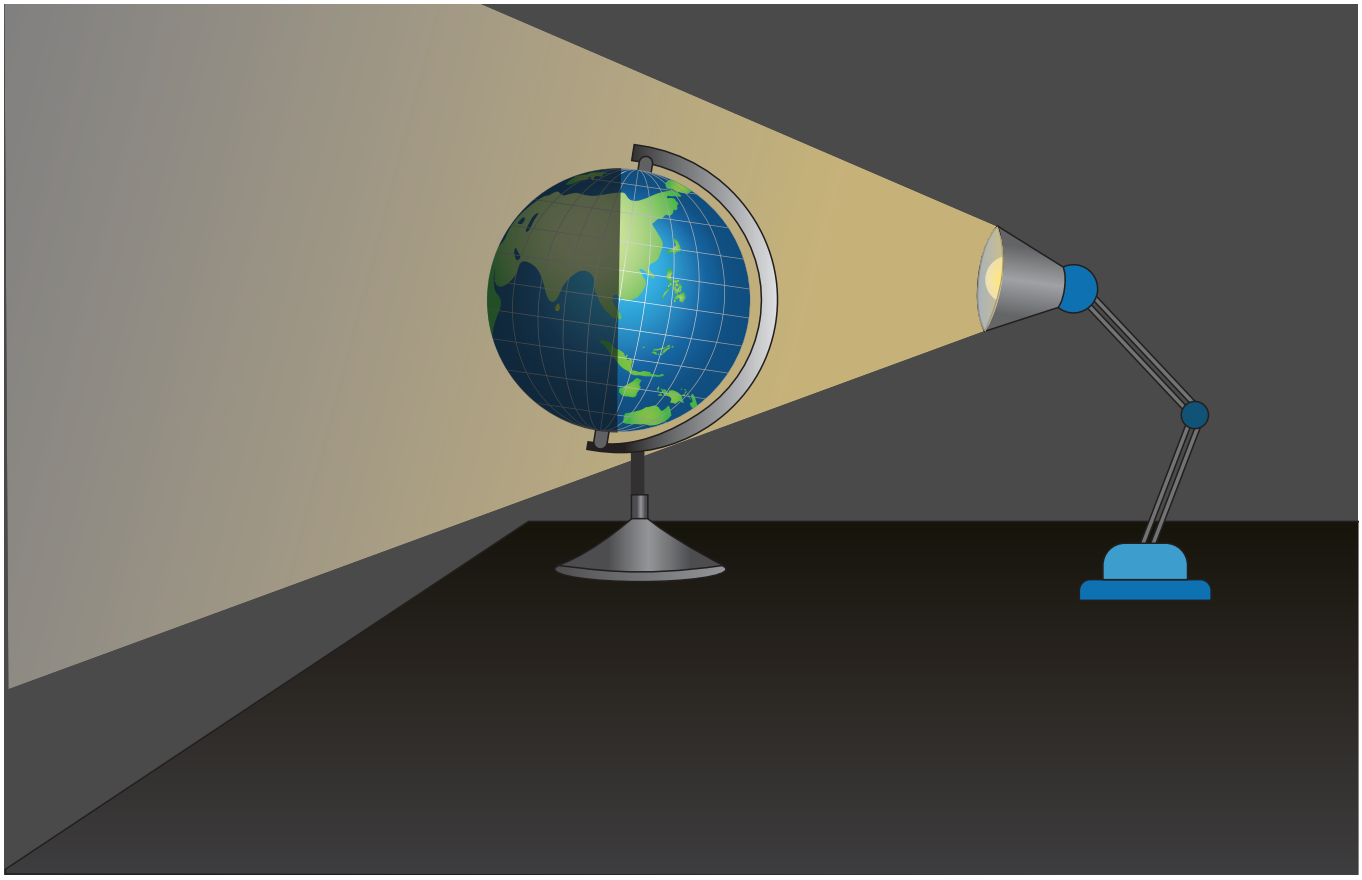


Figure 2.14 Shining a desk lamp representing the Sun on an Earth globe to model day and night

Quick check 2.1

1. **Explain** why the Sun and stars appear to move across the sky when they are not really moving.
2. **Explain** why it is cooler at night and warmer during the day.
3. **Explain** why it is generally warmer just after midday rather than just after sunrise or just before sunset.

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Explore! 2.2

INVESTIGATION

The length of shadows

A straight stick is fixed vertically in the ground on a sunny day (Figure 2.15). How long is its shadow? Is the length always the same? Is it random? What does it depend on? In what direction does the shadow point?



Figure 2.15 A gnomon is a stick or other object that casts a shadow which can be measured.

Scientists and astronomers in ancient societies used answers to these questions to solve problems in astronomy. The shadow reveals the position and angle of the Sun. The ancient Greeks used the word 'gnomon' for a stick or object that casts a shadow so its direction and length can be observed and measured. This data can be processed mathematically and scientifically to enable models and predictions to be made. In addition, the changes in the shadow shows that the Earth and the Sun have regular repeating patterns. Research different types of gnomons and their uses. Write down what and how they can tell us about time of day, time of year and location on the Earth's surface.

Section 2.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 2.2 questions

Remembering

1. **Recall** how long it takes Earth to complete one full rotation.
2. **State** what time of day the Sun reaches its highest point in the sky.

Understanding

3. **Explain** how Earth experiences day and night.

Applying

4. At what time of the day is it most important to wear sunscreen and seek shade? **Explain** your answer.

Analysing

5. **Explain** the relationship between the time of day and how the length of your shadow changes.
6. **Explain** why the day length in the winter in the Southern Hemisphere is shorter than the day length at the same time of year in the Northern Hemisphere.

Evaluating

7. 'If the Earth stopped rotating, one side of the Earth would be in total darkness all the time.' Decide whether you think this statement is true. Give your opinion on how life would be different if the Earth did not rotate and **justify** your answers.

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2.3 Earth's yearly cycle

WORKSHEET
Seasons

VIDEO
Earth's tilt and seasons

Learning outcomes

At the end of this section, I will be able to:

1. relate the yearly cycles of the Earth including seasons to its revolution around the Sun.
2. identify an example of local Aboriginal Peoples' mapping of the seasons.

The Earth revolves (orbits) around the Sun. The Sun has 333 000 times more mass than the Earth and so the **gravitational field** of the Sun causes the Earth to orbit the Sun. It takes 365.25 days for the Earth to travel around the Sun; the path is called an **orbit**, and the time to complete one orbit is called the **orbital period**. One complete orbit around the Sun is called a **revolution**. The calendar is made simple by using 365 days for a year and adding an extra day once every four years (a **leap year**).

gravitational field the region around a mass where another object can experience its gravity or pull

orbit the curved path of a celestial object or spacecraft round a star, planet or moon

orbital period (of an orbit) the time taken to complete one orbit or revolution

revolution one complete orbit

leap year a year that happens every four years and has an extra day on 29 February

Seasons

The tilt of the Earth's axis relative to the Sun's rays determines the seasons by changing the amount of solar radiation each part of the Earth receives throughout the year. Figure 2.16 shows the Earth in its orbit around the Sun, at positions three months apart. Its tilt does not change. Consider the location of New South Wales (NSW) at each position:

A The Northern Hemisphere is tilted towards the Sun, and the Southern Hemisphere is tilted away: In NSW, days are shorter than nights. The Sun is lower in the sky, its rays pass through more atmosphere, and strike the surface at an angle. NSW receives less solar radiation than at BCD, so it is **winter**.

B Three months later, the Earth's axis is tilted side-on to the Sun: In NSW, day and night are roughly equal. The Sun is higher in the sky than at A. Solar radiation has increased. It is **spring** in NSW.

C Another three months later, the Southern Hemisphere is tilted towards the Sun: NSW experiences longer days than nights. The Sun is high in the sky – close to overhead at noon. Its rays pass through less atmosphere and strike the surface more directly. NSW receives its maximum solar radiation, so it is **summer**.

D Three months on, the Earth's axis is again side-on to the Sun, like at B: Day and night are roughly equal in length, and the Sun is lower in the sky than at C. Solar radiation has decreased compared to summer, so it is **autumn** in NSW.

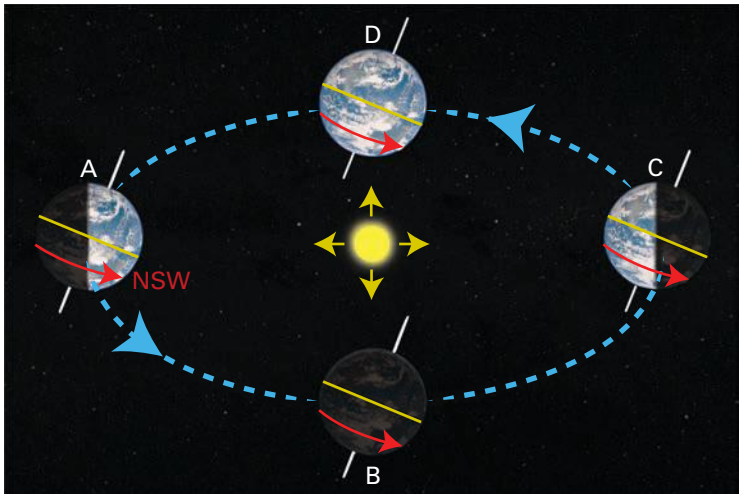


Figure 2.16 This image is NOT to scale! The Earth maintains its tilted axis of rotation as it revolves around the Sun, but relative to the Sun, the Northern Hemisphere tilts towards it at A then away from it at C. The red arrow shows the location of New South Wales on the Earth as it rotates.

Have a go yourself at working out the seasons for a location in the Northern Hemisphere. Consider also what happens at the equator.

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In the **Southern Hemisphere**, where Australia is located, the number of daylight hours decreases from January to June and increases from July to December. The day with the fewest daylight hours occurs around 21 June, this is called the winter solstice (position A in Figure 2.16). While the day with the most daylight hours occurs around 21 December, this is the summer solstice (position C). The opposite happens in the **Northern Hemisphere** where the summer solstice is in June and the winter solstice is in December. On the **equator**, there are 12 hours of daylight every day of the year. In spring and autumn (positions B and D in Figure 2.16), the daylight hours are equal to the night hours for all locations. This is called the equinox (Latin for 'equal night').

Southern Hemisphere the half of the Earth south of the equator

Northern Hemisphere the half of the Earth north of the equator

equator an imaginary line drawn around the middle of the Earth, equidistant between the North and South poles

Try this 2.3

Modelling the revolution of the Earth with a tilted axis

This activity uses the same globe and lamp as in *Try this 2.2* on page 84. The lamp could be the same type shown there, in which case it will need to be turned to shine in different directions. Alternatively use a lamp without a shade that shines in all directions.

Start with the same set-up as Figure 2.14. This represents position A in Figure 2.16. Repeat the rotation of the globe to model day length for a location on the Southern Hemisphere. Continue by moving the globe to positions B, C and D in turn, noting the relative day length for the Southern Hemisphere location each time. Relate each position to the season.

Explore! 2.3

A day at the poles

How long is a day in the North Pole or the South Pole? Have a look at the Figure 2.16 of the tilted globe and imagine it rotating about its axis. What happens to the amount of daylight at the North Pole? Conduct some research and find out the length of a day there.



Figure 2.17 Daylight in Antarctica near the South Pole

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Characteristics and features of the seasons

What do you observe throughout the year that can be explained by the seasons changing due to the revolution of the Earth around the Sun?

- The number of hours of daylight. During the year, the time the Sun rises and sets changes. In spring, the days get longer and in autumn the days get shorter.
- The places on the horizon where the Sun rises and sets moves. The Sun always rises in the east and sets in the west, but the position varies, moving towards the south in spring and towards the north in autumn.
- The average daily temperature is colder in winter and hotter in summer. The difference between average summer and winter temperatures increases as you move away from the equator.
- The height of the Sun in the sky at midday increases in summer and decreases in winter.
- Some animals and plants change their behaviour and appearance at different times of the year. In winter, deciduous trees lose their leaves, some animals hibernate, and others migrate. In the warmer months, birds nest and lay eggs, and plants produce flowers and then fruit, though there are winter-flowering plants as well.
- Seasonal changes also affect people. For example, farmers are heavily reliant on seasons for their livelihood. They can only sow and harvest at certain times of the year.

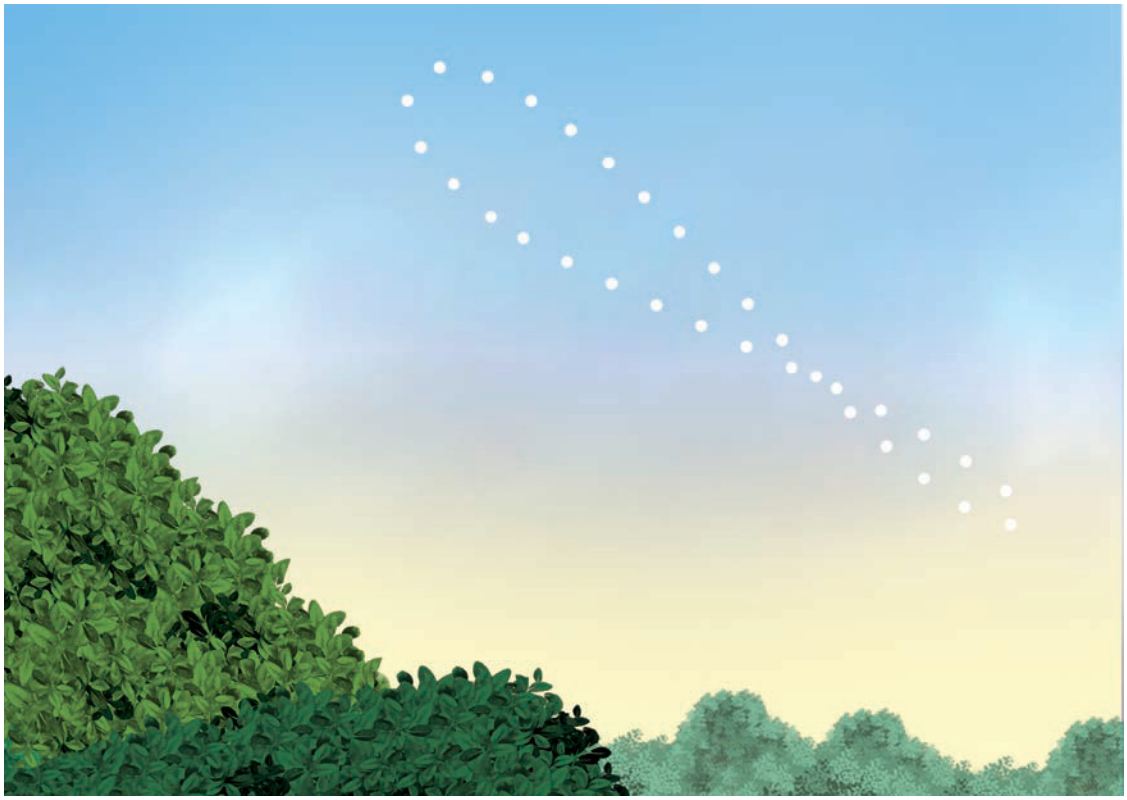


Figure 2.18 This illustrates the position of the Sun at the same time each week for a whole year. Which position do you think is summer and which is winter?

Quick check 2.2

1. **Define** the terms 'orbit', 'revolution' and 'leap year' in your own words.
2. **State** how long it takes for the Earth to orbit the Sun.
3. **Describe** things that change during the year due to the seasons.

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Explore! 2.4

The celestial Emu

Aboriginal and Torres Strait Islander Peoples have diverse and sophisticated ways of understanding and mapping the seasons. These systems vary significantly depending on the Country to which they belong, reflecting the unique landscapes, climates and ecosystems of regions. These seasonal calendars are not only vital to the cultural practices and sustainable resource management but also represent a profound connection to and knowledge of Country. They demonstrate a sophisticated understanding of ecological systems, which has contributed to advances in scientific fields such as botany, zoology, ecology and meteorology. Where possible you should investigate the seasonal calendars of communities local to you, using the respectful and culturally safe guidelines included with this resource. For example, for many Aboriginal groups, including the Kamilaroi and Euahlayi Peoples, the position of the celestial Emu (Figure 2.19) in the Sky signals the emu breeding season and guides the harvesting of emu eggs.

When the Emu appears clearly at dusk in March and April, it indicates that emu eggs are ready to collect. By June and July, the Emu lies horizontally in the sky, meaning the breeding season is over, and most eggs have hatched into chicks. This connection between the stars and the natural world demonstrates the deep understanding Aboriginal Peoples have of the environment and its cycles.

You can use the Stellarium software to explore how the Emu in the Sky looks at different times of the year. Set the date to the start of March and change the time to dusk. Find the Emu in the Sky, and start to move the date forward, keeping the time the same. Note how the constellation starts to change.

See *Section 2.6 Aboriginal and Torres Strait Islander Peoples' Cultural Knowledges of astronomy* in the Interactive Textbook for more.



Figure 2.19 The Emu in the Sky is a shape perceived in dark areas (dust and gas nebulae) in the Milky Way. In this image it is combined by with an Aboriginal rock carving of it, from a site in New South Wales.

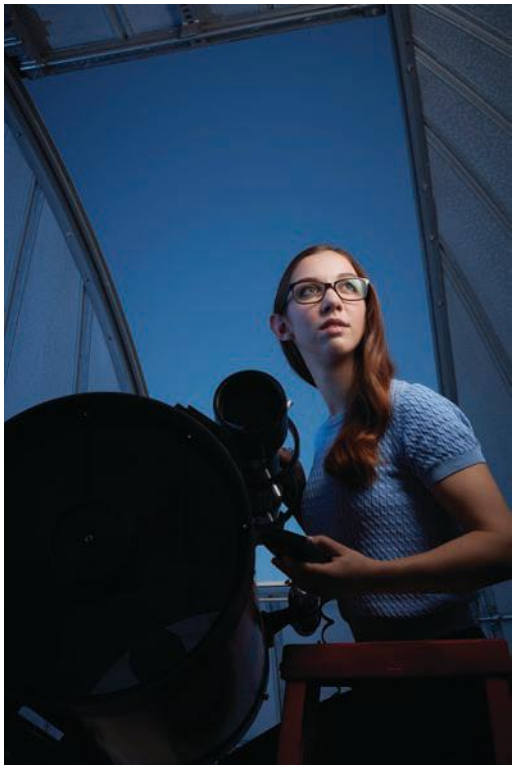


Figure 2.20 The Emu in the Sky dreaming story inspired Wiradjuri astrophysicist Kirsten Banks to share the astronomical knowledge of her ancestors. She regularly leads Aboriginal astronomy programs at the Sydney Observatory.

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Section 2.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.3 questions

Remembering

1. **Identify** how long a complete cycle of all four seasons takes.
2. **Describe** how plants and animals act differently in summer than in winter.

Understanding

3. **State** the reason for the seasons on Earth.
4. **Describe** how the seasons are different in tropical northern Australia, closer to the equator.

Applying

5. If an emu egg is found at a time when the celestial emu was approximately horizontal just after sunset, **explain** what a Kamilaroi person would do with it.

Analysing

6. **Describe** what the effect would be if the angle of tilt of Earth's axis of rotation was increased a bit, say by 5°.
7. The table shows hours of daylight in Sydney on 30 April 2021.

Date	Sunrise	Sunset	Hours of daylight
30 April	6:28 a.m.	5:15 p.m.	10 h 47 min

State whether you expect the number of daylight hours to be more or less than 10 hours 47 minutes on 1 May.

8. At 3 p.m. in winter your shadow will be longer than at 3 p.m. in summer. **Explain** why this is the case.

Evaluating

9. **Identify** at what time of the year the heating of the Earth's surface in NSW is greatest and **justify** your answer.
10. The summer solstice is when the Sun reaches its highest point in the sky, and the winter solstice is when the Sun reaches the lowest point in the sky. These are marked by the longest and shortest days respectively. Deduce in which months these occur in the Southern Hemisphere. **Justify** your answer.



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2.4 Movement of the Moon

Learning outcomes

At the end of this section, I will be able to:

1. model the movement of the Moon.
2. identify phases of the Moon and the cause of these.
3. identify the tidal effect the Moon has on the Earth.

WORKSHEET
Phases of the Moon

The phases of the Moon

phase of the Moon the bright area of the Moon and its shape when seen from Earth

waxing the period of about two weeks where the illuminated part of the Moon is increasing from a new moon to a full moon

waning the period of about two weeks where the illuminated part of the Moon is decreasing from a full moon to a new moon

The Moon orbits Earth, but this simple fact is not the end of the story. The Earth orbits the Sun as well, and that makes the Moon's path through space complicated. The location of the Moon as viewed from Earth is further complicated by the fact that the Earth rotates. However, to explain what the Moon looks like from the Earth, and its phases, we can just consider its orbit around the Earth (Figure 2.21). For the time being we will ignore Earth's rotation and its orbit around the Sun.

Although the Moon looks bright, it does not give out any light of its own. All the light that comes to us from the Moon is reflected from the Sun. Only the half of the Moon that faces the Sun is bright; the other half is in shadow. The area and shape of the bright side you can see from Earth is the **phase of the Moon** is in, and it varies in a regular cycle. Figure 2.21 shows the names of the phases of the Moon. Note that between a new moon and a full moon, the illuminated part is **waxing**. Between the full moon and a new moon, the illuminated part is **waning**.

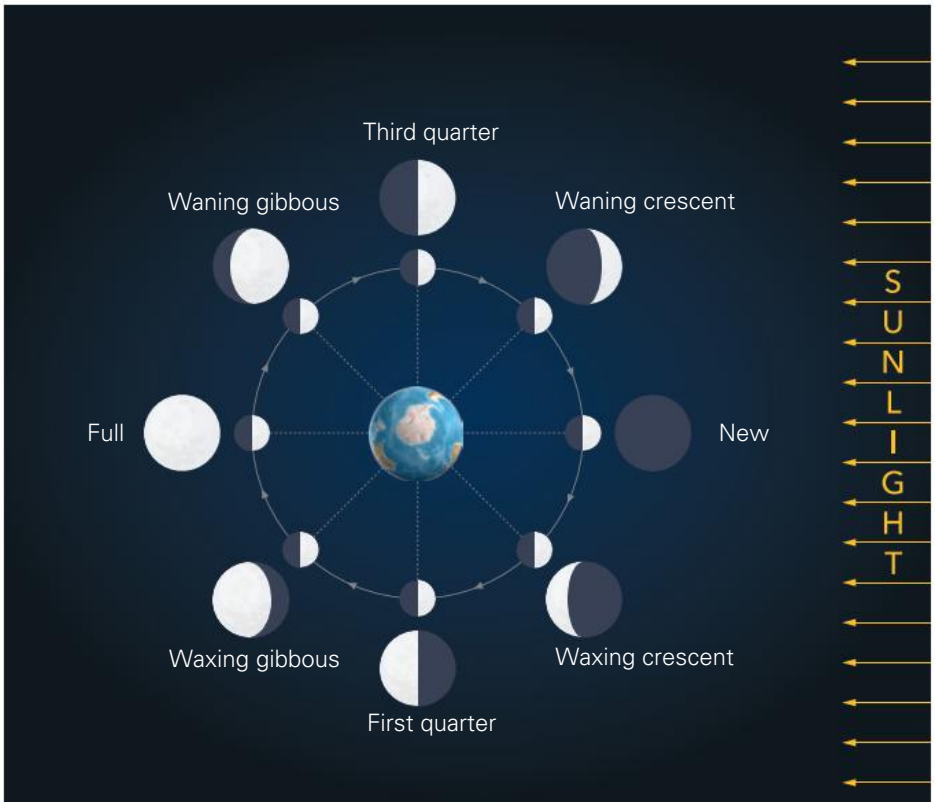


Figure 2.21 The inner part of this diagram shows the Moon's orbit around the Earth, and the outer part shows the phases of the Moon, somewhat enlarged. Although the phases are the same when viewed in the Northern and Southern Hemispheres, the orientation is different, because viewers in different locations north and south see phases from different angles. This diagram is orientated from the perspective of the Southern Hemisphere.

VIDEO
Moon phases as seen from space

WIDGET
Phases of the moon

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Moon orbit versus moon phase

One thing you might notice is that the time the Moon rises and sets changes every day. You might notice that each day the Moon's phase changes slightly. It takes 29.5 days to complete a cycle of phases from new moon to full moon and back to new moon (hence a month is about 30 days since it is defined as the average length of one cycle of phases). Recall that it takes 27.3 days for the Moon to rotate and orbit once around the Earth. Why are they different?

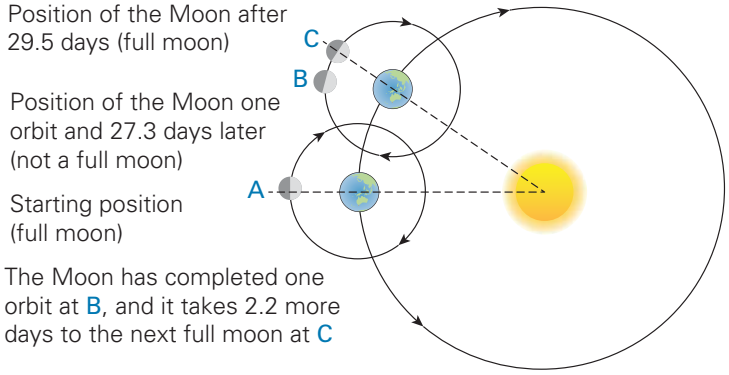


Figure 2.22 The time between full moons and the orbital period of the Moon is different by 2.2 days.

The reason is related to the Earth's movement around the Sun. A full moon occurs when the Moon, Earth and Sun form a straight line. After the Moon has completed an orbit 27.3 days later, the Earth has moved, and the Moon is no longer in line with the Earth and the Sun, as shown in Figure 2.22. To form the next full moon and to line up with the Earth and the Sun again, the Moon must keep moving for another 2.2 days.

Quick check 2.3

1. **Explain** how you can see the Moon if it does not give off any light of its own.
2. **Define** the terms 'waxing' and 'waning'.
3. **State** how long it takes to complete a full cycle of the Moon's phases.

How the Moon keeps the same face towards us

Have you ever wondered how the Moon keeps the same face towards the Earth? Observe the Moon over a period of two weeks. You will see that even though the phase changes, the craters and features on the Moon stay the same.

The reason the Moon always presents the same face to Earth is that it rotates on its axis as well as revolving around Earth. In addition, the time taken for it to rotate once is the same as the time it takes to orbit Earth – about 27.3 days. This is known as **synchronous rotation**.

synchronous rotation occurs when one rotation of an orbiting body takes the same length of time as one orbit

The Moon's apparent motion due to Earth's rotation

In the course of a 24-hour day the Moon rises and appears to move across the sky and then sets. As with the Sun's daily motion, this is due to the rotation of the Earth. Like the Sun, the Moon rises in the east and sets in the west, and it follows a similar path to the Sun.

On a clear, sunny day the Moon is often seen in the sky, especially when it is at the quarter and gibbous phases. A hazy sky will easily obscure it. The Moon is associated with night because it's more prominent then.

The Moon and the tides

The proximity of the Moon to Earth is responsible for tides. The force due to gravity between objects is greater the closer the objects are, and since water is a fluid that can easily move, we can clearly see its response. Therefore, high tide occurs on the side of Earth that is closest to the Moon (Figure 2.23). But wait! High tide also occurs on the side opposite, the side furthest from the Moon. Why is that?

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Remember this force due to gravity affects all matter, including the solid rock part of the Earth. The Moon pulls on the Earth more than it pulls on water on the side furthest from the Moon. This is the reason there is also a high tide on the opposite side of the Earth.

In Figure 2.23 the poles are in the centre and the Earth rotates around them. But the positions of high and low tides remain where they are relative to the Moon. This means locations on the coasts move through two high tides and two low tides in each 24-hour period. The timing of the tides for any location changes by about an hour each day due to the position of the Moon changing in its orbit around the Earth.

A very high tide called a spring tide occurs when the Sun and Moon are in line. Although the Sun is much larger, it is also much further away, and its pull due to gravity on the Earth is only about a quarter of the Moon's. However, when the pull of the Sun and the Moon combines, it causes a very high tide while the low tide is unaffected. When the Sun and the Moon are at right angles, the Sun's pull reduces the effect of the Moon's pull (Figure 2.24).

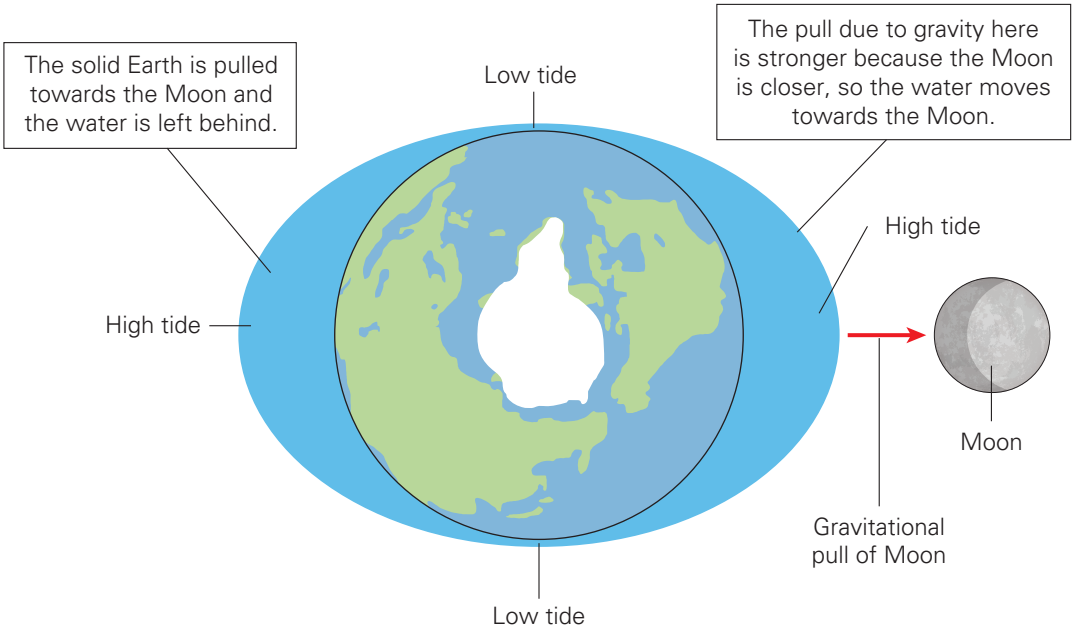


Figure 2.23 View of Earth from above the North Pole showing the pull of the Moon's gravity on the oceans (not to scale). High tides are caused by the Moon's gravity and always occur on the side closest to the Moon and its opposite side, which means low tides must also occur on opposite sides, at right angles to the high tide sides.

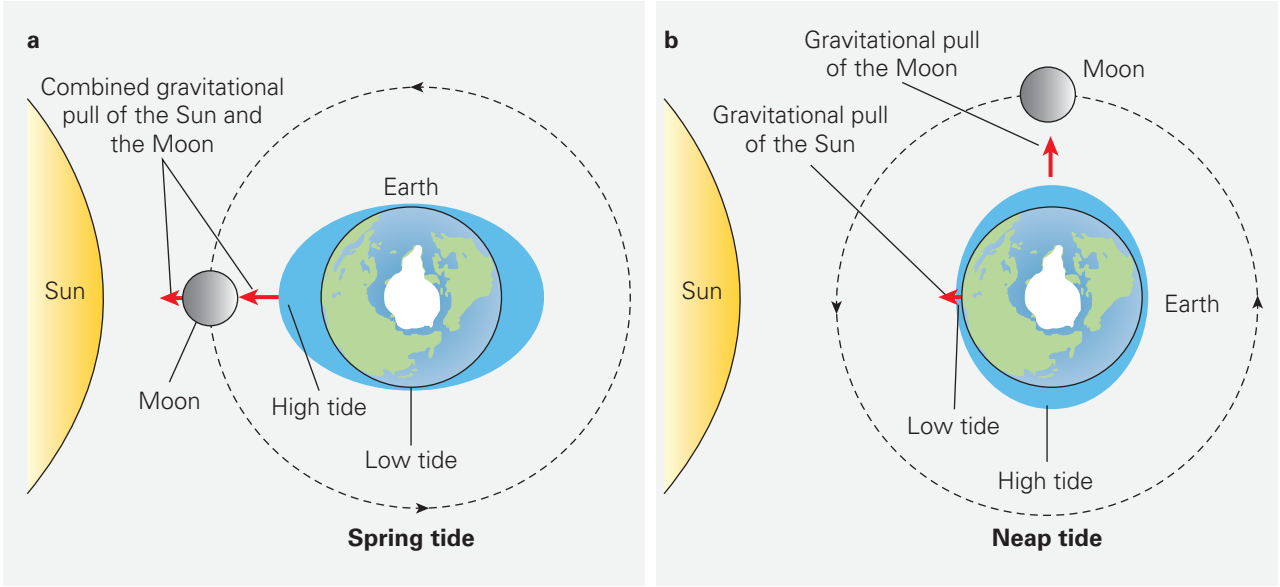


Figure 2.24 Diagrams are not to scale. **(a)** Spring tide occurs when the Sun and the Moon are in line. **(b)** Neap tide occurs when the Sun and the Moon are at right angles. Note: the gravitational pull of the Moon is about twice as strong as that of the Sun, because although the Sun is far more massive, it is nearly 400 times further away.

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Quick check 2.4

1. **Explain** why the Moon's surface always looks the same from Earth.
2. **Explain** how you can tell the Moon is actually moving relative to Earth, separate from its apparent daily motion across the sky.
3. **State** whether it is sometimes possible to see the Moon during the middle part of the day.
4. **Explain** what causes a normal high tide.

Try this 2.4

Modelling the phases of the Moon

Be careful

Take care when handling light sources after extended use they may be hot.

Using an electric lamp, an 8 cm polystyrene ball and a pencil, follow the instructions to model the phases of the Moon. Draw diagrams of your observations at each point in the cycle.

1. Stick the pencil into the foam ball so that the pencil can act as a handle. Place the lamp in the centre of a darkened room.
2. Extend your arm so you are holding the foam ball in front of you. The ball should be between your eyes and the lamp. The foam ball is modelling the Moon, the lamp is the Sun and your head is Earth. Note that the polystyrene ball does not generate light of its own; it reflects light from the lamp.
3. The Moon starts off in a 'new moon' position, as you can only see the unlit side.
4. Sweep your arm holding the ball in a clockwise direction to model the waxing moon phases. Move your head to the side to observe these phases. Record what you see in a results table.
5. Continue moving the 'Moon' clockwise and turn your body so you can keep looking at it. Once the Moon is behind your head, it will be in the 'full moon' phase unless your head (Earth) is blocking the light and creating a lunar eclipse.
6. Continue turning your body around, moving the Moon clockwise back to the start to simulate waning phases of the Moon.
7. Describe where the ball was in relation to your head when it was at the following phases: new moon, full moon, waxing gibbous, waning gibbous, waxing crescent, waning crescent, first quarter, third quarter.
8. Propose how you could improve this simulation.

Go online to access the interactive section review and more!

Section 2.4 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 2.4 questions

Remembering

1. **State** a definition for the 'phase of the Moon'.
2. **Identify** the names of the phases of the Moon and sketch the shape of each one.

Understanding

3. **Explain** with the aid of a diagram how the Moon could be visible high in the sky on a clear sunny day.

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4. **Explain** with reference to the orbit of the Moon around Earth why a half-lit Moon is called a quarter moon and not a half moon.

Applying

5. **Explain** with the aid of a diagram why the Moon takes 27.3 days to orbit Earth and yet there are 29.5 days from one full moon to the next.
6. Use the chart in Figure 2.25 showing the phases of the Moon for a particular year to answer the following questions.

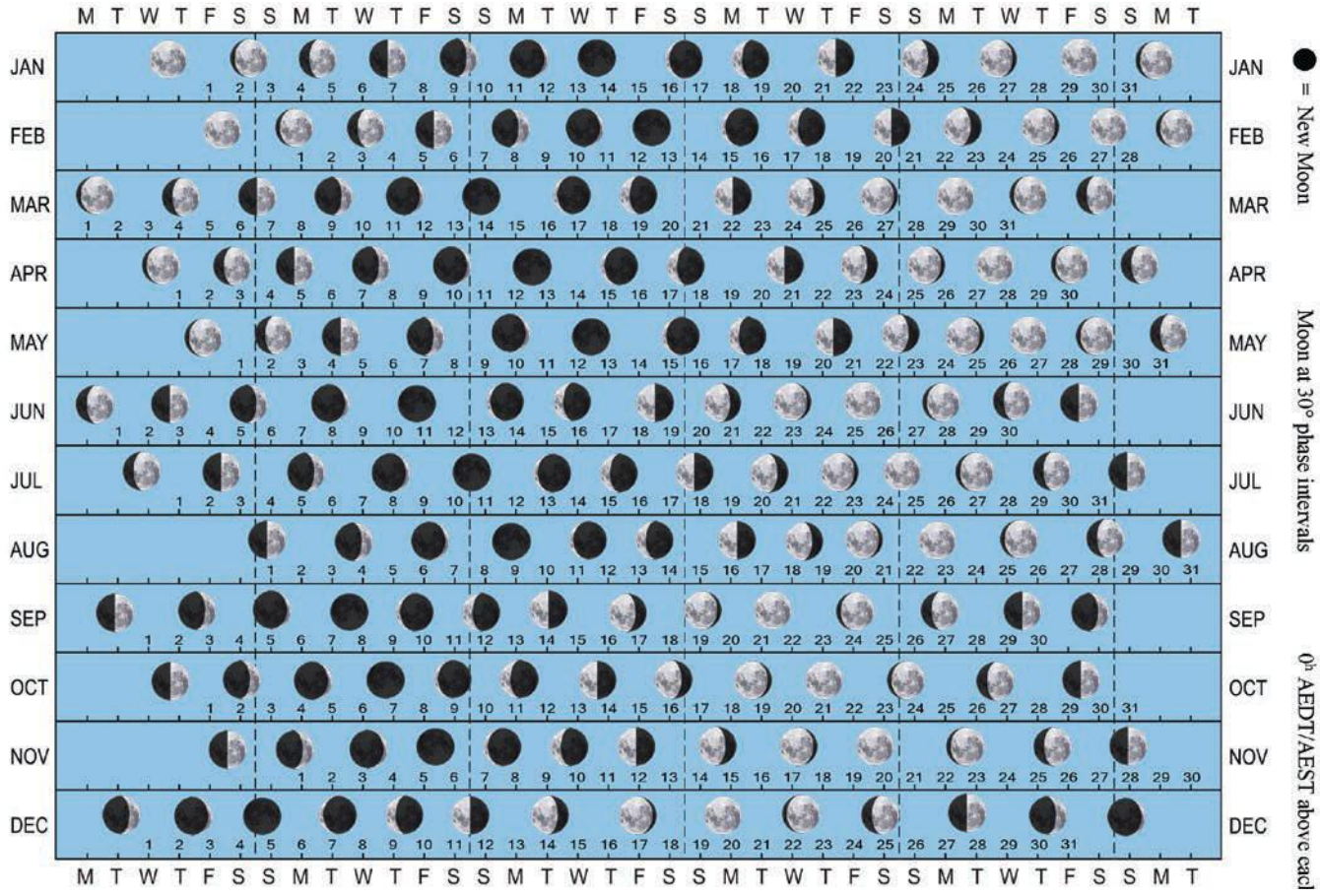


Figure 2.25 The chart from the Astronomical Society of Victoria shows the dates for each of the phases for 2021.

   a. **Describe** the phase of the Moon on 4 August.
   b. **Describe** the phase of the Moon on 27 October.
   c. The saying 'Once in a blue moon' is used when discussing anything that happens rarely. A blue moon occurs if there are two full moons in a month. **Analyse** Figure 2.25 to see if there were any blue moons in that year.

Analysing

7. **Explain** how the Moon's gravity is mainly responsible for tides.
8. **Explain** why a spring tide could not coincide with a quarter moon.

Evaluating

9. A story includes the line 'a bright new moon was shining overhead'. **Explain** why this could not be possible.

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2.5 Eclipses

WORKSHEET
Eclipses

Learning outcomes

At the end of this section, I will be able to:

1. distinguish between solar and lunar eclipses.
2. identify the causes and features of each type of eclipse.

The motions of the Earth around the Sun and the Moon around the Earth are complex and require mathematics to describe them precisely. However, they are completely predictable. By looking for patterns in observations made over many years, ancient astronomers could anticipate with reasonable accuracy some of the events you are going to learn about, such as:

- **solar eclipses**, where the Moon blocks the light from the Sun and casts a shadow on a small part of the Earth
- **lunar eclipses**, which occur when the Earth blocks the light from the Sun, throwing a shadow onto the Moon.

solar eclipse
an event when the Sun partly or completely disappears from view, while the Moon moves between it and the Earth

lunar eclipse
an event when a full moon becomes dark as it enters the Earth's shadow

syzygy
the alignment in astronomy of three objects in a straight line

total eclipse
an event when the Sun is completely blocked by the Moon

umbra
the region in a shadow where the light is completely blocked

partial eclipse
an event when the Sun is partially blocked by the Moon

penumbra
the region in a shadow where the light is partially blocked

Solar eclipses

What happens when the Moon blocks the Sun?

As shown in Figure 2.26, once a month, in its orbit around the Earth, the Moon moves between the Earth and the Sun. Most of the time the three bodies don't line up exactly, but there is a chance that the Moon may come exactly between the Earth and the Sun. If this happens and the Sun, Moon and Earth all line up, astronomers call it a **syzygy**, and the result is a solar eclipse. Because the Moon is considerably smaller than Earth, a solar eclipse is only visible from a small region on the Earth's surface.

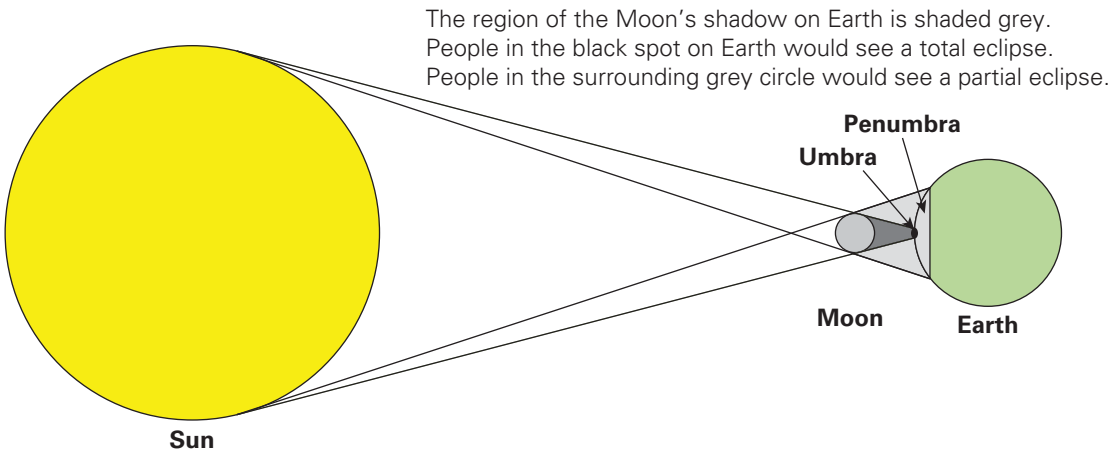


Figure 2.26 A solar eclipse occurs when the Moon comes between the Earth and the Sun. This diagram is not to scale, and the size of the shadow areas is greatly exaggerated.

Total versus partial eclipse

During a solar eclipse, the Moon blocks the light from the Sun on a small part of the Earth's surface. A **total eclipse** is visible from the dark-coloured central part of the shadow called the **umbra**. A **partial eclipse** occurs when the light from the Sun is partially blocked; it is visible from the area that is lightly shaded on the Earth called the **penumbra**. Both the umbra and penumbra are so small that even if there is a solar eclipse most people won't see it.

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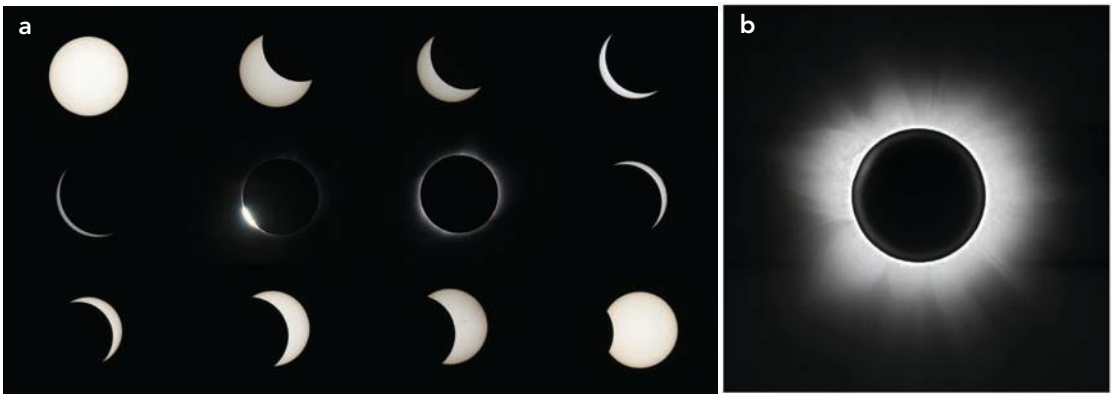


Figure 2.27 This series of images shows **(a)** the stages of a total solar eclipse, and **(b)** totality.



Figure 2.28 The shadow of a solar eclipse photographed from the International Space Station. The Moon's shadow covers only a small fraction of the the Earth's surface.

Try this 2.5

How far is it to the Sun?



Figure 2.29 The Earth and the Moon are drawn here to scale. The Sun is 400 times further away from the Earth than the Moon.



Figure 2.30 It might be tempting to think that the Sun is of a similar size to the Earth because its light can be blocked by the Moon, but the Sun is much larger than the Earth. In this image, the Earth is placed next to a portion of the Sun to show their relative sizes.

Measure the distance from the Earth to the Moon in Figure 2.29. Multiply the distance by 400 to work out how far away the Sun would be if it were also included in the picture. The distance between the Earth and the Sun is known as 1 Astronomical Unit (1 AU). This prevents us from having to write huge numbers when we are measuring in kilometres.

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What is an annular eclipse?

The Sun is about 400 times bigger than the Moon, but is also 400 times further away, so from the Earth, the Moon and Sun appear to be about the same size. This means that the Moon is just big enough to hide the Sun when it passes in front. However, the orbits of the Earth and the Moon are not perfect circles, and the Moon's apparent size can vary by up to 12% in its orbit around the Earth. If the solar eclipse occurs when the Moon is closest to the the Earth, (**perigee**), the result is a total eclipse. If the Moon is at its furthest point, (**apogee**), the result is an **annular eclipse**. The mathematical word for the shape you get when you cut a small circle from the centre of a larger circle is an annulus, so this type of eclipse is called an annular eclipse.

perigee
the point in the Moon's orbit when the Moon is closest to the Earth

apogee
the point in the Moon's orbit when it is furthest from the Earth

annular eclipse
an event when the Moon blocks the Sun, but the Moon is not at its closest point to Earth so the outer edge of the Sun is still visible



Figure 2.31 An annular solar eclipse seen through a cloud

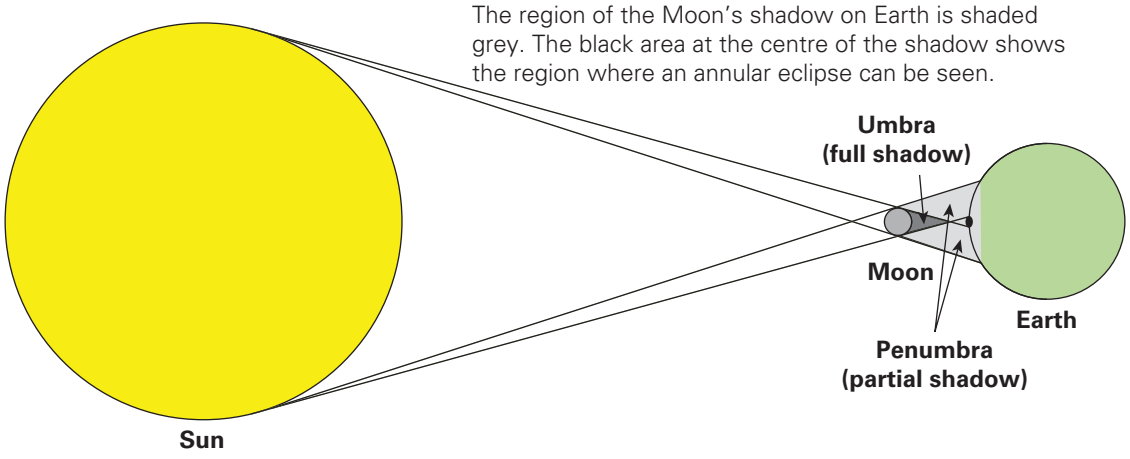


Figure 2.32 If the Moon is not at its closest to the Earth at the time of the eclipse, the result is an annular eclipse. The dark area is where an annular eclipse can be seen, and the lightly shaded region on the Earth's surface experiences a partial solar eclipse (not to scale).

INVESTIGATION

Explore! 2.5

Aboriginal and Torres Strait Islander Peoples' stories of the Sun and Moon

In many Aboriginal and Torres Strait Islander cultures, the Sun and the Moon are often described as ancestral spirits with unique roles and responsibilities. The Sun is often seen as a matriarchal spirit, bringing warmth, light and life to the world. She plays a nurturing role, caring for the land, the animals and the people. The Moon, on the other hand, is often seen as a patriarchal spirit, representing cycles, change and renewal, like the phases of the Moon and the tides. Many oral traditions involve one chasing the other across the sky, meeting whenever there was an eclipse.

1. Research the story that the Yolngu People of Elcho Island in Arnhem Land tell of Ngalindi (the Moon).
2. Research the story that the Euahlayi People tell of the Sun, Yhi, who chases Bahloo, the patriarchal Moon spirit.

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Quick check 2.5

1 **Define** the term 'syzygy'.
2 **Explain** why a solar eclipse is visible from only a small part of Earth.

Lunar eclipses

What happens when the Moon moves into Earth's shadow?

As shown in Figure 2.33, about once a month the Earth moves between the Moon and Sun. Most of the time the three bodies don't line up exactly, but when they do, a lunar eclipse occurs as the Moon moves into Earth's shadow.

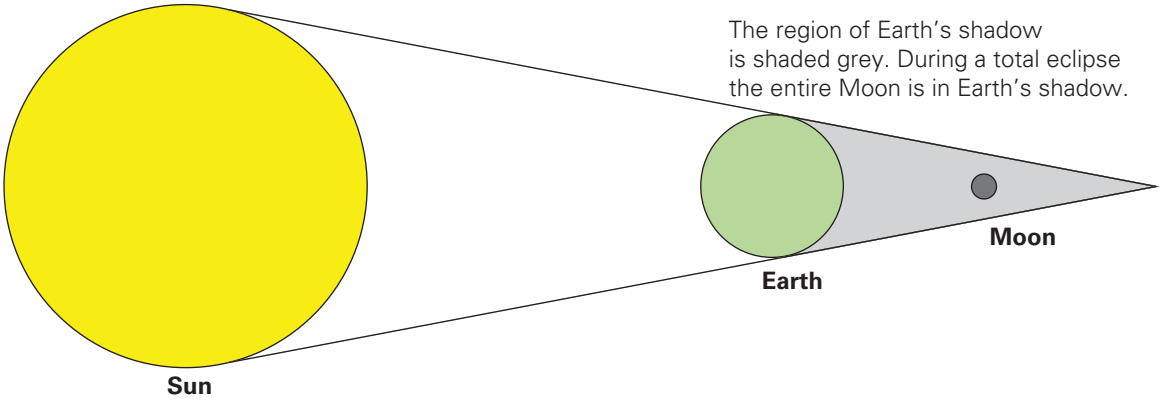


Figure 2.33 Earth is much bigger than the Moon, so Earth's shadow is big enough to cover the whole of the Moon.

When the Moon is completely in Earth's shadow during a total lunar eclipse, it is called a **blood moon**. The red colour is due to red light being refracted (bent) by the atmosphere around the Earth. Hence, only red light reaches the Moon during the total eclipse.

blood moon
a name given to the Moon during an lunar eclipse while it is completely in Earth's shadow



Figure 2.34 A total lunar eclipse in progress. The round edge of Earth's shadow is visible.



Figure 2.35 A blood moon during a total eclipse is due to the red light being refracted by Earth's atmosphere.

Comparison of solar and lunar eclipses

Although the Sun and Moon are involved in both kinds of eclipses, solar and lunar eclipses are very different. A solar eclipse is a less frequent event and results in the sky turning dark during the day, whereas a total lunar eclipse happens at night or just after sunset or just before sunrise, and results in the full moon moving into Earth's shadow.

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VIDEO
Solar and lunar eclipses

	Total solar eclipse	Total lunar eclipse
Duration	A few minutes	A few hours
Who can see it	A small area only	Everyone on Earth on the side facing away from the Sun
Occurrence	Once every 18 months	1–2 per year
Safety	Special equipment required to view	Safe, anyone can watch, no special equipment required
Cause	The Moon's shadow on Earth	Earth's shadow on the Moon

Table 2.1 Differences between solar and lunar eclipses

Try this 2.6

Modelling solar and lunar eclipses

Be careful

Take care when handling light sources after extended use – they may be hot.

Use the materials listed to model a solar eclipse and a lunar eclipse.

- bright lamp
- Earth globe
- tennis or golf ball
- string

Record your observations of the shadows created in this model. Explain how you modelled a solar eclipse in this activity. Explain how you modelled the lunar eclipse. Predict what would happen if you changed the size of the ball. Discuss how this model could be improved.


Go online to access the interactive section review and more!

Section 2.5 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 2.5 questions

Remembering

1. **Recall** how solar and lunar eclipses are created.

Understanding

2. **Explain** why a person is likely to see many more lunar eclipses in their lifetime than solar eclipses, even though lunar eclipses occur only a little more frequently than solar eclipses.
3. **Outline** why, although they are at hugely different distances from Earth, the Sun and Moon appear the same size in the sky.

Applying

4. **Recall** the phases of the Moon. Utilise the information to **decide** in which phase of the Moon a lunar eclipse occurs.
5. **Recall** the phases of the Moon. Utilise the information to **decide** in which phase of the Moon a solar eclipse occurs.

Analysing

6. **Compare** and **contrast** a partial and a total solar eclipse.

Evaluating

7. **Clarify** why eclipses are so infrequent.
8. **Outline** the factors that need to be considered when viewing a solar eclipse versus a lunar eclipse.
9. **Describe** how our experiences on Earth would be different if the Moon was larger.

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2.6 Aboriginal and Torres Strait Islander Peoples' cultural knowledges of astronomy (online)

Learning outcomes

At the end of this section, I will be able to:

1. compare and contrast examples of Aboriginal and Torres Strait Islander accounts and scientific explanations for phases of the Moon and tides.
2. explain examples of how Aboriginal and Torres Strait Islander Peoples use stars to identify specific weather phenomena.
3. describe examples of how Aboriginal and Torres Strait Islander Peoples predict seasonal phenomena based on their observations of the stars and phases.



WORKSHEET Aboriginal and Torres Strait Islander Peoples' cultural knowledges of astronomy

This section is online and can be found in the Interactive Textbook, with accompanying guidance for teachers in the online teacher resources. While a few examples of such cultural knowledge can be found in the print book, examples from local communities are preferable. For this reason, you should carry out your own research, and the online version of this section gives guidance on how to do this and some examples of what kinds of cultural knowledge to research.

In addition, there are a number of skills you should learn regarding the use of reliable sources and culturally safe and respectful practices, and these digital guidelines are linked in the online version.



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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
2.1	compare historical and current solar system models to show how models are modified or rejected due to new scientific evidence.	8
2.2	describe the effect of Earth's rotation on creating day and night, on daylength and on temperature.	5, 12
2.2	state the rotation time for Earth.	1
2.3	relate the yearly cycles of the Earth to its revolution of the Sun including seasons.	3, 11, 14
2.3	identify an example of local Aboriginal Peoples' mappings of the seasons.	4
2.4	model the movement of the Moon.	9
2.4	identify phases of the Moon and the cause of these.	2
2.4	identify the tidal effect the Moon has on Earth.	7
2.5	distinguish between solar and lunar eclipses.	6
2.5	identify the causes and features of each type of eclipse.	10, 13
2.6	compare and contrast examples of Aboriginal and Torres Strait Islander accounts and scientific explanations for phases of the Moon and tides.	*Examples depend on local communities*
2.6	explain examples of how Aboriginal and Torres Strait Islander Peoples use stars to identify specific weather phenomena.	
2.6	describe examples of how Aboriginal and Torres Strait Islander Peoples predict seasonal phenomena based on their observations of the stars and phases.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Recall** the approximate number of times Earth rotates in one month.
2. **Recall** the approximate number of phase cycles of the Moon in one year.
3. **Identify** what keeps planets in orbit around the Sun.

Understanding

4. **Describe** how an astronomical observation is used by the Kamilaroi people of New South Wales to determine the right season for harvesting emu eggs.
5. **Describe** two reasons why the average winter temperature is higher in Brisbane than in Sydney.

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6. **Explain** why an eclipse can never occur during a quarter-moon phase.
7. **Explain** what causes a spring (king) tide.
8. **Describe** the two main models of the solar system that have been dominant in mainstream science, and the evidence that led to adoption of the one that is currently in use.

Applying

9. The Moon is very slowly getting further away from Earth. **Illustrate** a labelled diagram to show why total solar eclipses will become less likely in the future.
10. **Contrast** the time taken for Earth to orbit the Sun with how long it takes the Moon to orbit Earth.
11. **Discuss** whether places near the equator experience distinct seasons and explain why there may be differences to locations further north or south.

Analysing

12. It is dark in Sydney and daylight in Perth. **Determine** if it is morning or evening.
13. **Discuss** if a solar eclipse and a lunar eclipse could occur in the same month.

Evaluating

14. **Predict** how the seasons and hours of daylight at different locations on Earth would be different from now if Earth did not have a tilt to its axis of rotation (i.e. if the axis of rotation was at right angles to the direction of the Sun).
15. There have been many things discovered about the solar system and universe throughout history. **Propose** what might be found in the future about the solar system with developing technology.



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Data questions

Just like Earth's moon, the Moon, there are moons that orbit the planet Jupiter. In fact, by 2024, 95 moons had been discovered orbiting Jupiter! These vary in size and distance from the planet. The eight innermost moons and the periods of their orbits are shown in Figure 2.36.

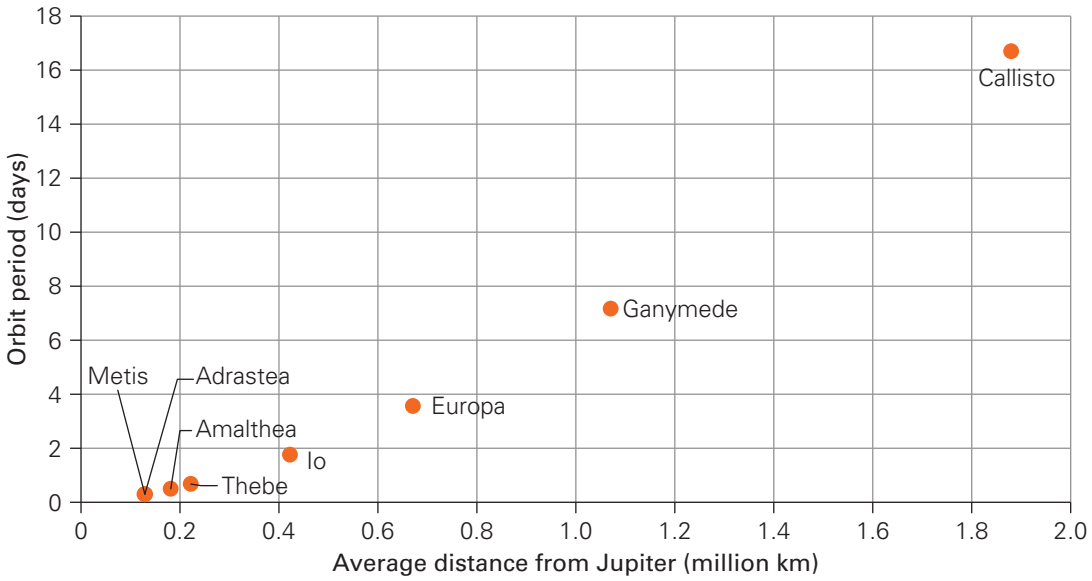


Figure 2.36 Orbital period of Jupiter's inner and Galilean moons

1. **Identify** which of the moons in Figure 2.36 orbits furthest in distance from Jupiter.
2. Use the data to **determine** which moon takes approximately 1.8 days to complete a full orbit of Jupiter.
3. Adrastea has a period of 0.3 days, whereas Amalthea has a period of 0.5 days. **Calculate** the difference in the number of hours it takes these moons to orbit Jupiter.
4. Galileo Galilei first discovered the four largest of Jupiter's moons in the seventeenth century, when he saw them through a telescope. They are those with an average orbit distance between 0.3 to 2 million km from Jupiter. **Categorise** the moons in Figure 2.36 as 'Galilean' or 'inner-orbiting' (for those that orbit at distances other than 0.3 to 2 million km).

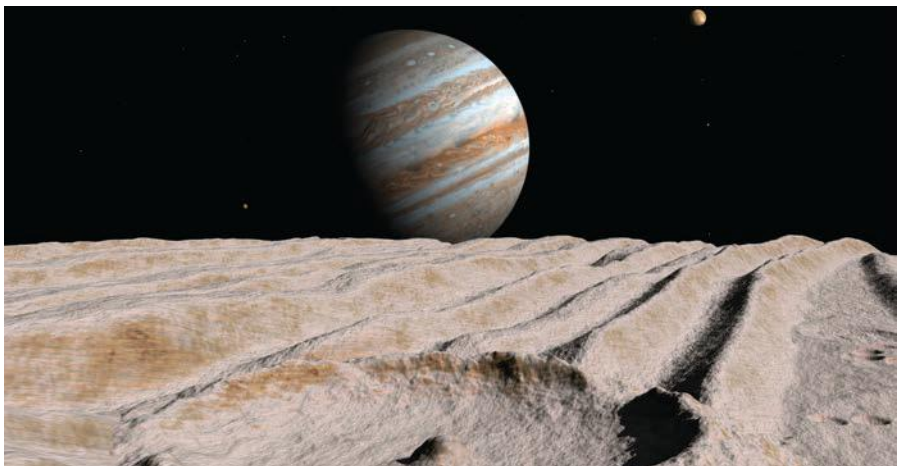


Figure 2.37 An artist's impression of the view of Jupiter, as if viewed from the surface of one of its moons, Ganymede

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5. **Distinguish** the Galilean moons from the inner orbiting moons by referring to their possible size.
6. **Identify** the trend in the average distance of a moon from Jupiter and the time it takes for the moon to complete a full orbit of Jupiter.
7. Jupiter's ninth moon is called Thermisto, and its average distance from Jupiter is approximately 7.3 million km. A student has estimated, based on the trend in Figure 2.36, that the orbital period for Thermisto would be approximately 20 days. Use the data to **deduce** whether this would be an accurate estimate.
8. Earth's moon, the Moon, has an average distance from Earth of approximately 0.4 million km and has an orbit period of 27.32 days. **Compare** this data point to those provided in Figure 2.36 for the moons of Jupiter. Does Earth's lunar orbital period fit the trend identified in Question **6**?
9. **Justify** your response to Question **8** with an appropriate scientific explanation.

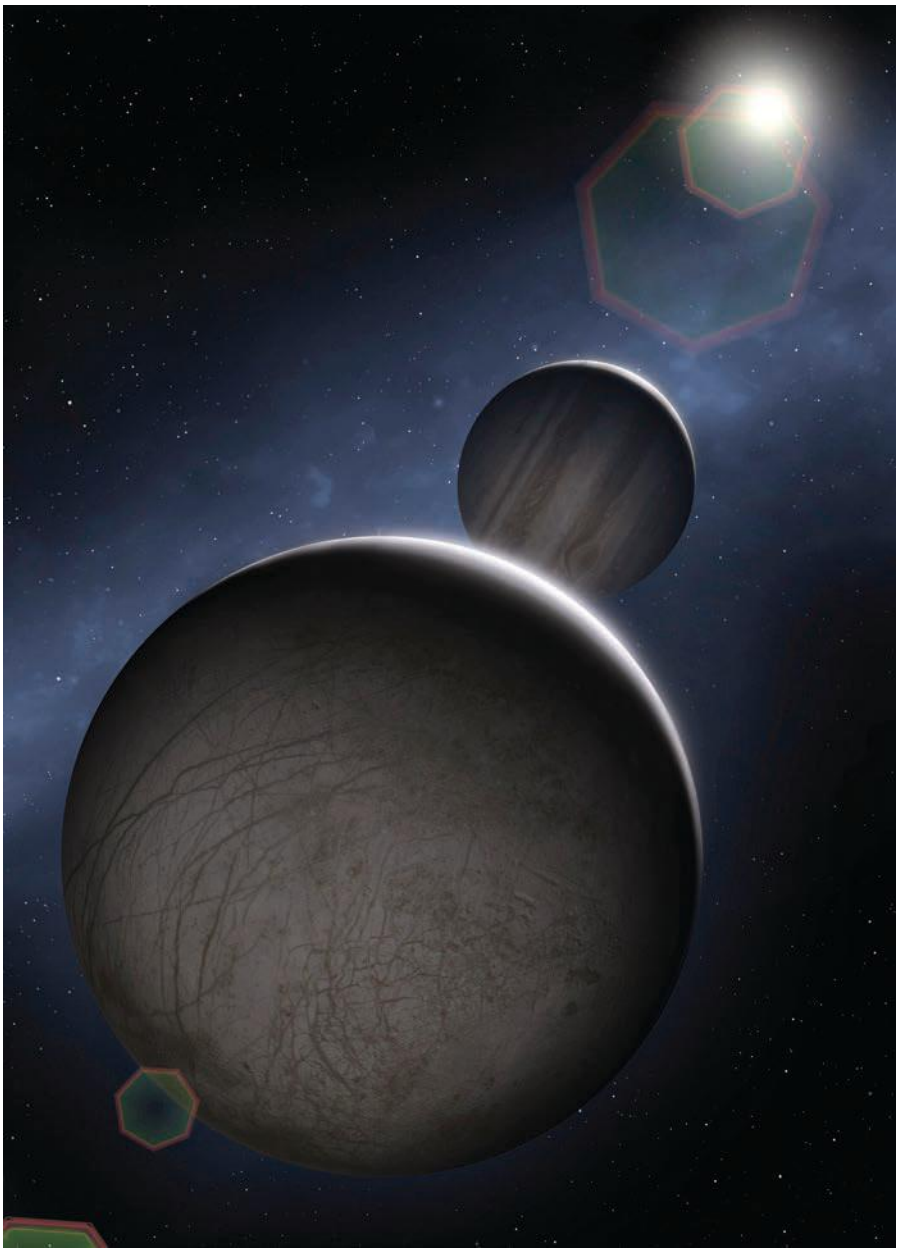


Figure 2.38 An artist's impression of Europa, with Jupiter visible in the background

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STEM activity: Simulating the orbit of planets

DESIGN BRIEF

Create a digital animation as a model or simulation of solar system planets orbiting the Sun.

Activity instructions

In this task, you will investigate how Kepler's laws of planetary motion explain why different planets orbit our Sun at different speeds. Kepler's laws of planetary motion are straightforward, summarised as:

> *A planet's orbital speed changes, depending on how far it is from the Sun. The closer a planet is to the Sun, the stronger the Sun's gravitational pull on it, and the faster the planet moves.*

We can observe the effects of Kepler's laws within our own solar system right now. Table 2.2 shows the relationship between distance and orbit of the planets Mercury, Venus, Earth and Mars.

Planet	Distance from the Sun (km)	Orbital period (days)
Mercury	57 000 000	88
Venus	108 000 000	225
Earth	150 000 000	365
Mars	228 000 000	687

Table 2.2 Distance and orbital period data for planets located in the inner solar system

Your task is to use Microsoft PowerPoint's animation tools or a suitable AI tool to create your very own simulation of the solar system (like the one shown in Figure 2.39), and to gain a visual understanding of how Kepler's laws of planetary motion apply to planets orbiting the Sun.

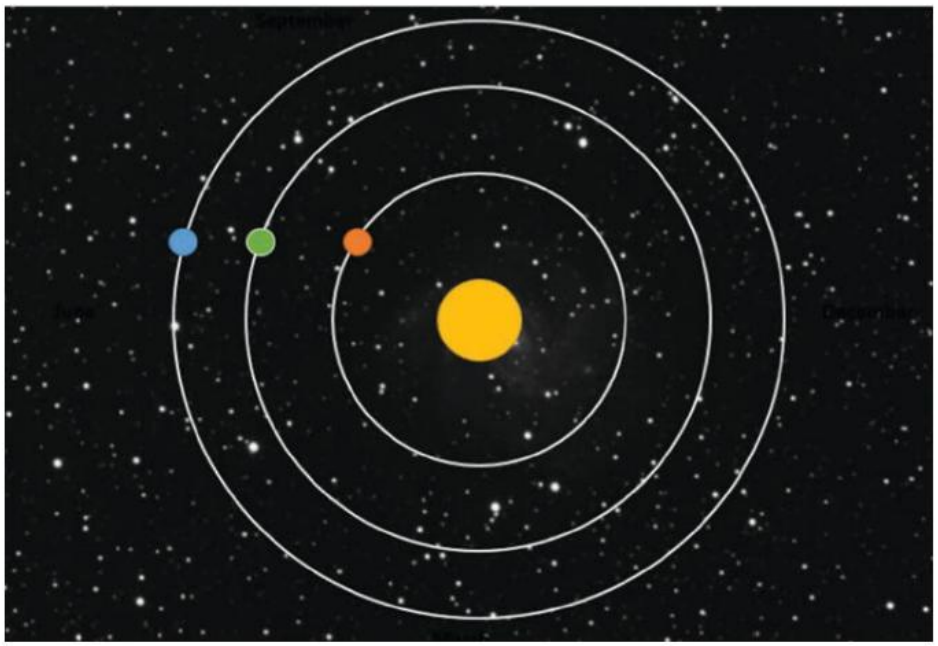


Figure 2.39 Model of the solar system

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Suggested materials

- laptop
- Microsoft PowerPoint (or an app with similar animation features)
- paper and pencil to perform simple calculations

Research and feasibility

1. Research our solar system, the names of the planets, their orbiting speed and distance from the Sun.

Design

2. Create a two-dimensional diagram representing the solar system. Create a scale for distance so that 1 cm on the diagram represents so many million kilometres, so that the four planets chosen for this activity will fit. Place each of the four planets at the scale distance from the Sun, and include suitable labels or captions that give relevant information on each planet. Include planet names, their orbital speeds and each planet's distance from the Sun.

Create

3. Use Microsoft PowerPoint or another app's animation feature to move each planet in a separate orbit around the Sun. To start with, set a time of two seconds for the orbital period to create your model.
4. Planets closer to the Sun (e.g. Mercury) have shorter orbital periods compared to planets located further away (e.g. Mars). Therefore, you should make changes to your animation to make it behave as closely as possible to the real solar system.
5. On your model, Mercury orbits the Sun in 2 seconds, and its actual orbital period is 88 days. Estimate the number of seconds required for Venus (orbital period = 225 days) to orbit in your animation ($\frac{225}{88} \times 2$ seconds = about 5 seconds). Do the same for Earth and Mars, taking the orbital periods from Table 2.2. After you finish your estimation, you can change the values (seconds) for the animation to make your model more realistic in terms of the relative times for the planets to complete one orbit.

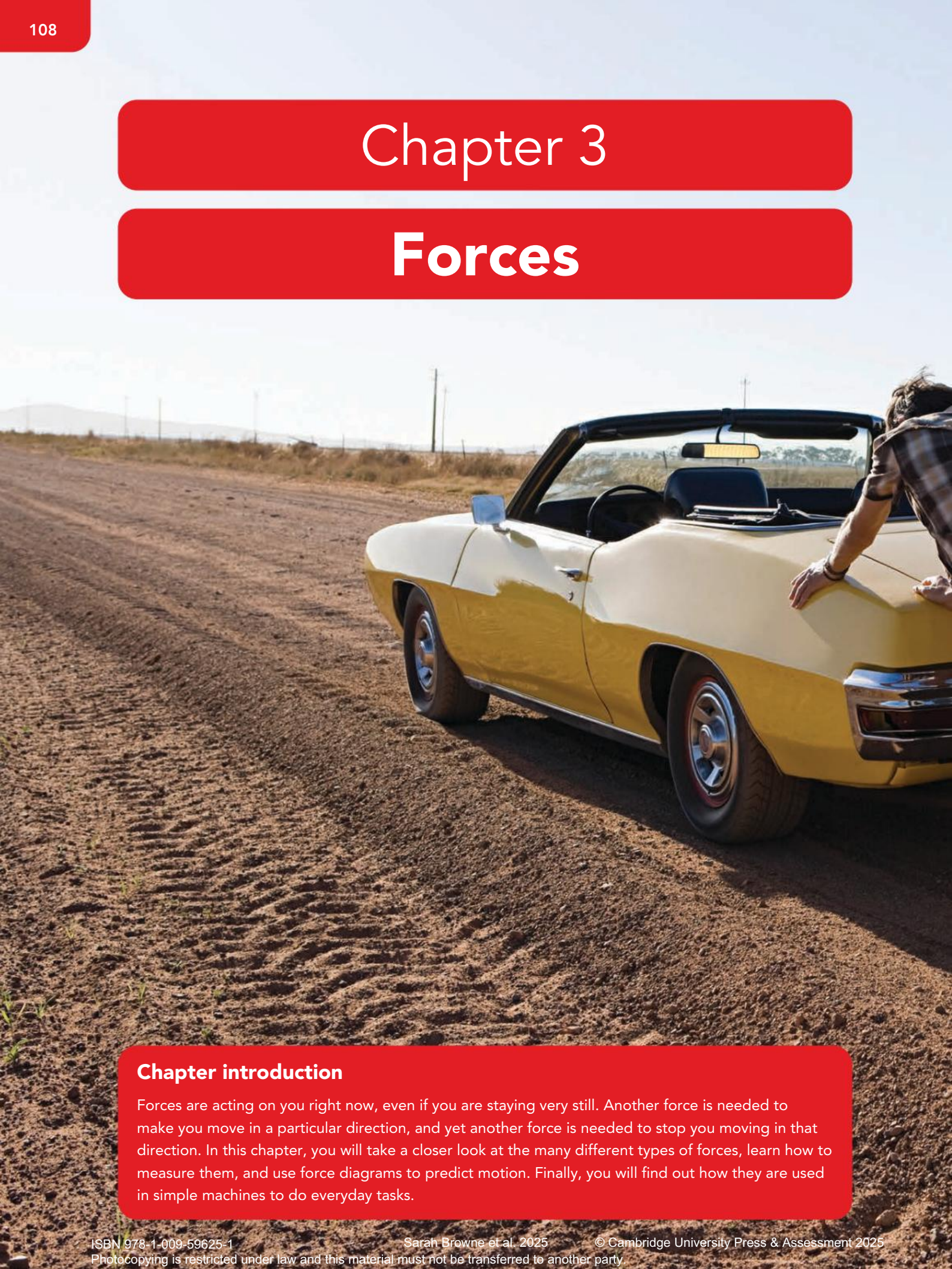
Evaluate and modify

6. Discuss with your group the challenges you have encountered throughout this project. List the strategies or actions that allowed you to overcome them.
7. Reflection is an integral and vital aspect of any project in the real world. In your honest opinion, list what you would like to have included, removed or modified from this challenge, as well as ways to improve the way we visualise our solar system.

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Chapter 3

Forces

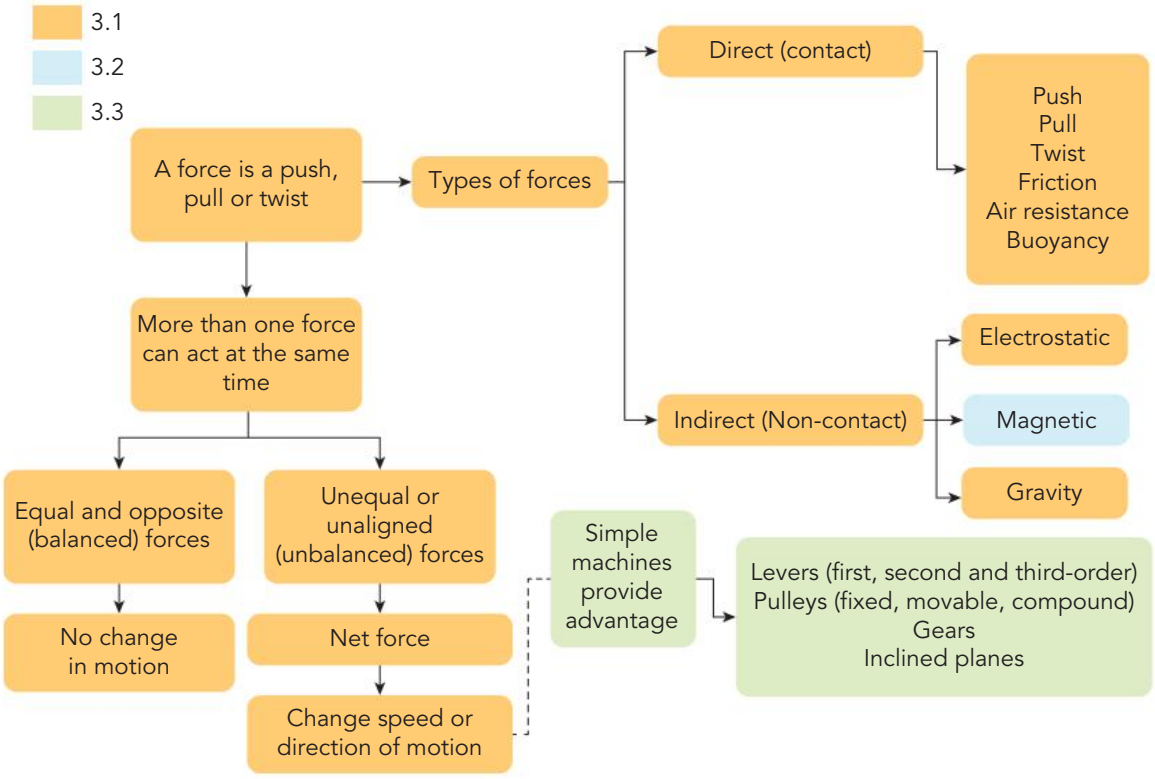


Chapter introduction

Forces are acting on you right now, even if you are staying very still. Another force is needed to make you move in a particular direction, and yet another force is needed to stop you moving in that direction. In this chapter, you will take a closer look at the many different types of forces, learn how to measure them, and use force diagrams to predict motion. Finally, you will find out how they are used in simple machines to do everyday tasks.

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Chapter map



Glossary terms

acceleration
acceleration due to gravity
air resistance
alloy
balanced forces
buoyancy force
deceleration
direct contact
drag
electromagnet
electrostatic force
energy
field
first-order lever
force
fulcrum
indirect non-contact
magnetic field
magnetic force
mass
mechanical advantage
meter
net force
normal force
pull
push
second-order lever
simple machine
speed
static electricity
third-order lever
twist
unbalanced forces
weight
work done

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3.1 Forces in action

WORKSHEET
Direct and indirect forces

VIDEO
Forces acting on objects

Learning outcomes

At the end of this section, I will be able to:

1. explain forces as direct/contact or indirect/non-contact and conduct practical investigations on a range of both types of forces in familiar contexts.
2. use force diagrams to model balanced and unbalanced forces and to make predictions.
3. examine the relationship between force and energy.
4. describe the electrostatic and gravitational forces between objects.
5. use forces to describe the motion of objects in orbit.
6. define weight force using $F = mg$ and use it to solve for F, m and g.

force
a push, pull or twist in a specific direction

push
to exert a force away from something

pull
to exert a force towards something

twist
to turn something

direct contact
(type of force) a force that is applied to an object by touching and pushing or pulling it

field
a region in space in which an object is affected by an indirect non-contact force

indirect non-contact
(type of force) a force that is exerted by a field rather than by direct contact

A **force** is being applied whenever something is given a **push** or a **pull**, or is rotated or **twisted**. Forces are part of our everyday life. They are found in sport, music, transport, at home and in the workplace. For example, when you push your pen across the paper to write, strum guitar strings or slam dunk a basketball … those are all forces! In nature, the forces from the flap of a bird's wings allows it to soar in the air, and the push in a grasshopper's legs lets it jump.



Forces can be applied by **direct contact** with an object. For example, when you push a door open, you make direct contact with the door by touching it and applying a push force. Forces can also be applied without direct contact to the object if they are in a field. For example, Earth's gravity exerts a force on objects, causing them to move towards it, like when you ski down a slope. Forces exerted by a **field** are referred to as **indirect non-contact** forces. Table 3.1 lists some direct and indirect forces.

Try this 3.1

Observing forces

This image demonstrates forces in action. Make a list of all the pushing and pulling forces you can see and describe what it is in each case that is doing the pushing or pulling.



Figure 3.1 Being a superhero means many forces are in action.

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	Type of force	Description	Example
Direct forces	Push	One object moves or tries to move another object that it is touching away from it	Pushing a trolley
	Pull	One object moves or tries to move another object which it is attached to towards it	Pulling on rope in tug-of-war
	Twist or turn	Simultaneous push or pull in opposite directions about a central point	Turning a tap
	Elastic	The force exerted by a stretched or compressed material trying to return to its original shape	Spring or rubber band
	Friction	The force between two objects rubbing together that makes them (or tries to make them) slow down relative to each other	Brake pads rubbing on the wheel of a bike
	Air resistance	The force opposing the motion of an object through air, slowing it down	A parachute
	Buoyancy	The push upwards against gravity in a liquid causing objects to sink more slowly or to float	A boat floating on water
Indirect forces (acting at a distance)	Gravitational	The force of attraction between two objects with mass	Falling to the ground when you trip
	Magnetic	The attraction or repulsion of magnets and materials with magnetic properties	A magnet picking up paperclips
	Electrostatic	The attraction or repulsion of objects that have an electric charge	Attraction of your hair to a balloon when you rub them together

Table 3.1 Direct and indirect forces

VIDEO
Direct forces

VIDEO
Indirect forces



Figure 3.2 A newton meter is used to measure the force of a pull.

Try this 3.2

Observing the effect of direct and indirect forces

1. The changing number of paperclips or pins that stick to a magnet as you vary the distance you hold the magnet from them.
2. Rub a balloon against your hair to charge it. Holding the balloon near your hair will lift it up (if it is long enough).
3. Drop a sheet of paper, then scrunch it up and drop it again, measuring the time it takes to reach the floor each time.
4. Make a boat out of folded aluminium foil and see how many washers you can fit on it before it sinks.

Measuring forces

Forces are measured using a unit called the newton (N). The unit is named after Isaac Newton, who pioneered experimental work on the motion of objects and described the patterns he observed using mathematical equations.

A newton **meter**, also called a force meter or spring balance, can be used to measure the force of a pull. Look closely at the readings of the newton meter pictured in Figure 3.2. A newton meter usually provides two different scales, one in newtons (N) and one in kilograms (kg) or grams (g).

meter
a measuring or recording instrument (do not confuse with metre, a unit of length)

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mass
the amount of substance in an object measured in kilograms

weight
the force of gravity on an object measured in newtons

speed
the rate of change of position of a moving object (called velocity when direction is specified), measured as change in distance over time, with units such as metres per second (m/s) or km/h

acceleration
the rate of change of speed of a moving object, measured as change in speed over time, with units such as metres per second per second (m/s/s); positive values mean speeding up and negative values mean slowing down (negative acceleration)

deceleration
an alternative term for negative acceleration

acceleration due to gravity
acceleration experienced by a mass due to gravitational force of another mass; it is given the symbol *g*, and close to the surface of the Earth its rounded-up value is 10 m/s^2

When a newton meter is at 0 g or 0 N, it means that there is no object attached to the hook. The newton meter reads a **mass** of 0 g and a weight of 0 N. Now imagine you attach a 50 g object to the hook as shown in Figure 3.2; the object would experience a weight force due to gravity and pull the hook down as it is attached to a spring. Read the scale in the diagram to find the weight force in newtons.

The scale reads approximately 0.5 N. This means a mass of 50 g will experience a force of 0.5 N due to Earth's gravity.

Weight is a force. It is measured in newtons. It is the force experienced by a mass due to gravity. Mass is measured in kilograms or grams (1 kg = 1000 g).

Isaac Newton observed a relationship between mass and weight. He noticed that weight is directly proportional to mass, as shown on the scale of the newton meter. The amount of force an object experiences depends not only on the mass of the object but also on the acceleration due to gravity. If you drop an object, it will fall towards the ground with an increasing **speed**. This increasing speed is called **acceleration**. Acceleration is measured in units of metres per second per second. For example, this means a person on a bicycle travelling with a speed of 5 metres per second starts accelerating by 1 metre per second, each second. So, after 1 second their speed is 6 metres per second, and after 2 seconds their speed is 7 metres per second. A shorter way of saying this is that they are accelerating at 1 metre per second per second. This unit of acceleration can be abbreviated to m/s/s, or using index notation it can be written as m/s^2.

What if instead of speeding up, an object slows down? This is acceleration with negative (minus) values and is optionally called **deceleration**. Friction is a force that can produce a deceleration on a moving body. Deceleration has the same units, m/s^2, but negative values, such as −2 m/s^2, meaning that speed decreases by 2 metres per second every second. It would be valid to say, 'the vehicle experienced an acceleration of −5 m/s^2'.

Close to the surface of the Earth, objects fall with increasing speed – they accelerate downwards, with constant acceleration, called the **acceleration due to gravity**, which is almost 10 m/s^2. (It's actually 9.8 m/s^2, but in this course we will usually approximate it to 10 m/s^2.) The acceleration due to gravity is the same anywhere on Earth (near the surface) because the mass of the Earth is the same. The equation Isaac Newton used to describe this relationship states that weight force, *F*, (N) is equal to the mass, *m*, (kg) multiplied by acceleration due to gravity, *g* (m/s^2).

Mathematically the equation is written like this:

$$F = mg$$

Kitchen or bathroom scales (also called a balance) are used to measure the force of a push, for example, your weight. But weight is a force in newtons, not a mass in kilograms! Mass and weight are used interchangeably in everyday language. The reason for this is because we all live on the same planet, and the value of *g*, the acceleration due to gravity, is the same for all of us. However, mass and weight are not the same thing in science. An object's mass is determined by the amount of material that it contains, measured in grams or kilograms, and it is fixed regardless of where it is in the universe. An object's weight is not fixed and will change depending on where it is in the universe. The weight of an object is the force with which gravity pulls it. This equation can be used to measure the weight force of an object anywhere in the universe, as long as you know the mass of the object and the acceleration due to gravity at that location. For example, the acceleration due to gravity on Mars is almost 4 m/s^2. So, if your mass is 50 kg, you will weigh 500 N on Earth but only 200 N on Mars. You would feel much lighter on Mars compared to Earth where you experience a greater force due to gravity.



Figure 3.3 The weight force you experience due to gravity depends on where you are in the universe, but your mass does not.

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Worked example 3.1

Mass and weight

Compare your weight on Earth to your weight on the Moon if you have a mass of 54 kg. The acceleration due to gravity on Earth is 10 m/s^2 and on the Moon it is 1.6 m/s^2.

Working	Explanation
m = 54 kg On Earth: g = 10 m/s^2	Identify the values given in the question.
$F = mg$	Identify the formula needed to answer the question.
$F = mg$ $= 54 \times 10$ $= 540$ N	Substitute the relevant values into the formula.
On the Moon: g = 1.6 m/s^2	Identify the values given in the question.
$F = mg$ $= 54 \times 1.6$ $= 86.4$ N	Substitute the relevant values into the formula.
Comparison: You will feel much lighter on the Moon because you will experience a smaller force. But your mass is the same on both.	Remember to answer the question that asked for a comparison.

Practical skills 3.1

Stretching springs

Aim

To observe the relationship between force and extension for a spring.

Materials

- spring
- retort stand, bosshead and clamp
- set of slotted weights
- ruler

Procedure

1. Using a retort stand, hang a spring on a bar and place an empty weight holder on the end of the spring.
2. Tape a ruler to the vertical bar of the retort stand. Use the scale of the ruler to record the initial position of the bottom of the weight holder.
3. Add masses to the weight holder. Each time a new mass is added, record the new position of the bottom of the weight holder. Be careful not to overstretch the spring.

Results

Mass (g)	Extension (m)	Weight force (N)

continued …

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1. Calculate the force applied to the spring by dividing the mass in grams by 1000 to give kilograms and multiplying by 10, the value for gravity.
2. Draw a graph of how force affects the extension of the spring.

Discussion

1. Identify the trend in your graph.
2. Identify any outlier results in your graph.
3. Can you use your graph to make predictions about other masses?

Conclusion

From this investigation we can claim that the extension of a spring depends on _____. This is supported through observing _____.

Try this 3.3

Jumping on planets: Mass versus weight

Use a metre ruler and sticky tape to calculate how high you could jump on different planets.

1. Tape the ruler to a table leg or wall so that it is vertical.
2. Get a partner to kneel down so their eyes are level with the ruler.
3. Jump as high as you can while your partner records the height you achieved.
4. Repeat the jump two more times.
5. Swap roles so you are now recording the jump height of your partner. Repeat steps **2–4**.
6. Copy the table below into your book and calculate the mean jump height.

	Jump height (m)			
Student name	**Jump 1**	**Jump 2**	**Jump 3**	**Mean**

7. Calculate how high you could jump on each planet, the Sun and the Moon. Divide your mean height by the surface gravity of each celestial body in the table below. For example, if you jumped a mean height of 0.65 m and wanted to calculate how high you could jump on Venus, you would divide 0.65 by 0.91. This would tell you that you could jump 0.71 m if you were standing on the surface of Venus.

Member of the solar system	Ratio of the surface gravity of each location to Earth's surface gravity	The height I could jump at each location (m)
Sun	27.90	
Mercury	0.38	
Venus	0.91	
Mars	0.38	
Jupiter	2.36	
Saturn	0.92	
Uranus	0.89	
Neptune	1.12	
Pluto	0.06	
Earth's moon	0.16	

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Practical skills 3.2

Using a spring balance

Aim

To select the most appropriate spring balance.

Materials

- a range of spring balances (e.g. 1 N, 5 N, 10 N, 50 N)
- various items to complete tests (pencil case, textbook, sticky tape, school bag)

Procedure

1. Copy the results table into your science book.
2. Follow the instructions in the table with each item using the spring balance and determine the force needed to complete the actions in the table.

Results

Item	Force required (N)
Hold your pencil case	
Drag this textbook across the table	
Remove a piece of sticky tape from your desk	
Open the lab door	
Drag your stool across the floor	
Hold your school bag	

Discussion

1. State whether the forces applied to the items are push or pull forces.
2. Name the forces involved when hanging and dragging an item.
3. Sequence the items in order from most to least force required to drag them.
4. Explain why the same spring balance could not be used for all the actions.

Advances in science 3.1

A new device to measure the force of a bird's wings while flying

In 2015, research came out about a new device that is going to help scientists understand the forces birds generate while flying. You know that a bird flaps its wings to fly, but determining how a bird generates lift has been a problem for scientists. The device is called an aerodynamic force platform, and it works like the force platforms that have allowed bioengineers to study the forces that humans exert to walk or run. Essentially, it is a box the size and shape of a large birdcage, with supersensitive force sensors attached to the bottom of the box. As the bird flies, each beat of its wings pushes against the air, which in turn pushes against the bottom of the box. These forces are recorded to produce a precise measurement for each stroke of the bird's wings.



Figure 3.4 Identifying how a bird generates lift has been an issue for scientists.

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WORKSHEET
Balanced and unbalanced forces

Force diagrams

Force diagrams, also called free body diagrams, are used to show all the forces acting on an object. These diagrams can be used to predict if the object will move and if so, in which direction. Arrows are used to show both the direction and size of the force. If the arrows are of equal length and in opposite directions, the object will not move, because forces are **balanced.** Figure 3.5 is a force diagram showing the forces on a physics book resting on a table.

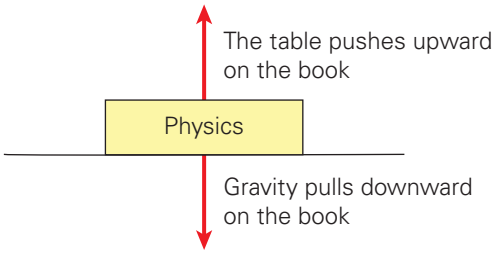


Figure 3.5 Balanced forces acting on a physics textbook resting on a table

balanced forces
Forces of equal magnitude in opposite directions will not change the motion of an object.

normal force
the force applied by a surface on an object

unbalanced forces
A force of greater magnitude will cause the object to move or deform.

Notice how the table is pushing up on the book. If the table was not there, the book would fall down, because the force due to gravity pulls it down.

The upward force applied by the table to the book is equal and opposite to the force due to gravity, so the book does not move. Balanced forces do not cause a change in motion. The force opposing the gravitational force is called the **normal force**.

If you were to apply a force to push the book off the table, the force may come from the left or right. The force due to the friction between the book and the table always acts in the opposite direction to motion. Forces can be applied in any direction, but here will deal with up, down, left and right only, as shown in Figure 3.6. The symbol for force is an F, with a subscript naming the type of force. The force of gravity, F_{gravity}, is also called the weight force.

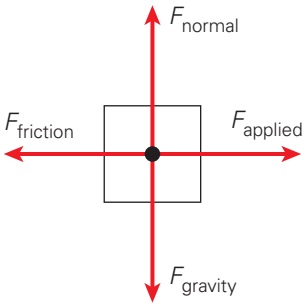


Figure 3.6 Force diagram. The arrows originate at the object's centre of mass.

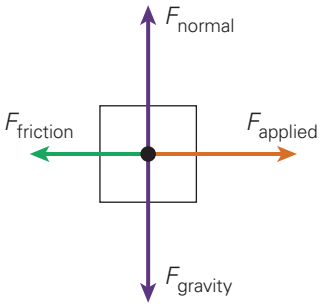


Figure 3.7 The applied force is larger, so the object will move to the right.

Unbalanced forces, on the other hand, cause a change in motion. The longer arrow means a greater force. The object will move in the direction of the greatest force.

An unbalanced force can also result in the deformation of the object – for example, pushing your finger into a ball of playdough, or the front of a car crumpling in a collision.

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Try this 3.4

Force diagrams

Force diagrams are useful for predicting what will happen due to the forces shown.
Draw the forces acting on the objects in these images. Which are balanced forces and which are unbalanced, and what motion (if any) will result?







WORKSHEET
Analysing force diagrams to make predictions

WIDGET
Fly a helicopter

Quick check 3.1

1. **Define** the following key terms in your own words: force, newton, balanced, unbalanced.
2. **Identify** which of the following activities use a push force and which use a pull force.
   - **a.** Catching a fish on a fishing rod
   - **b.** Dragging your toboggan behind you in the snow
   - **c.** Cutting up vegetables for lunch
   - **d.** Writing in your exercise book
   - **e.** Typing on your computer
   - **f.** Lifting a heavy schoolbag
   - **g.** Hitting a cricket ball
   - **h.** Putting on your Ugg boots at night
3. **Match** each force to its approximate value.

Weight of an apple	700 N
Weight of a car	1 N
Weight of an adult	100 N
Weight of a dog	7000 N

4. **Draw** a force diagram of:
   - **a.** a surfer riding a wave
   - **b.** a plane flying at a constant speed 10 km above the surface of Earth.

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Try this 3.5

Investigating forces in familiar contexts

Use the materials listed to perform the tasks in the table below.

- rubber band
- lump of modelling clay
- tennis ball
- bar magnet
- paperclip
- inflated balloon
- plastic counter

Copy and complete the table and record your observations. Include a force diagram for each situation.

Task	Observations	
	Change in motion or shape	Force that caused the change
Stretch a rubber band		
Squash a lump of modelling clay		
Drop a tennis ball and catch it when it bounces		
Bring a bar magnet close to a paperclip		
Use your hands to compress an inflated balloon (be careful not to pop it)		
Rub an inflated balloon against your head and then hold it near your hair		
Use your fingers to flick a plastic counter across a table		

Buoyancy

buoyancy force the upward force experienced by an object that is partially or fully submerged in a fluid, e.g. water or air

The **buoyancy force** is the upward push that occurs when an object is partially or fully submerged in fluid such as water or air. If an object placed in water sinks, the buoyancy force acting upwards is smaller than the weight of the object. If it floats, the buoyancy force is equal to the object's weight.

There is also an upwards buoyancy force on an object in a gas, but it is much smaller, and can only be seen in an object that is very light compared to its size, such as a helium balloon. The air's upwards buoyancy force on a helium balloon can be greater than the balloon's weight (when it will rise) or equal to its weight (when it will float at a constant height).

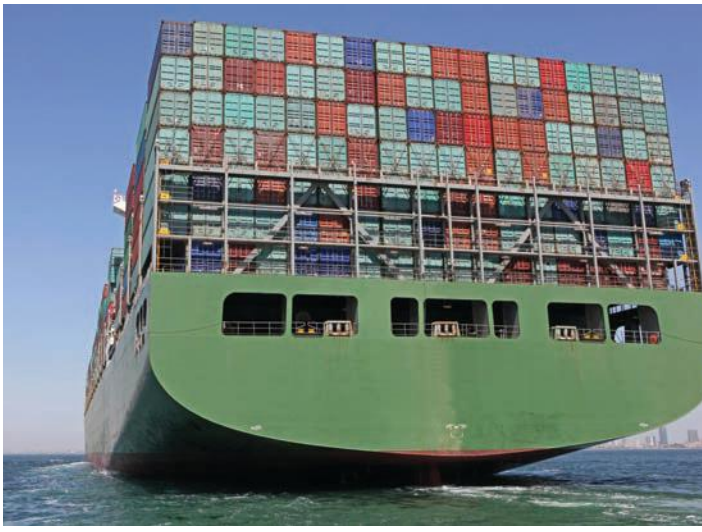


Figure 3.8 Buoyancy forces allow heavy container vessels to float.

Did you know? 3.1

Ice floats!

This is an unusual phenomenon in nature, but it is one that allows life on Earth to exist. Most substances in their solid form are more dense than liquid. But not ice! Solid water is less dense than liquid water, so it floats, allowing life beneath the water to survive through winter.



Figure 3.9 Ice floats on water.

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Friction

Imagine life without friction. Walking would be difficult because your shoes would have no grip on the floor. Normally you push your foot backwards against the ground and the ground pushes back on you (note: the friction is pushing you forward here), but if there were no friction, it would feel like everything was covered in a thin film of slippery soap. This type of friction is called traction. Without friction, car brakes would not work and without the grip of the tyres on the road, cars would not be able to move backwards or forwards, or turn around corners.





Practical skills 3.3

Surfaces and friction

Aim

To observe the effect of various surface types on the frictional force on a moving object.

Materials

- large block of wood with hook attached
- spring balances (10 N, 20 N and 100 N)
- a variety of different surfaces (e.g. vinyl floor, carpet, concrete, polished concrete, sandpaper, grass or bitumen in a safe area).

Procedure

1. Copy the results table into your science book. Ensure the independent variable is in the left-hand column and the dependent variable trials and mean sit at the right of the table. Don't forget units in the headers.
2. Place the block of wood on the first surface and attach the appropriate spring balance. (Hint: Which spring balance would be the best for each surface? How would this be determined?)
3. Pull the block of wood at a constant speed across the surface and read the force on the spring balance. The force on the spring balance will be equal to the force of friction. Record this reading in your results table.
4. Repeat the measurement four more times and record the values in your table.
5. Repeat steps **1**–**4** on three other different surfaces.

Results

Surface		Friction force (N)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean

Discussion

1. Why was it necessary to measure the friction of each surface five times? Find the mean and record it on your table.
2. List your surfaces in order of lowest to greatest friction force.
3. Explain why some surfaces create more friction than others.

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Friction between surfaces

As you may have found completing *Practical skills 3.3*, friction depends on the surfaces that are rubbing together. Rough surfaces tend to produce more friction than smooth ones. Friction also depends on the weight of an object. Think about trying to move an armchair across the floor. If several of your friends sit on the chair while you are moving it, there will be more friction opposing the push you are giving. Friction also depends on the speed at which an object is moving. It tends to decrease as the speed increases. This is why it is important to use the same constant speed in an experiment.

energy the ability or capacity to do work

As a side effect, friction also causes heating. When two surfaces rub against each other, the friction force can transfer **energy**, which increases the temperature. On a cold day you may have rubbed your hands together to make them warm, or maybe you have rubbed sticks together at high speed to start a fire. However, heating is not always beneficial because it can represent wasted energy or be dangerous.



Figure 3.10 Petrol engines need oil to lower the friction inside and minimise heating.

One way to reduce friction between two surfaces is to use lubrication such as oil or graphite. This allows the surfaces to move over each other with less friction and thus generate less wasted energy. In Figure 3.10, clean oil is put into an engine to lower the friction between the moving parts. If there is no more oil, the extra heat generated from frictional forces will destroy the engine because the metal expands as the temperature increases.

Another way friction can be reduced, especially when moving heavy loads from one place to another, is to use a wheel and axle. By using a wheel and axle, trains, cars, trucks and even aircraft taking off and landing can all move with little friction. On snow and ice, surfaces have low friction, and using skis or sledges on runners is more effective.



Figure 3.11 Seaplanes use floats instead of wheels to land on water.



Figure 3.12 A sled is effective on snow and ice due to the low friction of these surfaces.

Try this 3.6

Sandpaper and friction

The friction of sandpaper on wood causes heat to be generated. Sand a piece of wood slowly at first and then speed up until it is so hot you need to let go. Try again, and this time don't vary the speed; instead, gradually increase the pressure you apply. Does it get hot? You could also change the sandpaper to be coarser or finer, or you could change the surface you are sanding.

Air resistance

drag the frictional force of a liquid or gas

air resistance the frictional force of the air

Friction between a solid and a liquids or gases (fluids) is called **drag**, or **air resistance**. Drag can occur underwater or within any fluid. Drag and air resistance always oppose the direction of motion, and the magnitude increases with speed. The greater the surface area of the moving object, the greater the amount of drag or air resistance.

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Practical skills 3.4

Surface area versus air resistance

Do all objects of the same weight fall at the same rate? If they do, then identical pieces of paper, no matter how they are folded or not folded, should fall at the same rate. See whether this is the case or not in the following activity.

Aim

To determine how surface area and mass affect air resistance.

Materials

- one piece of A4 paper
- one piece of A4 card
- metre ruler
- stopwatch

Procedure

1. Copy the results table into your science book.
2. Take the A4 paper and measure its length and width to calculate its surface area. Record this in your table.
3. Drop the paper from a height of 1.5 m and record the time it takes to reach the ground. Repeat this two more times.
4. Fold the paper in half and then repeat steps **2** and **3**. Continue doing this until you have folded the paper four times.
5. Repeat steps **2–4** using the piece of card.

Results

		Time taken to drop paper (s)			
Number of folds	**Surface area of paper (cm^2)**	**Trial 1**	**Trial 2**	**Trial 3**	**Mean**
0					
1					
2					
3					
4					

		Time taken to drop card (s)			
Number of folds	**Surface area of card (cm^2)**	**Trial 1**	**Trial 2**	**Trial 3**	**Mean**
0					
1					
2					
3					
4					

Plot both sets of results onto the same graph to compare them. Plot the surface area of each item against the mean time it takes to drop.

Discussion

Identify any trends, patterns or relationships in your results.

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The experiment in *Practical skills 3.4* demonstrates that the reason different objects hit the ground at different times is due to the interaction of the object with air: the air resistance of the object. When the flat piece of paper is used, the air resistance is much greater because it has to push more air out of the way. This is related to the area of the paper that pushes against the air. The face of the paper is a very big area, so it falls much more slowly than the folded piece of paper, where a smaller area pushes the air out of the way.



Figure 3.13 In a vacuum (without air resistance), these two objects fall at the same rate if dropped from the same location.

If these experiments were repeated without air (in a vacuum), then all the objects released from the same height at the same time, regardless of their mass, would hit the ground at the same time.

In fact, without air resistance, objects of different weights would also fall at the same rate. It has been shown that when dropped in a vacuum, a feather and a bowling ball hit the ground at the same time.

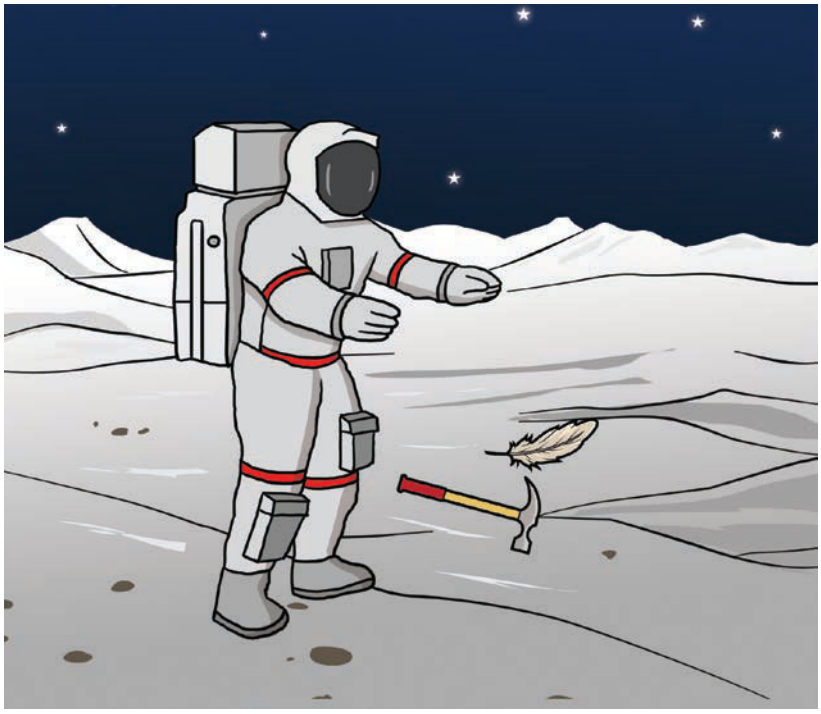


Figure 3.14 An astronaut performs an experiment in space to gather evidence to support a theory. A hammer and a feather are dropped and are observed falling at the same speed in the absence of an atmosphere.

When air resistance is equal to the force of gravity, you will fall at a constant speed. The speed at which air resistance equals the weight of a falling object is called the terminal velocity.

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Parachutes are a practical application of air resistance. You can fall through the air safely if you have a parachute because the parachute increases your air resistance to the point where it overwhelms your weight, thus enabling you to slow down.

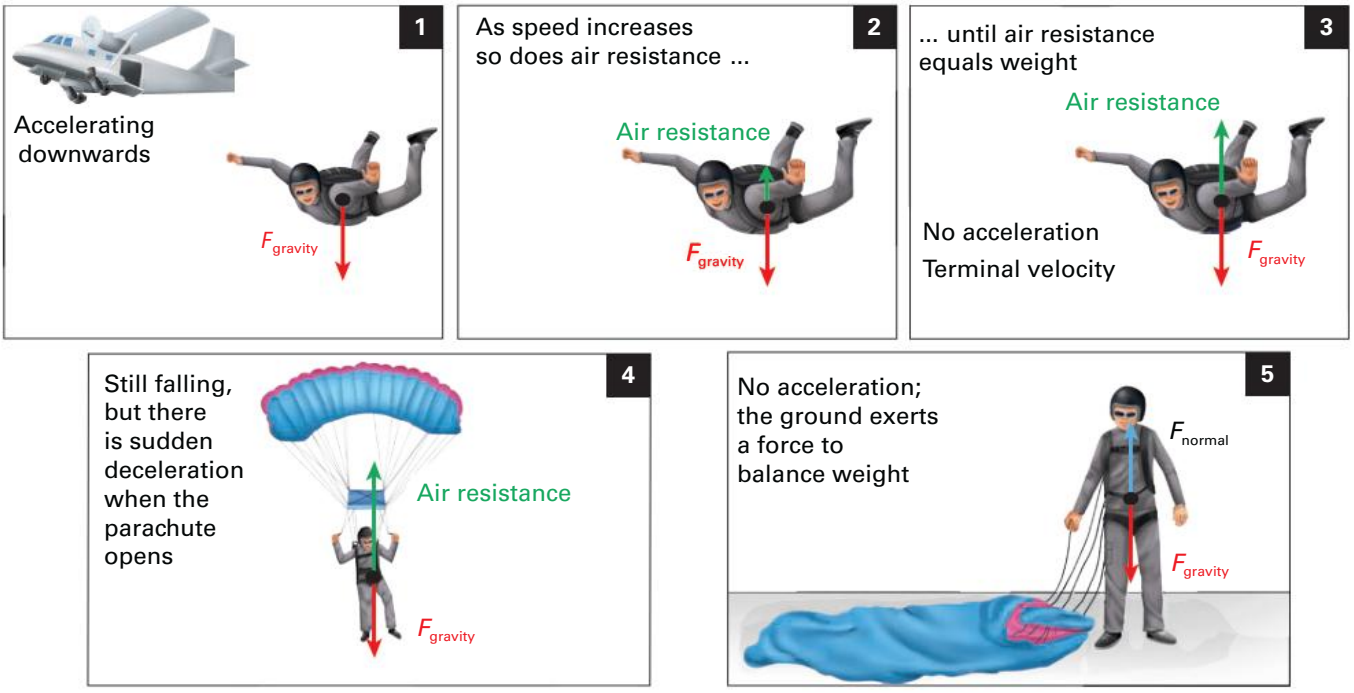


Figure 3.15 The way a parachutist falls depends on the size of the pull of gravity and the air resistance from their body and the parachute.

Try this 3.7

Drop time of a parachute

Materials

- plastic freezer bags
- scissors
- modelling dough
- stopwatch
- cotton or string
- metre ruler

Instructions

In small groups, use the materials listed to design and build a parachute. Compare your group's design to other groups' designs to explore the effect of one of the following variables on the drop time of a parachute:

- mass of the sky diver
- surface area of the parachute
- shape of the parachute
- length of the connecting string.

Fish have a streamlined shape that helps them move through water easily. The part of the fish that points in the direction of its motion has a smaller surface area than the rest of its body, which reduces its friction with the surrounding water. The same shapes are used by the designers of boats and submarines to reduce drag and to enable them to travel at high speed in water.



Figure 3.16 The streamlined shape of fish helps them move through water easily.

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Figure 3.17 Over time, trains have been designed to be more streamlined, allowing them to reach greater speeds.

Quick check 3.2

1. **Explain** the meaning of the terms 'air resistance' and 'terminal velocity'.
2. **Explain** what friction is and how it works.
3. **Explain** the link between friction, drag and air resistance.
4. **Explain** why a shark's body is streamlined, whereas a koala's is not.

Forces and movement

It is very important to note that just because a force is balanced, it does not mean there is no movement going on. Look at the example of the car in Figure 3.18. There are four forces acting on the car. The thrust from the engine pushes the car forward, while air resistance slows it. The weight of the car pulls it down and the road surface pushes it back up. If these forces are balanced, the **net force** acting on the car is zero. Therefore, it will continue to move at a constant speed. An unbalanced force is required to change its speed or direction or shape.

net force
the sum of all forces acting on an object

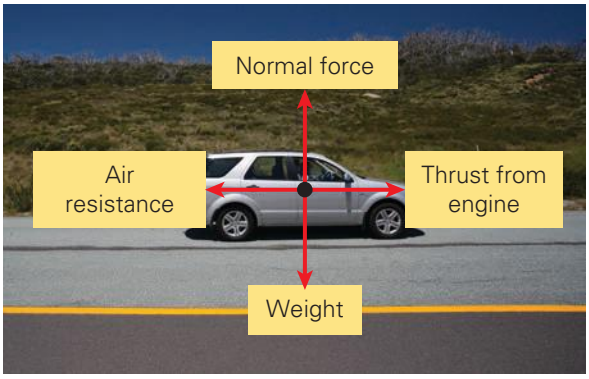


Figure 3.18 The forces on the car are balanced, and the car travels at a constant speed.

Quick check 3.3

1. A painting is hanging on a wall from a nail. **Decide** if the forces on it are balanced or unbalanced.
2. A drone is hovering in the sky. Its weight is pulling it downwards, and the force of its rotors is pulling it upwards. **Decide** if these two forces are balanced.
3. A swimmer is racing from one end of the pool to the other at a constant speed. **Explain** what must be true of the forces acting on the swimmer.
4. **Draw** a truck that is changing its speed and going faster as it travels along a highway. Add force arrows to your drawing, showing how the forces that are acting on the truck change.

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Advances in science 3.2

Bike helmets



Figure 3.19 Luke Bell of Australia wearing a helmet that protects his head and is also designed to minimise air friction.

Australia has a proud record of leading the way when it comes to road safety. The origin of road safety legislation has its roots in evidence collected by doctors stating that road accident victims often had injuries that were preventable. The head is especially vulnerable to injury, and for this reason both motorcyclists and cyclists are required to wear a helmet in Australia. The main functions of a helmet are to protect the skull by stopping penetrating injuries, spreading the force of impact over a larger area, and reducing the head's change in speed on impact by cushioning it with foam, thus reducing the force applied to the head. Similarly, occupants of cars wear a seatbelt to absorb the energy by spreading the impact forces over the chest and preventing the head from hitting the windscreen in an accident. The forces involved in the sudden changes of speed that can happen in a collision are very large, and so injuries can be prevented if these forces can be reduced by spreading the change in speed over a longer time, and the pressure reduced by spreading the force over a larger area, so the body is protected.

A major study presented in 2016 looked at the use of bike helmets around the world. With data on more than 64 000 cyclists, the study found helmets reduce the risks for a serious head injury by nearly 70%, face injury by 33% and fatal head injury by 65%. So, regardless of whether or not they are compulsory, wearing head protection is highly recommended!

Force and energy

To make something move, you need to apply a force. To apply a force, energy is needed. The amount of **work done** on an object to move it is equivalent to the energy needed. The amount of work done depends on the distance the object moved while the force was applied. There is a mathematical equation to describe this:

work done when a force moves an object, work done, W, is the force in newtons, F, multiplied by the distance in metres, d, through which it moves ($W = Fd$); it is equivalent to the energy needed and has the same units (joules)

$$\text{energy needed} = \text{work done} = \text{force} \times \text{distance}$$

Energy and work both have the same units. They are measured in joules (J). The unit for force is newtons (N) and distance is in metres (m).

Worked example 3.2

Force and energy

Calculate the energy needed to push a box with an applied force of 50 N a distance of 2 m.

Working	Explanation
force = 50 N distance = 2 m	Identify the values given in the question.
work = force × distance ($W = Fd$)	Identify the formula needed to answer the question.
work done = 50 × 2 = 100 J	Substitute the relevant values into the formula.
Therefore, the energy needed is 100 J.	Give the answer in words with correct units.

Work can also be done by fields. For example, the work done by Earth's gravitational field on a 1.5 kg science book falling out of a window at a height of 12 m is:

$F = mg = 1.5 \times 9.8 = 14.7$ N

$W = Fd = 14.7 \times 12 = 176.4$ J

Work done = 176.4 J

In Chapter 12 you will discover energy transformations and use this knowledge to identify the types of energy involved.

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Explore! 3.1

Footwear design

Shoes and boots these days are used for walking, running, playing sports, work and formal occasions. They are used to protect your feet from injury but also must provide support and comfort. Every time you walk or run, your foot is under pressure as forces are applied. Nowadays, footwear includes design features that help reduce the impact of these forces. These features include extra cushioning in the sole of the shoe. The cushioning is very flexible as it has elastic properties. Air pockets within the sole can also help reduce impact forces.



Figure 3.20 Stability, elasticity and density are among the properties considered for sports shoes.

Conduct some research to find out the types of materials that are used in shoe soles. Describe how each of these materials helps reduce the impact force on the wearer's feet. Make sure you look at formal shoes as well as sport shoes.

DOC
WORKSHEET
Gravity

Gravity and the motion of objects in orbits

You experience gravity as the force that pulls you towards the centre of Earth. There is a force of attraction between you and Earth. The effects of gravity near Earth's surface are familiar, but Earth's gravity also extends into space. It keeps the Moon and communication and weather satellites in orbit. Gravity is also the force that keeps all the planets in our solar system in orbit around the Sun.

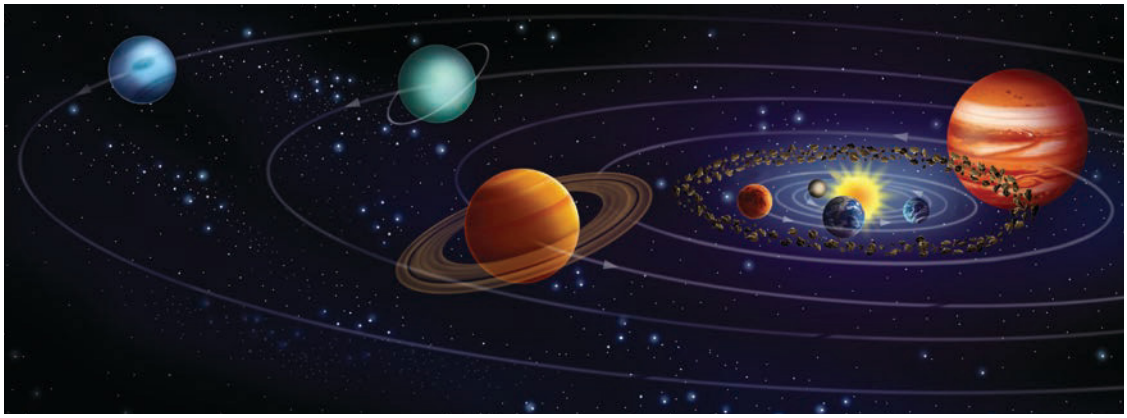


Figure 3.21 Gravity is the force responsible for the planets orbiting the Sun.

Sir Isaac Newton thought about this concept in the 1600s. He knew that if you fire a cannonball horizontally, it falls to the ground in curved path (A in Figure 3.22). He reasoned that if you used more gunpowder and fired again, you would get a longer curve shape from a faster cannonball (B in Figure 3.22). What if you fired it even faster, and ignore air resistance so it doesn't slow down? Eventually, because the surface of the Earth is curved, you would get such a long curve that the cannonball would circle all around the Earth and never crash into it (C in Figure 3.22). That is an orbit!

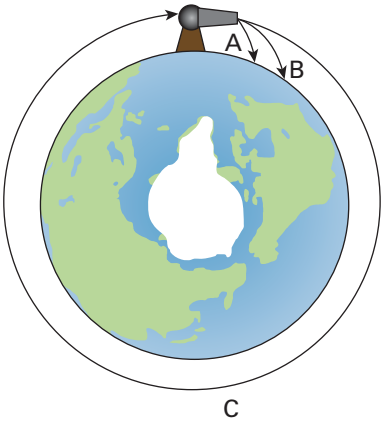


Figure 3.22 Newton's explanation of orbits, published in 1687

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No gun has successfully fired a projectile into orbit because overcoming the air resistance would require such a huge explosive charge, but a rocket launch is substantially the same. Instead of a force applied almost instantaneously in a gun, it is applied by a rocket engine for a few minutes to get the projectile above the atmosphere, where there is no friction to slow it down so forward momentum keeps it moving around the planet.

Figure 3.23 shows that a satellite in orbit is constantly falling towards Earth. In other words, an orbit is falling with style! It is the reason astronauts feel weightless in a space station orbiting Earth. The astronauts and the space station are in orbit, so they are both falling together at the same speed and appear weightless. This is called being in free fall. The force due to gravity does decrease with distance away from Earth, but if there was no gravity at all, they would float away into deep space.

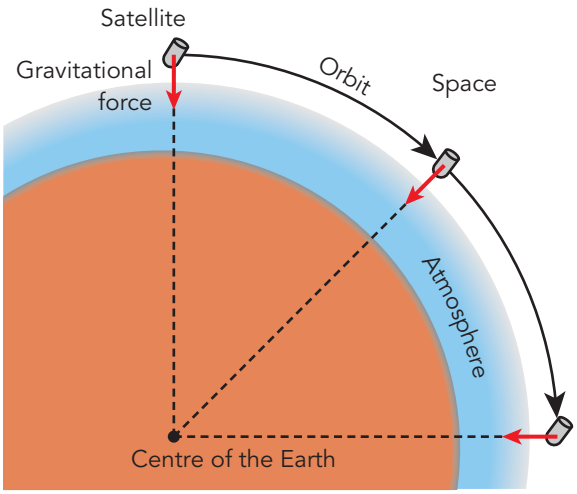


Figure 3.23 A portion of the Earth with a satellite in orbit showing that for three different positions, the force of gravity on the satellite is always vertically downwards, and is at right angles to the satellite's movement (its orbital path). The satellite is well above the atmosphere and no other force acts on it. Its movement results from the momentum it gained when it was launched.



Figure 3.24 Flying through the air has been described as 'falling with style'. Orbiting a planet requires falling with style from a very great height – but never meeting the ground!

Explore! 3.2

INVESTIGATION

Fields

You may not be able to see gravity, but it is always there. Earth's gravity creates a field (an example of a force field) around it.

1. Find out what it means to say that Earth's gravity creates a field around it and summarise your findings.
2. Refer to Figure 3.25 and describe what happens to the strength of this field as you move closer to Earth. Describe the direction of the gravitational force as well.

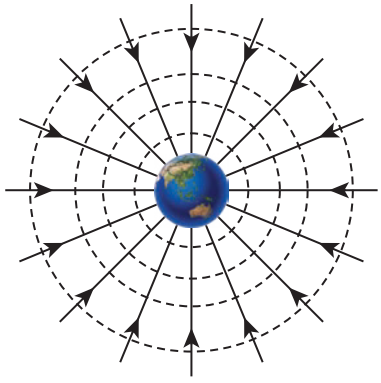


Figure 3.25 A diagram of Earth's gravitational field. The solid lines are field lines that show the direction of gravitational force. The field gets stronger where the lines get closer together. The optional dashed circles indicate that all the points on the circle have the same gravitational field strength.

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Electrostatic forces

Try this 3.8

Observing electrostatic forces

Take a piece of paper and rip it up into small pieces on your table. Rub a plastic pen against woollen material or a jumper. Bring the pen near the pieces of paper. What happens? Can you explain what you observe?

electrostatic force an indirect force between positive and negative charges: opposite charges attract; like charges repel

static electricity a build-up then flow of electric charge

The **electrostatic force** is the force responsible for that electric shock when you drag your feet on carpet (especially in winter when the air is dry) or the crackling of a jumper as you pull it out of the clothes dryer. It can be used to pick up pieces of paper with a balloon after rubbing it on your hair or clothes. On a much larger scale, electrostatic charges cause lightning to flash during a storm!

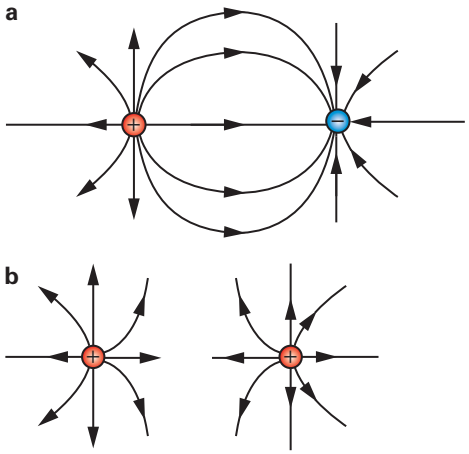


Figure 3.26 Electric fields around **(a)** two unlike charges attracting each other and **(b)** two like charges repelling each other. As with the gravitational field diagram, the field lines show the direction of electrostatic force, and the closer they are, the stronger the force.

There are two types of electric charge: positive (+) and negative (−). Opposite charges attract each other and like charges repel.

Like gravity and magnetism, objects with an electric charge also create a field around them. The electric field is the region in which charged particles will feel a force due to another charged particle (Figure 3.26).

The device the girl is touching in Figure 3.27 is called a Van de Graaff generator, and essentially it separates positive and negative charges. In this device, the negative charges are the ones that move, while the positive charges stay in place in the metal dome. Because the girl is touching the dome, the negative charges from her hair flow to the dome, making her hair positively charged. Remember, like charges repel, so with all her hair becoming positively charged, they all try to get away from each other! This flow of negative charges is called **static electricity**.



Figure 3.27 Electrostatic forces can make your hair stand on end.

So why do you get these small electric shocks after dragging your feet on the carpet?

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Try this 3.9

Observing static electricity



Materials

- 2 balloons
- string
- a metre ruler
- woollen cloth

Instructions

1. Rub the inflated balloon with the woollen cloth and place it against a wall. Record your observations.
2. Suspend the balloon from the metre ruler using the string.
3. Suspend the second balloon so it is close to, but not touching, the first balloon.
4. Rub both balloons with the woollen cloth on the sides that are facing each other.
5. Record your observations of any movement in the balloons.

Discussion

Discuss the following questions with your classmates.

1. What is the purpose of rubbing a balloon with a woollen cloth?
2. Did the balloon stick to the wall? Propose reasons as to why or why not.
3. Describe the movement of the two balloons when hung next to each other.
4. Does the movement indicate that the balloons had like or unlike charges? How do you know?

Explore! 3.3

INVESTIGATION

Lightning formation

Lightning is a natural phenomenon. It is a sudden discharge of electrostatic charges that have formed in a cloud.

Research lightning to answer the following questions.

1. Describe how clouds become electrically charged.
2. Explain why the electrical discharge that causes lightning happens.
3. Are there any ways that the build-up of electrostatic charges in clouds can be avoided?
4. What is a lightning rod?



Figure 3.28 Fear of lightning and thunder is known as astraphobia.

Quick check 3.4

1. **Define** the key terms 'electrostatic force' and 'static electricity'.
2. **Complete** the following sentence: Opposite charges _____ and like charges _____.
3. **Explain** why a Van de Graaff generator causes hair to stand up.
4. **Explain** why you sometimes get a small electric shock from friction with a carpet.

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Section 3.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.1 questions

Remembering

1. **State** the units for mass and weight.
2. **Recall** direct and indirect forces.
3. **Recall** the term to describe a net force of zero.
4. **List** three possible effects of a force on an object.
5. **Recall** the upward force that causes objects to float.
6. **Identify** which forces are acting on a dropped book that falls to the floor.
7. **Identify** the two types of electric charge.

Understanding

8. **Name** an everyday example of each of the following results caused by forces.

Result of the force	Everyday example
Speeding up of object	
Slowing down of object	
Rotating of object	
Changing direction of object	
Changing shape of object	

9. If a boat is travelling at a constant speed in a straight line on the water, what can you **infer** about the drag and the force of the engine?
10. **Provide** an example from everyday life for each of the following types of force.
    a. A force that changes the motion of an object
    b. A force that changes the shape of something
    c. A force that stretches or bends something
11. **Determine** the force needed by the monkey in Figure 3.29 to lift the 500 mL bottle of water (1 mL has a mass of 1 g).
12. There are many forces between the parts of Sydney Harbour Bridge. Are all the forces between the parts balanced or unbalanced? **Explain** your answer.
13. A falling object is pulled down by Earth. Earth is pulled up toward the object. **Explain** why the movement of Earth cannot be detected.



Figure 3.29 This monkey is working against gravity.



Figure 3.30 The Sydney Harbour Bridge

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14. **State** whether the mass of an object changes as it moves around the universe.
15. If you travelled to the Moon, **state** whether your weight would increase, decrease or stay the same.
16. **State** what your weight would be in deep space where gravity would be negligible.
17. **State** which ball, if they are all the same size and air resistance is ignored, will hit the ground first: a wooden ball, a plastic ball or a metal ball.

Applying

18. You push a door and find it is locked and will not open. **Apply** your knowledge of forces to decide if you still exerted a force even though the door did not move.
19. If you hold a carton of milk at arm's length in front of you, **determine** whether you are still exerting a force on it if the milk carton is not moving.
20. You are sitting on the couch at home after a big day at swimming sports. Sketch yourself and **draw** arrows to represent the forces acting on you (alternatively, you can just describe it). **Examine** whether the forces are balanced.
21. In Figure 3.31 the weight (force of gravity) of the gymnast is balanced by the tension in the ropes. **Draw** a force diagram of the gymnast.



Figure 3.31 A gymnast

22. **Calculate** the weight of a 5 kg cat on Earth (g = 9.8 N/kg) and on Mars (g = 3.7 N/kg).
23. Which would take longer to fall: a rock dropped from 1 metre on the Moon (gravity is about one-sixth of Earth's) or a rock dropped from 1 m on Mars (gravity is a little over one-third of Earth's)? **Explain** your answer. You can ignore air resistance on both planets.
24. **Describe** three situations where air resistance is useful and one situation where it is not useful.
25. Two balloons are hanging loosely near each other. One balloon is given a negative charge, and the balloons start to move away from each other. **Explain** what is happening and what the charge on the other balloon must be.

Analysing

26. **Analyse** Figure 3.32 and describe or draw the forces on the cyclist. Assume they are moving at constant speed in a straight line.
27. You know force is measured in newtons. How could you **explain** to a friend in a different class how big a 30 N force is?
28. Would a hammer and a feather hit the ground together if dropped from the same height at the same time on the planet Mercury, where there is no atmosphere? **Justify** your answer.
29. Parachutes are made of large pieces of material. **Explain** what the purpose of the material is and distinguish between how it makes an object speed up or slow down.
30. Figure 3.33 shows a scientist inspecting seagrass. Around his waist he is wearing a heavy belt made of metal. Apply your knowledge of forces to **explain** the function of this belt.



Figure 3.32 A cyclist



Figure 3.33 Diver wearing a weight belt

Evaluating

31. Three cycling triplets are identical in every way, including their size, mass and clothing, and they have identical bikes. They start a sprint race side by side at the same time. After 10 seconds, Albert has gone 200 m, Ben has gone 160 m and Charlie has gone 120 m. Was the average force each exerted on the pedals the same during the 10 seconds, or different? Who exerted the highest force, and who exerted the lowest? Was it a fair comparison? **Justify** your reasoning.
32. **Evaluate** the effects of living in a low-gravity environment for a long time.

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3.2 Magnets in everyday life

WORKSHEET Electrostatic and magnetic forces

Learning outcomes

At the end of this section, I will be able to:

1. describe magnetic attraction and repulsion in relation to polarity.
2. conduct a practical investigation to test how magnetic force varies with distance.
3. observe and map the magnetic fields of magnets.
4. conduct a practical investigation to make electromagnets and compare their strength.

Magnetic force is an indirect force. This means objects do not have to be touching to have an action. Magnets exert their force through **magnetic fields**. Like gravity and electric fields, the force due to a magnetic field varies with distance.

There are two types of magnetic poles, north and south, and they always occur as a pair. Even if you break a magnet in half, it will still have a north and south pole at the ends of each of the pieces. North and south poles attract each other while two like poles (i.e. north and north) repel each other. The force of attraction or repulsion is strongest at the poles.

magnetic force an indirect force between a magnet and another magnet or magnetic metal

magnetic field the area around a magnet where the magnetic force acts

alloy a substance composed of two or more metals

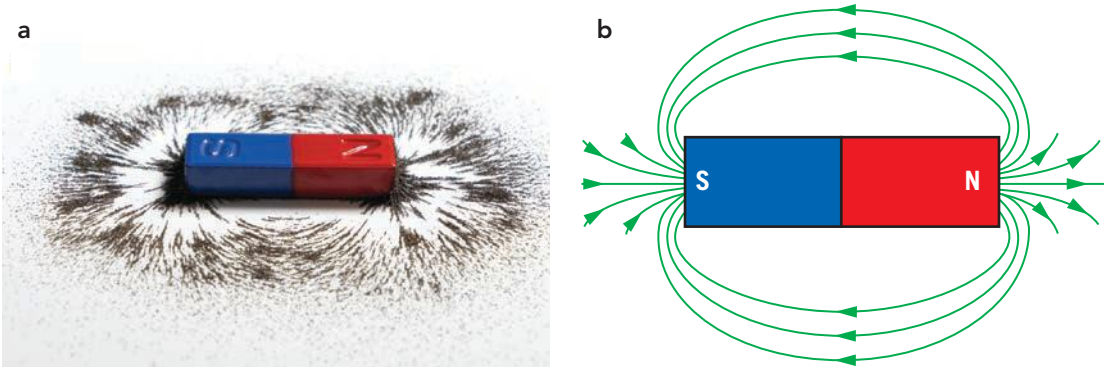


Figure 3.34 Magnetic fields around a magnet form a particular pattern, shown as an image **(a)** and a field diagram **(b)**. Note that the field lines become very close at the north and south poles - this is where the magnetic force is strongest.

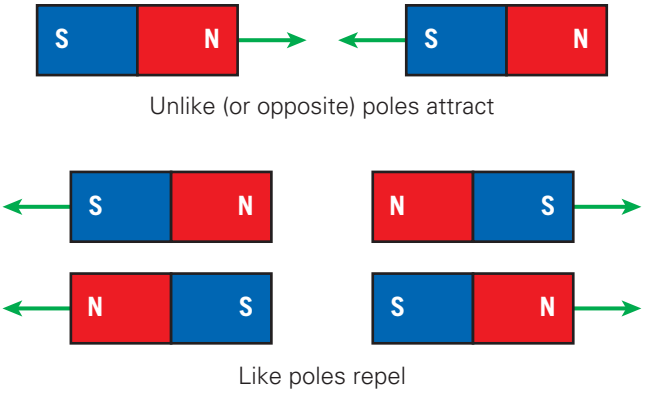


Figure 3.35 Forces between magnets

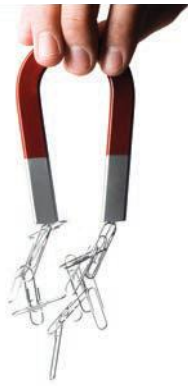


Figure 3.36 Paperclips become temporarily magnetised when near a permanent magnet.

Some magnets always retain their ability to be magnetic, and so they are called permanent magnets. An example would be a fridge magnet: they are always magnetic. On the other hand, metals like soft iron become magnets only when they are near a permanent magnet; they can become a temporary or induced magnet. Try hanging a paperclip from a magnet. While it is there, it will behave like a magnet and can be used to attract other paperclips. Magnets also attract iron, cobalt, nickel and some of their **alloys**, such as steel (an alloy of iron).

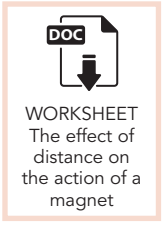
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Try this 3.10

Magnetic materials

Collect the following items: bar magnet, pencil, pen, paper, plastic straw, coins, paperclips, iron nail, metal spoon, aluminium foil, copper wire.

1. Hold the magnet close to each of the items and record whether they are attracted to the magnet. What do the objects attracted to the magnet have in common?
2. Using the bar magnet, carefully pick up paperclips one at a time, forming a chain of paperclips. How are you able to do this?



WORKSHEET
The effect of distance on the action of a magnet

Practical skills 3.5

Magnetic field lines

Aim

To visualise the shape of the magnetic field of different magnets.

Materials

- 2 bar magnets
- horseshoe magnet
- iron filings
- piece of A4 paper
- plastic sandwich bag
- compass

Procedure

1. Place the bar magnet in the plastic bag on a table and cover it with a piece of paper.
2. Sprinkle iron filings on the paper and look at the pattern formed.
3. Hold the compass at different points around the magnet. The direction that the compass points in indicates the direction of the magnetic field lines.
4. Repeat steps **1**–**3** with the horseshoe magnet.

Results

Draw a sketch of the pattern formed by the iron filings.

Discussion

1. Using your diagram, determine where the magnet's poles are.
2. Identify where the magnetic field appears to be the strongest.
3. Investigate different patterns formed with two or more magnets placed near each other.

Quick check 3.5

1. **Explain** why magnetism is considered an indirect (non-contact) force.
2. **Complete** the following sentence: Opposite poles _____ each other while poles that are the same _____ each other.
3. **Explain** the difference between a permanent and a temporary magnet.
4. **Describe** a magnetic field. Draw a picture of the field around a bar magnet.

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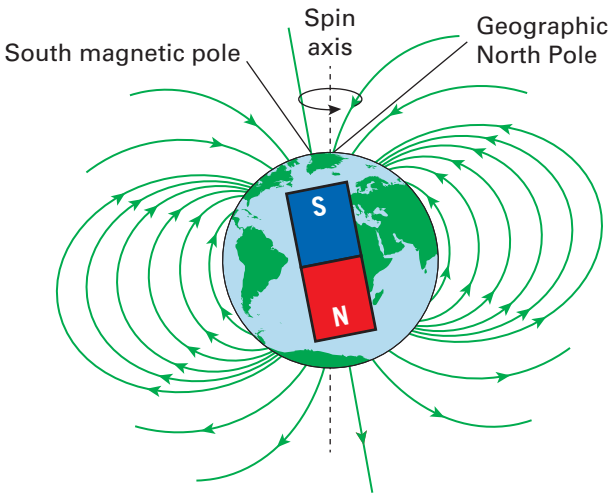


Figure 3.37 This diagram represents Earth's internal magnet as a bar magnet, which would generate the same field (in reality, the magnetic field is generated by electric currents in the molten outer core that result from Earth's rotation, convection currents and other phenomena).

Earth's magnetic field

Earth has a magnetic field (Figure 3.37). Have you ever gone hiking and used a compass to find your bearings? The compass needle is actually a magnet. The north pole of the magnet, the compass needle, points to the south magnetic pole of the Earth. This means that near the geographic North Pole there is a magnetic south pole, and near the geographic South Pole there is a magnetic north pole.

As you can see in Figure 3.37, the axis of the magnetic poles is not quite in line with the spinning axis of the Earth. There is about 23 degrees difference, but this changes over time. In Earth's geological history the magnetic poles have flipped many times. We know this because rocks formed from lava that contains iron have preserved the direction of the magnetised iron when the lava cooled and solidified.

INVESTIGATION

Explore! 3.4

Flipping poles

As mentioned above, geological evidence indicates that Earth's magnetic poles have flipped many times. There are many theories on when Earth's magnetic field will flip again, and even more theories on what will happen when it does. Will birds know which way to migrate? Will our dependence on technology be impacted? Can we predict when this will occur? Carefully assess the reliability of your sources. Can you trust the information is correct? How do you know?

Try this 3.11

Making a compass

Use a steel nail, a strong magnet, a piece of cork (or polystyrene foam) and a bucket of water to make a compass.

Method

1. Stroke the steel nail with the strong magnet in one direction. After each stroke, be sure to lift the magnet away from the nail before your next stroke. Repeat this process about 50 times.
2. Test your nail to see if it has become magnetised by holding it near some paperclips.
3. Place the piece of cork or polystyrene in the bucket of water. Then place the nail on top. This allows the nail to rotate freely. It will line up with the Earth's magnetic field lines.
4. Check the accuracy of the homemade compass with another compass. You could use a compass app on your smartphone.

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Did you know? 3.2

Sea turtles use Earth's magnetic field to find home

Female sea turtles always return to the beach where they were born to lay their own eggs. Sometimes this means swimming thousands of kilometres, and the way they do this is by relying on Earth's magnetic field. Scientists are unsure how turtles detect the magnetic field, but it is possible that tiny magnetic particles in their brains help the turtles navigate.



Figure 3.38 The sea turtle is guided along the coast by Earth's magnetic field.

Electromagnets

Magnetism and electricity are closely related; wires carrying electricity create a magnetic field around them. A coiled wire with electricity flowing through it behaves like a magnet, and so it is called an **electromagnet**. An iron nail inserted into the coil becomes magnetised too, increasing the strength of the magnet. When the current stops, the magnetic field ceases. This makes electromagnets very useful for many applications, for example, separating and moving metal as shown in Figure 3.40.

electromagnet a magnet made by passing electricity through a coil of wire

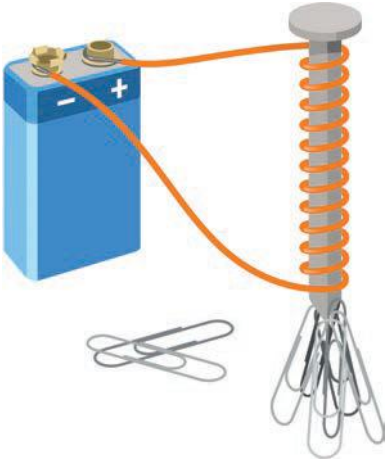


Figure 3.39 A simple electromagnet



Figure 3.40 Industrial use of an electromagnet

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Investigation 3.1

Making a simple electromagnet

Be careful
Make sure you only turn on your electromagnet for a short time. If left on, it will get hot.



Research question
How do the number of coils on an electromagnet affect its strength?

Aim
To investigate how changing the number of coils on an electromagnet will affect its strength.


INVESTIGATION

Materials
- DC powerpack with insulated output wires and alligator clip ends, set to 6 V output
- large-diameter iron or steel nail, bolt or bar
- compass
- 1 long enamelled wire
- emery paper (sandpaper)
- paperclips

NOTE

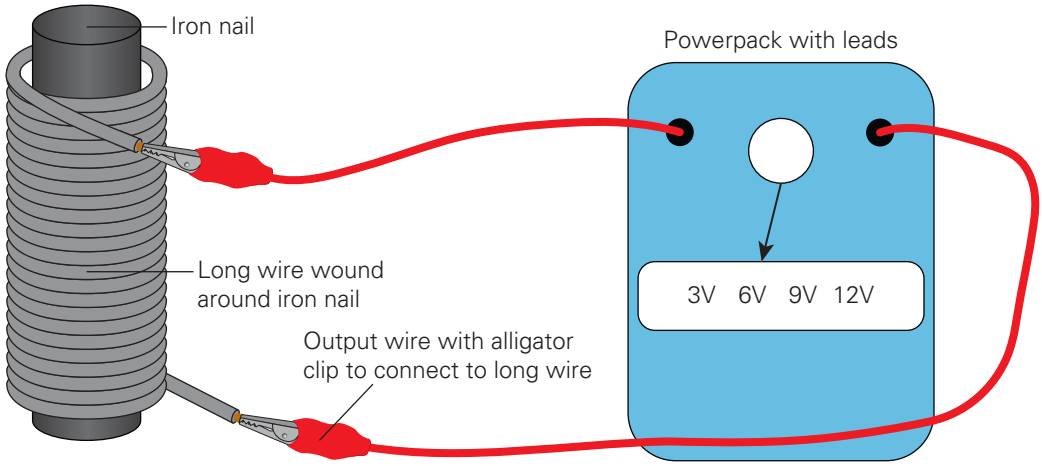
a 3 V or 6 V battery could be used instead of a powerpack, but you will need to connect it in the circuit with a switch.

Planning
1. You need to provide some background information on the investigation. Research electromagnets. Write a brief paragraph to explain how electromagnets work and the factors that can affect their strength.
2. Identify the independent variable in this investigation.
3. Identify the dependent variable in this investigation.
4. Develop a hypothesis by predicting how the independent variable will affect the dependent variable.
5. Identify the controlled variables in this investigation.
6. Create a risk assessment for this investigation that includes the risk of the wires overheating and burning you if the voltage is too high.

Procedure
1. Copy the table shown in the results section into your science book.
2. Carefully wrap the long wire around the nail 10 times, ensuring to only wind in one direction and avoiding any overlap of wires. Use the emery paper to remove 1 cm of the enamel insulation from both ends of the long wire so it can be connected to the powerpack.
3. If you are using the DC powerpack, set it to to 6 V and make sure the switch is OFF.
4. Connect the battery or powerpack to both ends of the long wire using its insulated wires and alligator clip ends.
5. Turn the powerpack ON.
6. Test your electromagnet by seeing how many paperclips it picks up. Record this number in the results table.
7. Retest the electromagnet two more times and record.
8. Repeat steps **2–7**, increasing the number of coils each time, according to the results table.

continued …

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Results

Independent variable: Number of coils	Dependent variable: Number of paperclips				
	Trial 1	Trial 2	Trial 3	Mean	Range
10					
20					
30					
40					

Use a spreadsheet application, such as Excel or Google Sheets, to create a digital graph that displays the mean for each group. Label each axis appropriately and add an appropriate title.

Peer review

1. Swap graphs with a peer. Give each other feedback on how easily the graph can be used. Feedback should identify if the graph displays only the mean results, has appropriate labels, units and title, and any other features that could be improved to enhance how well the experimental results are communicated, such as scale or formatting.
2. After receiving feedback, make alterations to the graph to address the identified issues.

Discussion

1. Identify the trend in your graph.
2. Identify any outlier results in your graph.
3. Extrapolate your graph to find out how many paperclips could be picked up if there were 80 coils.
4. If you had any outlier results (ones that were very different from the others), explain how these may have been caused.
5. Describe how the investigation could be improved if you had the chance to do it again.

Conclusion

1. Propose a valid conclusion that can be drawn from these results.
2. Justify this conclusion using data from your results.
3. State whether your hypothesis is supported or not.

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INVESTIGATION

Explore! 3.5

Magnetism in familiar contexts

You may not realise it, but electromagnets and permanent magnets are used everywhere and every day. For example, they can be found in electric motors, doorbells, computer hard drives, MRI machines, phone speakers and microphones, drills, hair dryers and credit cards!

Research any two of these examples and write a short report on each. Include a picture and details of how an electromagnet or permanent magnet is involved and how the object functions.

Quick check 3.6

1. **Explain** how an electromagnet is different from a bar magnet.
2. **Name** some examples of electromagnets used every day.
3. **Describe** the advantages of an electromagnet over a permanent magnet.

Go online to access the interactive section review and more!

Section 3.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.2 questions

Remembering

1. **Identify** some objects which use electromagnets.
2. **Recall** which poles attract.
3. **Define** the term 'magnetic field' and illustrate with a picture.

Understanding

4. The north pole of a magnet points north ward if it is free to move. **Clarify** what magnetic pole must be near the geographic North Pole.

Applying

5. **Summarise** how you can visualise the magnetic fields that surround a bar magnet.
6. **Describe** how charged objects and magnets are similar.

Analysing

7. **Examine** how a compass works. Why is it useful?
8. Metal recycling takes place in most cities, and aluminium, copper and steel are the most common metals that are recycled. After collection, the first step is to flatten the metal and then cut it into small pieces. The second step is to separate the iron and steel from the aluminium and copper, before finally melting the metals ready to be used again. **Identify** a method that could be used to easily carry out the second step.

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3.3 Simple machines

Learning outcomes

At the end of this section, I will be able to:

1. explore simple machines, from now and in the past, as used in everyday life.
2. conduct practical investigations of the action of forces using simple machines.
3. investigate how levers and pulleys and inclined planes are used to change the magnitude of force needed when performing a task.
4. identify examples of Aboriginal and Torres Strait Islander Peoples' application of knowledge about forces.

WORKSHEET Simple machines

History of the use of simple machines

Simple machines have been around a very long time. Look at the next four images. Before reading the text, can you identify which of these simple machines is a lever, an inclined plane or a pulley?



8000 BCE – The oldest existing well (right) is located in Israel. However, India, China, and Europe also had hand-dug wells built with stones and logs. To draw water from the wells, a variety of pulley systems were used, often with a rotating log instead of a wheel.



700 BCE – Archimedes was given credit for this device (right) after he described it in Greece in about 200 BCE, so it is called Archimedes's screw, but he never claimed to have invented it. In fact, such a device was thought to have been used to irrigate the Hanging Gardens of Babylon!



400 BCE – The Greek Dionysius the Elder of Syracuse invented the catapult (right) around 400 BCE. It may have been much older as it was also used in ancient India. The trebuchet originated in China around the same time. The invention spread across Eurasia and had reached the Mediterranean region by the sixth century CE. This is an example of the use of levers and was used as weapon in warfare.



130 BCE to 1453 CE – The Silk Road (right) was an ancient network of trade routes that was used to transport all sorts of goods to sell them in different parts of the world. It was so named because silk, a highly prized commodity, was made in China by craftsmen and sold in Arabia and the Roman Empire. There are many mountains on this journey and therefore many winding roads, which are essentially inclined planes, to allow for the transport of heavy loads of goods.

Today, simple machines are still used for everyday tasks, from changing a tyre and opening tins, to moving house and using an elevator.

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INVESTIGATION

Explore! 3.6

Archimedean screw

Archimedean screws are found in dams, snow blowers, chocolate fountains and more.

Research how an Archimedean screw works and make a presentation or a model to demonstrate this principle.

Mechanical advantage

simple machine a basic mechanical device for applying a force and changing either its size or direction

mechanical advantage the ratio of the output force to the input force

A **simple machine** provides an advantage to achieve a task. This advantage may be a directional advantage, a distance advantage, a speed advantage or a **mechanical advantage.** A mechanical advantage reduces the effort applied to achieve a task by increasing the distance over which a smaller force acts. Levers, ramps and pulleys all provide a mechanical advantage.

Explore! 3.7

Rube Goldberg machines

A Rube Goldberg machine, named after American cartoonist Rube Goldberg, is designed to perform a task in a rather complicated series of steps.



Figure 3.41 A Rube Goldberg machine includes many devices that can make things move. How many can you find?

VIDEO Assistive technology

1. Using a generative AI tool accessible online, create a drawing or a description of a Rube Goldberg-type chain reaction to achieve a simple task. The task could be pouring a glass of water or pushing a toy car down a ramp.
2. Analyse the AI output. Does the machine achieve the task? How many steps are in the chain reaction?
3. Describe how a simple machine would achieve this task. Do you think this machine would make the task easier or harder?

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Levers

fulcrum
the point on a lever where the arm pivots

A lever consists of a solid bar or arm that rotates (pivots) about a fixed point called a **fulcrum**. Examples of levers include a seesaw, a door handle and even a pair of scissors.



Figure 3.42 Levers are found in many everyday settings. After learning about the types of levers, come back and see if you can identify what type the levers above are.

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VIDEO
Lever orders

There are three types of levers: first, second and third-order. The type of lever is classified according to the position of the fulcrum, the location of the load or object to be moved, and the location where the effort is applied. The mechanical advantage achieved depends on the distances of the load and effort from the fulcrum.

WORKSHEET
Levers

First-order levers

In a **first-order lever**, the load and effort are on either side of the fulcrum.

first-order lever
a lever in which the fulcrum is between the load and effort

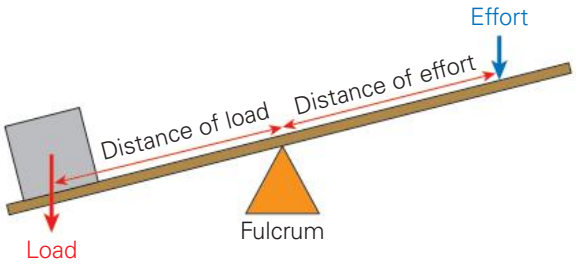


Figure 3.43 A first-order lever with the fulcrum between the load and the effort

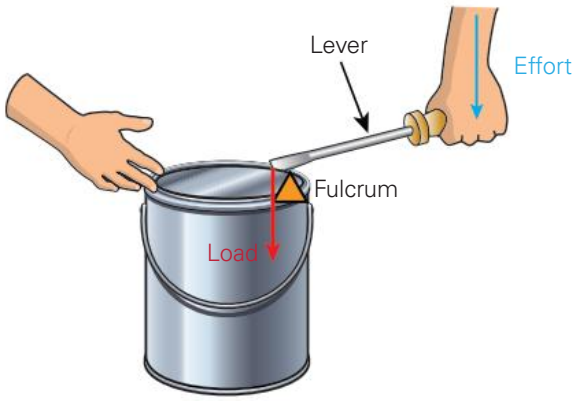


Figure 3.44 A screwdriver opening a paint can is a first-order lever. The effort is shown in blue. In this case, the load in red is the paint lid being lifted.

Consider a seesaw where both sides are the same length. Let's say there is a large box on one end and when you lift it, it is very heavy. So, you walk to the other side and push down on the seesaw. You still need the same amount of force, but now you can push downwards instead of pulling upwards. This is a direction advantage. Even though you need the same force, you can use your body weight to help you, and it seems easier. What if the box is closer to the fulcrum? This time, when you push down on the other end of the seesaw, you need less force, and it is even easier to move it! How much easier? This can be easily calculated.

The mechanical advantage of a lever can be calculated using the following formula.

$$\text{mechanical advantage} = \frac{\text{distance of effort from fulcrum (m)}}{\text{distance of load from fulcrum (m)}} = \frac{\text{load (N)}}{\text{effort (N)}}$$

A mechanical advantage value of 2 means it is twice as easy to move an object, or half the force is required. Since mechanical advantage is a ratio, it is expressed as a number with no units. Note also that distances from the fulcrum are measured to where forces are applied, which is vertically through the centre of mass in the case of the force of gravity.

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On each side of the fulcrum, the turning effect of a lever can be calculated. This is called a moment. The moment of a lever can be calculated using the following formula.

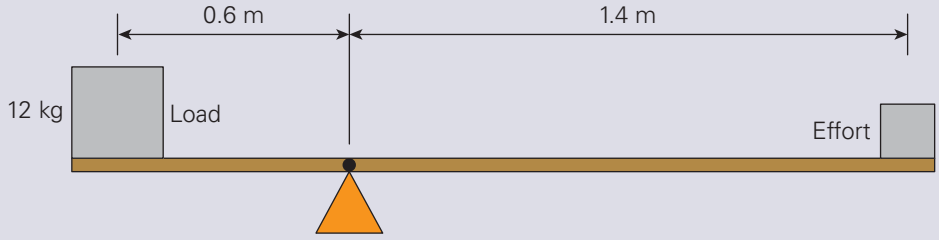
$$\text{moment (N m)} = \text{force (N)} \times \text{distance (m)}$$

Where force is measured in newtons (N), the distance from the fulcrum is measured in metres (m) and the moment is measured in newton metres (N m).

Worked example 3.3

Mechanical advantage

Refer to the data in the diagram and answer the following questions.



a. Calculate the mechanical advantage.
b. Find the mass of the small box.
c. Show that the moment, in N m, is the same on both sides of the seesaw.

Working	Explanation
a. mechanical advantage	
distance of effort from fulcrum = 1.4 m distance of load from fulcrum = 0.6 m	Identify the values given in the question.
$\text{mechanical advantage} = \frac{\text{distance of effort}}{\text{distance of load}}$	Identify the formula needed to answer the question.
$\text{mechanical advantage} = \frac{1.4}{0.6}$ $= 2.3$	Substitute the relevant values into the formula. Remember: mechanical advantage does not have units as it is a ratio.
b. mass of small box	
mass of load = 12 kg	Identify the values given in the question.
$\text{mechanical advantage} = \frac{\text{mass of load}}{\text{mass of effort}}$	Identify the formula needed to answer the question.
$\text{mass of effort} = \frac{\text{mass of load}}{\text{mechanical advantage}}$ $\frac{12}{2.3} = 5.2 \text{ kg}$	Rearrange the formula and substitute the values in.
c. moment	
moment = force × distance	Identify the formula needed to answer the question.
On side of big box: moment = $m \times g \times$ distance $= 12 \times 10 \times 0.6$ $= 72$ N m	Substitute the relevant values into the formula. Use $g = 10$ m/s^2 for acceleration due to gravity.
On side of small box: moment = $m \times g \times$ distance $= 5.2 \times 10 \times 1.4$ $= 72$ N m	Repeat for the other side of the seesaw.
Therefore, the moment is the same on both sides of the seesaw.	Conclude by answering the question in words.

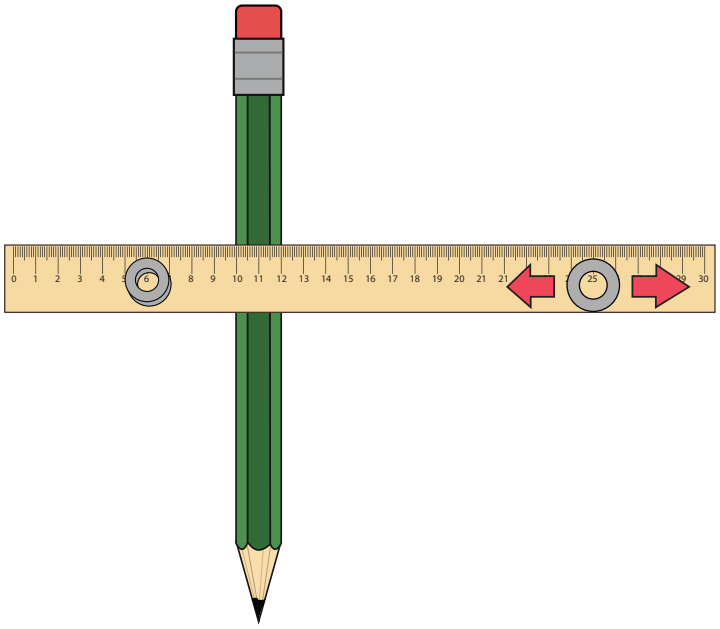
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Try this 3.12

Modelling a seesaw

Model a seesaw using a ruler and a pencil and some washers.

Use the pencil as the fulcrum and balance the ruler on the pencil. Place two washers 10 cm from the fulcrum on one side and try to balance this with one washer on the other side of the fulcrum. At what distance did you have to place the single washer to lift the other two?



Second-order levers

second-order lever a lever in which the fulcrum is at one end and the load is between the fulcrum and the effort

A **second-order lever** has the load in the middle, for example a wheelbarrow. The effort distance from the fulcrum is always longer than the load distance from the fulcrum. This gives a mechanical advantage. Notice how the effort to lift a load in a wheelbarrow moves a greater distance upwards that the load moves upwards, but with less force needed.

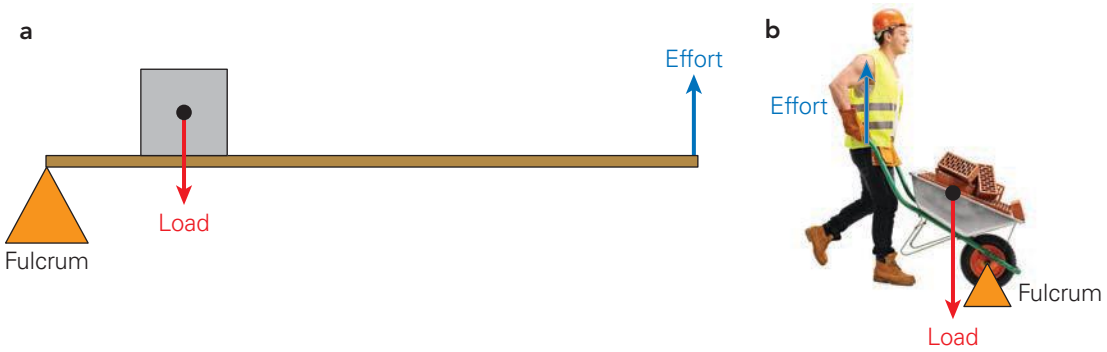


Figure 3.45 (a) A second-order lever. The fulcrum is at one end and the load is between the fulcrum and the effort. **(b)** A wheelbarrow is an example of a second-order lever. The worker does not have to apply as much effort to lift the load. Without this simple machine, it would be nearly impossible to lift that number of bricks!

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Third-order levers

A **third-order lever** has the effort applied in the middle. This means the load distance from the fulcrum is greater than the effort distance from the fulcrum. In fact, there is no mechanical advantage! More force is needed to lift the load, but it can be lifted a greater distance. This is a distance advantage.

third-order lever a lever in which the fulcrum is at one end and the effort is between the load and the fulcrum

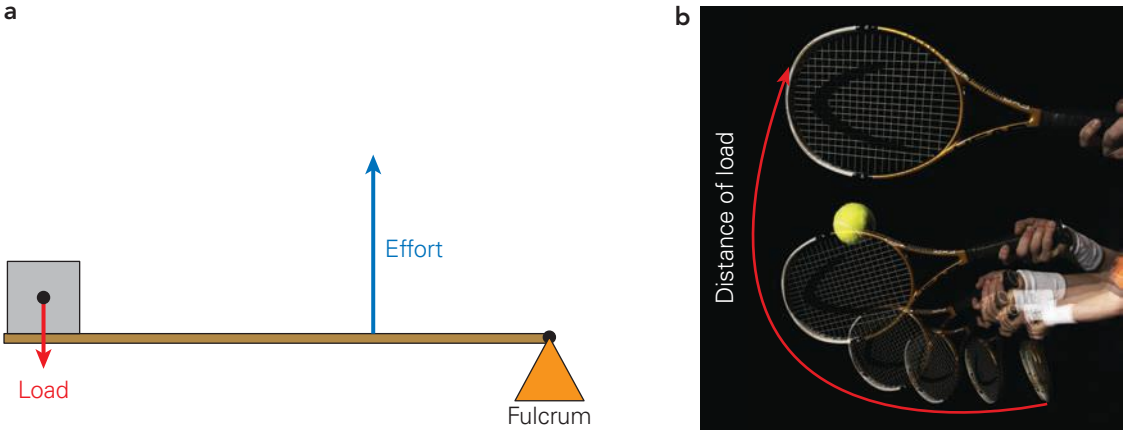


Figure 3.46 (a) In a third-order lever, the fulcrum is at one end and the effort is between the load and the fulcrum. **(b)** Sports scientists apply this knowledge of forces to help their clients improve their sporting performance. This knowledge has helped tennis players to now make serves at speeds above 250 km/h!

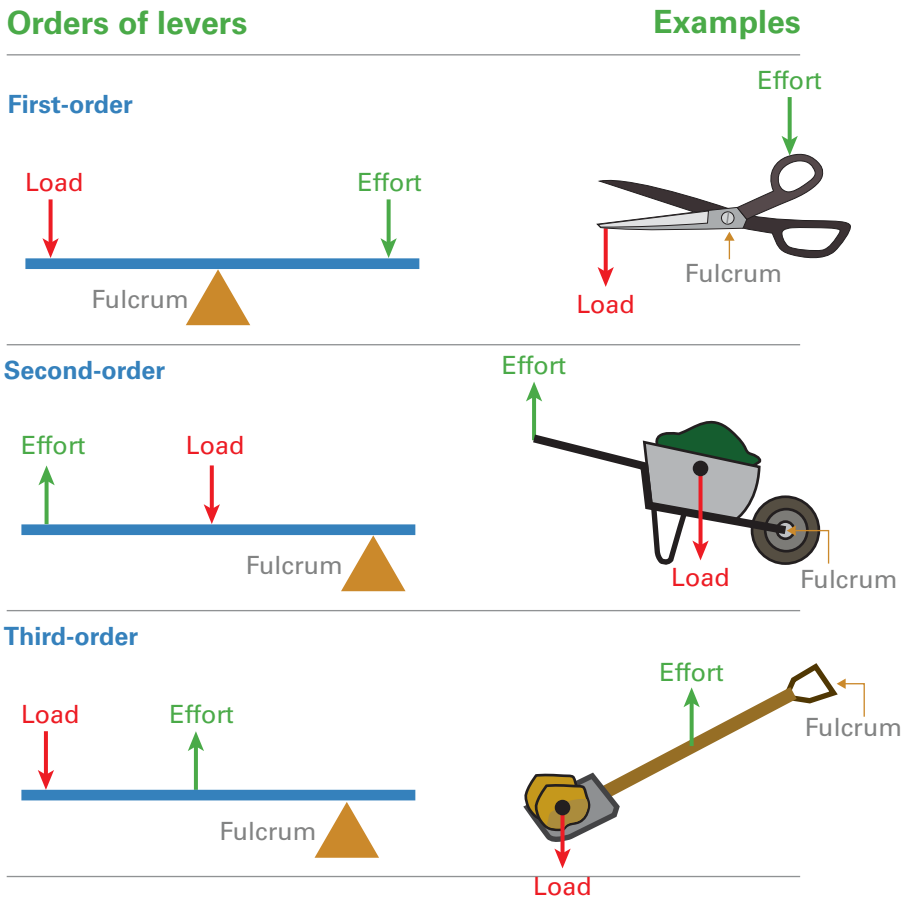


Figure 3.47 The three orders or levers

FLE is a useful acronym to remember the differences between first, second and third-order levers. The letters tell you what is in the middle of the lever: **F**ulcrum (first-order), **L**oad (second-order) and **E**ffort (third-order).

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INVESTIGATION

Explore! 3.8

Aboriginal and Torres Strait Islander Peoples' use of simple machines

Spear-throwers, such as a woomera, are simple machines that were developed by Aboriginal and Torres Strait Islander Peoples to help with hunting. Indigenous spear-thrower devices are commonly about 50 cm long and made from hardwood timber. At one end, a hand grip is often coated with spinifex resin. At the other end is a peg, made either from wood or a large tooth, which is attached to the spear-thrower using animal sinew and resin to hold the spear in place.

The spear-thrower acts as a lever, multiplying the force that a hunter can apply to the spear, as well as improving its projectile accuracy. It allows spears of up to 3 m in length to be thrown at speeds of up to 150 km/h. The peg helps hold the spear (or dart) in position, and focuses the throwing force.



Figure 3.48 The design of the spear-thrower will depend on which Aboriginal and/or Torres Strait Islander group that developed it. Spear-throwers are refined and altered by the people of each area to suit their own particular needs.

Torres Strait Islander Peoples also used another simple machine, the bow and arrow, in hunting. This was not used by Aboriginal Peoples on mainland Australia, likely due to heavier spears being required to hunt larger animals such as kangaroos.

The bow is also a lever, multiplying the force acting on an arrow for hunting small animals.

Conduct research and watch videos of the spear-thrower and bow and arrow being used to answer the following questions. Ensure you source information from a reliable and anti-racist source.

1. Draw a spear-thrower and spear and identify where on the spear-thrower the load, force and fulcrum are located.
2. Draw a bow and arrow and identify where on the bow the load, force and fulcrum are located.
3. Deduce what type of lever is being utilised in the spear-thrower and the bow and arrow.



Figure 3.49 An example of a simple bow

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Pulleys

Simply slinging a rope over a tree branch to lift something gives you a direction advantage. Why? Because pulling down on a rope allows you to also use your body weight, so it is easier than pulling up. But with all that rubbing or friction, the rope might break. Using a wheel with a groove in it for the rope makes a much smoother motion. This is called a fixed pulley.

An elevator is an example of a pulley. It uses a counterweight to reduce the effort or applied force to move the elevator. A counterweight is a weight added to the effort end of the rope, that is less than the load, and reduces the force you need to apply to move the load. For example, if the load exerts a force of 100 N downwards and you add a counterweight of 80 N to the effort part of the rope, then you only need to pull with a force of 20 N to move the 100 N load!

If you use both arms to lift a heavy box, it is easier than using just one arm. This is because the load is shared between the two arms, so each arm only needs to provide half the effort or force needed. A moveable pulley can provide the same advantage.

To calculate the mechanical advantage in pulley systems, count the number of ropes that are lifting the load. In the movable pulley in Figure 3.52, two sections of ropes are lifting the load, so the mechanical advantage is 2.

The mechanical advantage of a pulley system can be calculated using the following formula.

$$\text{mechanical advantage} = \frac{\text{load (N)}}{\text{effort (N)}}$$

A combination of pulleys can give a mechanical advantage as well as a direction advantage. This is called a compound pulley. For example, a fixed and a movable pulley can be combined to form a compound pulley.

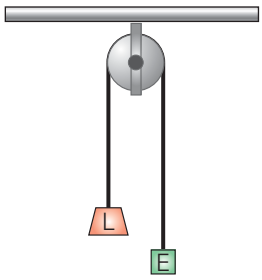


Figure 3.50 A simple fixed pulley. The downward effort, E, lifts the load, L, upwards. This is a directional advantage, enabling you to pull down with your body weight instead of lifting the load from the ground.

VIDEO
Pulleys

DOC
WORKSHEET
Simulating pulley arrangements



Figure 3.51 Workers install an elevator. Note the large counterweights at the top that balance the weight of the elevator car, reducing the force needed to lift it when full.

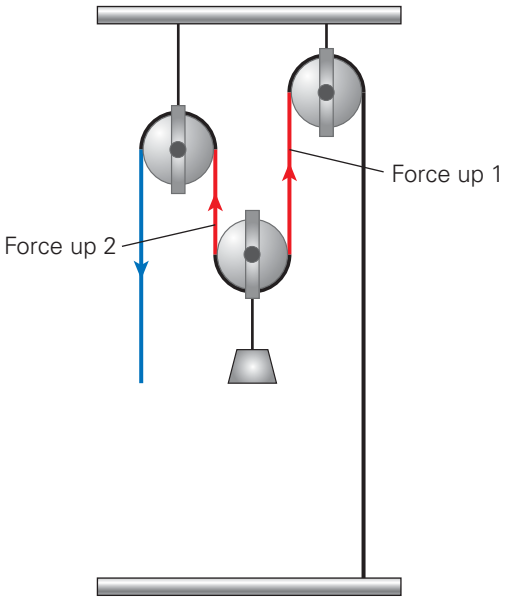


Figure 3.52 A movable pulley between two fixed pulleys. This pulley system has a mechanical advantage of 2, as there are two sections of the rope (in red) lifting the load.

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Both of the images below show same compound pulley with a mechanical advantage of 2. Can you spot the similarities and differences between the two images in Figure 3.53?

The arrangement in Figure 3.53b is called a block and tackle. Both arrangements are the same mechanism, but a block and tackle is more compact.

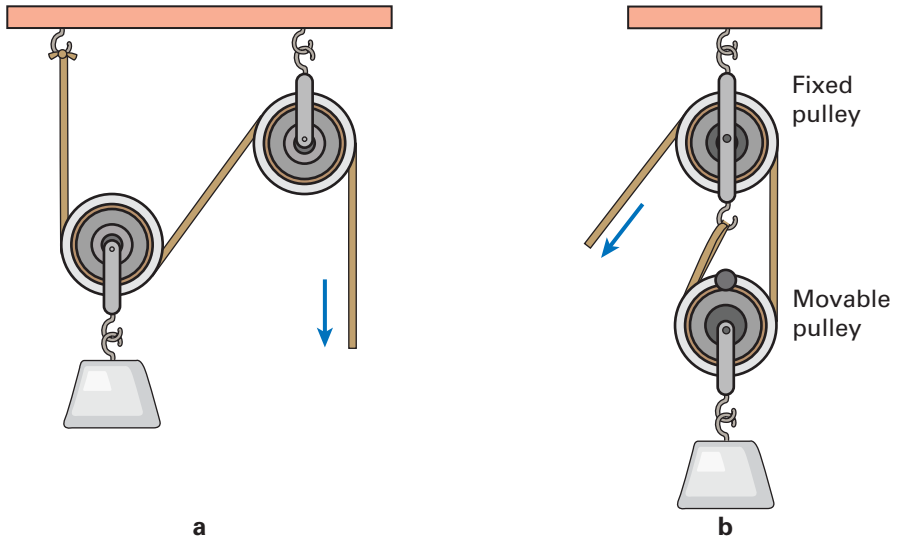


Figure 3.53 A compound pulley **(a)** and a block and tackle pulley **(b)**

Sometimes you may need a bigger mechanical advantage to lift even bigger loads. To do this you need even more pulleys so you can have more ropes lifting the load, arranged in a block and tackle.

Note that the black ropes have a fixed length and do not contribute to the effect of the pulley.

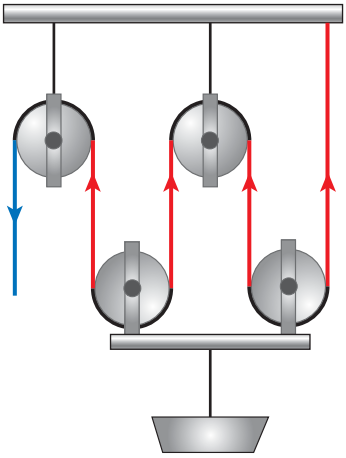


Figure 3.54 A pulley system with a mechanical advantage of 4

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Explore! 3.9

INVESTIGATION

Ski lifts

Ski lifts use pulley systems to move people up and down mountains. Research how this gives the lifts an advantage (directional or mechanical) to reduce the force required.



Inclined planes

Trucks carry very large loads from the bottom of a mining pit to the top. However, they don't just lift loads to the top in a straight line. That requires a lot of force. Instead, trucks lift loads by travelling up a long winding road. It is a much further distance, but it requires much less force. This is an example of an inclined plane or ramp.



Figure 3.55 Inclined planes are used to move material from the bottom of the mine to the top.

An inclined plane is a rigid sloping surface. Ramps are a type of inclined plane. When you need to lift a heavy object up a step, it is easier to push it up a ramp because it requires less force. However, you do need to push it a greater distance. How much less effort is required to push the object up the ramp? This is the mechanical advantage.

The mechanical advantage of a ramp can be calculated using the following formula.

$$\text{mechanical advantage} = \frac{\text{length of ramp (m)}}{\text{height of ramp (m)}}$$

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If the ramp is twice as long as the height, then only half the force is needed to push the object up the ramp compared to lifting it straight up. However, it needs to be pushed twice the distance. Be aware that, depending on the surface of the ramp, friction may also be significant and increase the force required.



Figure 3.56 Use a ruler to find the length and height of the ramp and calculate the mechanical advantage. How much harder would it be to lift the load straight up?



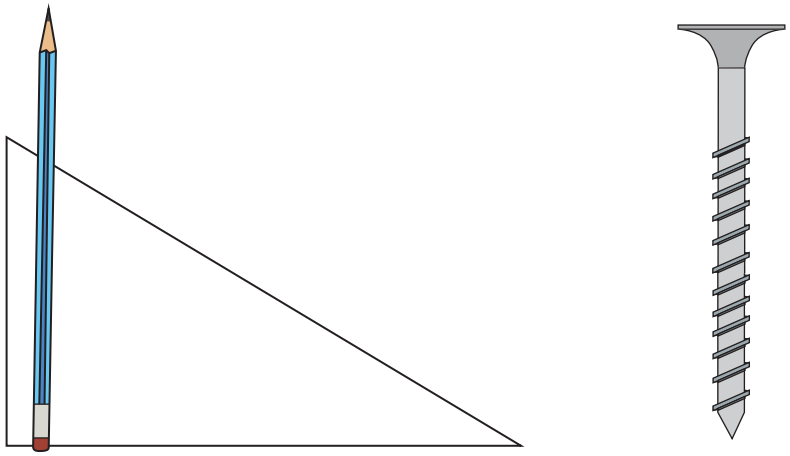
Figure 3.57 A wedge is another example of an inclined plane. A wedge is essentially two inclined planes joined together. These can also have various levels of steepness. For example, they can be used to pry open a coconut or chop wood.

Try this 3.13

Screws as an inclined plane

Screws are also an example of an inclined plane. How can that be?

Cut a piece of paper into a triangle as shown below. Place a pencil on the short edge of the triangle and roll the paper around it. Now take a close look, can you see how it resembles a screw?



Repeat with another, much steeper triangle. What effect does that have on the resulting shape of the thread of the screw?

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Extension: Gears

Gears are interlocking wheels that are a very clever modification of levers. They alter the magnitude and distance over which a force is applied to provide an advantage. Turning a small wheel, which has a small radius and hence a short distance between fulcrum and load/effort, will displace a large wheel by only a small angle. This is because a large wheel has a large distance between the fulcrum and the load/effort. Remember, the moment is equal to the force multiplied by the distance from the fulcrum – in this case the centre of the wheel.



Figure 3.58 Gears are made of many small levers.

Since the wheels of a gear have teeth or notches that fit into the teeth of the adjoining wheel, the mechanical advantage can be calculated by comparing the number of teeth in each wheel. A smaller wheel with fewer teeth will need to rotate faster to keep up with a larger wheel with more teeth.

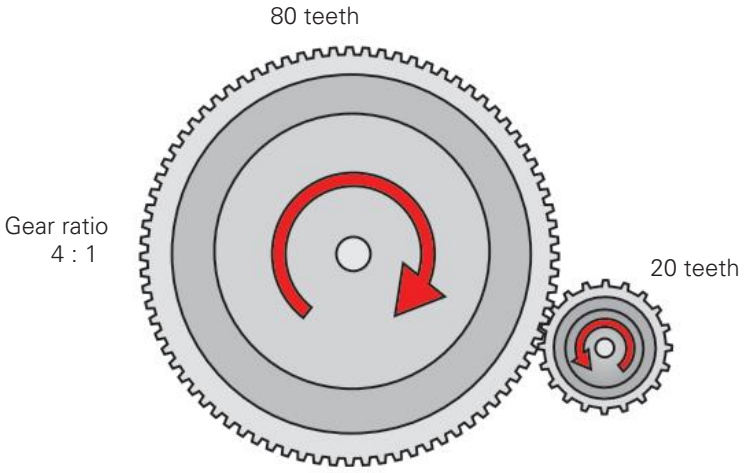


Figure 3.59 The smaller wheel will move four times faster than the larger wheel.

Quick check 3.7

1. **Define** the following key terms in your own words: lever, pulley, inclined plane.
2. **Identify** an advantage of using a lever, a pulley or an inclined plane.

Section 3.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 3.3 questions

Remembering

1. **Identify** the missing words in the following sentence: To calculate the mechanical advantage of an inclined plane, you must divide _____ by _____.

Understanding

2. If the mechanical advantage is 3, **calculate** the maximum load force if the effort force is 50 N.
3. If the mechanical advantage is 4, **calculate** the minimum effort force required to lift a load force of 120 N.

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Applying

4. Most schools and public buildings now have ramps designed for wheelchair access. **Use** your knowledge of ramps and forces to explain why the maximum gradient of those ramps is about 1:10 as a ratio of rise:run

Analysing

5. **Classify** each of the following as a first, second or third-order lever, and justify your response by describing where the fulcrum, load and effort are located for each one.
   - **a.** Crowbar
   - **b.** Wheelbarrow
   - **c.** Seesaw
   - **d.** Barbecue tongs
   - **e.** A screwdriver used to open a can
6. **Distinguish** between a first, second and third-order lever, what they magnify and the trade-offs.
7. An experiment was done with the pulley system shown in Figure 3.60, and the results are shown in the table below. Use the formula given to **complete** the table and hence **calculate** the average mechanical advantage to two decimal places.

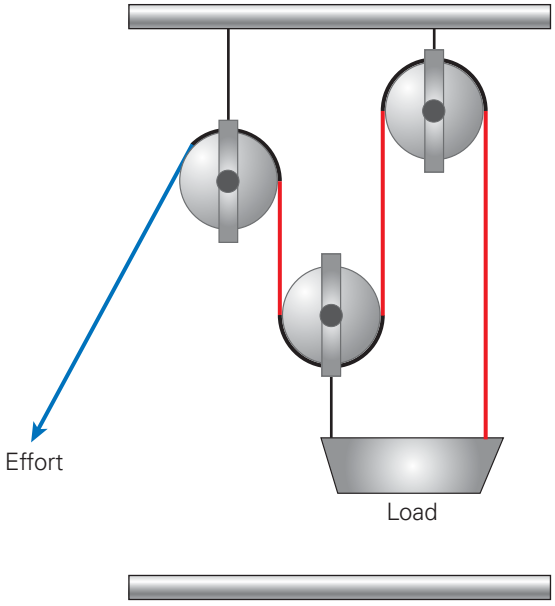


Figure 3.60 A load system

$$\text{mechanical advantage} = \frac{\text{load (N)}}{\text{effort (N)}}$$

Load (N)	Effort (N)	Mechanical advantage
88	30	
121	40	
147	50	
185	60	
Average		

Evaluating

8. **Consider** whether the lower beaks of birds are examples of levers. Use your knowledge of simple machines to justify your answer by identifying the load force, effort force and fulcrum. Do you think your jaw is also lever? If so, what order of lever is it?

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
3.1	explain forces as either direct/contact or indirect/non-contact and conduct a practical investigation on the effects of a range of direct and indirect forces.	2
3.1	use force diagrams to model balanced and unbalanced forces and analyse them to make predictions.	4, 19
3.1	examine the relationship between force and energy.	12
3.1	describe the electrostatic and gravitational forces between objects.	8, 14
3.1	use forces to describe the motion of objects in orbit.	5, 13
3.1	define weight force using $F = mg$ and use it to solve for F, m and g.	1
3.2	describe magnetic attraction and repulsion in relation to polarity.	11
3.2	conduct a practical investigation to test how magnetic force varies with distance.	3
3.2	observe and map the magnetic fields of magnets.	7
3.2	conduct a practical investigation to make electromagnets and compare their strength.	15
3.3	investigate how levers and pulleys and inclined planes are used to change the magnitude of force needed when performing a task.	6, 16
3.3	identify examples of simple machines.	9
3.3	explore the role of simple machines, from now and in the past, as used in everyday life.	10
3.3	identify examples of Aboriginal and Torres Strait Islander Peoples' application of knowledge about forces.	19

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

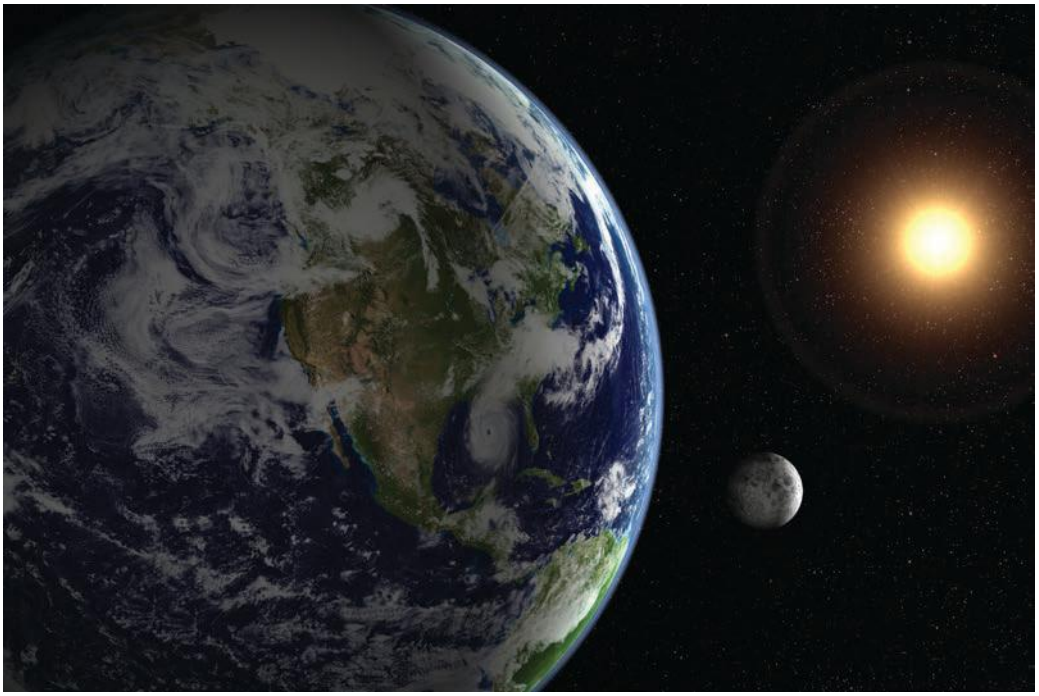
1. **State** the unit of force.
2. **List** three direct forces and three indirect forces.
3. **State** whether the strength of the magnetic force of a magnet on pieces of iron gets stronger or weaker with distance from the magnet.



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Understanding

4. **Draw** a balanced and an unbalanced force diagram and predict the movement that will result from them.
5. **Describe**, using your knowledge of forces, why the Moon orbits Earth and why Earth orbits the Sun.

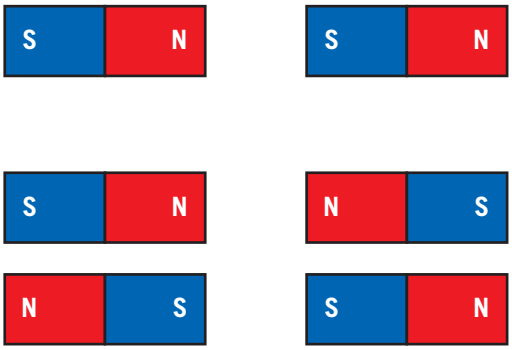


6. **Explain** how simple machines allow us to do something that would otherwise be difficult.
7. **Draw** the magnetic field around a bar magnet, labelling the poles and showing the direction of magnetic force on selected field lines.
8. **Compare** the electrostatic force between two opposite charges and the gravitational force between a star and planet.
9. **Identify** the type of simple machine that is being used to split a log in this image.



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10. **Identify** past and current uses of pulleys to raise water.
11. **Compare** the magnetic forces between two north poles, between two south poles and between a north and south pole (where 'pole' refers to the pole of a magnet).



Applying

12. When a force doubles in strength but acts over the same distance, **explain** what changes about the energy required to provide the force.
13. **Draw** a force diagram for a satellite in orbit.



14. On the surface of another planet, a mass of 50 kg has a weight of 15 N. **Calculate** the acceleration due to gravity, *g*, for that planet.
15. To make an electromagnet stronger, **explain** what changes could be made to its design.
16. A first-order lever has a mechanical advantage of 3. **Compare** the size of the load force and the effort force required to move the load.

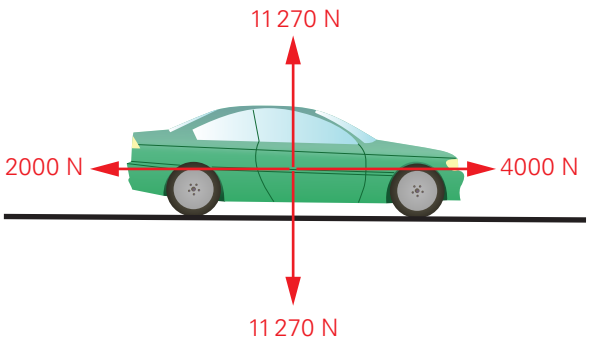
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Analysing

17. If a car is travelling at a constant speed in a straight line down the Hume Highway, what can you **infer** about the drag and force of the engine?



18. Predict the movement that will result from the forces in this diagram, saying if the movement will change if the forces continue to be applied. **Justify** your answer.



Evaluating

19. Explain, with the aid of a diagram, how a spear-thrower used by Aboriginal and Torres Strait Islander Peoples is a type of simple machine.

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Data questions

Earth's Moon and the planets in our solar system have different forces of gravity on their surface than Earth because they have different masses. The graph below plots the surface gravity of different planets relative to that of Earth.

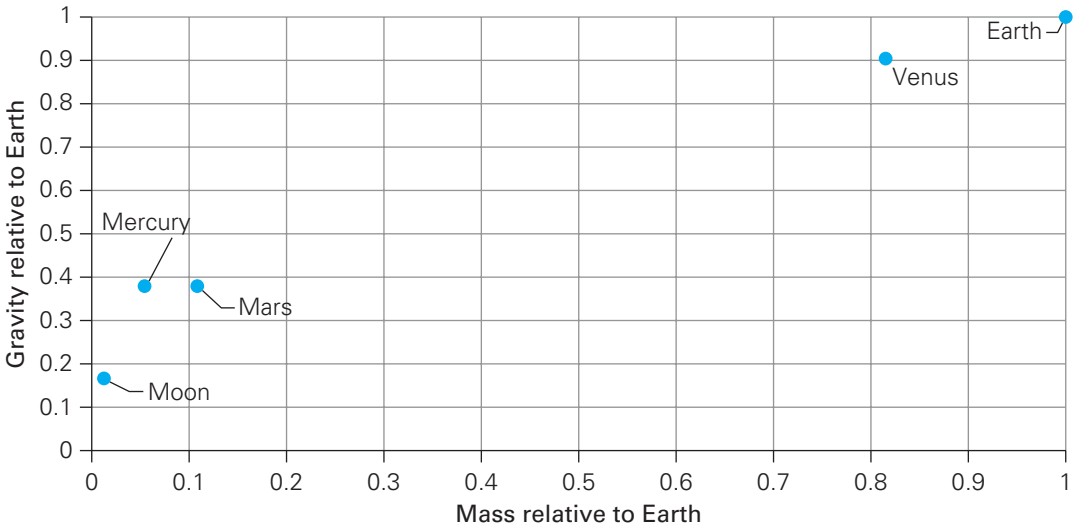
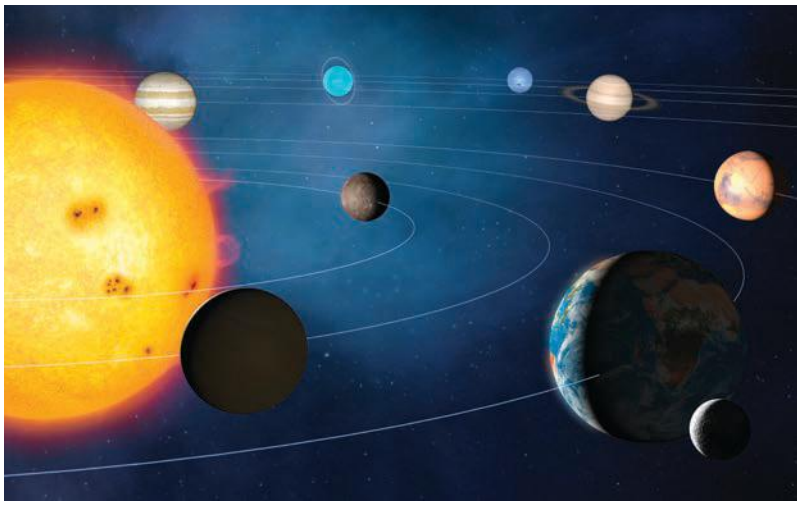


Figure 3.61 Gravity on the Moon and planets relative to that of Earth given their relative masses

1. **Identify** which planet in the graph has the lowest mass.
2. **Determine** which planet has a force of gravity closest to that on Earth.
3. If the acceleration of Earth's gravity is 9.8 m/s^2, and Mars's gravity is 38% of that of Earth, **calculate** Mars's actual gravitational force.
4. **Identify** the general relationship between the mass of a planet and the force of gravity.
5. Use the data presented in the graph to **contrast** the gravitational force of Earth and Mercury.
6. **Deduce** why the Moon orbits Earth, instead of Earth orbiting the Moon.
7. The mass of Jupiter is approximately 318 times that of Earth. **Predict** whether the gravitational force on Jupiter would be greater or less than that of Earth.
8. Among the planets shown, two of them are such that a person standing on their surface would weigh about the same. **Infer** which two planets they are.
9. Pluto has a relative force of gravity of 0.07 to that of Earth. Use the relationship identified in Question **4** to **justify** that Pluto will have a mass less than that of Earth's moon.



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STEM activity: Designing and prototyping a ferry

Background information

Ferries are used worldwide to connect two or more points (e.g. Parramatta RiverCat or Sydney Ferries). They carry passengers, goods and sometimes vehicles. Ferries are vital for transport in many developing countries, since highways are expensive to build, and most waterways come free.

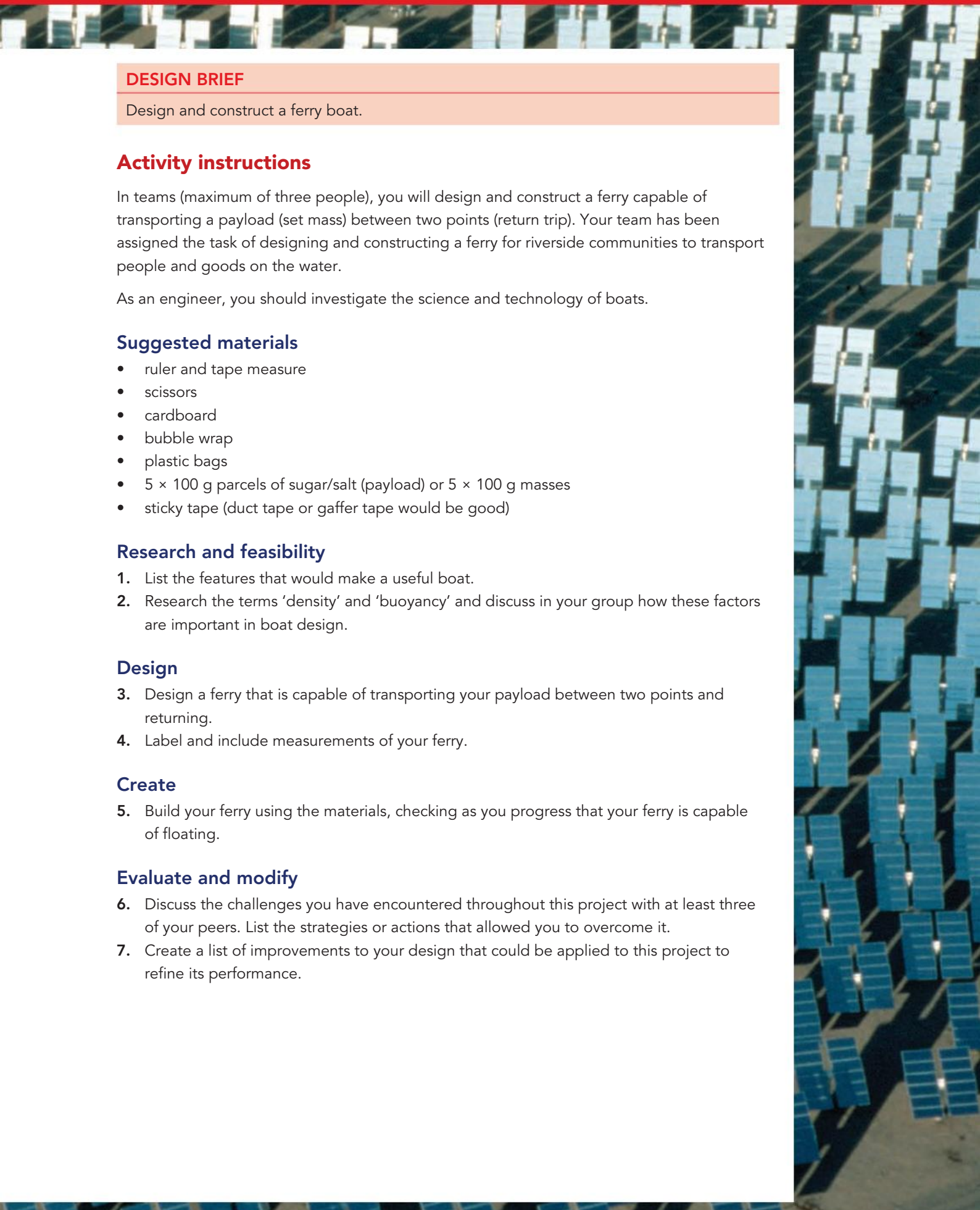
Ferries float in water as a result of buoyancy. Any object placed in water will either sink or float: if an object is denser than water, it will usually sink; and if it is less dense, it will float. But how can a steel ship, capable of carrying thousands of passengers and cars, float in the ocean when a metal ring or coin would sink in your bathtub?

It is time to investigate how design can affect the buoyancy of a ferry!



Figure 3.62 Ferries are part of the public transport system in many places in the world.

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DESIGN BRIEF

Design and construct a ferry boat.

Activity instructions

In teams (maximum of three people), you will design and construct a ferry capable of transporting a payload (set mass) between two points (return trip). Your team has been assigned the task of designing and constructing a ferry for riverside communities to transport people and goods on the water.

As an engineer, you should investigate the science and technology of boats.

Suggested materials

- ruler and tape measure
- scissors
- cardboard
- bubble wrap
- plastic bags
- 5 × 100 g parcels of sugar/salt (payload) or 5 × 100 g masses
- sticky tape (duct tape or gaffer tape would be good)

Research and feasibility

1. List the features that would make a useful boat.
2. Research the terms ‘density’ and ‘buoyancy’ and discuss in your group how these factors are important in boat design.

Design

3. Design a ferry that is capable of transporting your payload between two points and returning.
4. Label and include measurements of your ferry.

Create

5. Build your ferry using the materials, checking as you progress that your ferry is capable of floating.

Evaluate and modify

6. Discuss the challenges you have encountered throughout this project with at least three of your peers. List the strategies or actions that allowed you to overcome it.
7. Create a list of improvements to your design that could be applied to this project to refine its performance.

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Chapter 4

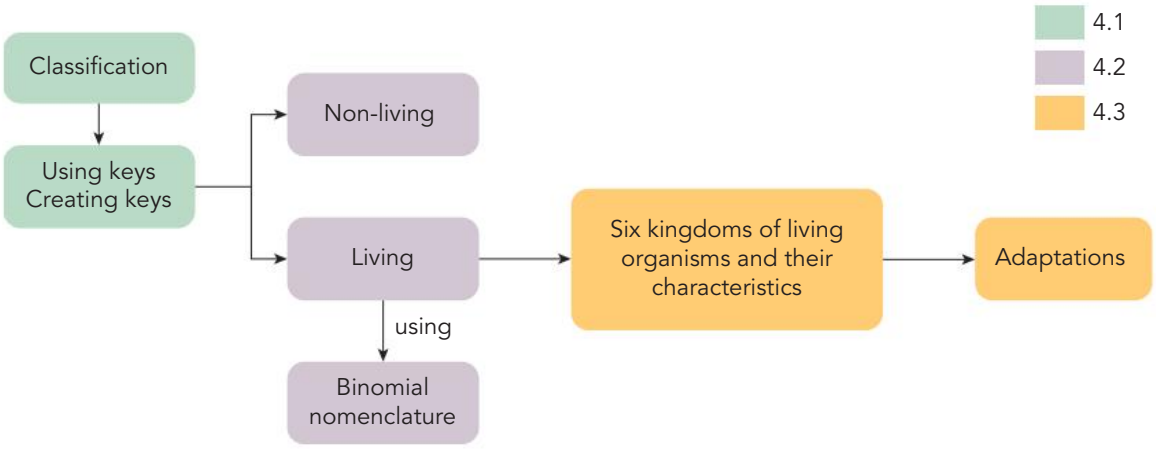
Classification of living things

Chapter introduction

When you organise your clothes, your kitchen cupboards or your documents, you are unknowingly grouping things together based on similarities. This process is called classification. In this chapter, you will explore the way scientists use classification systems to share their knowledge and organise groups of all the living organisms on Earth.

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Chapter map



Glossary terms

bilateral symmetry
binomial nomenclature
characteristic
class
classification
dichotomous key
DNA
domain
ectothermic
endothermic
eukaryote
extremophile
family
genre
genus
hierarchical
invertebrate
kingdom
metamorphosis
misnomer
motile
non-vascular
order
organism
phylum
prokaryote
radial symmetry
sessile
species
taxonomy
unicellular
vascular
vertebrate

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4.1 Classification and keys

WORKSHEET
Drawing keys

Learning outcomes

At the end of this section, I will be able to:

1. describe how the characteristics of living organisms are used to classify them.
2. interpret and construct a dichotomous key.
3. conduct an investigation to observe and identify similarities and differences of organisms.

classification
the grouping of similar objects or organisms together

genre
a category used to group media such as music, art or books

Classification is the process of organising things into groups based on similar characteristics. You do this every day without even thinking about it.

Imagine visiting a library where all the books were placed randomly on the shelves in no order.

It would be almost impossible to find what you were looking for! This is why classification is necessary. Libraries split books into fiction and non-fiction and arrange the books by the author's surname from A to Z. They may further separate books into **genre**.

People are also classified in many ways. How many times have you been asked your year level, subject choice, house group or date of birth? These are all ways that you can be placed into a group.



Figure 4.1 Libraries are a place where classification is important; otherwise, how would you be able to easily find the book you need?

Try this 4.1

Classification

Look at the image below.



1. **Decide** how many groups are in the picture.
2. **Justify** your answer.
3. **Compare** your answer with other people in your class.
4. **Discuss** why different people may have different answers.

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How to classify

When classifying, you should make observations about the things being classified. You can consider their **characteristics**. This will allow you to then group the things with the most similarities together.

characteristic
a feature or quality of something

Consider the dice in the following picture. What are their observable characteristics? How could you classify or group them? Which dice are most similar and should be grouped together?



Try this 4.2

Observing characteristics

Practise observing the different characteristics or features of living things. Describe the features of each animal and compare your observations with your classmates. Did you observe the same features?



Figure 4.2 Living things have many different features that we can use to classify them.

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Did you know? 4.1

Not actually a bear ...

Some common names given to animals can be confusing because they suggest something that is not the case. To be considered a bear, an animal must belong to the genus *Ursus*, which the koala does not. Koalas (*Phascolarctos cinereus*) are marsupials, but they've been mistakenly called 'koala bears' because they resemble small bears. They do not belong to the genus *Ursus*. They are more closely related to wombats, bandicoots and possums than to true bears, so to avoid confusion, it's best to simply call them koalas.



Figure 4.3 A koala (*Phascolarctos cinereus*)

The word 'koala' originates from the Indigenous language Dharuk. The original name, gula, means 'no drink', reflecting the koala's behaviour of rarely coming down from trees to drink water.

Some other animal **misnomers** include starfish, sea cucumbers, guinea pigs and flying foxes. Can you think of any more?

misnomer
a wrong or inaccurate name

dichotomous key
a tool used to identify organisms, where there are a series of questions with only two alternatives

organism
a living creature, such as a plant or an animal

Unlocking classification with a dichotomous key

Before you explore different types of classification systems, it is important to understand how to use a **dichotomous key**. Keys allow you to follow a series of yes/no questions to identify living things, based on observable features. Dichotomous means 'branching into two' and will lead the user to the name of the **organism** by giving two choices for each question. Each choice leads the user onto another two descriptions. Keys begin with general characteristics and become more specific. Figure 4.4 shows six different species of mammal that are found in New South Wales. You can use the key to determine their names.

Organism 1



Organism 2



Organism 3



Organism 4



Organism 5



Organism 6



Figure 4.4 Some mammal species native to New South Wales. Use the key in Figure 4.5 to identify them.

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Using keys

Imagine you are a scientist wanting to focus your research on the sugar glider. You have been sent a photo of Organism 6 as shown in Figure 4.4 but are not sure if it is the sugar glider. To determine if you have the correct organism, you must use the following key in Figure 4.5. Can you work out whether the name of Organism 6 is the sugar glider?

Start at the top and at each step in the process, make a yes/no decision. At each stage, it gives you two options based on the organisms you are looking at, allowing you to narrow down the possible choices. If the organism falls into one category, you go to the next indicated couplet. There is no right or wrong way to start a key, as long as it has two options and is specific. A key can also be drawn as a table. Test whether you get the same answer using the key in Table 4.1 as you do when using the branching key in Figure 4.5.

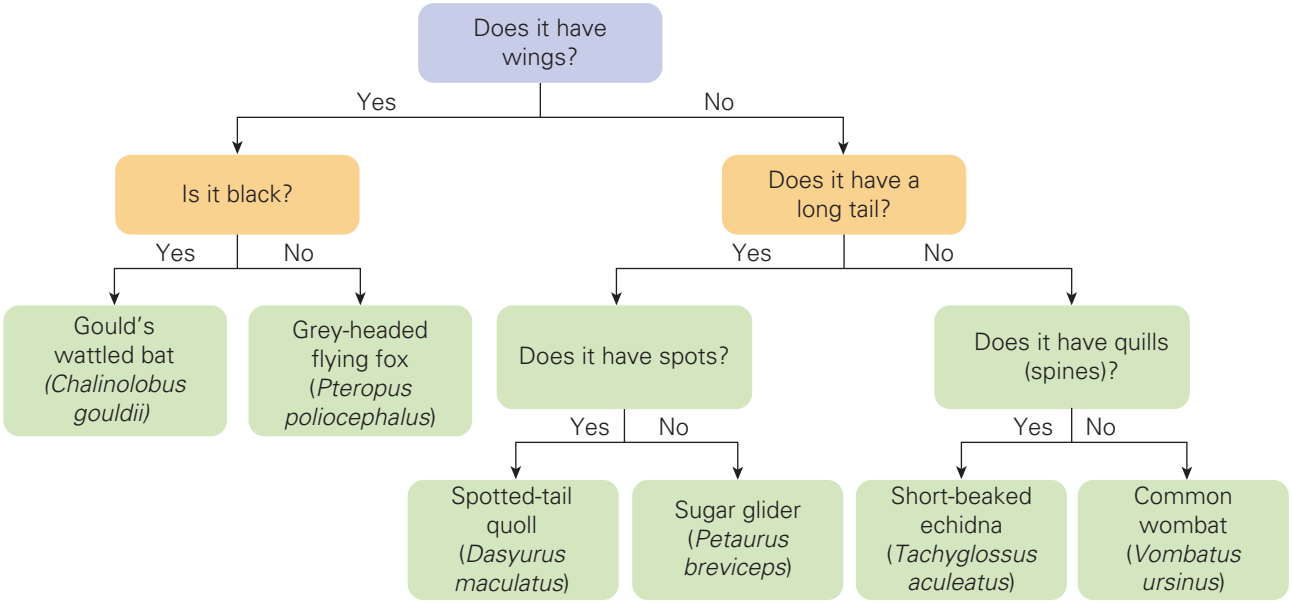


Figure 4.5 A branching dichotomous key for classifying the mammal species native to New South Wales in Figure 4.4

1a	Has wings	Go to Question 2
1b	No wings	Go to Question 3
2a	Black	Gould's wattled bat
2b	Not black	Grey-headed flying fox
3a	Long tail	Go to Question 4
3b	Short tail	Go to Question 5
4a	Spots	Spotted-tail quoll
4b	No spots	Sugar glider
5a	Quills	Short-beaked echidna
5b	No quills	Common wombat

Table 4.1 A dichotomous key in table format

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WIDGET
Classifying Australian animals

Creating a key

Here are some things to think about when creating a key.

- Will the characteristics change over time? For example, colour?
- Are the characteristics specific? Are they clear and unambiguous to someone else? Are measurements given for sizes or other data?
- Narrow down the choices – make sure that the features are unique to that organism or at least different from others.

Try this 4.3

Creating a key for butterflies

The diagram below shows eight different butterflies found in New South Wales (**A–H**).

A



B



C



D



E



F



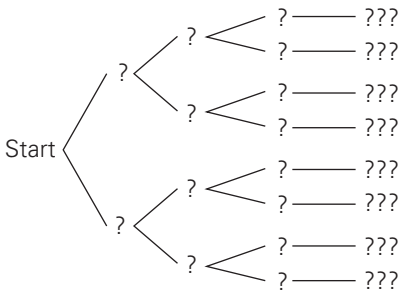
G



H



1. Observe the different butterflies and describe their main differences.
2. Use the main difference between the butterflies to separate them into two groups. Create and label a tree diagram, shaped like the example to the right, to a piece of paper to show these divisions.
3. Separate each group into two further groups, and then continue until there are eight individual butterflies on the final level of the tree diagram.



4. Use the differences you have identified to construct a dichotomous key for the insects.
5. Pass the key to a classmate and get them to use it on your butterflies to make sure it is easy to follow. In other words, your classmate should end up with the eight butterflies in the same categories at the bottom of the diagram, as you intended.
6. After you have tested the key, make any alterations that you need to for it to work.
7. Explain the main difficulties you faced when you constructed your key.
8. Discuss the reason for any changes you made after testing the key with a classmate.

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Section 4.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 4.1 questions

Remembering

1. **Define** the term 'classify'.
2. **Outline** why scientists need to classify things.
3. **Recall** the term given to a key that has two possible options at each stage.

Understanding

4. **Select** the characteristic which would be best to use when making a classification key for birds.
   - **A.** Where the bird was last observed
   - **B.** What food the bird likes to eat
   - **C.** The number of birds in your suburb
   - **D.** Colour markings on the bird's wings
5. **Explain** why the shape of an animal may not be the best defining feature to focus on when creating a key. Suggest some features that would be useful.

Applying

6. **Identify** which of the following features would be useful when creating a key to identify types of animals. (There may be more than one correct answer.)
   - **A.** Short legs versus long legs
   - **B.** Smooth scales versus spiny scales
   - **C.** Big versus little
   - **D.** More than 0.45 m long versus less than 0.45 m long
   - **E.** Yellow spots on its wings versus no yellow spots
   - **F.** Dark blue colour versus light blue colour
7. **Organise** these animals into groups based on similar characteristics. State why you chose the characteristics that you used to group them.



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Analysing

8. Aboriginal and Torres Strait Islander Peoples use many native plants for medicinal purposes. Some of these are shown below.

Native/sweet sarsaparilla



Desert lime



Emu apple



Doubah



Bush plum



Desert fig



a. Classify the native fruits into two groups based on a specific characteristic. **Outline** the features of each fruit that led you to your classification.

b. Now use the images again to classify these native fruits, but this time into three groups. **Outline** the features of each native fruit that led you to your classification.

c. Ask to see the groups your classmates listed and **compare** these with yours.

9. **Distinguish** between qualitative characteristics and quantitative characteristics.

Evaluating

10. Copy the following table.

a. **Decide** whether the features are good or weak descriptors to use in a dichotomous key for humans.

b. **Justify** your choices.

Feature	Good or bad descriptor	Justification
Blue or brown eyes		
Long hair		
150–160 cm tall		
Likes cats		
Size 6 shoe		

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4.2 Classifying living things

Learning outcomes

At the end of this section, I will be able to:

1. discuss the role and importance of classification in organising knowledge of the diversity of life on Earth.
2. use the binomial system of classification to classify and name organisms.
3. explain how Aboriginal and Torres Strait Islander Peoples classify organisms based on their uses, forms and functions.

WORKSHEET Classifying striped animals

VIDEO The seven criteria of living things

Is it alive?

One of the most basic classification systems that can be used is whether something is 'living' or 'non-living'. We are surrounded by living and non-living things. MRS GREN is an acronym for the processes performed by living organisms and is used as a set of criteria to determine if something is living or non-living. Can you work out what these processes are? The flow chart in Figure 4.6 will give you some clues. However, sometimes it is not so easy to decide if something is living or non-living. A kangaroo jumping across a paddock is obviously living. The magpie flying to a tree is also living. But some non-living things may show some of the seven processes of living things. A car can move, and it gets rid of waste gases. Crystals can grow when conditions are right.

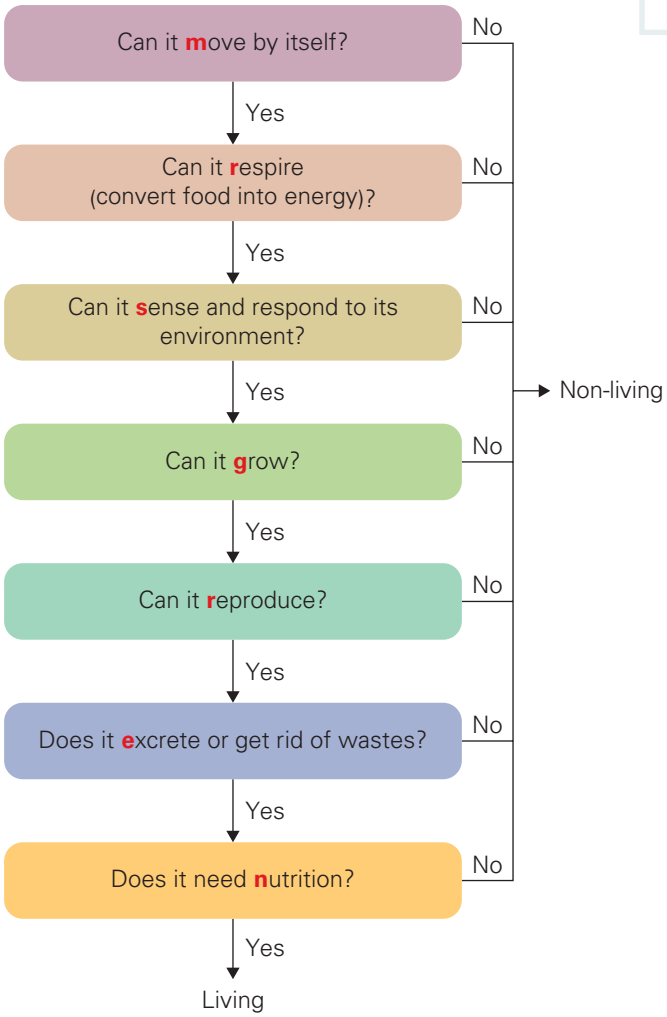


Figure 4.6 Unless all seven criteria are met, a thing cannot be classified as living.

It is also important to remember that a non-living object is different to one that is dead. A non-living object is one that has never been alive whereas something that is dead used to exhibit all the processes of living things.

The first characteristic, movement, needs some explanation. Movement from one location to another – locomotion – is easy to see, such as the kangaroo jumping across a paddock, but sometimes movement can be quite difficult to observe. Examples are a change in orientation (e.g. plants moving leaves towards the light), moving parts of the organism in relation to the whole (e.g. flowers opening and closing, or a venus flytrap closing), or internal movement, such as movement of sap, or movement seen inside cells with a microscope.

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Quick check 4.1

1. **State** the characteristics that all living things share and describe an example for each.
2. **Explain** what non-living means.
3. **Distinguish** between non-living and dead.
4. Copy and complete the following table.
   - Tick if the characteristic is present.
   - Classify the object as living, non-living or dead.

Object	Tick if the characteristic is present							Living? Non-living? Dead?
	M	R	S	G	R	E	N	
Wind								
Mushroom								
Coral								
Bicycle								
Fallen leaf								
Book								
Fossil								

Did you know? 4.2

Are you related to a banana?

DNA deoxyribonucleic acid, a chemical present in cells of living things that carries genetic information

Every living organism on this planet has evolved from a common ancestor. Scientists have discovered this by studying the similarities in **DNA**. DNA is found in every living cell and basically gives the cell or organism instructions on how to grow and function. On average, humans share about 90% of our genes with rats. This is not too surprising as we both have eyes, hearts, legs and many other similarities. This is why rats are used in laboratories as experimental animals for human disease research. However, we humans also share about 50% of our genes with bananas. This does not imply relation, however, but rather similarities in cell processes such as cell division, the cell cycle and DNA replication. Can you see how classifying organisms by their DNA might not be the only answer?



Figure 4.7 Humans, rats and bananas are quite different, but we share many of the same genes!

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Taxonomy

So far, you have learned that classification is the process of putting things into groups. Now you are going to look at how biologists use classification to organise all organisms. **Taxonomy** is the study of relationships between organisms and then formally classifying them into groups and naming them based on these relationships. Taxonomy used to simply consider the physical similarities between organisms, but now also considers genetic similarities.

Scientists have classified nearly 2 million species on Earth, but estimates for the total number of existing species vary widely. One commonly quoted estimate is that there are 8.7 million species in existence, but this can range from 5 million to 1 trillion! There are also many more extinct species to classify. Of the 4 billion species that have existed on Earth, 99.9% are now estimated to be extinct. That's a lot of organisms that scientists need to classify!

taxonomy
a branch of science that groups and names organisms based on their relationships



Figure 4.8 Natural history museums maintain collections of specimens and related data. This includes distribution and diet information, tissue samples and vocal recordings. This helps taxonomists to classify different organisms.

Traditional classification systems

Aboriginal and Torres Strait Islander Peoples may classify plants and animals as being edible or inedible, or as being totemic or non-totemic. 'Totemic' refers to a spiritual connection between a group of people or an individual and a specific animal, plant or natural object. Many living things are grouped based on their use, and they can be further grouped based on whether they are alive or dead. For example, when the native cherry (*Exocarpus cupressiformis*) is alive, its sap can be used to treat snake bites, but when dead, its wood is used to make spear-throwers.

Living things are sometimes put into groups based on features such as form and function. This differs to the approach used in Western science, which groups living things by their relatedness. For example, wood-bearing plants may be named based on the function of their finished products, such as spear trees, shield trees, canoe trees and resin trees.



Figure 4.9 *The Sea and the Sky* is a 1948 bark painting by Yolngu artist Munggerawuy Yunupingu, displayed at the Art Gallery of South Australia. The upper section of the painting depicts monsoonal thunderstorms, while the stingrays breeding during the wet season symbolise the artist's totemic ancestors. The linear patterns surrounding the stingrays represent the movement of the seas.



WORKSHEET
Reading with a pen



DEPTH STUDY IDEA
Aboriginal and Torres Strait Islander Peoples' systems of classification

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Did you know? 4.3

When two species become six

In 2020, DNA analysis confirmed that the greater glider and sugar glider are actually three different species each, increasing the number of Australian possum species by four. The greater glider has been split into the northern greater glider (*Petauroides minor*), central greater glider (*Petauroides armillatus*) and southern greater glider (*Petauroides volans*). The sugar glider is now split into the sugar glider (*Petaurus breviceps*), Krefft's glider (*Petaurus notatus*) and savanna glider (*Petaurus ariel*).



Figure 4.10 Southern greater glider (*Petauroides volans*)

Hierarchical classification

hierarchical where smaller groups are placed within larger groups, with no overlap between groups

kingdom the highest and broadest classification on the Linnaean taxonomic rankings

phylum the taxonomic ranking below kingdom and above class

class the taxonomic ranking below phylum and above order

order the taxonomic ranking below class and above family

family the taxonomic ranking below order and above genus

genus the taxonomic ranking below family and above species

species the most specific taxonomic ranking of a group of organisms

A major step in taxonomy was taken 250 years ago by Carl Linnaeus. He sorted organisms into **hierarchical** groups based on their physical similarities. He called the largest group 'kingdom', and this was then divided into groups, and each of those was divided further, and so on, all the way to the smallest group, 'species'. An example of this is shown in Figure 4.11. The levels of classification that he developed were **kingdom**, **phylum**, **class**, **order**, **family**, **genus** and **species**. He managed to classify over 13 000 organisms during his life, and the basis of his classification system is still used today.

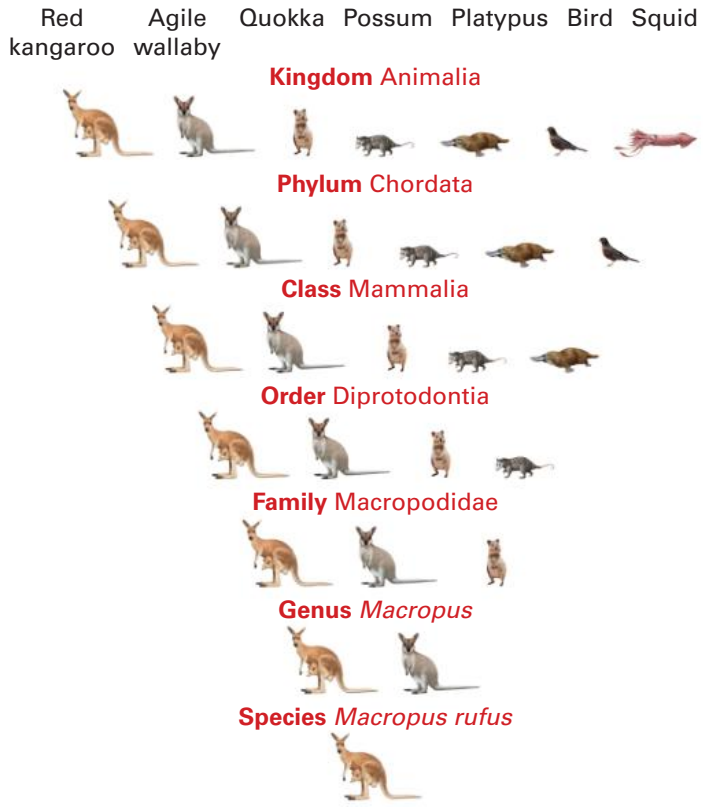


Figure 4.11 Linnaeus's hierarchical classification system: as you move down the levels, the organisms become more similar and share more characteristics.

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Explore! 4.1

INVESTIGATION

Classification systems of Aboriginal and Torres Strait Islander Peoples

The classification systems of Aboriginal and Torres Strait Islander Peoples differ in many respects from Linnaean taxonomy. Nothing is seen in isolation; rather, everything is interconnected and based on cultural significance and kinship. Different nations employ different methods, such as criteria that links the organism's use, form, function, age, stage in life cycle, sex, social status or totemic association. Investigate why Aboriginal and Torres Strait Islander Peoples may classify turtles, barramundi and dugong in the same group.

Try this 4.4

Classification mnemonic

The order and names of Linnaeus's different levels of classification can be remembered by using a mnemonic device such as **K**ing **P**hillip **C**omes **O**ver **F**or **G**reat **S**paghetti, or **K**ittens **P**refer **C**ream **O**r **F**ish **G**enerally **S**peaking. Try to make up your own mnemonic to remember each level.

Modern classification

The current taxonomic system has added **domains** above kingdoms, and recognises six kingdoms.

domain
the highest taxonomic rank above kingdom and even broader

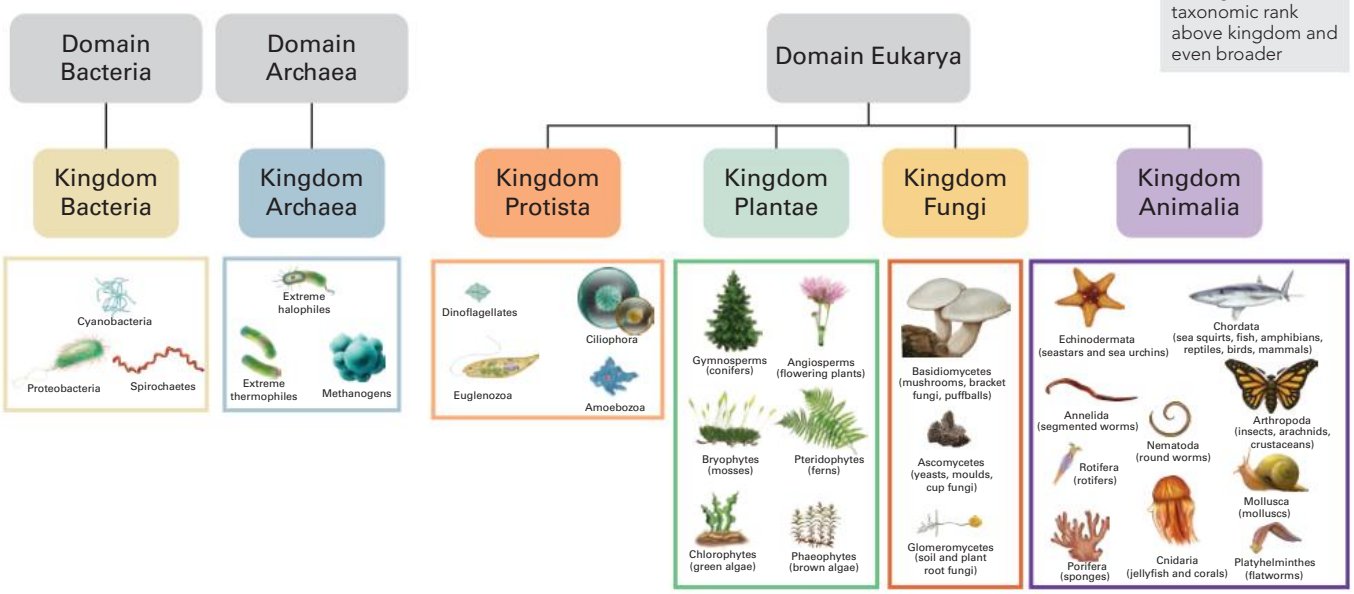


Figure 4.12 The six-kingdom classification of living organisms, with some representative groups within each. Note that there are many more groups than the ones shown, especially in the kingdoms Bacteria, Archaea, Protista and Fungi.

Explore! 4.2

INVESTIGATION

Changes in classification

The classification of many species continues to be argued over as scientists discover new information or interpret evidence in new ways. Scientists have suggested hierarchical groupings such as empires, superkingdoms and dominiums.

Even when species are being classified, arguments can be complex. Species can have their classification changed, but only after a lot of information has been collected. One reason why species are being re-examined is because of DNA analysis. This new information can change ideas of how closely two species are related and so change their classification. By analysing DNA, we can see that even things that don't look alike can be classified together. Research the link between the horseshoe crab and spider; the whale and hippo; the elephant, manatee and hyrax; and the horse and rhino.

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Quick check 4.2

1. **Define** the term 'taxonomy'.
2. **Explain** why the classification system is constantly being updated.
3. **Recall** the names of the six kingdoms.

Binomial nomenclature



Figure 4.13 Look at the picture and decide why Linnaeus chose to call the cutleaf groundcherry '*Physalis angulata*'.

Another reason for classification is to enable clear communication among scientists. Between the fifteenth and seventeenth centuries, scientists usually conducted their work in two languages. When discussing their work in conversation, they used their native language, but Latin was used when writing about their work or corresponding with scientists elsewhere. Latin did not belong to any specific country, and scholars worldwide could access it. It essentially became the universal language of the time in Europe and related regions.

In Linnaeus's classification system discussed earlier in this section, all species were given a specific two-part name using a form of Latin or Ancient Greek. This replaced much longer names, such as the one for the cutleaf groundcherry: *Physalis amno ramosissime ramis angulosis glabris foliis dentoserratis.* Linnaeus renamed it *Physalis angulata*, from the Ancient Greek *phusallís* meaning bladder, and the Latin *angulāre*, meaning to make angled.

By the nineteenth century, French, English and German made up most of the scientists' communication and published work. By the twentieth century, English was dominant. However, we still use Linnaeus's system of naming organisms, which is known as **binomial nomenclature**. The use of a standardised classification system allows scientists to discuss and share information about organisms across different fields and locations, ensuring that scientific knowledge is accurate and consistent.

binomial nomenclature a system of naming in which two names are used to identify an individual species of organism

Why are scientific names important?

In everyday life, it is rare to use the scientific names of plants and animals because the words are often hard to pronounce and remember. If you were asked to identify the organisms in Figure 4.14 as *Osphranter robustus*, *Dendrobium speciosum* or *Climacteris picumnus*, you probably would not be able to. However, if you were to use their common names – common wallaroo, rock orchid, and brown treecreeper – it would be much easier. You may ask, why can't you just use the common name? Well, the rock orchid is also known as the cane orchid, and the wallaroo can be known as euro or hill wallaroo.



Figure 4.14 (a) Common wallaroo (*Osphranter robustus*), **(b)** rock orchid (*Dendrobium speciosum*), **(c)** brown treecreeper (*Climacteris picumnus*)

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Some common names for animals are also repeated all over the world, but they are not the same species. For example, the brown treecreeper is a completely different species from the Eurasian treecreeper. In fact, they are not even in the same family! It is likely that the name originated from European colonial settlers, who saw a bird with similar behaviour and appearance to a familiar species from their homeland and named it accordingly.



Figure 4.15 Eurasian treecreeper (*Certhia familiaris*)

How to write binomial scientific names

When writing an organism's scientific name, there are a few rules that need to be followed.

- The first part of the name (genus) is written with a capital letter.
- The second part of the name (species) starts with a lowercase letter.
- If you are typing a name, *italics* should be used.
- If you are writing the name by hand, you should underline the name.

For example, *Limnodynastes dorsalis*, *Limnodynastes peronii*, *Limnodynastes salmini* and *Limnodynastes tasmaniensis* are all different types of frog native to Australia, southern New Guinea and some Torres Strait Islands. The genus name (first part of the name) for all these species, *Limnodynastes*, is from the Latin meaning 'Lord of the Marshes'. Looking at Figure 4.16, it is easy to see they share many similarities but are all unique. That is why the species (the second part of the name) is used to identify specific organisms.



Figure 4.16 (a) *Limnodynastes dorsalis*, **(b)** *Limnodynastes peronii*, **(c)** *Limnodynastes salmini* and **(d)** *Limnodynastes tasmaniensis*

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Common name	Rakali
Kingdom	Animal
Phylum	Chordate
Class	Mammal
Order	Rodent
Family	Muridae
Genus	*Hydromys*
Species	*chrysogaster*
Scientific name	*Hydromys chrysogaster*

Table 4.2 Although known by the descriptive common name of the water rat or Australian otter, Aboriginal and Torres Strait Islander Peoples may know it as the rakali.

Try this 4.5

Classifying Australian mammals

Look up the following scientific names of some Australian mammals. Use the internet to find out their taxonomic classification (kingdom, phylum, class, order, family, genus and species). Can you determine which species are more closely related to each other? How does their classification tell you this?

- *Potorous tridactylus*
- *Tachyglossus aculeatus*
- *Sminthopsis murina*
- *Planigale ingrami*
- *Pseudantechinus mimulus*
- *Notamacropus agilis*
- *Ornithorhynchus anatinus*
- *Planigale maculata*

Choose one species from the list and explain the features that led scientists to classify it in a particular manner. Produce a scientific poster on your chosen species that would be useful to display in a zoo.

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Quick check 4.3

1. **Define** the term 'binomial nomenclature'.
2. When looking at a list of scientific names, **describe** how you would know which organisms were most similar.
3. **Discuss** some of the difficulties scientists would experience if they only used the common names of organisms.
4. **State** two reasons why we classify organisms.

Try this 4.6

Taxonomy exercise

Find out the kingdom, phylum, class, order, family, genus, species and scientific name of the platypus. Then, in a table, research and list the characteristics of a mammal in one column, a bird in another column and a reptile in a third column. Complete some research into the characteristics of the platypus. Now use your table and highlight which characteristics the platypus shares with mammals, birds and reptiles.

Try this 4.7

Creating an animal

In this activity you will create a new animal. You may draw it or use an online app.

1. Obtain sketch paper and pencils or search for 'make new animals' on the internet.
2. Draw your animals or use an online animal building tool to create a new animal with features of many different types of animals (e.g. Switchzoo).
3. Take a screenshot of your creation and then create a description of the animal.
   Your description should include:
   - name of animal
   - habitat: aquatic, terrestrial, both
   - behaviours
   - diet
   - how it uses the features you have chosen
   - warm-blooded or cold-blooded
   - how its offspring are born
   - how long it lives.
4. Classify your animal into a group (insects, birds, mammals, reptiles etc).
5. Using your description, justify why you classified your new animal as you did.

Section 4.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 4.2 questions

Remembering

1. **Name** the person who invented binomial names for organisms.
2. **List** the six kingdoms.
3. **List** the seven characteristics of living things.
4. **List** the eight levels of classification, from general to specific.
5. **Recall** the correct way to write the genus and species name of the domestic cat.
   Hint: the unformatted name is felis catus.

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Understanding

6. The scientific name for the pale hunter dragonfly is *Austrogomphus amphiclitus*. **Identify** the country or countries for which this name is applicable.
7. **Outline** the main problems with using common names in scientific articles.
8. **Summarise** what you have learned about scientific names.



Figure 4.17 Female pale hunter (*Austrogomphus amphiclitus*)

Applying

9. The pangolin is one of the world's most illegally traded animals. Its body is covered in hard scales, it is nocturnal, and it gives birth to live young that feed on milk from their mother. As an adult, it eats mainly ants and termites, which it captures with a tongue that is as long as its body. Use this information to **decide** what class the pangolin belongs to. Give reasons for your answer.
10. **Explain** an example of how Aboriginal and Torres Strait Islander Peoples' classification systems are different from Linnaean classification systems.

Analysing

11. The platypus is a monotreme, which is a type of mammal. **Examine** the illustration of the platypus in Figure 4.18 to explain why some of the features of the platypus might have confused early explorers with their classification.



Figure 4.18 A female platypus (*Ornithorhynchus anatinus*)

Evaluating

12. **Predict** how closely related each fish (A-F) in Figure 4.19 is to the clownfish on the left, based on physical characteristics. Give reasons for your answer.

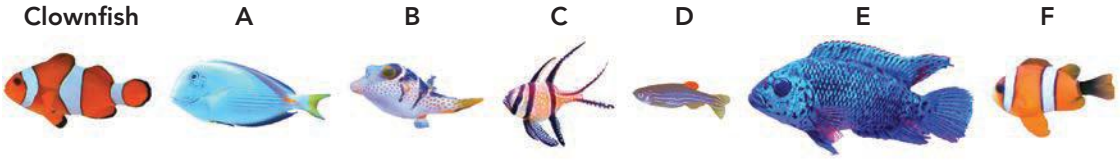


Figure 4.19 Tropical fish

13. **Critique** the way the following binomial names have been written.
    - calyptorhynchus lathami
    - Litoria Cooloolensis
    - ornithoptera Richmondia
    - *Grantiella picta*

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4.3 Taxonomic kingdoms

Learning outcomes

At the end of this section, I will be able to:

1. give examples of the classification of organisms into kingdoms and the diversity of life on Earth.
2. investigate and report on how organisms in Australia are adapted to their environment.

WORKSHEET Kingdoms

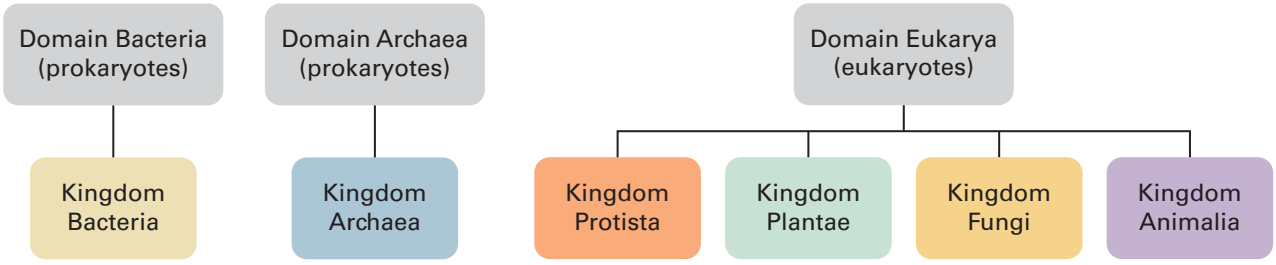


Figure 4.20 The three domains and six kingdoms of living organisms. Note: prokaryotes can be either bacteria or archaea, while eukaryotes make up all other kingdoms.

Prokaryotes

VIDEO Kingdoms: Archaea, Bacteria and Protista

Most living organisms on Earth are **unicellular**, meaning they exist as single cells. Unicellular organisms are microscopic, meaning they are too small to see without a microscope. Unicellular organisms can be **prokaryotes** or **eukaryotes**. All prokaryotes are unicellular and very simple, have no nucleus and are protected by a cell wall. Prokaryotes are divided into two distinct groups: the bacteria and the archaea. These two groups are ancient and have a lot in common, but they are genetically quite different.



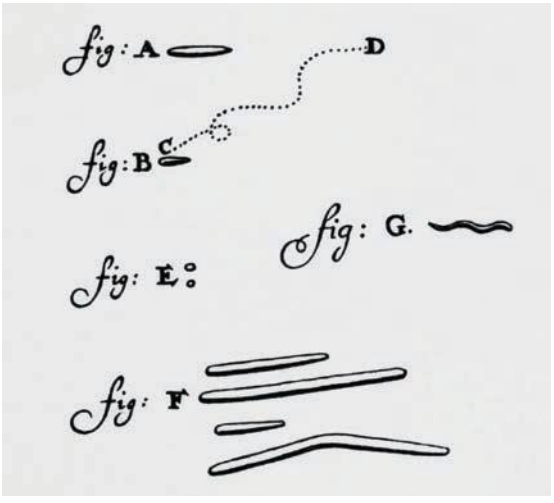


Figure 4.21 Biological classification has changed over time through improvements in microscopy. Antonie van Leeuwenhoek crafted his own microscope lenses, which were powerful enough for him to discover protists in 1674 and bacteria in 1683. The drawings are from a letter van Leeuwenhoek wrote in 1683, showing bacteria from the human mouth.

unicellular consisting of one cell

prokaryote a unicellular organism that lacks membrane-bound organelles and a nucleus

eukaryote any cell or organism that possesses membrane-bound organelles and a nucleuss

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VIDEO
What are archaea?

extremophile
an organism that thrives in conditions of extreme temperature, pH or chemical concentration

Archaea

- Prokaryotic
- Oldest form of life on Earth, dating back 3.5 billion years
- Many are **extremophiles**, able to survive in a range of hostile environments.
- Majority of species are found in the oceans.

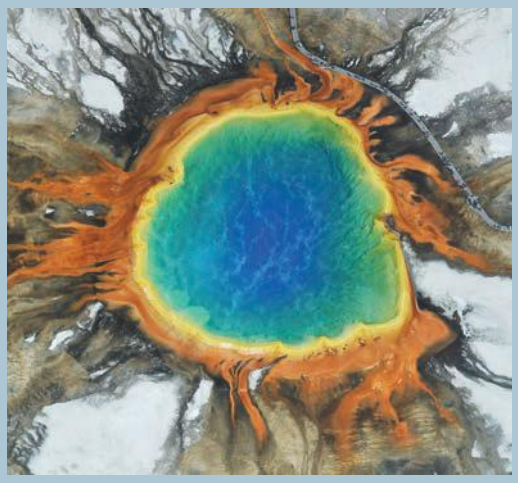


Figure 4.22 The Grand Prismatic Spring in Yellowstone National Park is the largest hot springs in the USA. The water temperature is 70 °C, and the vibrant colours are due to mats of growing archaea that thrive in this harsh environment.

Bacteria

- Prokaryotic
- Not as old as Archaea, appearing about 2.5–3 billion years ago
- Human bodies are home to approximately 100 trillion 'good' bacteria, mostly found in the gut.
- Decompose waste material
- Can increase the productivity of soil
- Used to produce food (miso, tempeh, cheese, yoghurt) and industrial materials
- Some are disease-causing.

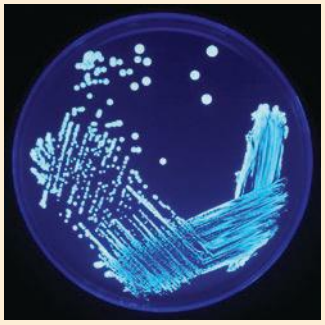


Figure 4.23 *Legionella longbeachae* bacteria are typically found in air conditioning cooling towers, bodies of water like spas, and in soil or potting mix. In January 2024, New South Wales health authorities advised people who had visited Sydney CBD to monitor themselves for symptoms, after a spike in Legionnaires' disease cases.

Did you know? 4.4

Methane producers

Archaea that live in the digestive tracts of many animals are known as methanogens because they produce methane gas. Methane is a greenhouse gas that has been linked to increasing global temperatures due to its ability to trap heat.



Figure 4.24 Kangaroos produce less methane than cows, yet they both eat grass.

University of Queensland scientists have found that some native herbivores release less methane than livestock species when they digest food. By understanding why this happens, scientists are hoping to decrease methane emissions caused in agriculture and positively impact climate change.

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Eukaryotes

Eukaryotes are a diverse group of organisms that share a fundamental characteristic: their cells contain a nucleus and other membrane-bound organelles with specialised functions. This feature makes them different from prokaryotes. Eukaryotes include a wide range of organisms, from single-celled protists to multicellular animals and plants.

WORKSHEET Prokaryotic and eukaryotic cells

Protista

- Eukaryotic
- Mostly unicellular but can be multicellular
- A group of organisms that do not fit into any other kingdom: some scientists call this kingdom the 'junk drawer'! As a result, organisms in this kingdom are very diverse.
- Many are parasites and cause disease, such as *Plasmodium*, which causes malaria, or *Giardia*, which causes giardiasis.
- Phytoplankton protists are photosynthetic and produce almost half of the oxygen on Earth.

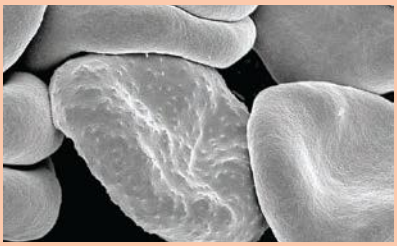


Figure 4.25 This electron micrograph shows red blood cells infected with *Plasmodium falciparum*, the parasite responsible for malaria in humans. During its development, the parasite forms protrusions called 'knobs' on the surface of the host red blood cell, helping it evade destruction.

VIDEO What are protists?

Quick check 4.4

1. **State** a difference between a prokaryote and a eukaryote.
2. **Define** the term 'microscopic'.
3. **Summarise** the key characteristics of bacteria.
4. **Name** an organism in the Protista kingdom.
5. **Decide** whether all single-celled organisms are harmful. Justify your response.

Plants

Plants use energy from the Sun to convert water and carbon dioxide into substances that are the foundation of all life on Earth. As producers, they start most food chains and are a source of energy for other organisms. You will learn more about this in Chapter 9.

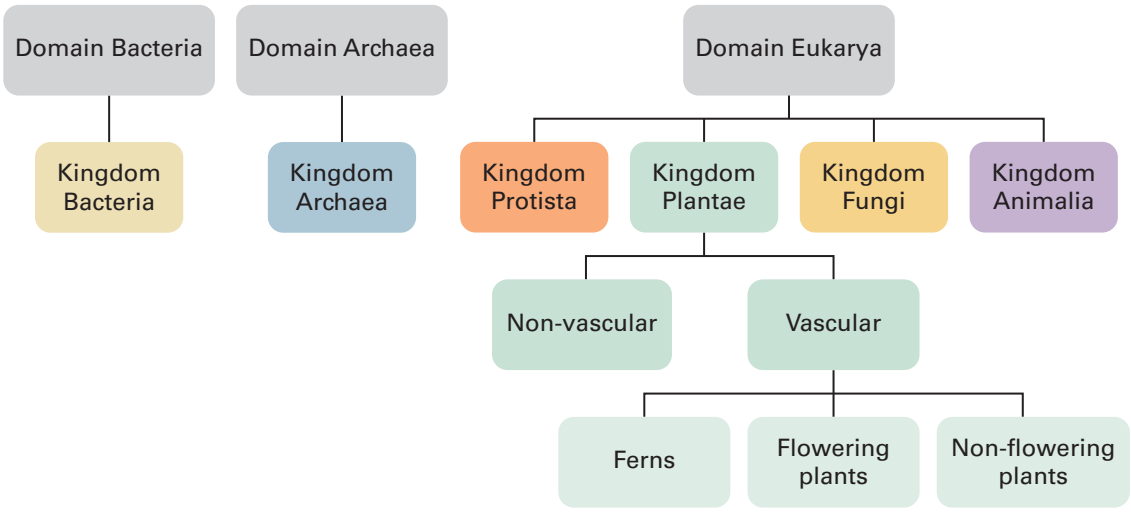


Figure 4.26 The kingdom Plantae is divided twice – once based on whether they have vascular tissue, and then again, based on whether they produce seeds.

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Non-vascular

non-vascular
not containing veins or specialised fluid vessels

Non-vascular plants do not have specialised cells that can transport water and nutrients from one part of the plant to another.

All the plants in this division share some common characteristics:

- They cannot grow very big.
- They are often found spread across rocks or the ground in cool, moist, shaded areas.
- They reproduce using spores (a single-celled reproductive unit) released from a stalk.

Examples include mosses, liverworts and hornworts, and some algae.



Figure 4.27 A global study led by UNSW Sydney has revealed that mosses are crucial for ecosystem health. They enhance nutrient cycling, organic matter decomposition, and pathogen control in soils, as well as help store an estimated 6.43 gigatonnes of carbon, six times more than emissions from agricultural land use changes.

Vascular

vascular
containing veins or specialised fluid vessels

Vascular plants have specialised vascular tissue made of specialised cells that can transport water and nutrients around the plant. Ferns, non-flowering plants and flowering plants all have vascular tissue that make up stems and roots.



Figure 4.28 The veins that you can see on leaves are special pathways for water and nutrients to flow called xylem (for water transport) and phloem (for sugars and nutrients).

Flowering plants

- Plants that produce flowers and fruits that allow them to reproduce
- Use brightly coloured flowers and sweet nectar to attract insects, birds and other animals that can help spread pollen to produce seeds.





Figure 4.29 Hairpin banksia (*Banksia spinulosa*) is usually orange, yellow or red. However, in 2023, Indigenous horticulturalists took 21 cuttings of the first known purple variant, discovered at a property outside Braidwood, southern NSW.

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Ferns

- Some of the earliest land plants, existing on Earth for approximately 360 million years
- Reproduce using spores
- Do not produce seeds
- Grow well in moist, humid, shaded areas.





Figure 4.30 The fossil record shows us that ferns appeared millions of years before dinosaurs.

Non-flowering plants

- Include cycads and conifers
- Reproduce using seeds that are exposed or in cones, not enclosed in fruit
- Male cones produce pollen that fertilises female cones. Female cones protect the seeds.



Figure 4.31 The Wollemi pine is an ancient non-flowering, seed-producing conifer that is only found in the remote canyons of Wollemi National Park, west of Sydney.

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INVESTIGATION

Explore! 4.3

Traditional knowledge of plants

It is estimated that as much as 84% of the plants in Australia are endemic to the country. Aboriginal and Torres Strait Islander people have a vast knowledge of the medicinal properties of these plants, built over millennia. Through trial and error over many generations, they have come to understand which plants are dangerous to consume, which have medicinal value, and what processes are required to make toxic plants safe. Consider the following questions:

- Why do the plants used as medicine vary in different parts of Australia?
- What is biodiscovery?
- What is the Nagoya Protocol?
- Professor Daniel Robinson and Dr Margaret Raven from UNSW work with indigenous people in Asia, Australia and the Pacific Islands to assert their rights regarding biodiscovery. They support indigenous communities in negotiating fair agreements with researchers and companies when entering partnerships. Discuss the potential ethical, environmental, social and economic implications of such partnerships.



Figure 4.32 In 2024, the first ever National Symposium on Australian Traditional Medicine was hosted by NICM HRI Western Sydney University in collaboration with the Australian National University.

Did you know? 4.5

What is a fruit?

Flowering plants produce fruits, and when you think of fruit, you may think of apples, oranges, and pears. But did you know that there are many more categories of fruit? In the kitchen, many plants that people would consider vegetables are actually fruits.



Figure 4.33 How many fruits can you see?

The most famous example is probably the tomato. In 1893, the US Supreme Court had to rule on whether imported tomatoes should be taxed under a rule that only applied to vegetables and not fruits. The court decided that tomatoes were vegetables, despite them being fruit!

Capsicums, coconuts, cucumbers, pumpkins, corn kernels, peas and peanuts are all fruits!

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Quick check 4.5

1. **Define** the terms 'vascular' and 'non-vascular'.
2. **Recall** if organisms in the Plant kingdom are unicellular or multicellular.
3. **Recall** the groups of plants that produce seeds.
4. Copy and complete the following table to **summarise** the characteristics of different plant groups.

Characteristics	Non-vascular	Vascular		
		Ferns	Non-flowering	Flowering
Roots and stems				
Maximum height				
Spores or seeds				
Flowers or no flowers				
Examples				

Practical skills 4.1

Observing and identifying similarities and differences of *Euglena* and *Amoeba*

Be careful

Ensure proper microscope handling and use is observed.

Aim

To observe and compare two different single-celled organisms under the microscope.

Materials

- *Euglena* and *Amoeba* samples
- pipette
- compound microscope
- dimple slide
- coverslip
- sharp pencil
- plain paper
- glycerol (optional)

Procedure

1. Set up the microscope on your bench.
2. Place a small drop of the *Euglena* sample into the dimple on the slide. One drop of glycerol can be added to slow the movement of the *Euglena*.
3. Lower the coverslip on an angle over the drop to protect the sample.
4. Place the slide onto the stage of the microscope and focus, using the lowest-power magnification first.
5. Draw a scientific drawing of the *Euglena* you observe. Use a sharp pencil.
6. Use the internet to research the structure of *Euglena*. Label your scientific drawing.
7. Repeat steps **1**–**6** for *Amoeba*.

Discussion

Make notes on the characteristics of *Euglena* and *Amoeba*, such as appearance, structure and movement. List characteristics that are the same and those that are different. From your observations, justify whether you believe these two organisms are classified in the same kingdom, and whether they are more similar to animals or plants.

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Fungi

Fungi are a group of organisms that include mould, mushrooms and yeast. They are not producers so cannot produce their own food. Instead, they digest organic material and absorb the nutrients. Fungi reproduce by spreading spores. Fungal cells are surrounded by a rigid cell wall made of chitin that provides structural support and protection and distinguishes them from other organisms.

Fungi (as well as some bacteria, archaea and protists) are decomposers and grow well in warm, moist conditions. They have one of the most important roles on Earth. By decomposing waste material and dead matter, they release vital nutrients that can be recycled back into the ecosystem.

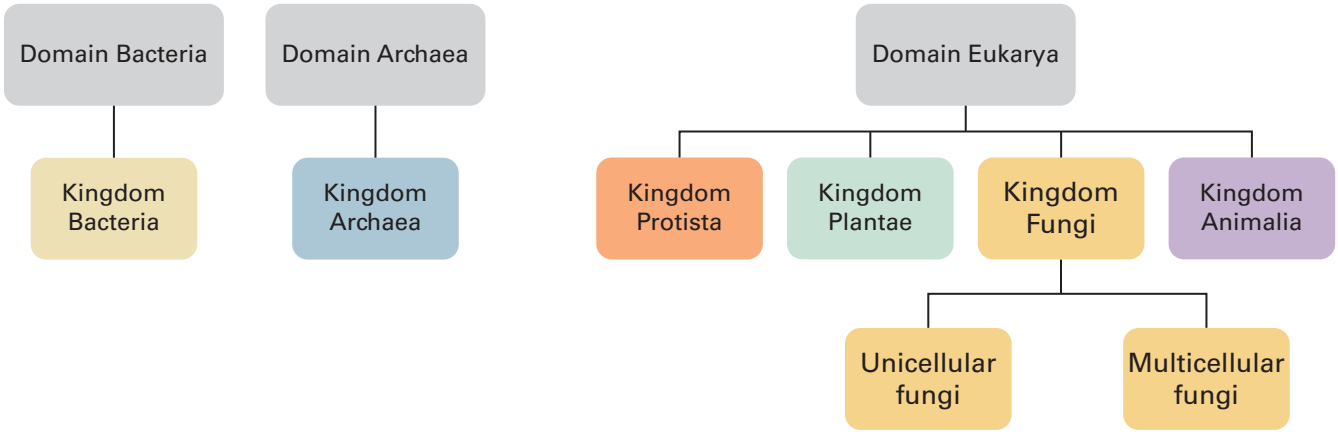


Figure 4.34 The Fungi kingdom is divided based on whether the species are unicellular or multicellular.

Single-celled fungi

Yeast is a unicellular fungus used in breadmaking and alcohol manufacturing.



Figure 4.35 In breadmaking, yeast feeds on the sugars in flour and releases carbon dioxide that makes the bread rise.

Multicellular fungi

Multicellular fungi grow as thread-like filaments called hyphae. They can be moulds made of very fine threads, or larger fungi that have fruiting bodies that you would recognise as mushrooms.



Figure 4.36 The desert shaggy mane (*Podaxis pistillaris*) was used by many Aboriginal desert peoples for body painting and to darken the white hair in old men's beards.

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Quick check 4.6

1. **Recall** the characteristics of fungi.
2. **State** the characteristics that plants and fungi have in common.
3. Do some research to **identify** some examples of fungi that can be both beneficial and dangerous to humans.
4. **State** the conditions that are best for mould or fungi to grow.

VIDEO
The importance of fungi

Try this 4.8

Classification super-challenge!

To check if you know the key characteristics of the different kingdoms, try this super challenge! Read the description, see if you can identify the kingdom the organism belongs to and then find a picture of a possible organism that fits the description.

Description	Kingdom	Picture
I am a single-celled organism. I live in the large intestine of mammals like humans to help food break down. I reproduce very quickly.		
I am a multicellular organism that uses sunlight to make my own food. I grow flowers to produce seeds inside of fruits.		
I cause dead animals to smell really bad when I slowly digest their tissues, producing methane. I am a single-celled organism with no nucleus in my cell.		
I am a unicellular organism that can move and live in pondwater. My body is covered with little hairs to help me move and I can swim very fast. I eat bacteria.		

The animal kingdom

The animal kingdom is the largest kingdom, with over a million classified species. It might surprise you to know that most of the animals on our planet are microscopic and look nothing like the animals you are more familiar with, like birds, mammals, and fish. All organisms that are placed in the animal kingdom share some defining features that set this kingdom apart from the others.

motile
able to move independently from one place to another

sessile
fixed in one place and not able to move

vertebrate
an animal that has a backbone

invertebrate
an animal that does not have a backbone

All animals:

- are eukaryotes, so have cells with a nucleus and membrane-bound organelles
- are multicellular (made up of more than one cell working together)
- eat other organisms or their products to gain energy
- can independently move their location if they are **motile**, or their body parts if they are **sessile**.

Animal phyla

There are currently 35 recognised phyla (plural of phylum) in the animal kingdom, but here we will focus on the nine key ones, as shown in Table 4.3. Animals can be classified based on whether they have a backbone. A **vertebrate** is an animal with an internal backbone or endoskeleton, while an **invertebrate** is an animal with no internal backbone. Instead, invertebrates may have a hard outer casing called an exoskeleton. Despite vertebrate and invertebrate being important terms to know and understand, they are not used as an official level in the classification system.



Figure 4.37 The varroa mite is an example of a microscopic animal. Varroa mites are a significant threat to bee populations in NSW. These tiny parasites attach themselves to bees and feed on their bodily fluids, weakening the bees and making them more susceptible to diseases. They can also transmit viruses between bees, further endangering colonies.

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radial symmetry a form of symmetry where an organism's body can be divided into identical parts around a central axis

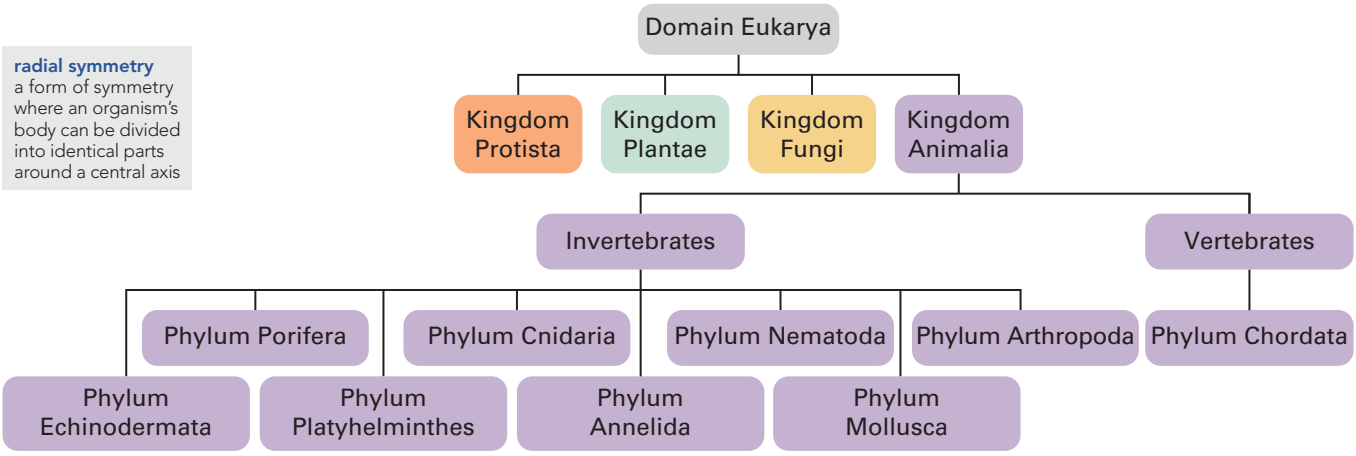


Figure 4.38 Kingdom Animalia includes these nine phyla – these can be informally grouped into invertebrate and vertebrates, but they are not formal levels of taxonomy.

Invertebrates

Poriferans

(pron. *pore-if-er-ans*)

- Sponges (from the Latin *porus* meaning pore, and *fera* meaning bearing)
- Simple animals with no organs
- Sessile
- Feed by filter-feeding, drawing water through their pores and straining it to capture food



Figure 4.39 The pink stove-pipe sponge with its simple tube form for filtering water

Cnidarians

(pron. *nigh-dare-ee-ans*)

- Stinging aquatic invertebrates (from the Greek *knidē*, meaning nettle, a stinging plant)
- Include anemones, coral and jellyfish
- Soft, hollow body
- Have stinging cells that are used for feeding and defence
- Can replace lost or damaged parts by regeneration



Figure 4.40 In 2023, members of the Cronulla swim club reported a potentially new species of box jellyfish.

Platyhelminthes

(pron. *plat-ee-helm-in-thees*)

- Flatworms (from the Greek *platy*, meaning flat; and *helminth*, meaning worm)
- Soft, unsegmented bodies
- Have flattened shapes to allow them to easily obtain oxygen and nutrients
- Most species can be cut in half and then regrow new bodies.
- Many are parasites.



Figure 4.41 Flatworms come in many different colours.

Nematodes

(pron. *nee-ma-toads*)

- Roundworms (from the Greek *nematos*, meaning thread)
- The most abundant animals on Earth
- Soft, unsegmented bodies
- Many species are parasitic.



Figure 4.42 The roundworm *Caenorhabditis elegans* was the first multicellular organism to have its entire DNA sequenced.

Echinoderms

(pron. *eek-ine-o-derm*)

- Marine invertebrates with a hard, spiny or bumpy covering (from the Latin *echino*, meaning spiny, and *derm*, meaning skin)
- Includes sea stars, sea urchins, sea cucumbers, brittle stars and feather stars
- Have specialised organs, but no brain and no blood
- Most have **radial symmetry**.



Figure 4.43 When a starfish loses a limb, it can grow back.

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Annelids

(pron. *an-e-lids*)

- Ringed worms (from the Latin *anellus*, meaning little ring)
- Three main groups: earthworms, leeches and polychaetes that live in the ocean
- Soft, segmented bodies
- Need a moist environment, can survive on land



Figure 4.44 Australia has over 1000 native worm species and about 80 beneficial introduced ones. They vary in size; the 'Gippsland Giant' reaches 3 metres, while a NSW species is as thick as a garden hose!

Molluscs

(pron. *mol-usks*)

- Soft-bodied invertebrates with a muscular foot or tentacles (from the Latin *mollis*, meaning soft)
- Include squid, snails, slugs, octopuses and oysters
- Have a mantle (a cover or outer layer), and for some it forms a shell
- Have a radula, a scraping device for eating



Figure 4.45 Mount Kaputar, near Narrabri, includes areas of subalpine and other ecosystems that are home to the kaputar or giant pink slug.

Arthropods

(pron. *arr-throw-pods*)

- Invertebrates that have an exoskeleton, segmented bodies and paired jointed limbs (from the Greek *arthron*, meaning joint, and *podos*, meaning foot)
- Include insects, spiders, scorpions, millipedes, crustaceans (crabs, lobsters, prawns)
- Make up 80% of all animal species
- Have complex sensory organs such as compound eyes and antennae for hunting and detecting threats



Figure 4.46 A cicada with its moulted exoskeleton, known as its exuvia. At least once during their life, all arthropods must moult.

Vertebrates

Chordates

(pron. *core-dates*)

The word chordate is derived from the Latin *chordatus*, meaning having a spinal cord, which was originally taken from *chorda*, meaning string.

The chordate phylum contains the most complex animals. At some point in a chordate's life, they possess a notochord (this becomes a backbone, although note that some chordates do not have backbones and are therefore invertebrates), gills on the neck, a nerve running up the back and a tail. Humans are chordates, although you may be wondering why you don't have gills or a tail! This is because humans only have these features before birth.



Figure 4.47 A five-week-old human embryo, where a tail can clearly be seen. Through foetal development, the tail will disappear, and we are left with just the tailbone. Surprisingly though, sometimes the tail doesn't disappear, and babies can be born with tails!

We do have a long nerve running up our back called the spinal cord. The spinal cord connects the brain to the rest of the body and is protected by bones called vertebrae. Run your fingers down your back to feel your vertebrae. You may remember that animals with such bones are called vertebrates. Humans, all other mammals, fish, reptiles, amphibians and birds all belong to the chordate phylum but are further grouped into classes based on their similar characteristics.

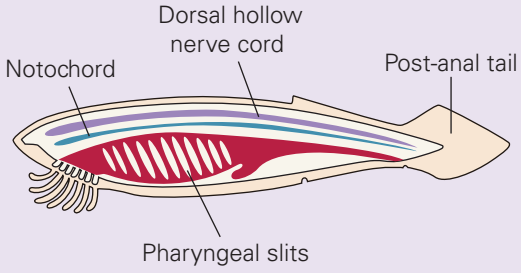


Figure 4.48 In chordates, four common features appear at some point during development: a notochord, a dorsal hollow nerve cord, pharyngeal slits and a post-anal tail.

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Animal kingdom		
Phyla (scientific name in brackets)	**Examples**	**Invertebrate or vertebrate**
Poriferans (Porifera)	Sponges	Invertebrates (they have no backbone)
Cnidarians (Cnidaria)	Jellyfish, sea anemones, coral	
Platyhelminths (Platyhelminthes)	Flatworms	
Nematodes (Nematoda)	Roundworms	
Annelids (Annelida)	Earthworms	
Molluscs (Mollusca)	Shelled animals	
Arthropods (Arthropoda)	Insects, spiders, crustaceans	
Echinoderms (Echinodermata)	Seastars, sea urchins	
Chordates (Chordata)	Fish, amphibians, reptiles, birds, mammals	Mainly vertebrates (animals with backbones), but some invertebrates

Table 4.3 Summary of the nine key phyla in the Animal kingdom. Note that eight of the nine phyla contain animals with no backbone.

Did you know? 4.6

All native birds, reptiles, amphibians and mammals (except the dingo) are protected in New South Wales by the Biodiversity Conservation Act 2016.



Figure 4.49 The dusky hopping mouse is considered endangered in New South Wales, but in 2023, scientists encountered the mouse at Scotia Wildlife Sanctuary in the Murray–Darling basin, more than 100 km outside their known range.

Symmetry

bilateral symmetry a form of symmetry where an organism's body can be divided into two identical halves.

When classifying animals into their correct phyla, their symmetry is can be used as a structural feature to help classify them. Radial symmetry means you can draw an imaginary line in several directions through the centre of the animal and you will get identical halves. **Bilateral symmetry** means you can only draw an imaginary line in one position to get identical halves.

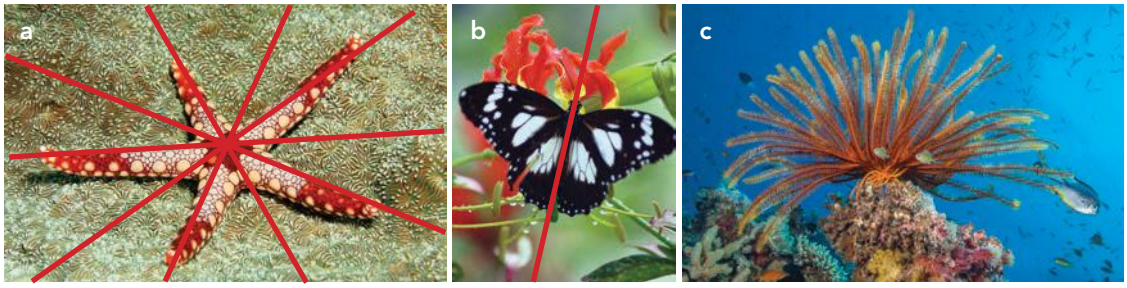


Figure 4.50 (a) The necklace sea star shows radial symmetry because it can be separated into identical halves in many directions. **(b)** The marsh tiger butterfly shows bilateral symmetry because it can be separated into identical halves in one direction. **(c)** Can you tell what type of symmetry the crinoid shows?

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Explore! 4.4

Asymmetrical animals

Most but not all animals have symmetrical body shapes. Investigate and find examples of animals that are asymmetrical (do not have symmetrical bodies).



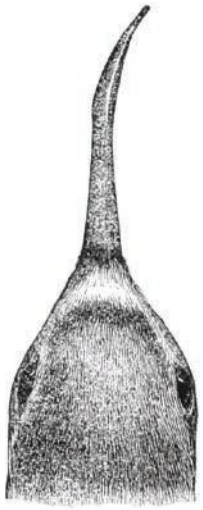


Figure 4.51 The wrybill is the only species of bird with a beak that is always bent sideways to the right.

Try this 4.9

Types of symmetry

Look at each of the following animals then decide whether they show radial symmetry, bilateral symmetry or no symmetry.



Quick check 4.7

1. Use the information about each of these species to **decide** which phylum they should belong to.
   - **a.** *Asaphus kowalewskii is* an extinct member of the largest phylum. All the members of this phylum had an exoskeleton, segmented body and jointed limbs.
   - **b.** *Ailurus fulgens* has a long tail and a nerve cord that runs down its back. This nerve cord is protected by hard bones.
   - **c.** *Monanchora arbuscula* is an animal that obtains food by filtering sea water through pores on its body.
   - **d.** *Pseudoceros susanae* is a colourful animal that is completely flat. It has bilateral symmetry and can be cut in half and survive.
   - **e.** *Cassiopea andromeda* has a soft body and a specialised cell called a nematocyst (pron. *nee-ma-toe-sist*) that fires a stinging spine at its target like a harpoon.
   - **d.** *Pisaster ochraceus* has radial symmetry and cannot survive in fresh water. It digests its prey by pushing its stomach out of its mouth.

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Classes in the phylum Chordata

We know there are six kingdoms, which are divided into phyla, and as we move through the hierarchical classification, the next level is class. You will now take a closer look at the seven classes of the Chordate phylum: Agnatha, Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia (Figures 4.53 to 4.62).

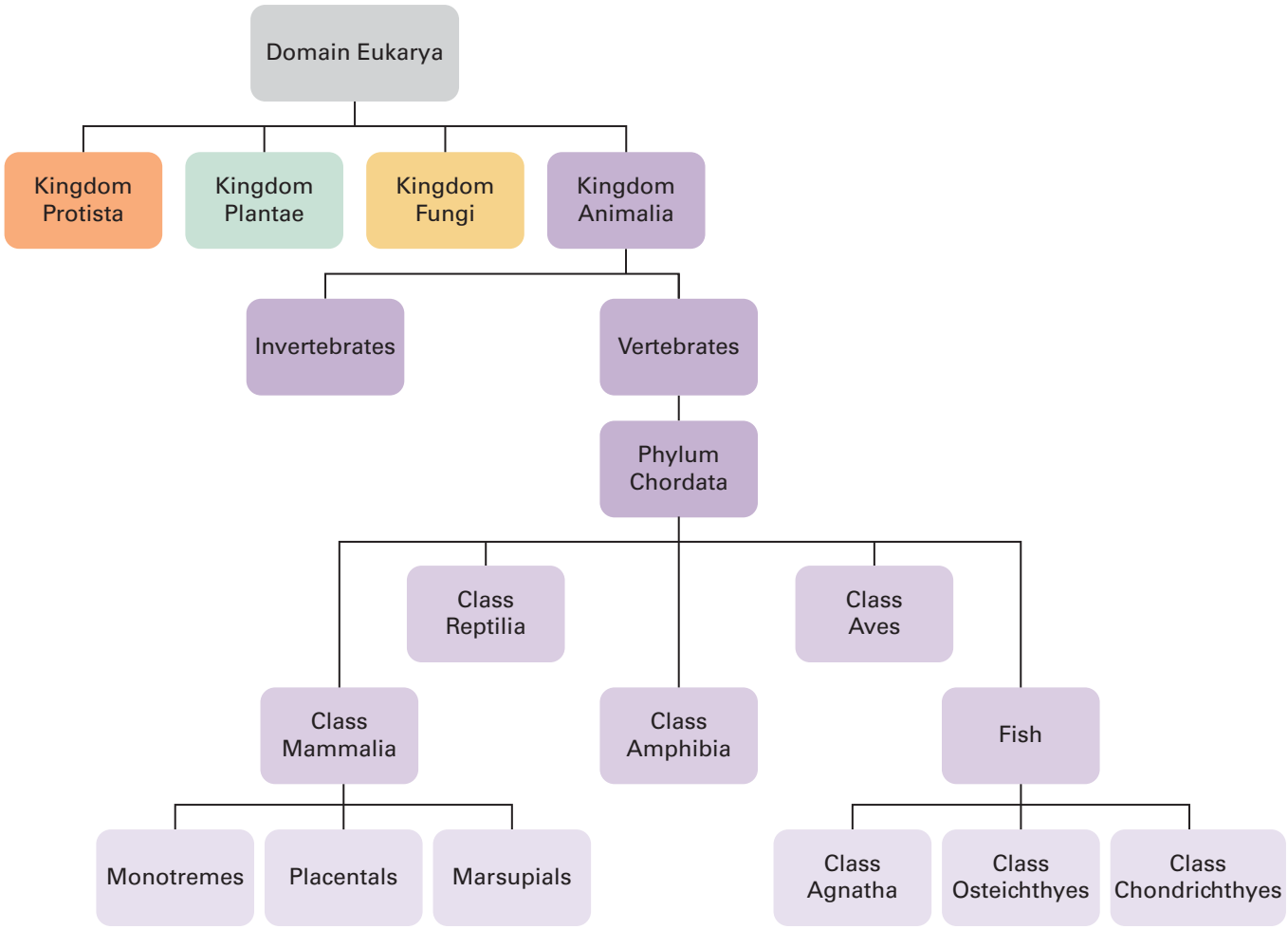
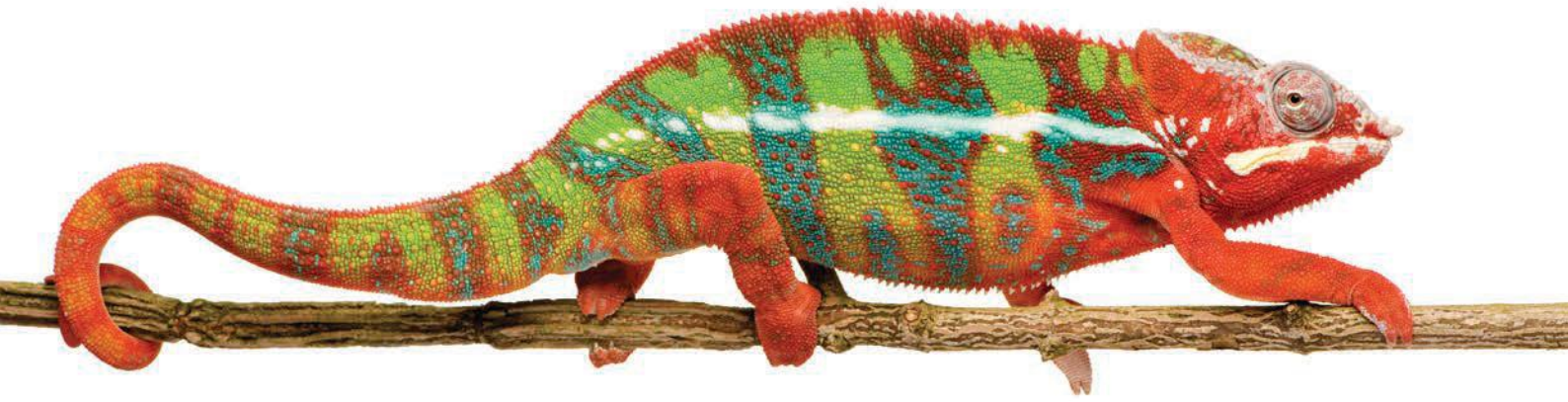


Figure 4.52 The Phylum Chordata includes seven classes. It's important to note that 'fish' is a common term but not a formal taxonomic classification.



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Agnatha (jawless fish)

(pron. *ag-na-tha*)

- Jawless, eel-like aquatic vertebrates
- Include lampreys, hagfish and many extinct species
- Oldest chordates and known as 'living fossils' as they have not changed in millions of years
- Often parasites or scavengers



Figure 4.53 Lamprey teeth are used to help it attach to its prey. Made of keratin (the same substance that makes up your hair and fingernails!), new teeth will grow and replace the old ones.

Osteichthyes (bony fish)

(pron. *ost-ee-ick-thees*)

- Fish with skeletons made from bone tissue
- Include salmon, tuna, eels, trout and clownfish
- Possess scales, paired fins and gills
- **Ectothermic** – the temperature inside their bodies is controlled by the temperature of their environment.



Figure 4.54 The southern purple spotted gudgeon (*Mogurnda adspersa*) is a small freshwater fish listed as endangered in NSW.

DEPTH STUDY IDEA How do we classify fish?

ectothermic a cold-blooded organism that cannot regulate its internal temperature

Chondrichthyes (cartilaginous fish)

(pron. *con-drik-thees*)

- Fish with skeletons made of cartilage (softer and more flexible than bone)
- Include sharks, skates and rays
- Have fins on the sides of their bodies (lateral fins) and on their backs (dorsal fins)



Figure 4.55 The grey nurse shark is estimated to number under 500 individuals off the east coast of Australia.

Amphibia (amphibians)

(pron. *am-fib-ee-a*)

- Ectothermic vertebrates with no scales that live on both land and water (from the Greek *amphibios* meaning 'living a double life')
- Include toads, frogs, newts and salamanders
- Require water or a moist environment to survive
- Use their moist skin and lungs to take in oxygen from the air
- Develop from an egg that becomes larvae
- Undergo **metamorphosis** (a change in form, usually allowing the organisms to transition from an aquatic to a terrestrial or semi-terrestrial life)



Figure 4.56 Forty-one per cent of amphibian species worldwide are threatened with extinction. Digital tools such as the citizen science FrogID project are encouraging people to upload audio recordings of frog calls to a database using an app. The data is improving scientists' understanding of Australia's unique frog species.

metamorphosis the process of transformation from an immature form to an adult form

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endothermic
a warm-blooded organism that can regulate its body temperature

Reptilia (reptiles)

(pron. *rep-til-ee-a*)

- Ectothermic vertebrates with waterproof scales
- Include snakes, lizards, turtles and crocodiles
- Most lay leathery eggs
- Have lungs for breathing



Figure 4.57 *Tiliqua rugosa*, also known as the shingleback skink or bobtail lizard, is a short-tailed, slow-moving species of blue-tongued skink endemic to Australia. The lizard has a short, wide, stumpy tail that resembles its head, possibly confusing predators. This tail also stores fat reserves used during brumation, a winter hibernation-like state.

Aves (birds)

(pron. *ah-vays*)

- Have feathers covering their body
- Lay hard-shelled eggs
- Have a beak with no teeth
- Winged, but not all birds can fly
- **Endothermic**



Figure 4.58 Birds such as emus and cassowaries have grown too large to fly and have adapted to a life on the ground.

Try this 4.10

Dichotomous key app

The use of digital tools, such as the FrogID app explained in Figure 4.56, has several benefits in encouraging public participation. With just a smartphone and the app, anyone can become a citizen scientist and contribute to real scientific research. Use the internet to research how you could use similar technology to design a dichotomous key app that allows the community to classify plants and animals in their local area.

Explore! 4.5

Are all chordates vertebrates?

Chordata is the only phylum that contains vertebrate animals. Most, but not all, chordates are vertebrates. Search on the internet for a chordate that is not a vertebrate.

Quick check 4.8

1. **Describe** two differences between amphibians and reptiles that allow reptiles to live away from water.
2. **Identify** the difference between birds and reptiles that allows birds to survive in more environments than reptiles.
3. **Recall** how an amphibian gets oxygen from the air.
4. **Name** two members of the Osteichthyes class.

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Mammalia (mammals)

(pron. *mam-ay-lee-a*)

- Feed their offspring on milk produced by mother's mammary glands
- Have a covering of hair or fur
- Possess three small bones in the middle ear
- Endothermic
- Have three subclasses based on how they produce offspring: placentals, monotremes and marsupials



Figure 4.59 An eastern grey kangaroo (*Macropus giganteus*) joey suckles from inside its mother's pouch.

Placentals

Placentals give birth to well-developed young. Throughout pregnancy, the young are nourished inside the mother's body through a cord attached to the mother's placenta. This allows the exchange of nutrients and wastes between the mother and foetus. Most mammals are placental mammals.



Figure 4.60 Mice of the genus *Pseudomys* are among only a few terrestrial placental mammals that naturally colonised Australia. In 2024, genetic analysis revealed that the delicate or little native mouse (*Pseudomys delicatulus*), previously believed to be a single species spread across a vast area from Western Australia to New South Wales, is actually three distinct species.

Monotremes

Monotremes, a unique group of egg-laying mammals, lay eggs with leathery shells like those of reptiles. The only monotremes that exist today are four species of echidna and the platypus. After laying their eggs, the female incubates them until they hatch. The young, known as puggles, are born in a highly underdeveloped state and stay in their mother's pouch, feeding on milk secreted from mammary glands.



Figure 4.61 In 2023, a group of eastern bettongs (*Bettongia gaimardi*) were reintroduced to Yiraaldiya National Park, in western Sydney, by NSW National Parks and Wildlife Service. These marsupials are crucial for ecosystem health, but they became extinct on mainland Australia in the early twentieth century due to habitat destruction and predation by introduced species.

Marsupials

Marsupials give birth to live young (called joeys) at a very early stage of development. The young will climb from the birth canal to the pouch, where they will latch onto the mother's nipple and remain there until they are fully developed. Marsupials include kangaroos, wombats, possums and koalas. They are only found in Australasia, South America, and, in smaller numbers, in Central America and North America.



Figure 4.62 A short-beaked echidna puggle

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WORKSHEET Animal kingdom

Try this 4.11

Exploring the Animal kingdom

Use your preferred web browser to research any four living species that you want. Your choices should each be from a different phylum.

Make a cue card for each one. Print out a small picture of the species and include the following information for each one.

- Common name
- Scientific name
- Phylum
- Characteristics of the phylum
- Three features of this species
- Three interesting facts about it

Now that you have gathered information on your animals, it is time to play 'Two truths, one lie' with a partner.

1. Choose two facts about each of your chosen species and create one lie about the species.
2. Read the two truths and one lie out to your partner to see if they can correctly guess the lie.
3. Swap after each animal to give your partner a chance to trick you.
4. When you have played this game with your partner, swap partners and play again.

VIDEO Adaptations

WORKSHEET Adaptations

How organisms in Australia are adapted to their environment

Adaptations are special features that allow organisms to survive in their environment. These features arise randomly but give the organism an advantage in survival over others of the same species, increasing their chances of survival and reproduction. These adaptations might enable them to secure more food, conserve water or evade predators more effectively.

Adaptation	Description
Behavioural	This type of adaptation involves actions or behaviours that organisms perform that increase their survival in a particular environment. For example, kangaroo rats in the desert are nocturnal, meaning they are active at night to avoid the daytime heat. Birds migrating to warmer climates during winter is another behavioural adaptation to ensure they have access to food and suitable living conditions.
Structural	Structural adaptations refer to the physical features of an organism that improve its survival. These adaptations can be related to the organism's shape, size or specific body parts. For example, the thick fur of polar bears helps insulate them against the cold Arctic environment. Cacti have thick, fleshy stems that store water, and spines instead of leaves to reduce water loss. The webbed feet of ducks are another example, allowing them to swim efficiently.
Physiological	Physiological adaptations involve internal processes that enhance an organism's ability to survive and reproduce. These adaptations are often related to metabolism, reproduction and other bodily functions. For example, camels can tolerate extreme dehydration and can drink large amounts of water when it is available, storing it in their bodies for future use. Other physiological responses include sweating to regulate body temperature in hot conditions. Plants like succulents can perform a special type of photosynthesis with minimal water, which allows them to thrive in arid environments.

Table 4.4 Three types of adaptations

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Australia is home to many unique organisms that have developed remarkable adaptations to survive in the diverse and often harsh environments of the country. Some of them are shown in Table 4.5. Can you identify which adaptions are structural?

Species	Adaptation
Thorny devil 	• Has spines that help channel dew and rainwater directly to its mouth • Camouflages itself among the desert sand and rocks to avoid predators • Has a specialised diet, feeding almost exclusively on ants, which it captures using its sticky, extendable tongue • To conserve water, it excretes highly concentrated urine and minimises water loss through its skin.
Kangaroo rat 	• Highly efficient kidneys produce very concentrated urine, minimising water loss. • Obtains moisture from the seeds it eats, requiring almost no direct water intake • Produces dry faeces to conserve water • Long hind legs enable high, long jumps to escape predators. • Large cheek pouches allow for efficient food storage and transport. • Nocturnal activity reduces water loss and exposure to predators. • Burrow living provides a cooler, more humid environment, reducing dehydration.
Koala 	• Specialised diet consisting almost exclusively of eucalyptus leaves • Has a long digestive tract to break down tough eucalyptus leaves and detoxify the plant's toxic compounds • Mostly sedentary to conserve energy due to the low-nutrient diet • Strong, sharp claws and opposable thumbs for climbing and gripping tree branches
Acacia 	• Small, reduced or modified leaves to minimise water loss • Leaves are covered with a thick, waxy cuticle that reduces water loss. • Have extensive root systems that allow them to access water from deep underground sources • Many have thorns or spines that deer herbivores from eating them. • Some shed their leaves during extreme drought conditions to reduce water loss.

Table 4.5 Adaptions of Australian organisms

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Did you know? 4.7

Unique marsupials

Wombats are an example of a marsupial in the mammal class. They have developed several different adaptations that make them unique. Aside from having distinctively cube-shaped faeces, they have a sturdy rump that serves multiple purposes. It is used for defence, burrowing, bonding, mating and potentially crushing the skulls of enemies against the burrow's roof. However, the exact functionality of this behaviour is still under debate. The wombat's rear end consists of four fused plates, surrounded by cartilage, fat, skin and fur. The animals utilise their backside to block their burrows, preventing predators from entering and safeguarding their more vulnerable body parts. Wombats have also developed a pouch that faces in the opposite direction from the pouches of other marsupials to protect their young from dirt when the mother is digging a burrow.



Figure 4.63 Australia is home to three existing species of wombat: the common wombat, the southern hairy-nosed wombat (shown here) and the northern hairy-nosed wombat.

INVESTIGATION

Explore! 4.6

Adapted to Australia

Organisms in Australian habitats have evolved many adaptations to thrive in their unique environments. The platypus has adapted to its semi-aquatic lifestyle by developing waterproof fur and webbed feet for efficient swimming and diving. It also uses electrolocation to detect prey in murky water. The sugar glider has adapted to life in the trees by developing a membrane of skin that allows it to glide between trees, conserving energy and avoiding ground predators. The echidna has adapted to its insectivorous diet by developing a long, sticky tongue to capture ants and termites from their nests, and the frilled-neck lizard has a frill around its neck that it can flare up to appear larger and deter predators. This adaptation also helps it to regulate its body temperature.



Figure 4.64 Bilbies have large ears that help them regulate their body temperature in hot desert environments. The large surface area of their ears allows for efficient heat exchange, helping them stay cool during the day.

Your task is to investigate how organisms in an Australian habitat are adapted to their environment and then write a scientific report about your findings. Start by researching different Australian habitats and choose one to focus on, such as a rainforest or desert. You should then research the organisms that are found there and how they are adapted to the environment. Write a scientific report summarising your findings and share with your classmates.

Quick check 4.9

1. **Describe** why adaptations are important.
2. **Distinguish** between behavioural, structural or physiological adaptations.

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Section 4.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Go online to access the interactive section review and more!

Section 4.3 questions

Remembering

1. **State** three examples of fungi.
2. **Define** 'vascular plant'.
3. **State** where you would find living sponges.
4. **Identify** three examples of an arthropod.

Understanding

5. **Describe** how two of the adaptations of an acacia tree allow it to conserve water.
6. **Identify** the characteristics you would use to differentiate between the following animals:
   - **a.** jellyfish and earthworm
   - **b.** kookaburra and koala
   - **c.** frog and tuna.
7. **Identify** whether all green plants have flowers.

Applying

8. **Choose** the most appropriate word to fill in the gaps:
   Yeast is a _____ organism.
   Fungi reproduce through the production of _____, which are similar to plant seeds.
   The body of a fungus is made up of tiny threads called _____.
9. **Distinguish** between unicellular and multicellular.
10. **Describe** the difference between a vertebrate and an invertebrate.
11. **Explain** why reptiles can live in deserts, whereas amphibians need a moist environment.

Analysing

12. **Classify** each of these species by placing them into the correct kingdom.
    - **a.** *Streptococcus pneumoniae* is an organism that can make you very sick. It belongs to the second-oldest kingdom and is made up of single cells.
    - **b.** *Trypanosoma evansi* is a single-celled organism that needs to eat other organisms to survive. Its cells have specialised structures inside of them.
    - **c.** *Osmunda regalis* is an organism that uses sunlight to make sugars and reproduces using spores. This organism has specialised vascular tissue.
    - **d.** *Tremella fuciformis* is an organism that reproduces using spores and is a parasite, living within other organisms to gain food.
    - **e.** *Haloferax volcanii* is a single-celled organism that can survive in extreme environments that no other organism could survive in.
13. **Compare** animals found in the Amphibia and Aves classes.

Evaluating

14. In the past, fungi were considered to be part of the Plant kingdom. **Propose** reasons why this might have been the case.
15. *Euglena* are single-celled organisms that can detect light, can swim and are able to photosynthesise. **Discuss** why it would be difficult to classify this organism.
16. Choose an Australian animal and **produce** an annotated diagram to evaluate how its adaptations allow it to survive in its environment.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
4.1	describe how the characteristics of living organisms are used to classify them.	10
4.1	be able to interpret and construct a dichotomous key.	6, 11, 12
4.1	conduct an investigation to observe and identify similarities and differences of organisms.	8
4.2	discuss the role and importance of classification in organising knowledge of the diversity of life on Earth.	5
4.2	use the binomial system of classification to classify and name organisms.	3, 5
4.2	explain using an example how Aboriginal and Torres Strait Islander Peoples classify organisms based on their uses, forms and functions.	13
4.3	give examples of the classification of organisms into kingdoms and the diversity of life on Earth.	1, 2
4.3	investigate and report on how organisms in Australia are adapted to their environment.	4, 7, 9, 14

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Name** the six kingdoms in modern taxonomy.
2. **Name** the seven classes of chordates.
3. **Identify** the language that the scientific names for genus and species names are mostly taken from.
4. **List** the three types of adaptations.

Understanding

5. **Summarise** why it is useful to classify organisms and give them a unique universal scientific name.
6. **Explain** the disadvantage of using qualitative descriptions (as opposed to measurements) in a dichotomous key.
7. **Describe** how structural adaptations help organisms survive in their environment.

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Applying

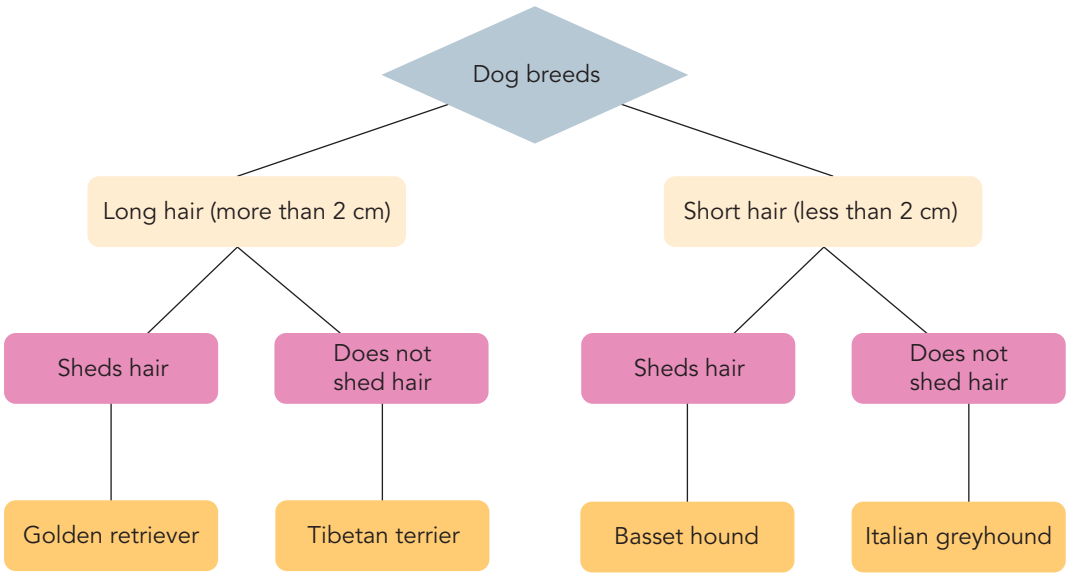
8. Mosses and fungi both produce spores when reproducing. **Describe** two differences between these organisms.
9. Choose an Australian plant or animal and **explain** how it is adapted to survive in its environment.
10. **Explain** why the soldier crab, *Mictyris longicarpus*, is classified as an invertebrate animal.



Figure 4.65 A soldier crab, *Mictyris longicarpus*

Analysing

11. Each step of the key below can be used to describe an organism. Use it to **describe**:
    - **a.** a Tibetan terrier
    - **b.** an Italian greyhound.



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Evaluating

12. Create a dichotomous key to classify the contents of your pencil case.



13. Discuss examples of how Aboriginal and Torres Strait Islander Peoples classify living things.

14. Many Australian animals are nocturnal. **Discuss** how this behavioural adaptation benefits them in their environment.



Figure 4.66 The grey-headed flying fox (*Pteropus poliocephalus*) is nocturnal.

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Data questions

Use the following Figures 4.67 and 4.68 to answer the questions below.

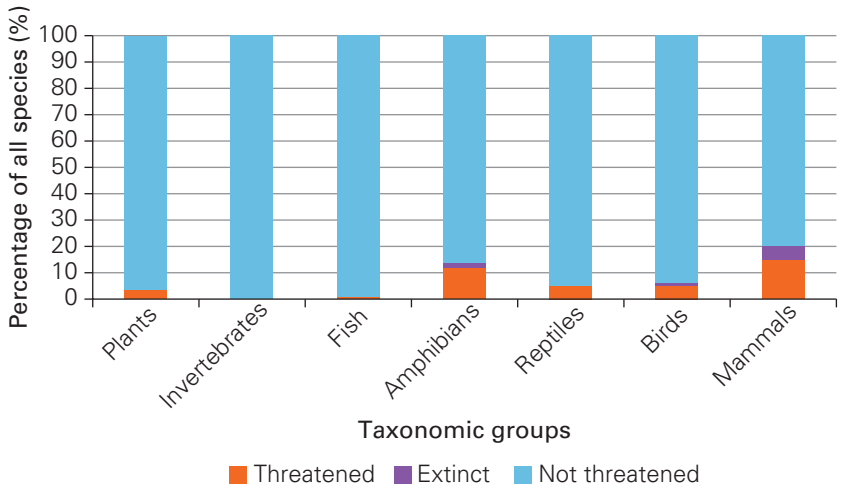


Figure 4.67 The conservation status of different taxonomic groups in Australia

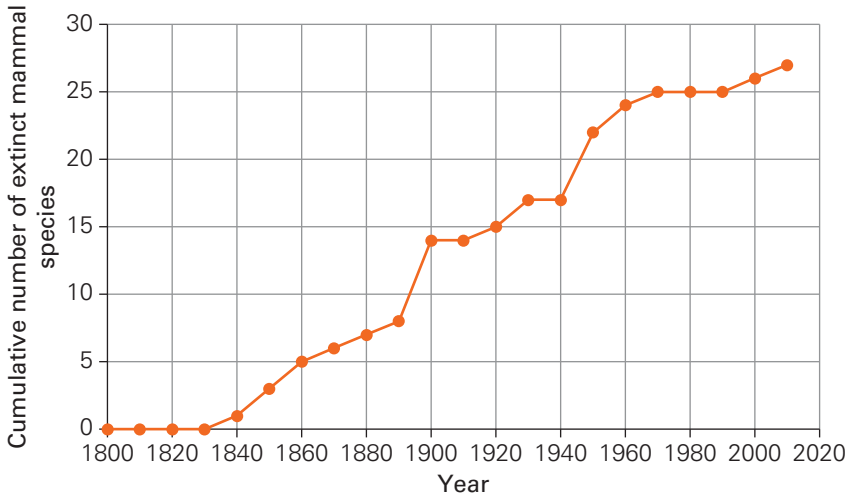


Figure 4.68 The cumulative number of extinctions of mammal species in Australia since 1800

1. **Identify** the taxonomic group that is under the least threat, using Figure 4.67.
2. There are 828 bird species in Australia. Six per cent of these species are considered as threatened. **Calculate** the number of species of birds that are considered as threatened.
3. **Calculate** the average rate of mammal extinctions per year from 1800–1920, using Figure 4.68.
4. **Organise** the taxonomic groups in Figure 4.67 from most threatened to least threatened.
5. **Contrast** the number of extinct and threatened species in mammals with the number of extinct and threatened species in amphibians in Figure 4.67.
6. **Predict** the number of extinct Australian mammal species in the year 2020, using Figure 4.68.
7. **Infer** the two worst decades for Australian mammal extinctions, using Figure 4.68.
8. **Justify** your answer to Question **7**.

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STEM activity: Biomimicry

Background information

Designers and engineers often look to the natural world for inspiration to develop innovative and sustainable clothing materials. Biomimicry, the practice of imitating biological processes and structures, can lead to the creation of fabrics that are more durable, comfortable and environmentally friendly. Examples of biomimicry in clothing include fabrics that mimic the water-repellent properties of lotus leaves, thermal regulation inspired by polar bear fur, and adhesive properties similar to gecko feet for better grip.

DESIGN BRIEF

Create a piece of clothing using principles of biomimicry to enhance functionality and sustainability.



Figure 4.69 Water-repellent fabrics inspired by the microstructure of lotus leaves help keep clothing dry and clean.

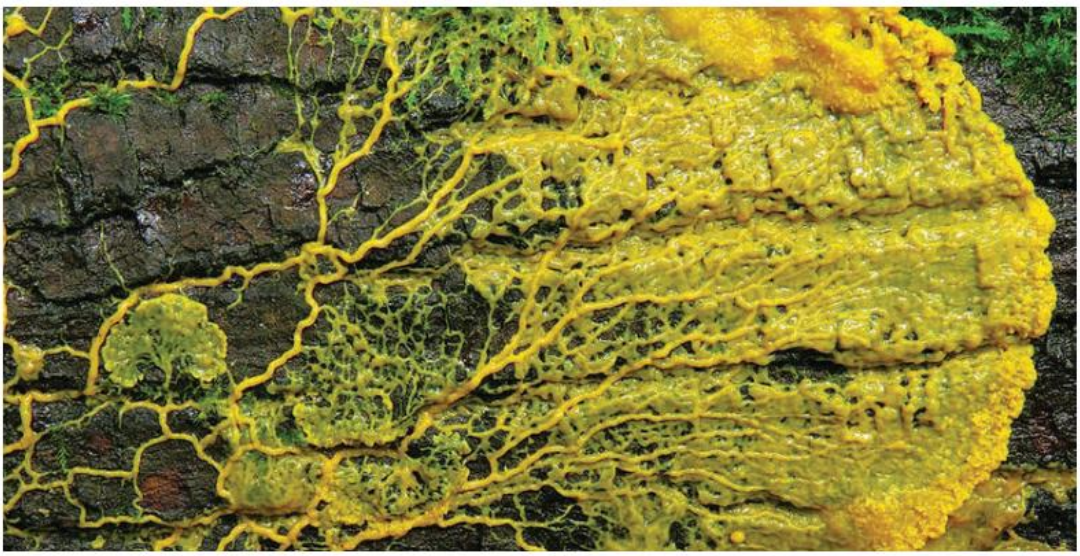


Figure 4.70 When a team of scientists in Japan placed the favourite food of a slime mould at various locations representing major cities in Japan, the organism mapped out the complex rail network in just five to six days. This feat, which took Japanese engineers years to plan and map, demonstrates the efficiency of natural systems. This technology holds potential for aiding traffic mapping in emerging countries in Africa and Asia, as well as urban and housing development planning.

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Activity instructions

In teams, you will become fashion designers and engineers who use biomimicry to design a piece of clothing that addresses a human need. Examples of issues you might consider include weather resistance, comfort, durability or sustainability. Your team will draw a detailed and labelled diagram of your design and describe it by listing the special features and the natural inspiration behind those features. Throughout the process, ask yourselves, 'What would nature do here?'

Suggested materials

- A3 and A4 paper
- pens, pencils
- ruler

Research and feasibility

1. Discuss and agree on a human problem related to clothing with your group. Start by researching the issue and listing the main aspects and effects of the problem. For example:

Major causes of uncomfortable clothing	Effects	What would nature do here?
Poor thermal regulation	Overheating or excessive cooling	Polar bears have fur that provides insulation while regulating temperature.

2. Explain the problem and its cost on society, including environmental, social and economic impacts.

Design

3. Identify your plant, animal, or natural process and its scientific name. Briefly describe why mimicking this natural solution could help solve the human problem.
4. Describe the unique features of your chosen organism or process. How do these features contribute to its efficiency and effectiveness in nature?
5. Describe how you will mimic the material, structure, and function of the natural inspiration to create a piece of clothing.
6. List the materials you plan to use, their physical properties, and their purpose in your design. You may wish to create a table.

Create

7. Create a scale drawing of your piece of clothing, including front, side and back views. Label all parts of your design clearly.
8. Describe your design by listing its special features and explaining which aspect of your organism or process inspired each feature.

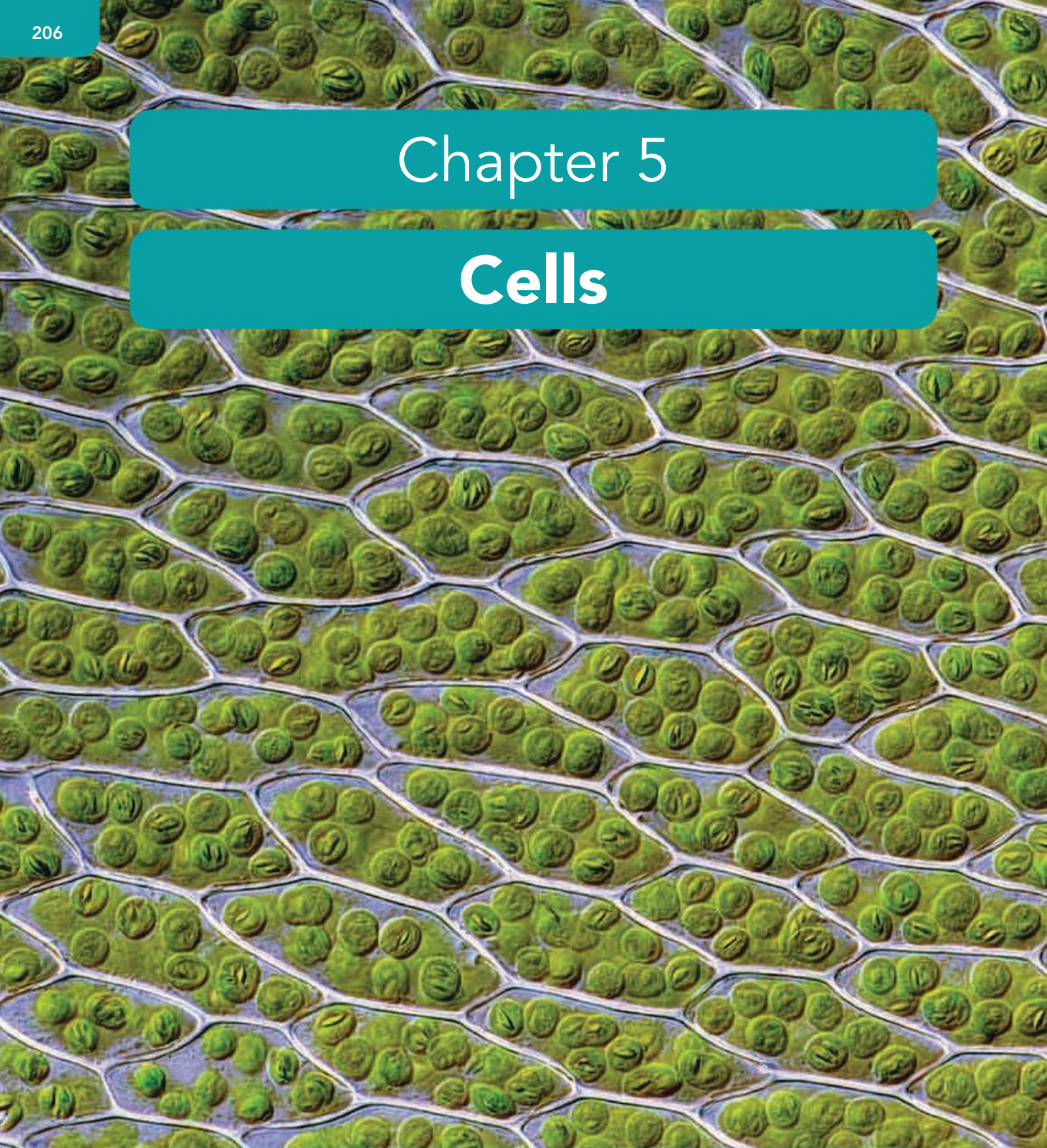
Evaluate and modify

9. Evaluate your design's effectiveness in solving the identified problem. What are its strengths and weaknesses? Suggest improvements and modifications to enhance its functionality and sustainability.

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Chapter 5

Cells

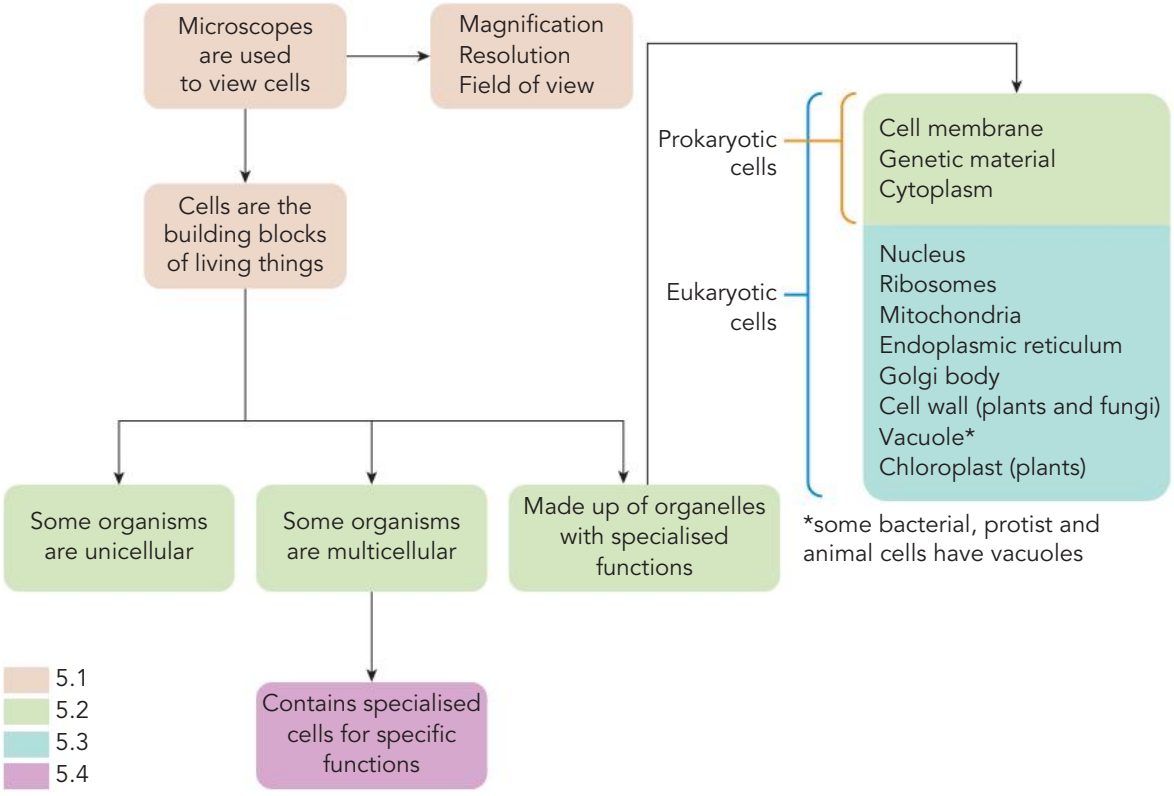


Chapter introduction

Cells are the smallest unit of life and are the building blocks that make up all living things. They are like tiny factories that carry out vital processes to keep us alive. In this chapter, you will learn about the important role that cells play in living organisms. You will discover the different types of cells and how they work together to keep organisms healthy. You will also learn about cell structure and the processes that cells use to carry out their functions.

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Chapter map



Glossary terms

bacteria
biconcave
cell membrane
cell wall
cellular respiration
chloroplast
cytoplasm
cytosol
differentiation
DNA
double helix
embryo
enzyme
eukaryote
function
macroscopic
membrane-bound organelle
microscopic
mitochondrion
multicellular
neuron
organ
organelle
photosynthesis
prokaryote
protist
ribosome
specialised cell
stem cell
structure
tissue
unicellular
vacuole
zygote

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5.1 Microscopes and cells

WORKSHEET
Parts of a microscope

Learning outcomes

At the end of this section, I will be able to:

1. outline how the invention of the microscope has contributed to understanding cell structure.
2. identify the parts of a light microscope and how to use it.
3. draw single-celled organisms from images produced by a microscope.
4. outline cell theory.

The microscope

Cells are the basic building blocks of all living things. They are the smallest unit of life that can carry out all the functions necessary for an organism's survival. To study cells, scientists use microscopes. Microscopes allow us to see and study the tiny details of cells that are invisible to the naked eye. Five hundred years ago, scientists used hand-held magnifying glasses to view small **macroscopic** specimens such as fleas – these were large enough to be visible to the naked eye. Scientists soon found that using two lenses together enabled them to see even smaller specimens. This discovery led to the invention of the first light microscope. The light microscope that you use today in school is not very different from those used by scientists hundreds of years ago, but the technology used to produce today's lenses is more advanced and enables us to see things at higher magnifications. Anything that can only be seen clearly with the use of a microscope is described as **microscopic**.

macroscopic visible to the naked eye

microscopic anything that can only be seen clearly with the use of a microscope

VIDEO
Leeuwenhoek and his simple microscope

Did you know? 5.1

Antonie van Leeuwenhoek

Antonie van Leeuwenhoek was a Dutch scientist who is often credited with being the first person to see and describe microorganisms. He is considered one of the pioneers of microbiology, and his discoveries were made possible by his remarkable skill in building and using microscopes. Van Leeuwenhoek created his own microscopes, which were simple, single-lensed instruments that he could use to magnify objects by up to 300 times. With these microscopes, he was able to observe and describe the shape and movements of single-celled organisms, including bacteria. He called these organisms 'animalcules', meaning 'little animals'.

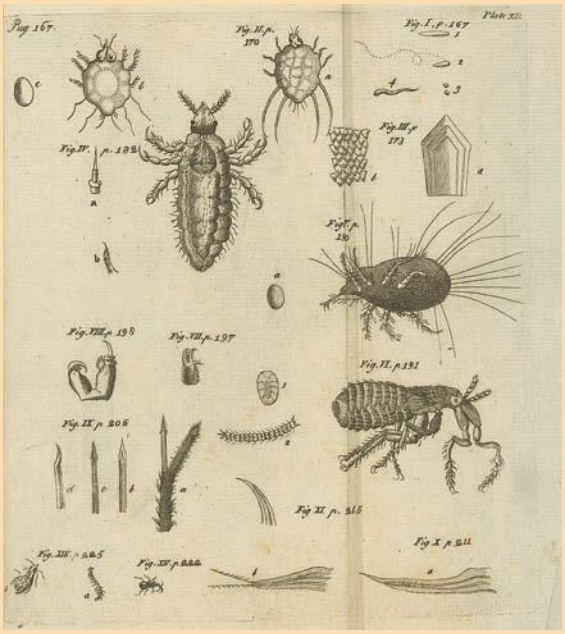


Figure 5.1 This plate from 1743 illustrates animalcules or unicellular organisms discovered under magnification when examining teeth (figure I), along with scabies (figure II), skin samples (figure III), insects and a snake.

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Light microscopes

Although some microscopes are more advanced than others, most of those you use at school are light microscopes that have the same basic components. The microscopes you use have at least two lenses: the eyepiece (ocular) lens and the objective lens, which are multiplied together to provide the total magnification. They also have a light source, a stage on which to place specimens and knobs to adjust the focus. The monocular microscope shown in Figure 5.2 is for use with one eye. Binocular microscopes can be used with both eyes.

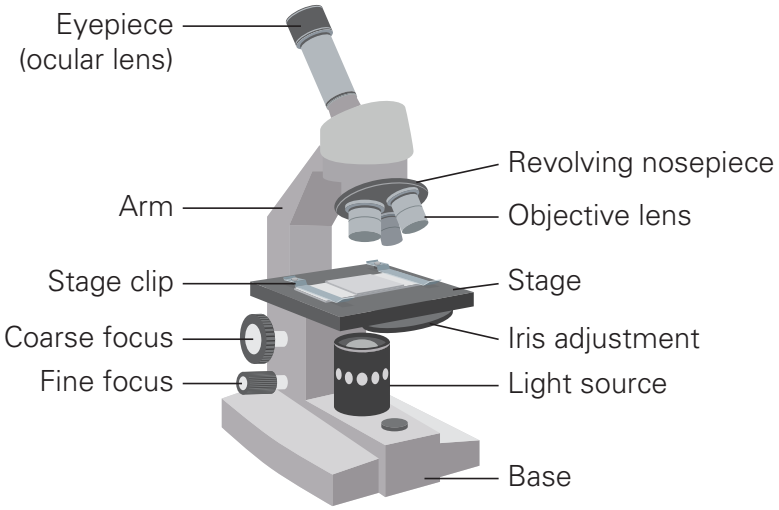


Figure 5.2 The parts of a monocular microscope

Binocular microscopes have an eyepiece for each eye. There are two types: compound binocular and stereoscopic. Compound binocular microscopes have one light path from the specimen, which is split and led to both eyepieces, so each eye has the same view. Therefore, the image looks flat (two-dimensional). Stereoscopic ('stereo') microscopes, which are much more expensive, lead two separate light paths from the specimen to each eye, so they have different views. The image has depth (three-dimensional). This is useful for manipulating or dissecting specimens, and the magnification does not have to be very large. There are also trinocular microscopes that have an additional eyepiece that a camera can be attached to (see Figure 5.3b).

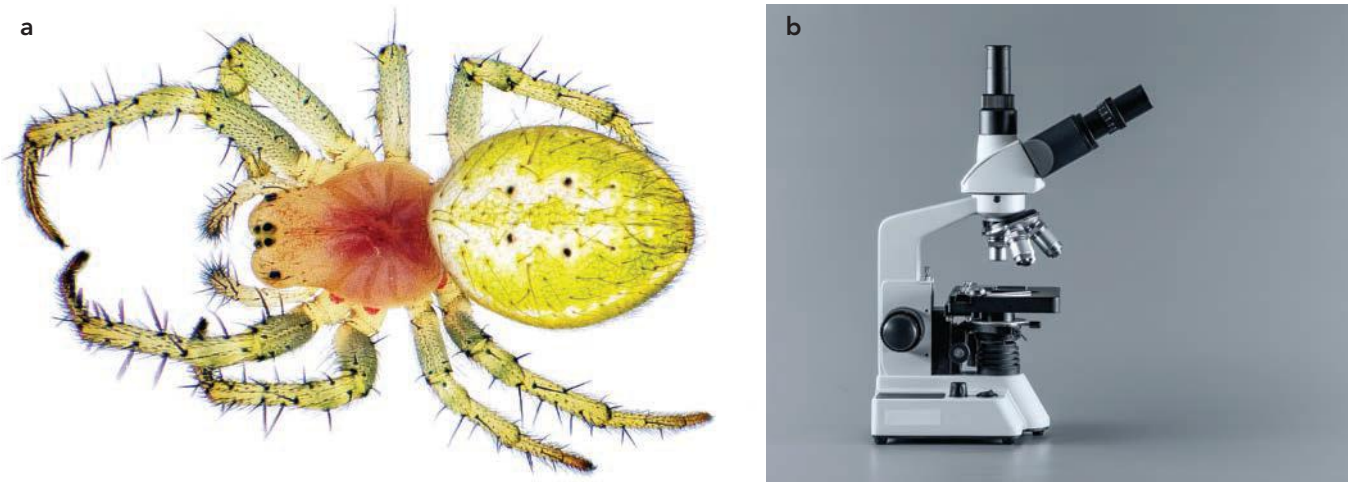


Figure 5.3 An image of a cucumber green spider **(a)** taken with a camera mounted on a trinocular microscope **(b)**

Try this 5.1

Parts of the microscope

Draw up a table with the parts of a microscope in the left column. Find out the function of each part and put this information in the right column.

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Microscope terms

When you use a microscope, you will often encounter special terms. Table 5.1 summarises some key terms.

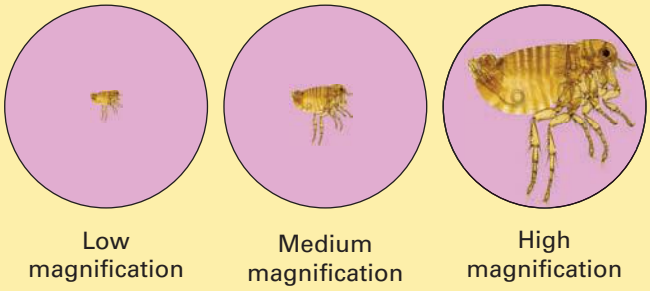
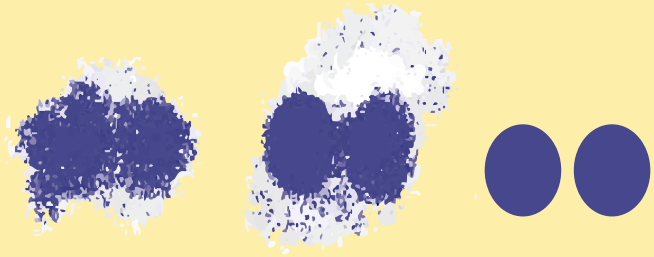
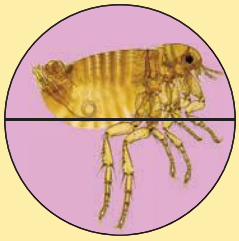
Term	Definition	Image
Magnification	How much the image of the specimen or object is increased in size (i.e. how much you are zooming in)	 Low magnification; Medium magnification; High magnification
Resolution	How detailed and clear the image is (i.e. how easy it is to tell two separate objects apart)	 Poor resolution; Better resolution; Best resolution
Field of view (FOV)	The maximum area that can be seen when you look through the eyepiece	 Human flea

Table 5.1 Some key terms used in microscopy

Digital microscopes

A variety of digital light microscopes have been developed by incorporating a digital camera into the microscope. Some come with a viewing screen and an output socket or cable to computer; others only have the output. An advantage of using a digital microscope as with all digital images is that imaging software can be used to enhance detail. Attachments are also available for fixing a smartphone camera to the eyepiece of a microscope. Alternatively, there are miniature microscope attachments that fit onto smartphones.

A variety of very expensive high-resolution digital microscopes are used by research laboratories. The most common is the electron microscope, which uses beams of electrons to create images rather than light. The disadvantage is that the target material must be specially prepared and cannot be living.

Limitations of light microscopes

Light microscopes are limited in their usefulness. They can magnify a specimen up to 1500×, which is enough to make bacteria visible. However, the resolution at this magnification is not very high, and this is a limitation due to the wavelength of light, so light microscopes do not enable you to view anything smaller than bacteria in any detail.

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Figure 5.4 Light microscope images taken of the heads of a horsefly, wasp and spider

Explore! 5.1

Types of microscopes

1. Do some research into the different types of microscopes that are used today: monocular microscope, stereo microscope, digital light microscope and electron microscope.
2. Copy and complete the following table.

Type of microscope	Magnification	Resolution	Advantages	Disadvantages	Example of what can be seen
Monocular light microscope					
Stereoscopic light microscope					
Digital light microscope					
Electron microscope					

VIDEO
Electron microscope

INVESTIGATION

DEPTH STUDY IDEA
Latest advances in electron microscopes

Quick check 5.1

1. **State** the maximum magnification of the monocular microscope, the stereo microscope and the electron microscope.
2. **State** what microorganisms were originally called.
3. **Define** the following key terms in your own words: magnification, resolution, field of view.
4. **Organise** the different types of microscopes in order from most powerful to least powerful.

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Practical skills 5.1

Using a microscope to observe and draw single-celled organisms

Aim

To become proficient in using a microscope.

Materials

- glass microscope slide
- cover slip
- light microscope
- pond water sample
- pipette

Be careful

Ensure that the microscope is carried appropriately. Carry it with one hand holding the arm and one hand under the base. Do not use the coarse focus knob to cause the objective lens to touch the glass slide and damage it.

Procedure

1. Use the pipette to place a drop of pond water in the centre of the glass slide.
2. Gently place a cover slip over the drop of water to create a wet mount.

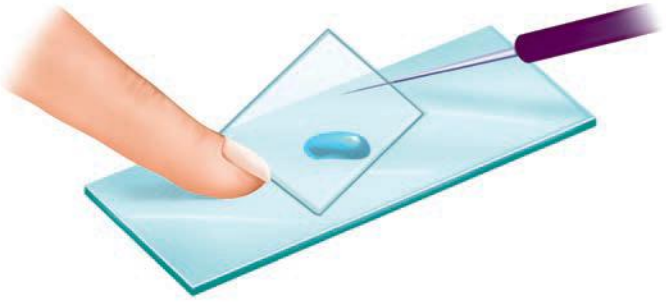


Figure 5.5 Lowering the cover slip slowly is very important when preparing a wet mount.

3. Place the slide on the stage of the microscope and secure it in place with the clips.
4. Set the lowest-magnification or smallest objective lens in place. Turn the coarse focus knob until it is as close to the stage as it will go while looking from the side of the microscope.
5. Wind the coarse focus knob to lower the stage until the pond water sample starts to come in to focus.
6. Try moving the stage left and right, forwards and backwards, and note what you observe about the movement of the image.
7. Repeat steps **3**–**6** for each of the optical lenses. You no longer use the coarse focus knob to focus now; use only the fine focus knob to focus your specimen.



Figure 5.6 Some organisms you may find in your sample: *Daphnia* (left), *Euglena* (middle) and algae (right)

continued …

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8. Draw the organism and label any recognisable parts and make notes about any colours or features visible, or any movement or behaviour observed. Record the magnification next to your drawing. To calculate the magnification, you will need to multiply the magnification of the eyepiece (ocular) lens by the magnification of the objective lens. For example, if the eyepiece is 10x magnification and the objective lens is 4× magnification, then the overall magnification is 10 × 4 = 40x.
9. Move the stage until a single-celled organism comes into view, then adjust the objective lens if necessary and the focus. Those organisms that move should be easy to spot, but others may be still.

Results

Your results will consist of your labelled drawing of the organism(s), together with magnification and notes.

Discussion

1. Explain what happened to the single-celled organism when viewed under the microscope at low magnification.
2. Describe what happened when you increased the magnification using the different objective lenses.
3. Describe what you observed as you moved the slide – did the organism go in the same direction as the direction in which you moved the slide?
4. As the magnification of an image increases, the resolution decreases. State the magnification at which you would have had the lowest resolution.
5. Explain what happened to the field of view as you increased the magnification of the objective lens.
6. Outline a safety precaution you would use when observing a specimen using the highest-magnification objective lens.
7. Summarise the advantages and disadvantages of using a light microscope.

Cell theory

Cells are extremely small, and most cells cannot be seen with the naked eye. They are described as being microscopic. It wasn't until 1665, when Robert Hooke built a compound microscope that lit up the specimen he was viewing, that we even knew cells existed. Because of his improvement of the microscope, he was able to observe that a dead cork plant appeared to be made of small blocks. He named these blocks 'cells' because they looked like the small identical 'cells' that monks lived in at the time.

Nearly 200 years later, after many other scientists had observed and catalogued many more types of cells, a cell theory was proposed.

This first cell theory stated that:

- Cells make up all living things.
- Cells are the basic building blocks of all living things.
- All cells form spontaneously from their environment, in a similar way to crystals forming.

We now know that the third part of this theory is incorrect, as cells do not just pop into existence.

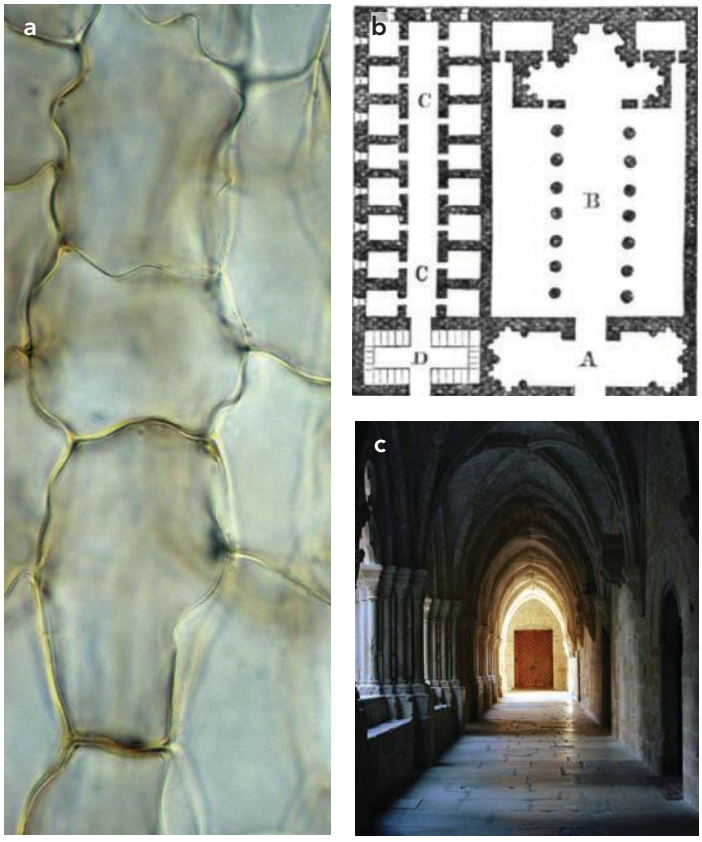


Figure 5.7 The cork cells **(a)** Hooke observed looked like the monks' cells in the building plans **(b)** of monasteries **(c)**.

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Modern cell theory states that:

- Cells make up all living things.
- Cells are the basic building blocks of all living things.
- All new cells are produced from existing cells.
- All cells contain genetic information, which is passed from cell to cell during cell division.

Did you know? 5.2

Egg cells

Cells come in many sizes. The main reason is simple: their size and structure depend on their function. Ova, also known as eggs, are some of the largest cells in the animal kingdom. They are typically much larger in size than other cells such as red blood cells, nerve cells and muscle cells. This size is necessary for the egg to contain all the nutrients and genetic material required for the development of a new organism. The size of an egg varies greatly depending on the species, with some bird eggs being over 100 times larger than a human egg. This large size allows the egg to provide enough sustenance and protection to the developing embryo until it hatches.



Figure 5.8 A human ovum in the fallopian tube. Ova are 'macro' cells. Macro means 'large-scale', and so they can be seen with the naked eye – that is, without a microscope. Some can be seen easier than others though. An ostrich egg is approximately 15 cm long, while a human ovum is only 0.12 mm long and only just visible to the human eye!

Quick check 5.2

1. **Name** the largest cell in the human body.
2. **Contrast** the terms 'micro' and 'macro'.
3. **Explain** why cells come in many shapes and sizes.

Try this 5.2

Cell size

In science, it is important to use appropriate units when measuring different objects. You would not measure the size of a bedroom in kilometres, or the size of an ant in metres. Therefore, when you measure cells, it is important to use a very small unit. This is usually a micrometre (μm). A micrometre is 1000 times smaller than a millimetre (mm).

Using Figure 5.9, convert the cell sizes in the table into millimetres (mm) or micrometres (μm).

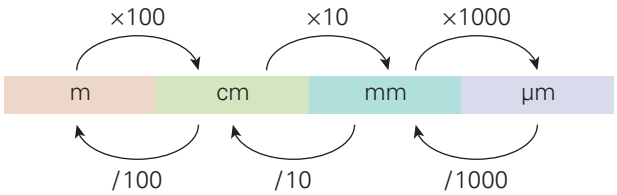
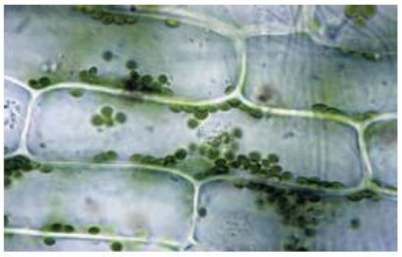
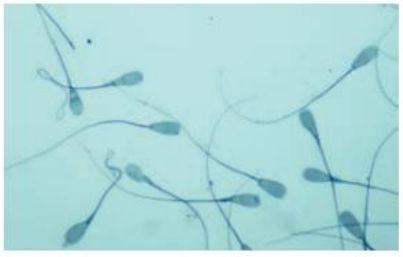


Figure 5.9 Conversions needed for different measurements

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Cell type	Size (mm)	Size (µm)
 **Figure 5.10** Red blood cells	0.0065	
 **Figure 5.11** Plant cells on a leaf surface		100
 **Figure 5.12** Sperm cells	0.05	

Section 5.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 5.1 questions

Remembering

1. **Define** the term 'microscopic'.
2. **Recall** the modern cell theory.
3. **State** the function of each of the following parts **A–E** of the microscope.

Part	Function
A. Stage	
B. Eyepiece	
C. Objective lens	
D. Coarse focus knob	
E. Fine focus knob	

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Understanding

4. **Summarise** the advantages of using a:
   - **a.** standard light microscope
   - **b.** digital light microscope.
5. **Summarise** why it is important to move the stage away from the objective lens before putting the slide on the stage. (Think about the safety notes.)
6. **Describe** four principles of modern cell theory.

Applying

7. A nanometre (nm) is 1000 times smaller than a micrometre (µm). Generally, a virus is around 0.0225 µm in size. **Calculate** this size in nanometres.
8. **Calculate** the magnification of the microscope when using the following objective lenses:

Eyepiece	Objective lens	Magnification of specimen
10×	10×	
10×	5×	
10×	80×	

9. Copy and complete the following table to **calculate** the sizes of the different specimens.

Specimen	Size		
	Nanometres (nm)	Micrometres (µm)	Millimetres (mm)
Atom	0.1		
Bacterium		1	
Virus	35		
Animal cell		10	
Chicken egg			50

Analysing

10. **Demonstrate** how you would determine the size of a cell.
11. **Draw** the following single-celled organism (*Paramecium*). Include a magnification if the actual length of the organism is 250 µm.



Evaluating

12. **Propose** the reason that different units are used to measure different-sized objects.
13. **Create** a detailed set of step-by-step instructions for a Year 6 student to safely use a microscope.
14. **Justify** the statement 'the development of microscopes has changed our understanding of cells'.

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5.2 Cell structure and organelles

Learning outcomes

At the end of this section, I will be able to:

1. distinguish between prokaryotic and eukaryotic cells.
2. identify common cell structures and organelles.
3. describe the functions of the cell membrane, cytoplasm, nucleus containing DNA, mitochondria and chloroplasts.
4. identify cellular respiration in mitochondria, and photosynthesis in chloroplasts, as important processes in specialised organelles.

WORKSHEET
Cell types and structure

All cells

Everything that we classify as living is made up of one or more cells. People, trees, fish and mushrooms are made up of many different cells working together and are known as **multicellular**. These cells depend on each other and cannot survive alone. Organisms in the kingdoms Bacteria, Protista and Archaea are made of single cells and are referred to as **unicellular**. Each of these single cells carries out all the processes needed to stay alive, by itself. Generally, unicellular organisms are quite simple and are similar to some of the oldest forms of life found on Earth, whereas the cells of multicellular organisms are specialised and much more complex.

All cells, no matter how simple, contain the following three components:

- a **cell membrane**
- genetic material in the form of **DNA**
- **cytoplasm**.

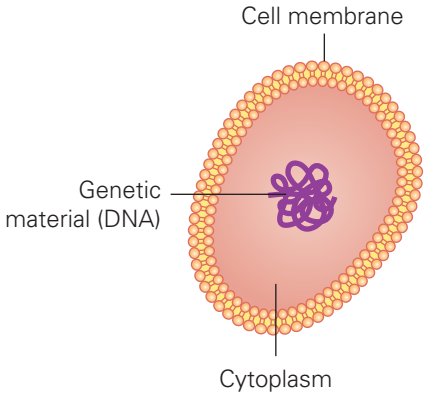


Figure 5.13 All cells, no matter how simple or complex, contain these three components. Images of examples are shown in Figure 5.14.

multicellular consisting of many cells

unicellular consisting of just one cell

cell membrane the barrier that separates the inside of the cell from the external environment

DNA deoxyribonucleic acid, a chemical present in cells of living things that carries genetic information

cytoplasm all the material inside the cell membrane, but outside the nucleus of eukaryotic cells, including organelles and other structures in a water-based fluid

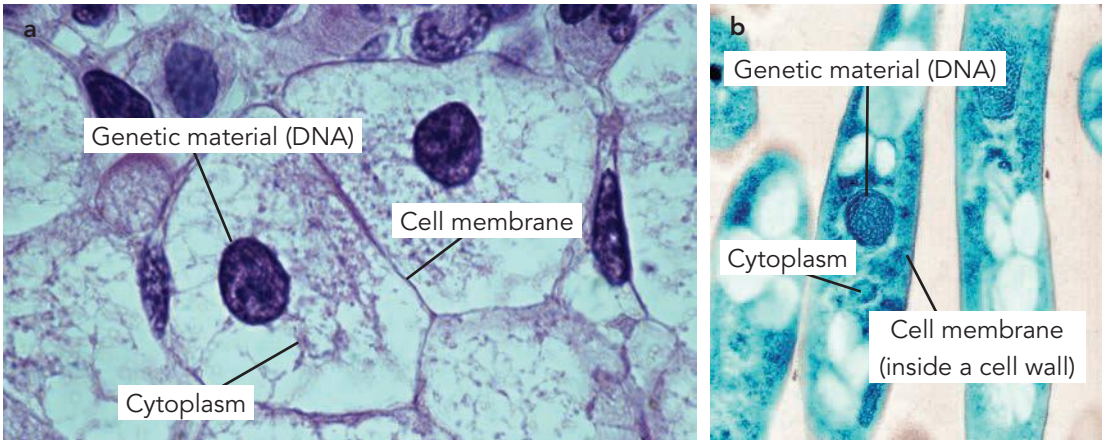


Figure 5.14 Images of **(a)** liver cells from a human, which is a multicellular organism, and **(b)** *Bacillus anthracis* bacteria, which are unicellular organisms

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Quick check 5.3

1. **Define** these terms and include examples of two organisms that fit each category: unicellular, multicellular.
2. **Recall** the three components that all cells have in common.

Organelles

Simple and complex cells

prokaryote
a unicellular organism that lacks membrane-bound organelles and a nucleus

eukaryote
any cell or organism that possesses membrane-bound organelles and a nucleus

bacteria
very small prokaryotic organisms that have cell walls but lack membrane-bound organelles and a nucleus

membrane-bound organelle
an organelle that is surrounded by an outer covering made partly of oil/fat

organelle
a specialised structure in a cell that has a specific function or role

All cells can be grouped into two main categories: **prokaryote** (simple) and **eukaryote** (complex). Prokaryotes are unicellular organisms such as **bacteria**, while eukaryotes can be unicellular or multicellular. Examples of eukaryotes are animals, plants, fungi and protists. The two categories of cell type are based on the structures found inside the cell. All cells have a membrane, cytoplasm and genetic material, but eukaryotic cells are more complex and also have many **membrane-bound organelles**, including a nucleus, that carry out specific functions. Prokaryotic cells do not have a nucleus or any membrane-bound structures.

The term 'prokaryote' means 'before (pro) nut/kernel (karyon)', meaning that these cells were present before eukaryotic cells. The specialised structures inside cells are known as **organelles** because they are like 'mini' organs with specific roles.

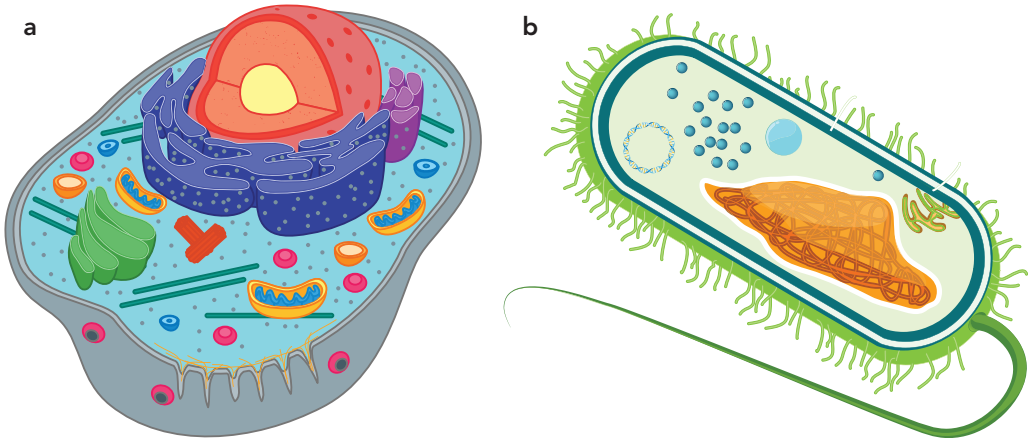


Figure 5.15 Three-dimensional representations of a eukaryotic cell **(a)** and a prokaryotic cell **(b)**. Can you identify the cell membrane, genetic material and cytoplasm in each cell type?

Try this 5.3

Observing 'friendly' prokaryotes under the microscope

Using your microscope and wet mount preparation skills, look at some bacteria under the microscope. You will need the stain called methylene blue and a sample of yoghurt or probiotic drink containing live bacteria strains. Look at the size and structure of the bacterial cells and consider their similarities and differences.

DEPTH STUDY IDEA
How are we responding to antibiotic resistance?

Try this 5.4

Prokaryotes versus eukaryotes

For the following list of organisms, identify which are examples of prokaryotic cells and which are examples of eukaryotic cells.

Mushrooms	Grass	Archaea	Potatoes
Cyanobacteria	Fruit flies	Tapeworms	*Escherichia coli*

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The cell city

VIDEO
Eukaryotic cells

Although all cells contain the three structures described previously, only complex eukaryotic cells contain the specialised membrane-bound organelles covered in this section. These organelles have a membrane around the outside that helps to compartmentalise them and allows them to do their jobs more efficiently. It is helpful to compare the cell to a city. A city has many needs, and each organelle caters for one or more of those needs.

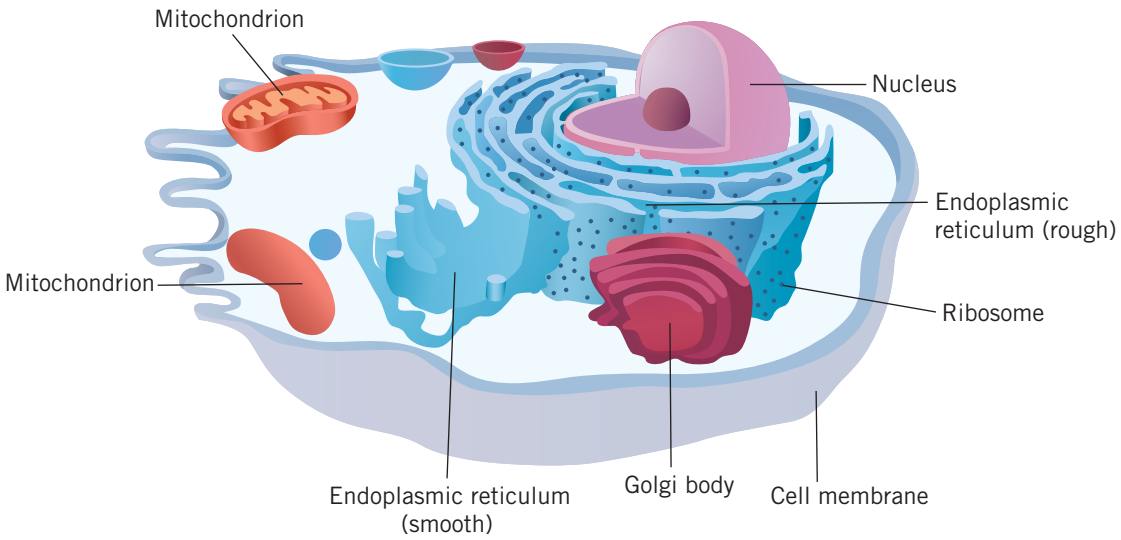


Figure 5.16 A eukaryotic cell with labelled organelles. The cytoplasm is everything inside the cell membrane except for the nucleus.

Nucleus

The nucleus is a large structure that holds the genetic material of a cell. It is like the brain of the cell and controls all its functions. In a city, the nucleus would be the top level of government, which keeps all the plans and blueprints and makes all the important decisions.

The genetic material found in the nucleus is called deoxyribonucleic acid (DNA). DNA is the coded information that makes you who you are and tells every cell what to do. The code has all the instructions that a living organism needs to grow, reproduce and function. A DNA molecule is shaped like a twisted ladder, and this shape is called a **double helix**. In the cell city, DNA would be the plans and laws that the government (the nucleus) uses to keep everything running smoothly.

double helix
a description of the structure of DNA where two strands wind around each other like a twisted ladder

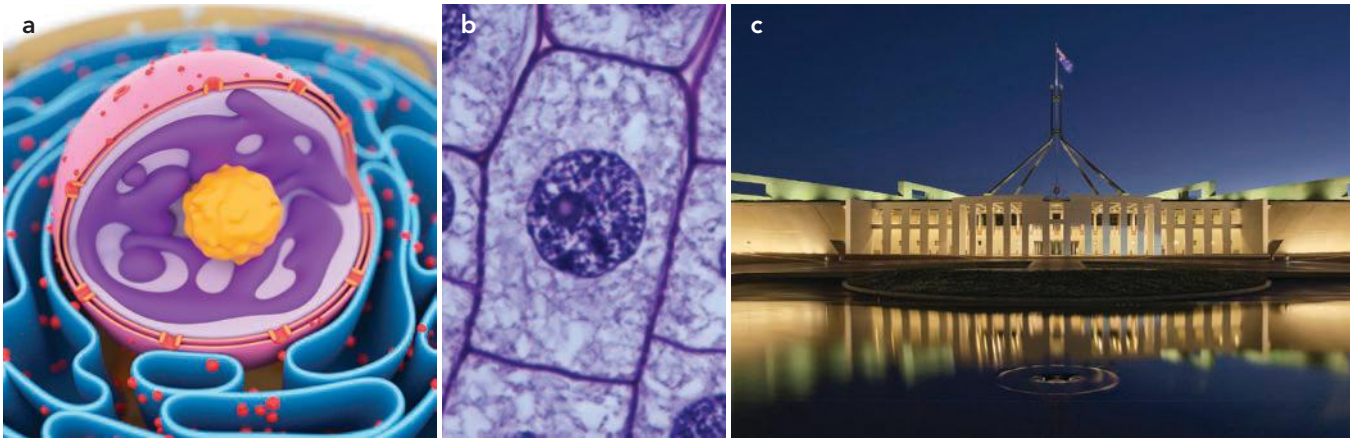


Figure 5.17 (a) Graphic representation of a nucleus. **(b)** An electron microscope image of a nucleus within a plant cell. **(c)** Parliament House, Canberra. The nucleus makes all the major decisions for the cell city.

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Figure 5.18 Graphic representation of part of a DNA molecule

Did you know? 5.3

To the Moon and back

If you stretched the DNA in one cell all the way out, it would be over two metres long. This means if you lined up the DNA from all your cells, it would reach to the Moon and back approximately 1500 times!

Cell membrane

The cell membrane is a thin double layer that separates the inside of the cell from its external environment. It contains molecules such as fats and proteins that play a role in checking what passes through the membrane. The cell membrane is like the border of the cell city with many checkpoints, controlling who enters and leaves.



Figure 5.19 The cell membrane (shown at left) provides 'border security' for the cell.

cytosol
the water-based mixture that fills the cell, containing different molecules; many chemical processes that happen within a cell occur in the cytosol

enzyme
a protein that speeds up chemical reactions in the body

Cytoplasm

The cytoplasm fills the interior of all cells within the cell membrane, with the exception of the nucleus in eukaryotic cells, which is regarded as separate. The cytoplasm has a liquid part, the **cytosol**, which contains the organelles and some other structures. Cytosol is a mixture of water and other molecules that plays a crucial role in many cellular processes. Although it appears mostly transparent under a light microscope, it has a very complex structure, with regions that vary greatly in composition, so parts of it may resemble jelly. Many of the chemical reactions that cells require to function take place between molecules dissolved in the water of the cytosol, controlled by **enzymes**. Many nutrients and other materials may be stored in the cytosol.

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Using the city analogy, the cytoplasm is all of the city except its border and government centre, and the cytosol makes the cell city like Atlantis, an underwater city.

Ribosomes

Ribosomes are very small structures that 'read' the codes sent to them from the DNA and use these to produce proteins that the cell needs to build structures and carry out different functions. Ribosomes would be the factories of the cell city, producing bricks, cars and different tools for the city to use.

ribosome
a structure in a cell that reads genetic information to assemble proteins

mitochondrion
a structure in a cell that converts the energy from food into the form needed by the cell during cellular respiration

cellular respiration
a process that occurs inside the mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

chloroplast
a structure in a plant cell that contains chlorophyll and conducts photosynthesis

photosynthesis
the process by which green plants, some protists and bacteria convert light energy into chemical energy in the form of sugars using carbon dioxide and water, and releasing oxygen

Mitochondria

Mitochondria (singular: **mitochondrion**) are where food is turned into energy, in a process called **cellular respiration**. Cells use this energy for many tasks, such as moving things into and out of the cell, and cell growth, repair and reproduction. The mitochondria can therefore be thought of as the power station of the cell.

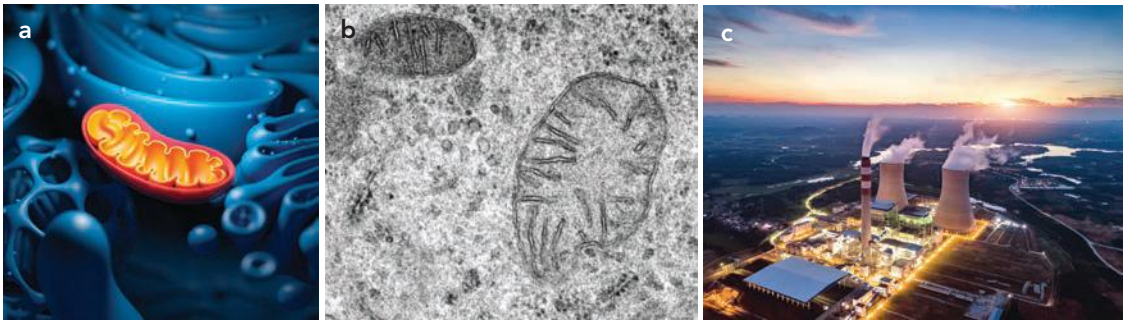


Figure 5.20 (a) Graphical representation of the inside of a mitochondrion. **(b)** An electron microscope image of mitochondria. **(c)** The mitochondria produce energy from food, much like power stations can produce electricity from coal.

Chloroplasts

A **chloroplast** is a special organelle in that carries out **photosynthesis** to produce sugar, providing 99% of the energy used by all living organisms on Earth. Chloroplasts contain a green pigment called chlorophyll, which captures the energy of Sun's light. It is because of this pigment in chloroplasts that plants and some protists appear green. In plants, chloroplasts are found in cells that are exposed to light (e.g. leaf cells) but not in cells of the roots. A chloroplast can be thought of as a solar-powered factory producing food.



Figure 5.21 (a) Graphical representation of the inside of a chloroplast. **(b)** An electron microscope image inside a chloroplast. **(c)** A solar-powered factory

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Other organelles

Table 5.2 gives an outline of some other organelles found in eukaryotic cells.

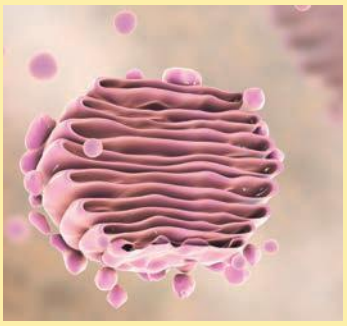
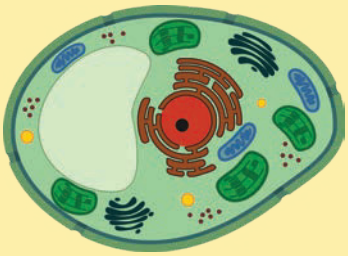
Name, description and types of organisms	Functions	Analogy	Diagram
Endoplasmic reticulum (ER) A folded membrane organelle in the cytoplasm, attached to the nucleus. Rough ER has ribosomes. Smooth ER has no ribosomes. Found in all eukaryotic organisms.	Making and transporting: proteins (rough ER) carbohydrates and fats (smooth ER)	Like a highway that produces and delivers substances to different parts of the cell	 **Figure 5.22** ER (blue) around the nucleus
Golgi body (GB) A folded membrane organelle in the cytoplasm that receives proteins and lipids from the ER and packages them in vesicles (bubble-like containers). Found in all eukaryotic organisms.	Modifying and packaging proteins and lipids and exporting them where required	Like the post office of the cell with 'postal vans' (vesicles) transporting the proteins and lipids	 **Figure 5.23** A Golgi body
Cell wall A rigid and durable structure located outside the cell membrane. It is found in all plants, fungi, some protists, bacteria, and archaea, but not in animal cells.	Protecting the cell and giving support and shape to cells and tissues	Like the brick or stone walls of a castle	 **Figure 5.24** Cell wall (outer dark border)

Table 5.2 Two additional organelles and a cellular structure

Try this 5.5

Organelles

Create a table with three columns. In the left column, list all the organelles covered in this section. In the middle column, provide a bulleted list of their functions. In the right column, include a simple labelled drawing of each organelle.

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Quick check 5.4

1. **State** the terms used for simple and complex cells.
2. **Define** the term 'organelle'.
3. Copy Figure 5.25 and **label** the following organelles: cell membrane, cytosol, nucleus (includes genetic material), ribosomes, mitochondria.

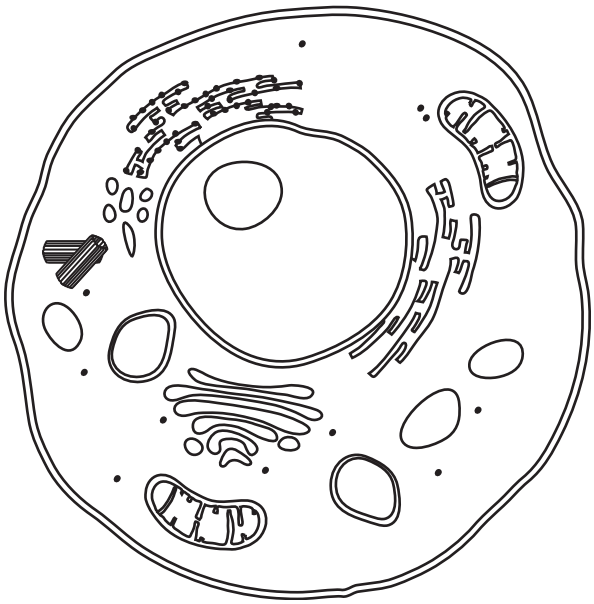
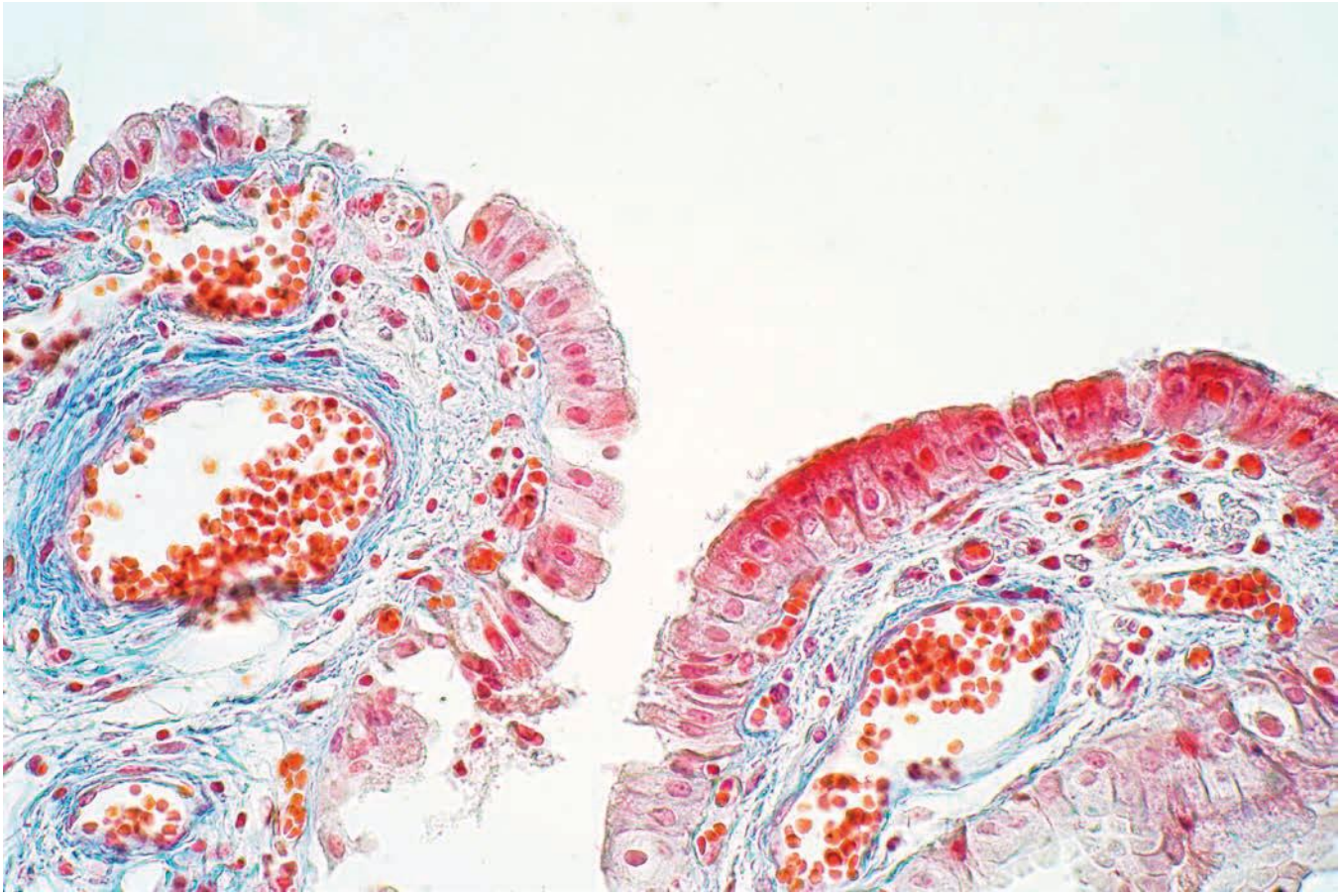


Figure 5.25 Diagram of a eukaryotic cell



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Section 5.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 5.2 questions

Remembering

1. **State** three organelles found in all cells.
2. **State** three organelles found only in eukaryotic cells.
3. **Identify** the correct organelle from each description.
   a. Produces energy for cells
   b. A barrier between the inside and the outside of cells that controls what enters and leaves
   c. Makes proteins using the instructions provided by the genetic material of the cell

Understanding

4. **Explain** the 'government' analogy for the role of the nucleus.
5. **Summarise** why the Golgi body can be thought of as the post office of the cell.

Applying

6. **Compare** the roles of the rough endoplasmic reticulum and the Golgi body. Discuss how they are related and work together and in what order.
7. **Compare** the function of the cell membrane with that of the nucleus.

Analysing

8. **Distinguish** between unicellular and multicellular organisms.
9. **Distinguish** between prokaryotic and eukaryotic cells.

Evaluating

10. Different cells have different numbers of mitochondria. **Propose** a reason why muscle cells contain more mitochondria than skin cells do.



11. **Propose** why cells would contain many ribosomes.

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5.3 Eukaryotic cells

Learning outcomes

At the end of this section, I will be able to:

1. identify structures and organelles common to plant and animal cells as well as their differences.
2. conduct an investigation to observe and record similarities and differences between plant, animal, fungal and bacterial cells using a microscope or images from a microscope.

WORKSHEET Plant and animal cells

Eukaryotic organisms are made of eukaryotic cells and therefore have many organelles in common. Eukaryotes can be found in the kingdoms Animalia, Plantae, Fungi and Protista. In this section, you will look at the differences between the cells of the organisms found in these kingdoms, as well as noting their differences to bacterial cells (prokaryotes).



Figure 5.26 Plants, animals and fungi living together

Animal cells

Animal cells typically contain all the organelles discussed in the previous section except chloroplasts, although the number of each organelle may vary depending on the specific cell type.

For example, muscle cells, which require energy for contraction, have many mitochondria to meet their energy demands. Liver cells, which are involved in detoxification, contain lots of smooth endoplasmic reticulum to process various metabolites. Metabolites are substances involved in or produced by chemical reactions in living organisms. Cells involved in protein secretion, such as pancreatic cells, have higher amounts of Golgi apparatus and rough endoplasmic reticulum to synthesise and package enzymes.

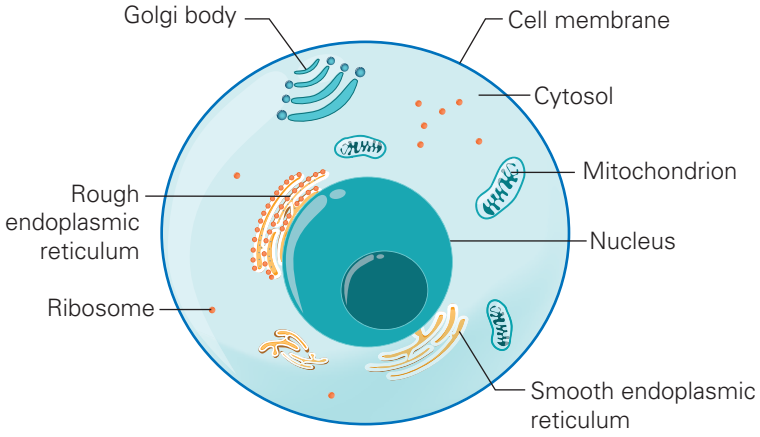


Figure 5.27 An animal cell showing the major structures and organelles

Quick check 5.5

1. **State** five organelles that are found in animal cells.

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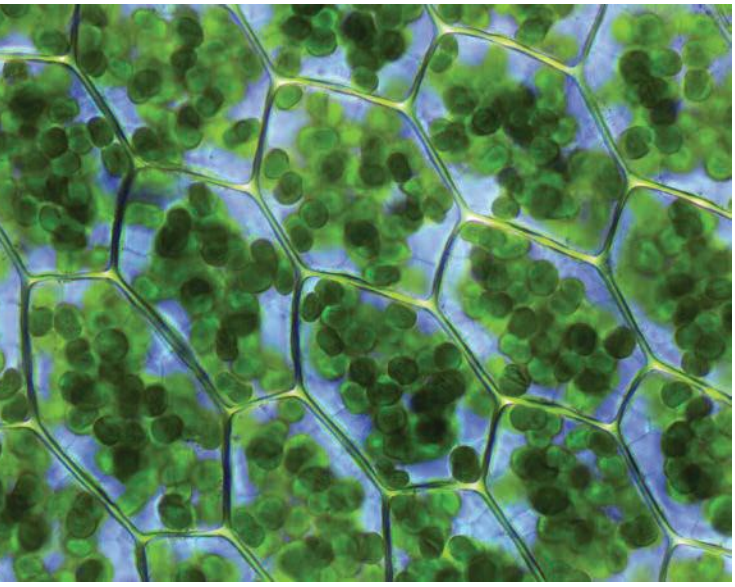


Figure 5.28 Plant cells; the green blobs are chloroplasts. Note the thick cell wall that surrounds each cell.

Plant cells

Plants are different from most other eukaryotic organisms in many ways. Most notably, they can make their own food in a process called photosynthesis. This difference means that plants have an organelle that animals and fungi lack: chloroplasts (see Figure 5.28). These solar-powered factories enable plants and some protists to make their own food. Some bacteria contain structures that are similar to chloroplasts. Animal cells do not have chloroplasts, and they need to take in food from other organisms. Plants and other photosynthetic organisms produce nearly all the organic material on Earth for growth and energy.

Because plants do not need to move, they lack a skeleton and muscles, but they still need to be able to support their weight so they can grow tall, towards the light from the Sun. This is why plant cells have a **cell wall**. The cell wall is a rigid structure that surrounds each cell (sitting outside the cell membrane) and provides shape and support for the plant. The cell wall is made of a substance called cellulose. Fungal cells have cell walls made of a different material: chitin. Some protists and bacteria also have cell walls of various materials.

cell wall
a rigid structure that surrounds each plant cell, shaping and supporting the cell

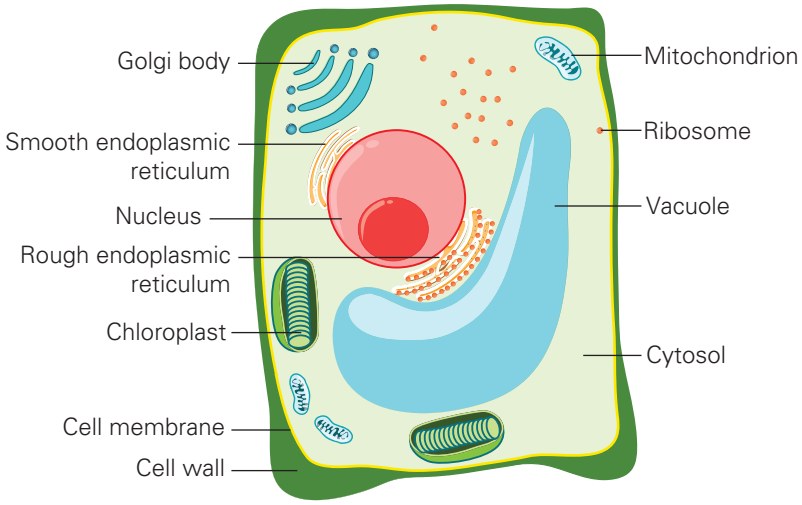


Figure 5.29 A plant cell showing the major structures and organelles

vacuole
a structure in a cell that stores water and nutrients

Plant cells also contain an organelle called a **vacuole**. This organelle stores water and other nutrients for the plant. It also works with the cell wall to help support the plant and give it shape. If you have ever forgotten to water your plants at home, you might have noticed that they droop and wilt, becoming floppy, and if not watered they will start to die. This is because the vacuoles in each cell lose so much water that the cells become flaccid, and so the plant cannot hold its shape.

Animal cells also contain vacuoles, but they are much smaller and are mainly used for storage of nutrients. The cells of some fungi, protists and bacteria may also have vacuoles.

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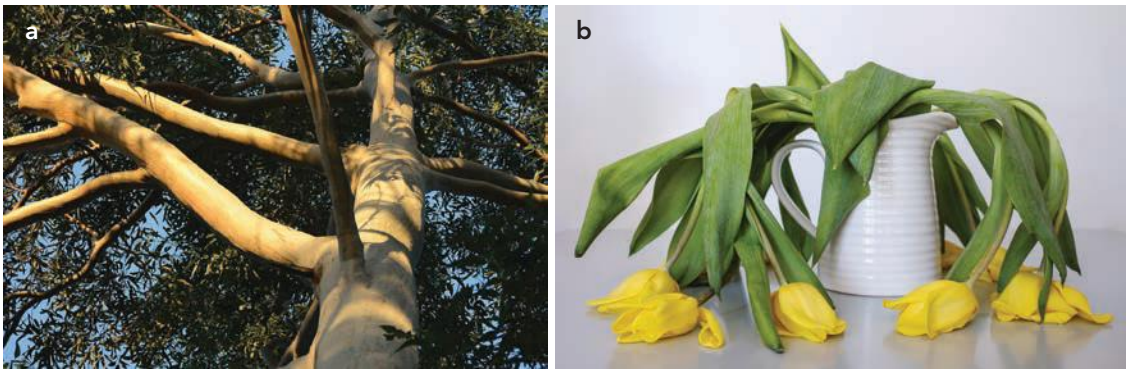


Figure 5.30 (a) Eucalyptus trees grow as tall as they do because of the rigid cell wall that surrounds each of their cells. **(b)** A thirsty plant: the vacuoles are no longer full of water and so they cannot help to support the plant in standing upright.

Try this 5.6

Cell exploration

Use the internet to find a free online interactive three-dimensional model that will allow you to understand the scale and scope of cells. You may want to consider the Cell Explorer by SCoPE or Cell Size and Scale by Learn. Genetics.

Distinguishing animal cells from plant cells

You have seen that animal cells and plant cells have many organelles in common, as they are both eukaryotic cells that have many processes in common. However, you have also learned about the additional organelles that plant cells have due to their different structures and functions.

It is generally easy to identify plant cells under the microscope (see Figure 5.31b), because the cell wall usually gives them a shape with rigid straight lines and a thick outline, whereas animal cells have a less uniform shape and a much thinner outline (see Figure 5.31a).

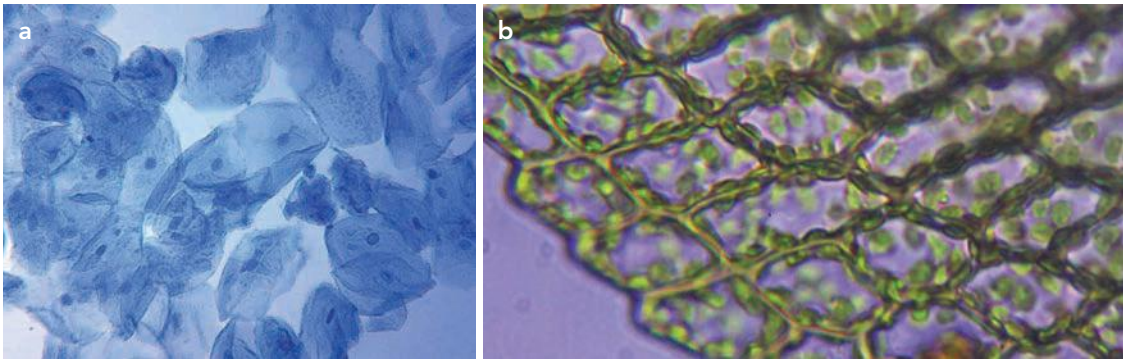


Figure 5.31 (a) Human cheek cells stained blue. **(b)** Leaf cells from moss

Quick check 5.6

1. **Name** the organelles or structures in a plant cell that an animal cell does not have.
2. **Explain** why plant cells have each of these 'extra' structures.

WIDGET
Eukaryotic organelles

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Practical skills 5.2

Observing and comparing plant, animal, fungal and bacterial cells under a microscope

Aim

To observe the characteristics of plant, animal, fungal and bacterial cells.

Materials

- light microscope
- glass slides and cover slips
- toothpick
- onion and celery
- iodine solution
- ripe and unripe bananas
- prepared fungal cell slides (or yeast)
- prepared animal cell slides
- prepared bacterial cell slides

Procedure

1. Prepare wet mounts:
   - **a.** Peel a translucent (partially see-through) piece of tissue from the onion.
   - **b.** Place the piece of onion tissue on a glass slide and add a drop of iodine solution.
   - **c.** Cover the slide with a cover slip, using your wet mount technique.
   - **d.** Repeat steps **a–c** for the celery.
   - **e.** Use the toothpick to collect some ripe banana cells and smear them as thinly as you can across a glass slide.
   - **f.** Add a drop of iodine solution and then cover the slide with a cover slip.
   - **g.** Repeat steps **e–f** for the unripe banana.
2. Observe the cells: Starting with the microscope on the lowest magnification, turn the coarse focus knob to move the stage away from the objective lens. Place your first slide on the stage and focus using the coarse focus knob. Once focused, turn to the next objective lens. Use only the fine focus knob to focus now. Once focused, move to the highest magnification and again focus using the fine focus knob.
3. Draw a diagram:
   - **a.** Using a pencil, draw diagrams of an onion cell, a celery cell, a ripe banana cell, an unripe banana cell, four animal cells, fungal cells and bacteria cells from the prepared slides.
   - **b.** Using a ruler and labels at the side of the diagram, label all the organelles you can see.
   - **c.** Record the name of the specimen and the magnification of the drawing, and determine the cell size.

Results

Your results will be in the form of diagrams for:

- four plant cells (onion, celery, ripe banana, unripe banana)
- four animal cells from the prepared slides
- fungi cells from the prepared slides
- bacteria cells from the prepared slides.

Discussion

1. Explain why stains are needed.
2. Compare the onion and celery cells: what similarities and differences did you observe?
3. Compare the ripe and unripe banana cells: what similarities and differences did you observe? Can you explain the differences?
4. What characteristics did you observe in the plant cells? In the animal cells? What did they have in common? Explain why there are differences.
5. Are the plant and animal cells all the same size? If there are differences, can you explain why?
6. What characteristics did you observe in the bacterial cells? In the fungal cells? What did they have in common? Explain why there are differences.

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Fungi

Fungi share characteristics with both plants and animals, and the majority are multicellular.

Fungi, like animals, do not photosynthesise, which means they must digest organic material from other organisms in order to gain nutrients. Fungal cells therefore don't have chloroplasts like plant cells do. Some may look a bit like plants in their form and growth, and they have a cell wall, but their cell wall is made of chitin, not cellulose.

The main body of a fungus is called the mycelium. This is a large network of small filaments, called hyphae, that can stretch for over 10 kilometres! You don't often see hyphae, as they are very small, and you only really notice a fungus when it develops a fruiting body when conditions are perfect. This fruiting body can be seen as a mushroom or a toadstool, a truffle or a puffball. This is why you often see mushrooms appear soon after heavy rainfall. The fungus makes these fruiting bodies to produce spores to reproduce.

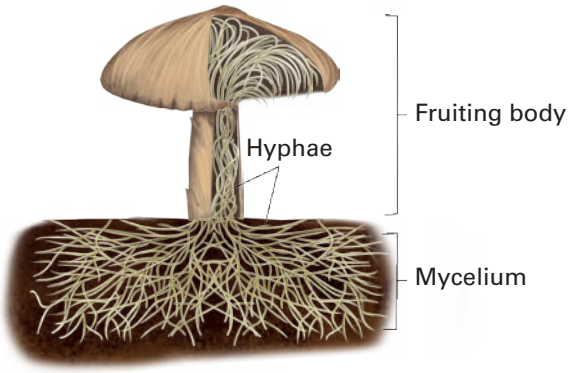


Figure 5.32 Diagram of a multicellular fungus, a mushroom



Figure 5.33 Fungi: **(a)** toadstool, **(b)** mould, **(c)** microscope view of yeast, a single-celled fungus

Did you know? 5.4

Fungi and beetles

The cell wall of fungal cells is made of chitin, and this is the same material that makes up the exoskeleton of insects such as beetles.



Figure 5.34 Beetle exoskeletons and fungal cell walls are made of the same substance: chitin.

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Quick check 5.7

1. **State** whether fungi are prokaryotic or eukaryotic.
2. **Contrast** the cell wall of a plant with the cell wall of a fungus.
3. **Explain** the function of the cell wall.

Protists

Protista is a kingdom that consists mostly of unicellular organisms; however, there are a few multicellular examples, such as kelp. They are eukaryotic, so they contain the organelles that you learned about in the previous section. However, scientists have changed the classification of many of these organisms several times because they display characteristics of both plants and animals. All **protists** need to live in a moist environment and so are very common in most aquatic environments. If you look at a sample of pond water under the microscope in the warmer months of the year, you will likely see many types of protists, such as *Euglena* and amoebas. Each of these types of protists is slightly different in structure, depending on its function.

protist
a eukaryotic organism that is part of the kingdom Protista

DEPTH STUDY IDEA
What are the challenges in classifying protists?

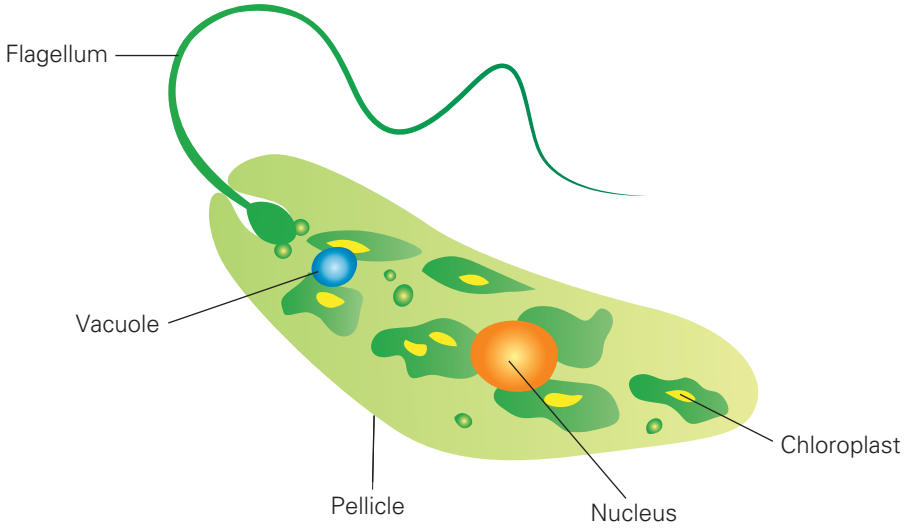


Figure 5.35 *Euglena* have chloroplasts, which are typically considered a plant cell organelle, but they also have a flagellum, which is more typical of an animal cell.

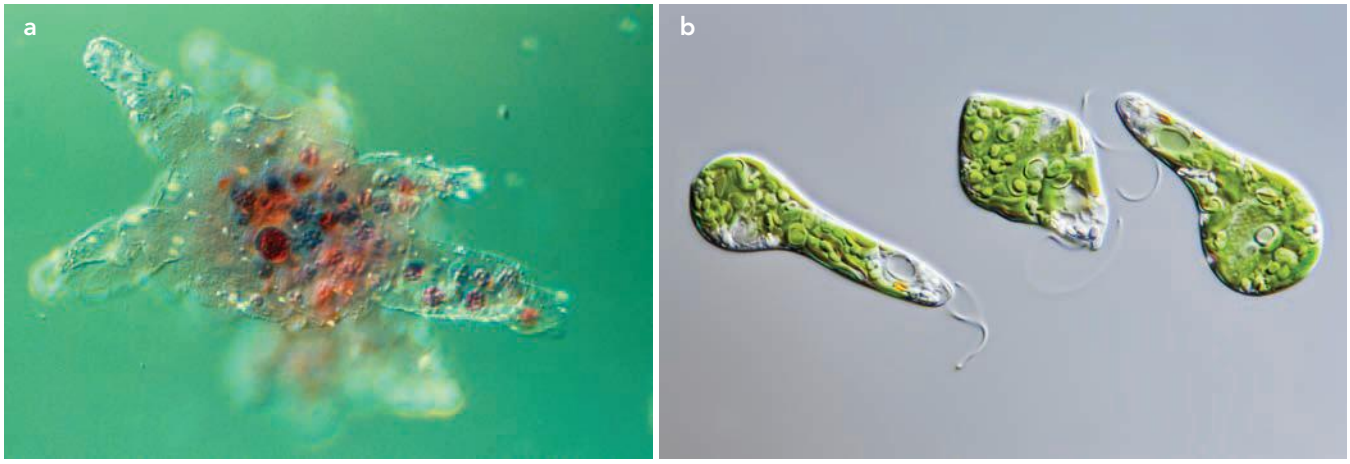


Figure 5.36 Protists: amoeba **(a)**, *Euglena* **(b)**

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Section 5.3 review

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Section 5.3 questions

Remembering

1. **State** the organelle involved in photosynthesis.
2. **Name** the three key differences between plant cells and animal cells in terms of their organelles or cellular structures.
3. **List** three examples of protists.

Understanding

4. **Outline** the two parts of a plant cell that provide support and explain how they work together.
5. **Explain** how fungal cells are similar to animal cells in terms of where they get their food and energy.
6. **Summarise** the steps you need to take when preparing a wet mount.

Applying

7. a. **Name** the organelles labelled A to E in the eukaryotic cell shown in Figure 5.37.
   b. What type of cell is shown in Figure 5.37? **Explain** your answer.

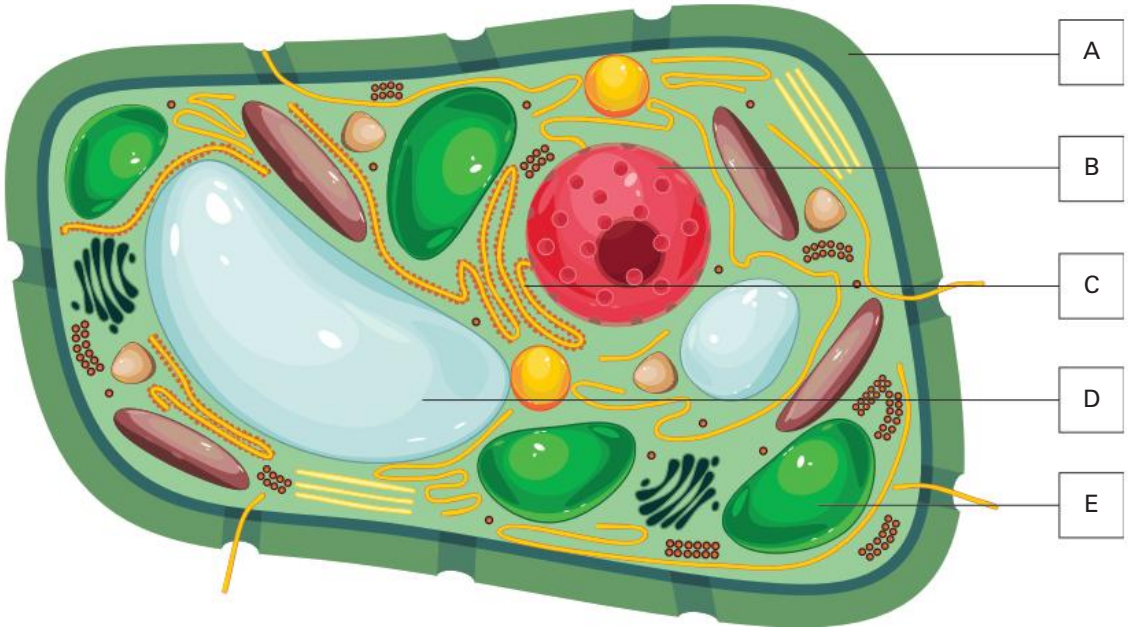


Figure 5.37 Eukaryotic cell

8. **Identify** where you are most likely to find protists.

Analysing

9. a. **Compare** an animal cell to a fungal cell in terms of the cell's structure and organelles. You may choose to present the information in a Venn diagram.
   b. **Compare** a plant cell to a fungal cell in terms of the cell's structure and organelles. You may choose to present the information in a Venn diagram.

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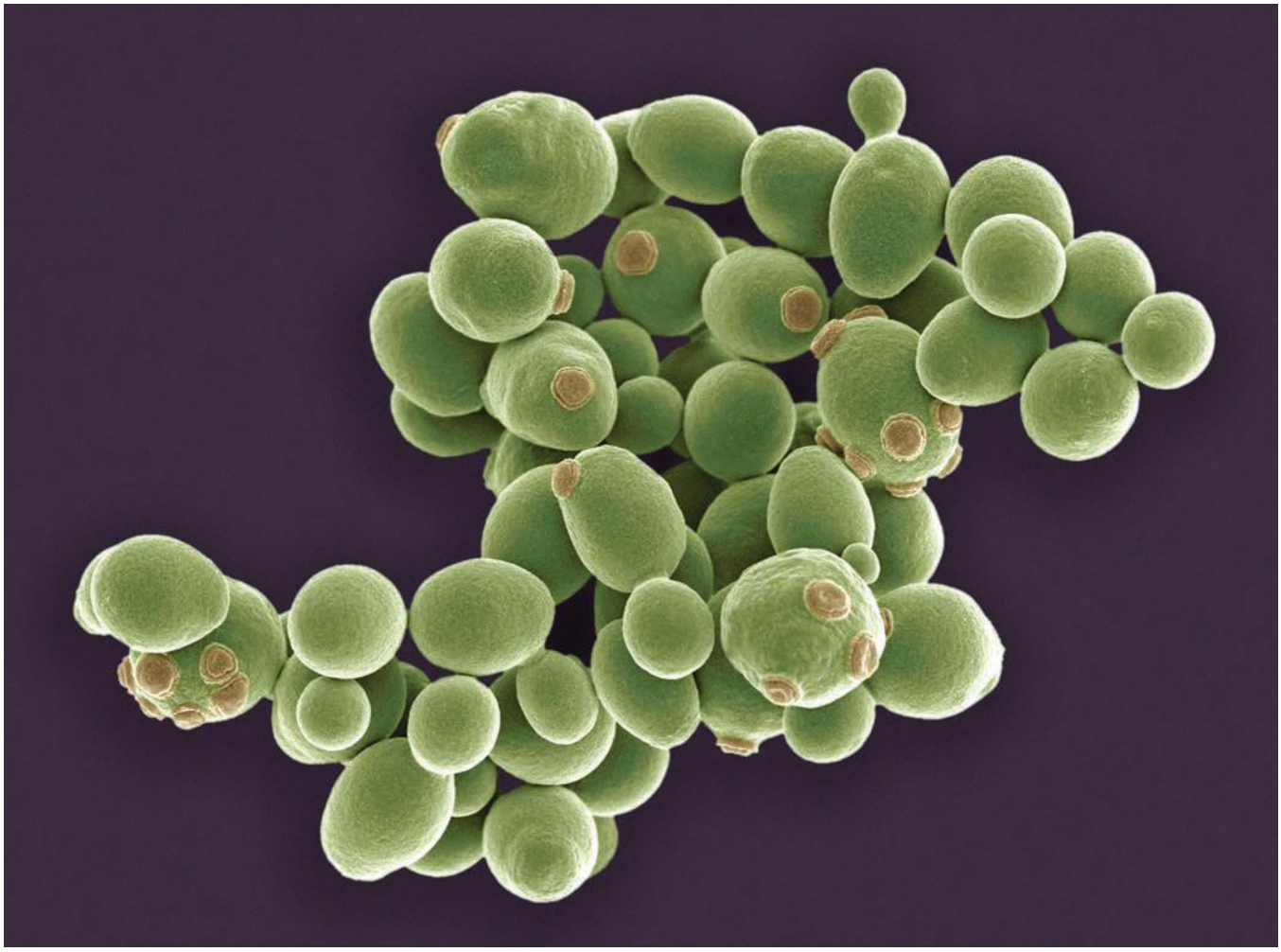
10. Yeast are unicellular eukaryotic cells and belong to the Fungi kingdom. A student conducted an experiment to test the effect of temperature on the activity of yeast, which will produce a gas when added to a solution of sugar in water. The student placed 2 g of yeast and 10 g of sugar into a glass apparatus full of water, designed to trap any gas produced in a narrow-closed vertical tube at the top. The amount of gas can be measured by the height of the column of gas that collects in the tube. They did the experiment three times with the apparatus containing water at three different temperatures and measured the height of the column of gas produced after 1 minute.

Temperature (°C)	Height of column of gas produced in the tube (mm)			
	Trial 1	Trial 2	Trial 3	Average
10	60	64	62	62
30	102	98	100	100
60	20	14	17	17

a. Using the student's results, **assess** the effect of temperature on yeast function.
b. **Identify** the optimum temperature for yeast activity.
c. **Suggest** the effect that an even higher temperature, such as 100°C, would have on the yeast being tested.

Evaluating

11. Propose reasons why protists are difficult to classify.



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5.4 Specialised cells

Learning outcomes

At the end of this section, I will be able to:

1. describe the role of specialised cells in multicellular organisms and explain the need for them.
2. describe the relationship between the structure and function of specialised cells.

WORKSHEET Specialised cells

In multicellular organisms, various **specialised cells** perform specific functions to ensure proper body function. Unlike unicellular organisms, where a single cell must carry out all life processes, multicellular organisms have cells that are differentiated to carry out particular tasks. These specialised cells play important roles in multicellular organisms by performing specific functions that contribute to the organism's overall survival. Specialised cells have structures that relate to their function. These structures help to identify them.

In this section, the examples will be taken from the human body, but it should be noted that all multicellular organisms have specialised cells.

specialised cell a cell that has undergone structural changes that allow it to perform a specific task

tissue a group of similar specialised cells that work together to carry out a specific function; different tissues make up organs

organ two or more types of tissue acting together to perform a specific role

zygote a fertilised egg cell

differentiation the process by which stem cells become specialised

embryo a fertilised egg in the early stages of growth and differentiation

stem cell a cell that can develop into many different types of cells

Tissues and organs

Specialised cells are organised into **tissues**, which are groups of similar cells working together to perform a specific function. These tissues are further organised into **organs**, which are structures composed of multiple tissue types that work together to carry out complex functions.

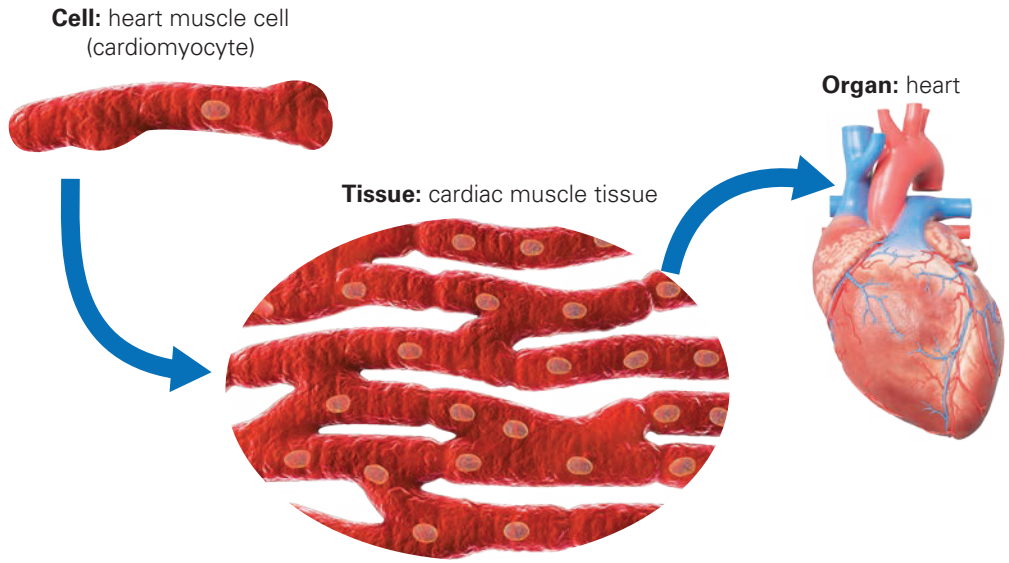


Figure 5.38 Heart muscle cells are specialised cells that form cardiac muscle tissue which, together with other tissues, make up the organ called the heart.

Stem cells

All cells in the body come from a single fertilised egg known as a **zygote**, which undergoes division and **differentiation** into different specialised cells, forming an **embryo**. Cells that have the potential to turn into any other type of cell are called **stem cells**. Once a stem cell differentiates into a specific cell type, it can only replicate into cells of the same type.

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Stem cells don't only exist in embryos. There are still some stem cells in your body today that are ready to turn into any type of cell you need. They can be found in different tissues around your body and are activated by certain triggers, such as an injury. For example, if you cut yourself, stem cells below the layers of your skin turn into skin cells to help replace the damaged cells. This replacement is not always perfect and, if the damage is too extreme, it can leave a scar.

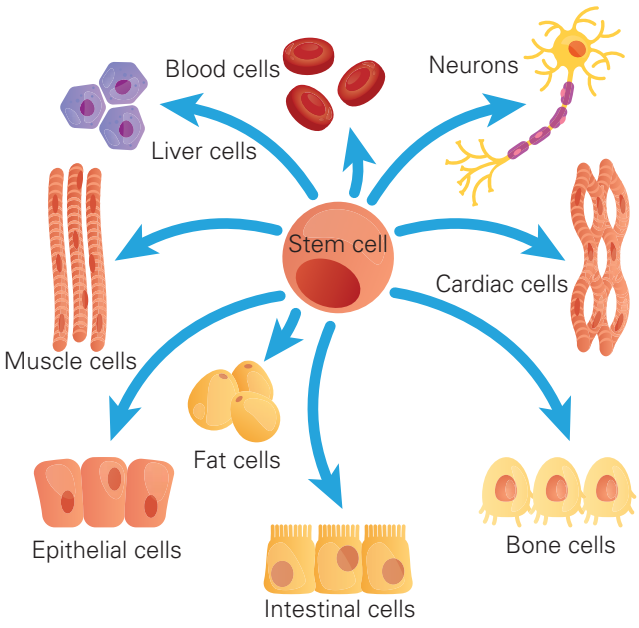
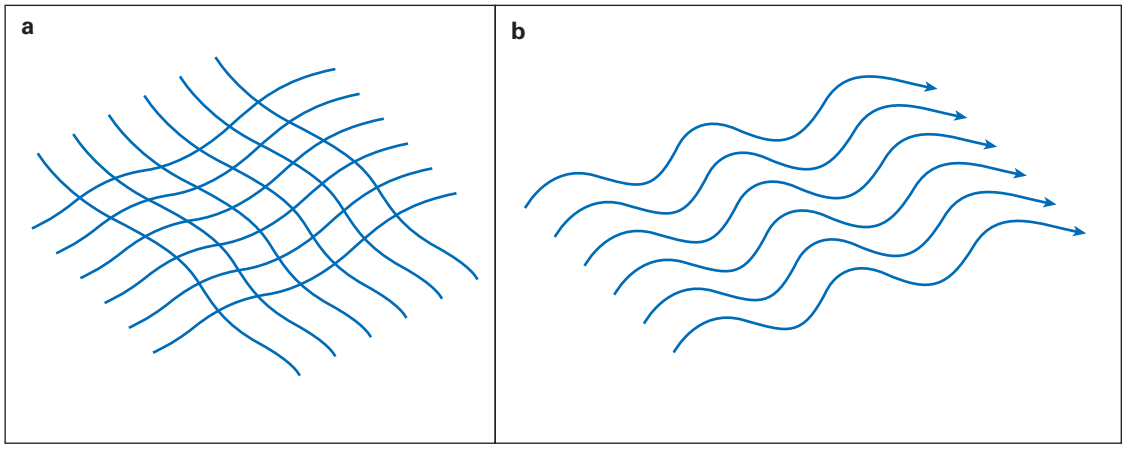


Figure 5.39 Embryonic stem cells can become many types of specialised cells in a process known as cell differentiation.

The tissue that makes up a scar is made of the same material as normal skin, a protein called collagen. In normal tissue, collagen has a cross-weave structure where the fibres are oriented randomly (Figure 5.40a). However, in scar tissue, it has a parallel alignment where all fibres run in the same direction (Figure 5.40b). There is a simple reason for this: open wounds are dangerous and need to be healed as soon as possible. Parallel alignment is the faster way of repairing this tissue.



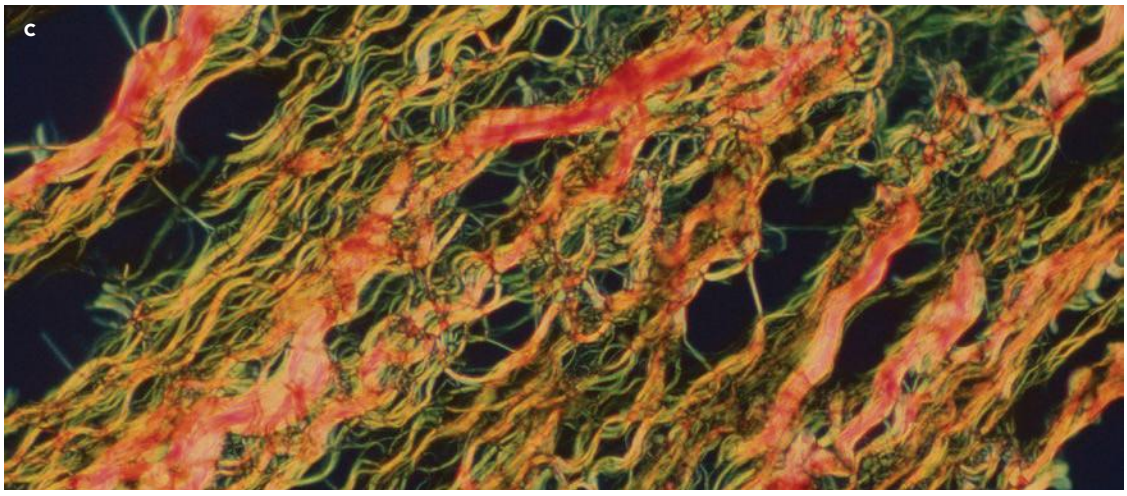


Figure 5.40 Collagen fibre structure in normal tissue **(a)** and scar tissue **(b)**. **(c)** Scar tissue.

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Explore! 5.2

INVESTIGATION

Stem cell therapy

Because stem cells can turn into any type of cell, they have the potential to be used in treating and curing many types of diseases and conditions. These treatments are known as stem cell therapy.

1. Research the blood cancer called leukaemia.
2. Investigate how stem cell therapy is used to treat leukaemia and summarise your findings.

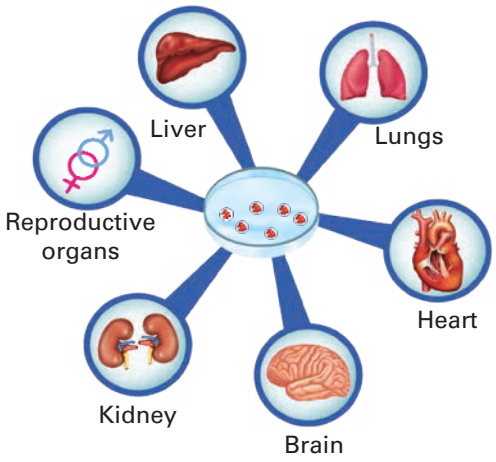


Figure 5.41 A stem cell can replicate and differentiate into any of the 200-plus cell types in the body, therefore forming all our organs.

Did you know? 5.5

Growing synthetic organisms

In 2022, researchers grew fully synthetic (no sperm or egg cells were involved) mouse embryos outside the womb using stem cells. The embryos were able to grow to day 8.5, developing the beginnings of a brain, intestinal tract, and a beating heart. This breakthrough will tell scientists a lot about embryo development and organ growth, including how to grow whole replacement organs from scratch.

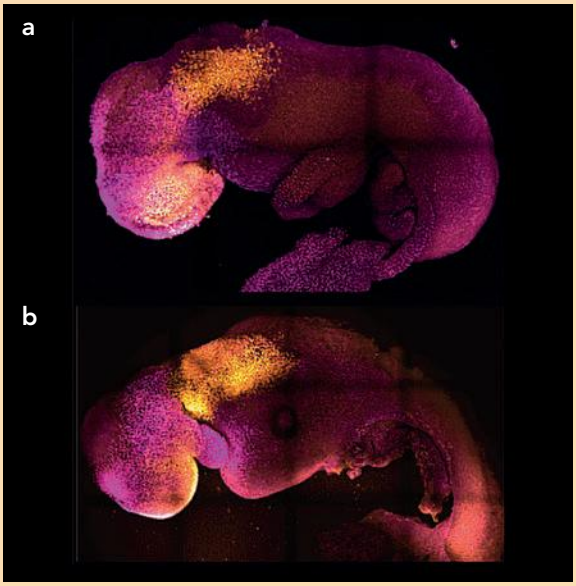


Figure 5.42 A naturally formed mouse embryo **(a)** compared with a synthetic embryo grown using stem cells **(b)**

Quick check 5.8

1. Multicellular organisms are often made up of specialised cells. **Describe** what the term 'specialised cells' means.
2. **Use** the term 'differentiation' to explain how specialised cells form.
3. **Describe** what stem cells are and their use in medicine.

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Examples of specialised cells

structure a physical part of an object

function the job that an object does

biconcave concave on both sides

neuron a nerve cell

Even though most of our cells contain the same basic components, the different types of specialised cells within our bodies all have certain features or **structures** that allow them to perform a specific **function**. A structure is any physical part of an object, and a function is an activity that the structure helps the object to complete.

Some examples of how specialised cells are adapted to their function are provided in Table 5.3.

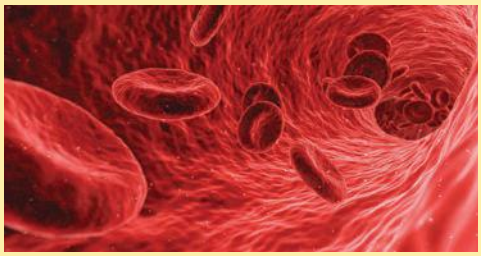
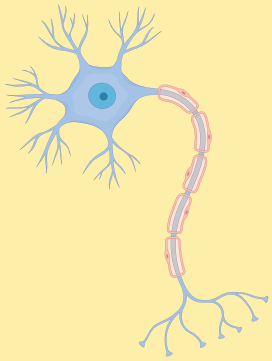
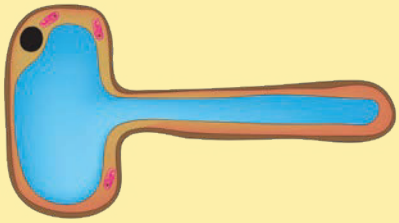
Specialised cell	How structure relates to function
Red blood cell  **Figure 5.43** Red blood cells flowing through a blood vessel	Red blood cells have a **biconcave** shape, which increases their surface area for oxygen transport and allows them to deform as they pass through narrow capillaries. They lack a nucleus to maximise space for haemoglobin, the oxygen-carrying molecule. As they do not have a nucleus, they cannot undergo cell division, and so all red blood cells are produced in the bone marrow. Your red blood cells are replaced every 120 days.
Neuron  **Figure 5.44** A neuron	Nerve cells or **neurons** allow all the parts of your body to work together, by transferring signals to and from your brain to each part of your body via the nervous system. They are long, thin cells that connect to each other via highly branched ends. They have long axons, which are specialised to carry electrical signals over long distances at very fast speeds. The longest nerve cell in your body is your sciatic nerve, which stretches from the bottom of your spine to your big toe.
Intestinal cell  **Figure 5.45** Intestinal cells in the small intestine	Intestinal cells have microvilli, tiny hair-like projections that increase the surface area for nutrient absorption.
Root hair cell  **Figure 5.46** Root hair cell	Root hair cells of plants have a large surface area sticking out into the soil, which increases water and nutrient absorption.

Table 5.3 How structure is related to function in some specialised cells

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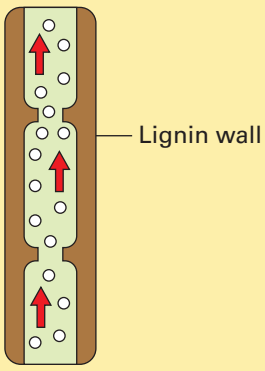
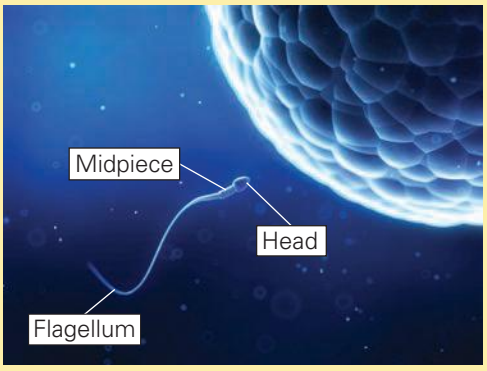
Specialised cell	How structure relates to function
Xylem cell  **Figure 5.47** Water flowing through xylem cells	Xylem cells are long and form continuous tubes from roots to leaves, allowing water flow. They are strong and lack cytoplasm, maximising water movement.
Sperm cell  **Figure 5.48** A sperm swimming towards an egg	Sperm cells carry half the genetic information of a normal human body cell. Their purpose is to combine with an egg cell in a process known as fertilisation, which is the first step of reproduction. This means that the sperm cells must be able to move. That is why they have a specialised tail, called a flagellum, which beats in a corkscrew motion and allows the sperm cell to swim. Sperm cells have many mitochondria in their midpiece, to provide energy for fast movement. Their head also contains an acrosome, a sac of digestive enzymes which digest through the membrane of the egg cell, allowing the sperm nucleus to enter.

Table 5.3 *(continued)*

Try this 5.7

Cells and classification in context

1. Choose an organism to research. This could be a plant, animal, fungus, protist or bacterium.
2. Research the classification of the chosen organism, including its kingdom, phylum, class, order, family, genus and species.
3. Describe how the chosen organism embodies all the characteristics of living things according to MRS GREN:
   - **a.** Movement. Explain how the organism moves or exhibits motility, if applicable.
   - **b.** Respiration. Describe how the organism obtains and uses energy.
   - **c.** Sensitivity. Explain how the organism responds to stimuli in its environment.
   - **d.** Growth. Describe how the organism grows and develops over its lifespan.
   - **e.** Reproduction. Explain how the organism reproduces to create offspring.
   - **f.** Excretion. Describe how the organism eliminates waste products.
   - **g.** Nutrition. Explain how the organism obtains and processes nutrients for energy and growth.

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Practical skills 5.3

Specialised cells

Be careful

Ensure that you carry the microscope appropriately. Carry it with one hand holding the arm and one hand under the base. Do not make big changes in magnification, so the glass slide does not get damaged.

Aim

To observe specialised cells under the microscope

Materials

- prepared slides of blood
- prepared slides of neurons
- prepared slides of blood vessels
- compound microscope
- transparent ruler

Procedure

Part A: Estimating the field of view

1. Place the transparent ruler on the stage of the microscope.
2. Starting on the lowest magnification, focus on the ruler.
3. Measure the diameter of the area you can see under the microscope (field of view) using the ruler.
4. Record this measurement (in mm) in the field of view (FOV) table.
5. Calculate the FOV diameter in micrometres (μm) by multiplying the FOV in millimetres by 1000.
6. Calculate the FOV for each of the higher magnifications by repeating steps **2–5**.

Part B: Estimating the size of the object

7. Place your first prepared slide on the stage of the microscope.
8. Focus on the object using the lowest-power lens.
9. Estimate how many of the cells will fit in a straight line across the middle of the FOV.
10. Divide the total FOV diameter that you have already calculated by the estimated number of cells that will fit across the FOV.
11. Record your estimated diameter for the object in the results table.
12. Draw a scientific drawing of the cell you are observing.
13. Repeat steps **8–12** for each slide.

Results

Copy the following tables and use them to record your observations and measurements.

Magnification (ocular lens × objective lens)	FOV diameter (mm)	FOV diameter (μm) (mm × 1000)

Cell	Scientific drawing and magnification	Number of times cell would fit across the FOV	FOV diameter	Estimated diameter of object (FOV/ number of times object fits across)
Blood				
Neuron				
Blood vessel				

continued …

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Discussion

1. Describe how the size and shape of each of the cells you observed benefits their function.
2. Assess the accuracy of your estimated sizes.
3. Suggest a way of improving your size estimates.

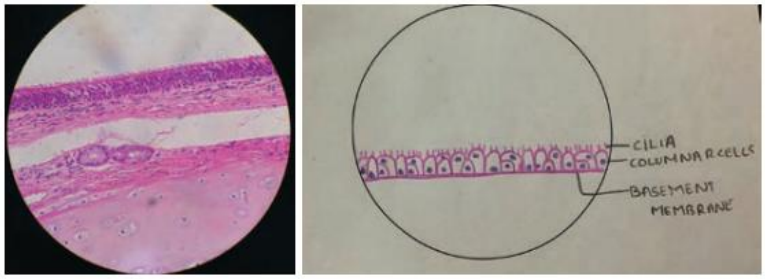


Figure 5.49 A prepared slide and drawing of ciliated columnar epithelium

Quick check 5.9

1. **Identify** the following specialised cells from their description:
   - **a.** a type of cell found in the small intestine, with a border of microvilli that increase the surface area for absorption
   - **b.** a type of cell found in the nervous system, responsible for transmitting electrical signals
   - **c.** a type of plant cell found in the roots, responsible for absorbing water and nutrients from the soil

Section 5.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

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Section 5.4 questions

Remembering

1. **Define** the term 'differentiation'.
2. **Name** three examples of specialised cells in the human body.

Understanding

3. **Explain** why specialised cells are important for the functioning of multicellular organisms.
4. **Describe** how the structure of a root hair cell is adapted to its function.

Applying

5. **Design** a specialised cell and describe its structure and function. Consider how its structure helps it to perform its specific role.
6. **Explain** how the shapes of various specialised cells help them to carry out their function within the body.

Analysing

7. **Analyse** the structure of a cell in the small intestine that allows it to efficiently absorb nutrients from digested food.

Evaluating

8. **Discuss** the ethical considerations surrounding the use of stem cells in medical research and treatment.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
5.1	outline how the microscope has contributed to understanding cell structure.	11
5.1	identify the parts of a light microscope and how to use it.	2
5.1	draw single-celled organisms from images produced by a microscope.	3
5.1	outline cell theory.	9
5.2	distinguish between prokaryotic and eukaryotic cells.	14
5.2	identify common cell structures and organelles.	4b, 11
5.2	describe the functions of the cell membrane, cytoplasm, nucleus containing DNA, mitochondria and chloroplasts.	4a, 5, 13
5.2	identify cellular respiration in mitochondria, and photosynthesis in chloroplasts, as important processes in specialised organelles.	5, 13
5.3	identify structures and organelles common to plant and animal cells as well as their differences.	11
5.4	describe the role of specialised cells in multicellular organisms and explain the need for them.	8
5.4	represent the arrangement of specialised cells in tissues and in organs.	16
5.4	describe the relationship between the structure and function of specialised cells.	8, 15

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Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. Of the four kingdoms – Animal, Plant, Fungi, Protist – **state** which have unicellular organisms and which have multicellular organisms.
2. **Name** the common components of the monocular light microscope.
3. **Illustrate** a single-celled organism with labelled features.

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Understanding

4. a. **Recall** the role of the following organelles in the cell.

- **i.** Nucleus
- **ii.** Cytoplasm
- **iii.** Ribosomes

b. Using Figure 5.50, **identify** the organelles listed in part **a**.

c. Is the cell shown in Figure 5.50 a plant cell or an animal cell? **Explain** how you know.

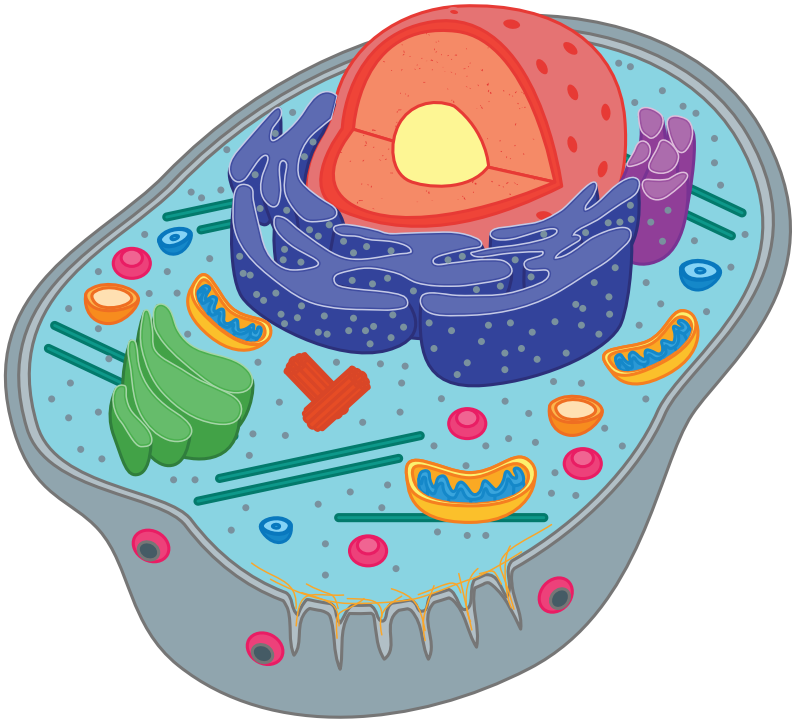


Figure 5.50 Eukaryotic cell

5. **Recall** the role of the mitochondria in cells and why they are so important.

6. **Identify** the type of cell that can turn into any other type of cell.

7. **Identify** the type of microscope that needs to be used to view objects smaller than a cell.

8. **Summarise** the relationship between cells and living organisms in terms of structure and function, saying where living organisms get their cells from.

9. **Recall** the four aspects of modern cell theory.

Applying

10. After going on holiday, you come home to find that all your plants are wilted. **Explain** why this has occurred, referring to parts of the cell.

11. Use 'yes', 'no' or 'some' to **summarise** the organelles or structures that are found in each cell type in the table below. 'Some' indicates that some organisms in that group have that organelle or structure.

	Animals	Plants	Fungi	Bacteria
Nucleus				
Cell wall				
Large vacuole				
Cytosol				
Cell membrane				
Chloroplast				

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12. **Explain** how improvements in microscope technology have helped scientists better understand cells.
13. **Explain**, using an analogy, the purpose of cellular respiration and photosynthesis to a cell, and state which organelles are involved in these processes.

Analysing

14. Draw a Venn diagram to **compare** prokaryotic cells (such as bacteria) with eukaryotic cells (such as plant and animal cells).
15. Choose a specialised cell, such as a nerve cell or muscle cell, and **describe** how its structure helps it perform its function.
16. **Create** a diagram explaining the cell/tissue/organ levels of organisation in the human body, showing (for example) a heart muscle cell, heart muscle tissue and a heart, correctly in each level. You may choose to use an example of a different organ.

Evaluating

17. **Evaluate** the use of models when explaining the structure of the cell.
18. **Discuss** why specialised cells are important in multicellular organisms.
19. Two prepared slides of plant slides have lost their labels and become mixed up. One is supposed to be of root hair cells and the other of xylem cells. **Explain** and **justify** what features you would look for in the cells on each slide in order to distinguish which slide is which.

Data questions

The human body is composed of trillions of cells that work together to carry out various functions necessary for life. Estimating the total number of cells in an adult human body is a challenging task, but researchers have made significant progress in recent years. By studying individual organs and tissues and using various methods, such as microscopy and cell culture, scientists have developed estimates for the number of cells in the human body, divided by cell type. These are shown in Figure 5.51.

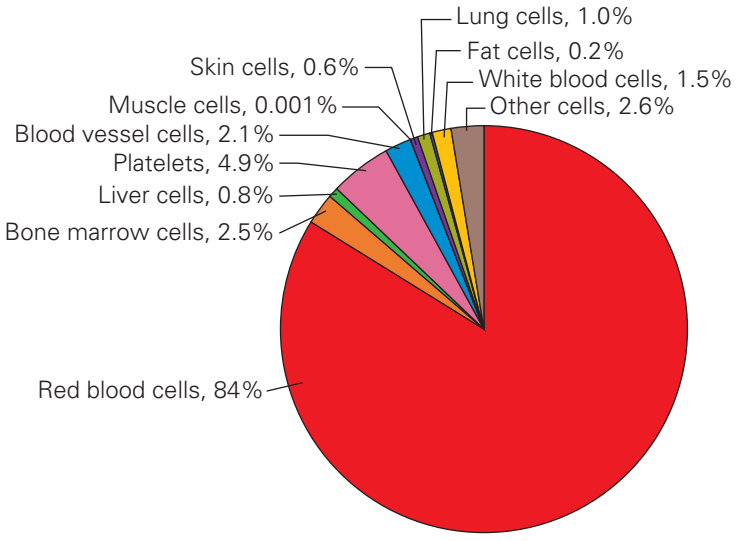


Figure 5.51 Estimated cell numbers in an average adult human, divided by cell type

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Cell turnover refers to the ongoing process of breaking down and recycling cellular components like proteins, fats and organelles, while also creating new molecules to build fresh cells. This continuous renewal is essential for maintaining good health and proper bodily function. The speed of cell turnover varies depending on the specific cell, tissue and organ. For instance, skin cells have a short lifespan of a few weeks, while liver cells can endure for years.

Figure 5.52 below shows the mean lifespan of different cell types and their total mass in an adult human.

1. **Identify** the most common cell type, using Figure 5.51.
2. **Identify** the least common cell type, using Figure 5.51.
3. If the estimated total number of cells in an adult human is 30×10^{12} (30 trillion), **calculate** the total number of erythrocytes (red blood cells), using Figure 5.51.
4. **Identify** the cell type that has the highest total cell mass, using Figure 5.52.
5. **Identify** the cell type that has a mass turnover of 0.08 grams per day, using Figure 5.52.

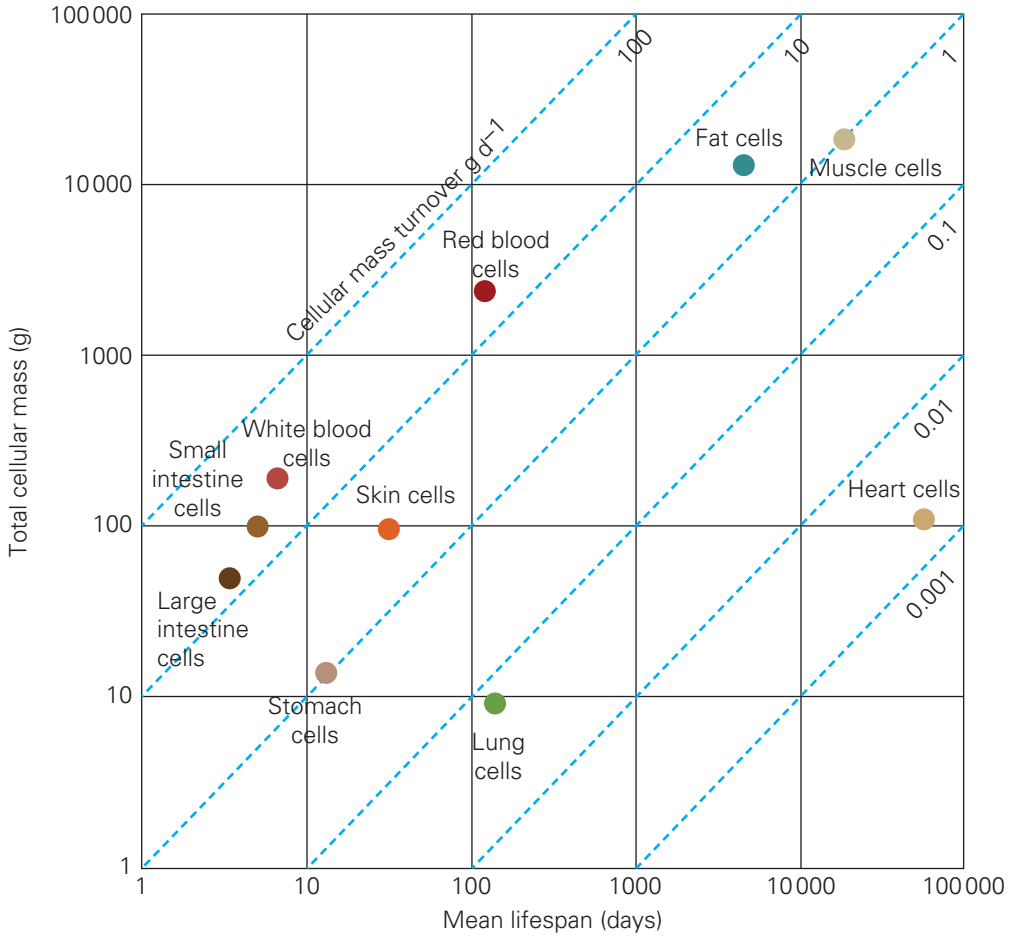


Figure 5.52 The mean lifespan (days) and total cell mass (grams) of different cell types in an adult human. Note that both the horizontal axis and the vertical axis increase by a factor of 10 at each interval.

6. **Contrast** small and large intestine cells, using Figure 5.52.
7. **Categorise** the following cells as having either a high turnover rate or a low turnover rate, using Figure 5.52: heart cells, white blood cells, red blood cells, lung cells.
8. **Compare** stomach cells and muscle cells, using Figure 5.52.

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STEM activity: Designing a self-sustaining community

Background information

Just as cells are made up of various organelles that perform specific functions to keep the cell alive and healthy, a community consists of different sectors and services that work together to ensure the wellbeing and functioning of its residents. Each sector, much like an organelle, has a specific role that contributes to the overall community. This can include sectors such as energy, healthcare, transportation, education, and waste management.

DESIGN BRIEF

Design a self-sustaining community using cells as a model.



Figure 5.53 A self-sustaining community is a community that can meet its own needs without relying heavily on external resources or support. It is able to produce its own food, generate its own energy, manage its waste effectively and provide for the wellbeing of its residents without depleting resources or causing significant harm to the environment.

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Activity instructions

In a group, use your knowledge of the functions of cell organelles and make comparisons with the functions of community sectors to create a modern, self-sustaining community design. Your design should address common challenges such as energy supply, healthcare access, efficient transportation, education and waste management. You can present your work to the class through a poster, PowerPoint or vlog/video.

Suggested materials/presentation format

- Poster
- PowerPoint
- Video

Research and feasibility

1. List all the major organelles and their functions. Research the issues/resources that face a city and then match the issues/resources required with the organelle.

Organelle	Function	Community sector/issue	How the organelle provides the solution
Golgi apparatus	Packaging and distribution of proteins	Logistics and distribution	Acts as warehouses and distribution centres, ensuring the flow of goods

Design and sustainability

2. Choose a type of community to model (e.g. urban, rural, coastal) and sketch a diagram of this community. Label the major sectors with the corresponding organelle.
3. Discuss the sustainability of the community you have designed. How could the community be completely self-sufficient in terms of its resource production? Consider factors such as renewable energy, local food production and efficient waste management.

Create

4. Reflect on your basic design and start building a larger, more detailed drawing that incorporates all your ideas. Keep thinking about all the challenges faced by communities and how they are managed.
5. Present your self-sustaining community model to the class, highlighting how each sector of your community corresponds to a cell organelle and explaining how the system maintains sustainability.

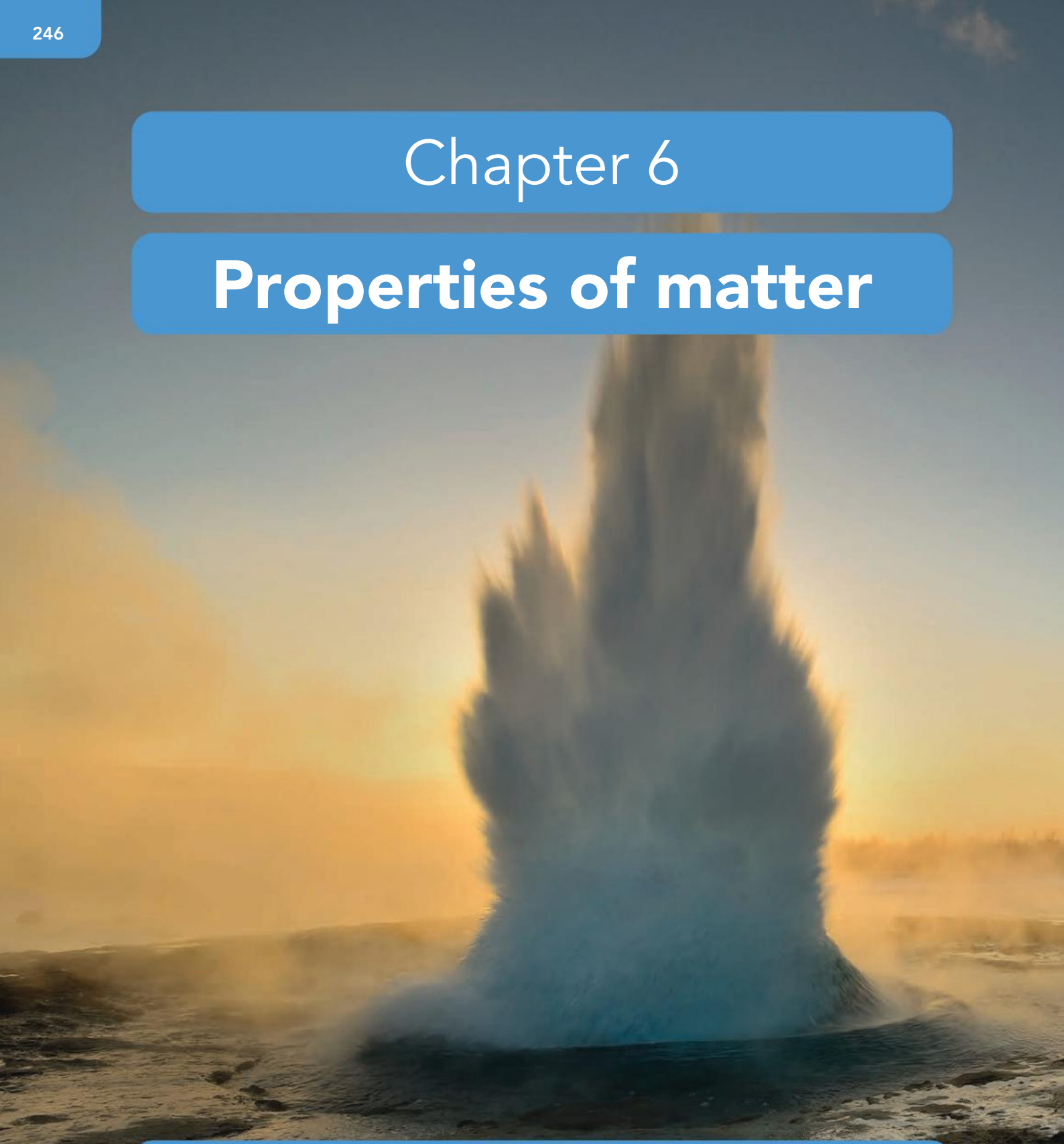
Evaluate and modify

6. Analyse the solutions you have come up with and comment on how achievable they would be in the real world today.
7. Explain any potential problems that might be encountered when implementing your solutions in the real world. Discuss the types of technologies that could be incorporated into your solutions (e.g., smart grids, vertical farming, waste-to-energy systems).

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Chapter 6

Properties of matter

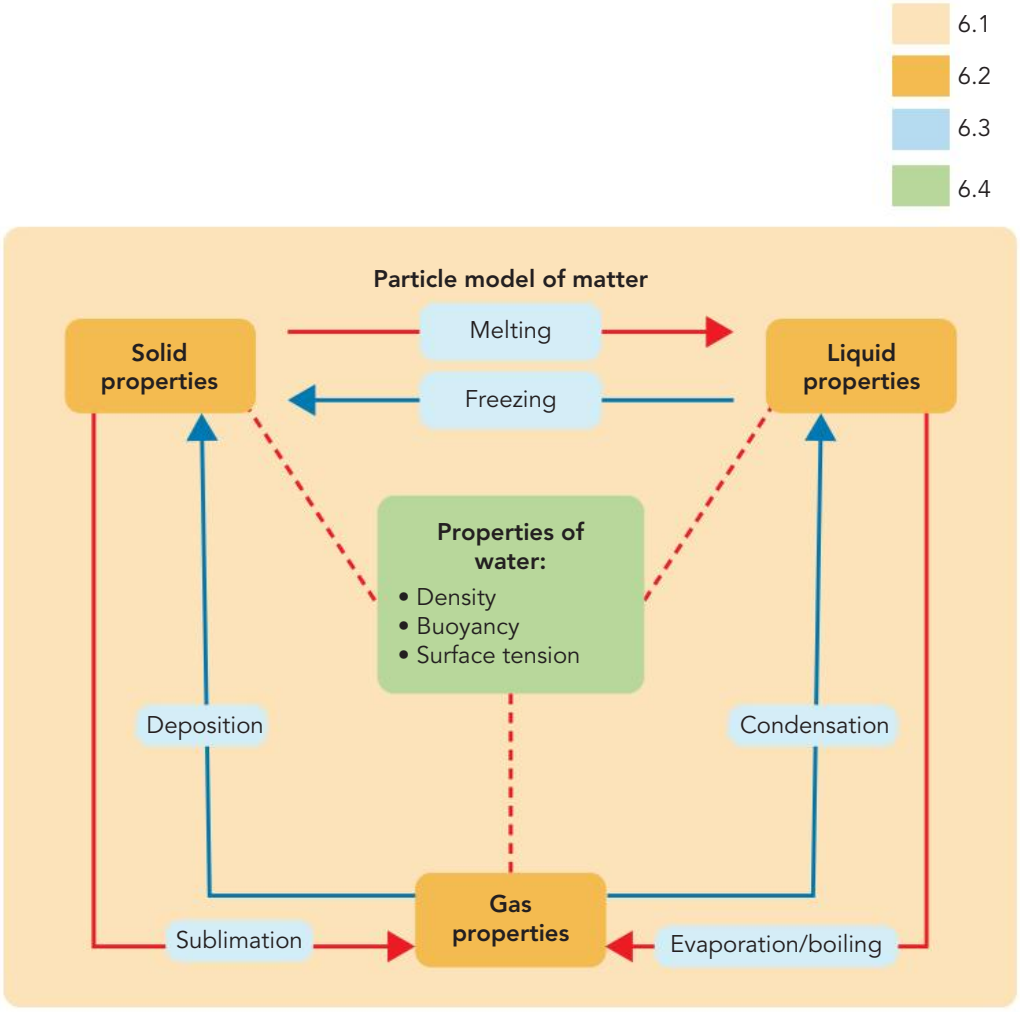


Chapter introduction

This chapter will introduce you to the amazingly tiny world of particles and the idea that everything in our universe is made up of them – yes, everything! You will focus on the three states of matter (solids, liquids and gases) and investigate how the particle model can explain not only their changes of state but also their properties. You will learn about these states in relation to one of the most important substances on Earth: water. You will also learn about some of the other fascinating properties of water.

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Chapter map



Glossary terms

boiling
Brownian motion
buoyancy
compress
concentration
condensation
contraction
density
deposition
diffusion
evaporation
expansion
freezing
gas
liquid
mass
matter
melting
melting point
particle model
physical property
pressure
solid
state
sublimation
surface tension
vibrate
volume

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6.1 States of matter and the particle model

Learning outcomes

At the end of this section, I will be able to:

1. describe the different states of matter (solids, liquids and gases) using the particle model.
2. describe how the different states of matter are represented in the water cycle on Earth.
3. describe the effect of heating and cooling on matter using the particle model.

What is matter?

matter
anything that has mass and volume

mass
the amount of substance in an object that never changes, measured in kilograms

volume
the space an object occupies

state
one of the distinct forms matter can exist in

What do cars, water and air have in common? They are all made up of matter! **Matter** is essentially anything that takes up space and has **mass** and **volume**. Mass is the amount of matter in a substance or object, and volume is the amount of space the substance or object takes up. There are three **states** of matter that are commonly found in our world: solids, liquids and gases. Look at the images in Figure 6.1, and identify the solids, liquids and gases. What do the solids all have in common? What do the liquids all have in common? What do the gases all have in common? What makes them different?



Figure 6.1 Identify the states of matter: solids, liquids and gases. What are the similarities and differences between the three states of matter illustrated above? Sometimes the differences are not obvious. Is tomato sauce a liquid and vegemite a solid? Is smoke a gas?

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Did you know? 6.1

A fourth state of matter

Other than solids, liquids and gases, there is one other naturally-occurring state of matter that is common in the universe: plasma! Plasmas are highly energised gases that are not common here on Earth, but stars, including the Sun, are covered in plasma. Plasma can be created by lightning strikes and is even used in plasma TVs in the form of ionised gas. Plasma can actually be made by microwaving cut grapes, but this should be left to YouTubers and scientists. Do not try this at home as it can be dangerous and is likely to ruin your microwave. Other 'extreme' states of matter can also be created under experimental conditions and are very rare in the universe.



Figure 6.2 Plasma, a fourth state of matter, produced from grapes

States of matter: water

Water is one of the most important substances on Earth, and it is essential for life. It can be found in each of the three common states: as ice or snow (solid), water (liquid) or water vapour (gas). Can you think of examples of where you see water appearing as a solid, liquid and gas? Even before school today you may have experienced water in all three states. You may have filled up your water bottle with liquid water for school. If it is hot, you may have added solid water from the freezer in the form of ice. If you made a hot chocolate, you may have seen water vapour (steam) shooting out of your kettle.



Figure 6.3 Water appearing as a solid **(a)**, liquid **(b)** and gas (arrowed), **(c)** around the home. Note that water vapour is invisible; the 'steam' we see is small water droplets.

Where on Earth is water found and how does it circulate?

While the total amount of water on our planet and in its atmosphere remains more or less constant, the water particles themselves are in continuous circulation. Figure 6.4 shows the water cycle. Can you think where the solid water is found? It is found in snow and other examples, like icebergs, glaciers and hail stones. Liquid water covers a significant area of our Earth in the oceans, but most of the liquid water on our planet is out of sight, below ground. Finally, gaseous water vapour is found in the atmosphere. To have the circular 'cycle' effect, the water must change state and move. Can you see where solid water becomes liquid? In the melting of ice and snow. Where does liquid water become gas? Both from the evaporation of surface water such as from lakes and oceans, and as trees draw up liquid water from their roots and release water vapour into the air. The vapour then condenses as it forms back into liquid water in clouds. These liquid water drops grow until they fall back to Earth. If it is cold enough, they freeze, forming solid snow or hail.

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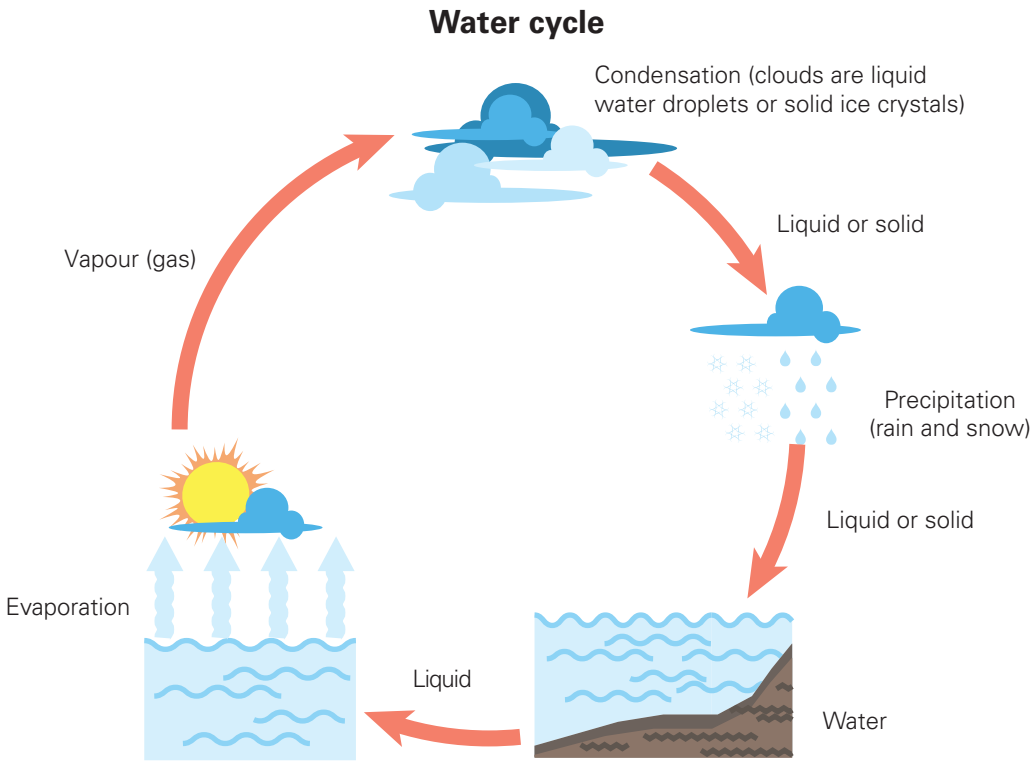


Figure 6.4 Water constantly changes between states in the water cycle.

Did you know? 6.2

We may be drinking the same water as the dinosaurs!

Due to the way water circulates on Earth, around 95% fresh water is believed to be below the surface and out of sight in Earth's crust. Scientists think we are likely to be drinking the same water as animals like woolly mammoths and dinosaurs that have been extinct for many millions of years!

The particle model

The ancient Greeks wondered what would happen if you could keep dividing matter up into smaller and smaller pieces. Would you eventually come to a particle that you could not split? Although they had no way of observing them, they assumed that these particles existed and must explain some of the properties of matter. This belief led to the **particle model**.

particle model all matter is made of particles that behave differently depending on whether they are solid, liquid or gas

Before we get into the details, it is important to clarify what a model is. In science, models are used to represent different aspects of real-world objects (like models of trains and cars) and phenomena (like Earth circling the Sun). Sometimes, though, scientists make models to test out ideas, like making model bike helmets and seeing how well they prevent an uncooked egg from breaking when dropped. And other times, scientists use models to represent what they cannot see to try to explain how it might work. This is the case with the particle model.

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To better understand what makes a solid a solid or a gas a gas, you will need to begin by looking at the particle model. This model suggests that:

1 All matter is made up of extremely small particles that are invisible to the naked eye.
2 The particles in matter are attracted to each other, very strongly in solids, strongly in liquids and weakly in gases.
3 Due to the different strengths of attraction, solids have virtually no space between particles, liquids have very few and very small spaces between particles, and gases have large to very large spaces between particles.
4 Particles are always moving because of the energy they have, and the more energy they have, as measured by temperature, the faster they will move. Heat is the form of energy most likely to be added to or taken away from particles. Particles will always have some energy and so will always move, even if it is just a little bit.
   a In solids, the particles **vibrate** in fixed positions.
   b In liquids, the particles also vibrate but slide past each other and collect at the bottom of their container.
   c In gases, the particles also vibrate but move randomly in all parts of their container, filling it.

In liquids and gases, the way particles move is totally random, and in science, this is called **Brownian motion**.



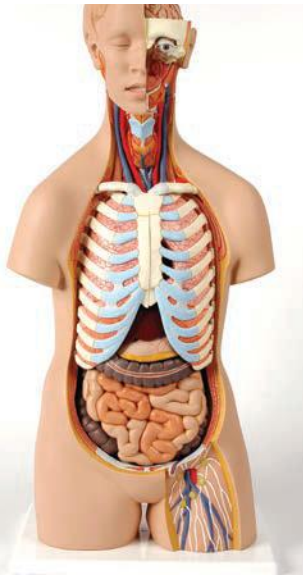


Figure 6.5 Models: a model of the solar system from the eighteenth century and a modern model of the human body used in schools.

vibrate move in a periodic (back and forth) motion

Brownian motion the random movement of particles in fluids and gases

Explore! 6.1

INVESTIGATION

Brownian motion

Brownian motion is named after the botanist Robert Brown, who first observed this in 1827.

Use the internet to explore the phenomenon of Brownian motion. See if you can find some examples of Brownian motion in everyday life.

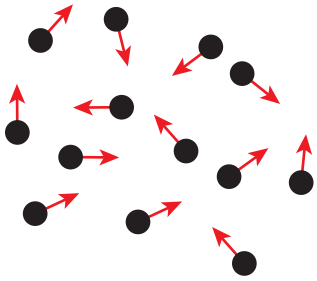


Figure 6.6 A representation of particles randomly moving

Quick check 6.1

1. **Define** the term 'matter'.
2. **State** the three common states of matter.
3. **Summarise** the key points of the particle model by completing the following sentences.
   a. All matter is made up of _____.
   b. The particles are always _____.
   c. Particles move faster if the substance is _____.

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Try this 6.1

States snap!

- Cut an A4 piece of paper into 12 roughly even-sized cards. On each card write one example of a solid, liquid or gas, so that you have four cards that name a solid, four that name a liquid and four that name a gas.
- Shuffle your cards. Find a competitor who also has their 12 cards ready. Place your pile face down in front of you, and the same for your competitor.
- Count to three and turn over both top cards between you. If both words describe the same state, call out which state it is. For example, if you turned over a card that said 'brick' and they turned over 'laptop', you would both try and be the first to say solid.
- The first to say the correct state gets both cards added to the bottom of their pile. If the cards show different states, turn over another card. The entire piles will then go to the first correct call. The winner is the one who has the most cards at the end.

Solids

solid
a substance that has a fixed shape and constant volume

liquid
a substance that flows freely and takes the shape of its container but has constant volume and its particles are tightly packed

gas
a substance that expands freely to fill space

concentration
the number of particles present in a given volume

diffusion
the movement of particles from an area of a high concentration of particles to an area of a low concentration of particles

In a **solid**, the particles are packed tightly together. The forces of attraction between particles are very strong. Because of this, the particles in solids cannot move freely; instead, they vibrate in their places.

Liquids

In **liquids**, particles are held together by forces of attraction. The forces of attraction between particles are strong, but not as strong as in solids. This means that the particles do not vibrate in a fixed position but can move freely. However, they are still packed closely and there is hardly any space between them. We know this because it is very hard to compress water, unlike a gas.

Gases

The particles in a **gas** are in constant motion as they have much more energy than those in solids or liquids. The attraction between the particles in a gas is weak and the particles are further apart. We know this because a gas can be compressed quite easily, as in an air pump. This also means the particles spread out to take up any space that is available. The movement of particles from an area of a high concentration of particles to an area of a low **concentration** of particles is a process called **diffusion**.

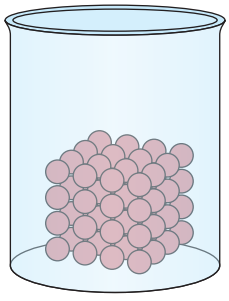


Figure 6.7 Diagram showing the arrangement of particles in a solid. Particles in a solid are very closely packed together and just vibrate in their places.

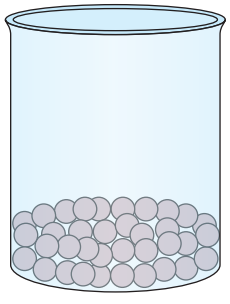


Figure 6.8 Diagram showing the arrangement of particles in a liquid. Particles in a liquid are packed closely together but can still move about and slide over one another. Gravity pulls the liquid down into the shape of the container.

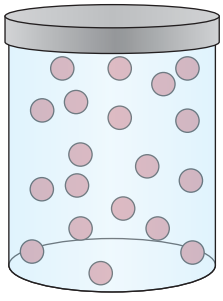


Figure 6.9 Diagram showing the arrangement of particles in a gas. Gas particles are always moving and spreading out to fill any space they are in.

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Try this 6.2

VIDEO
Animation of water particles

Modelling the three states

1. Working with your classmates, role-play what a solid, liquid and gas look like. Make sure you can explain what the particles are doing in each state of matter.
2. Use polystyrene balls and pipe cleaners to make a model of each state of matter. Draw and label diagrams of what the three models look like.

Quick check 6.2

1. Copy and **complete** the following table.

State of matter	Describe the strength of attraction between particles	Describe the movement of particles	Diagram of particle arrangement
Solid			
Liquid			
Gas			

Try this 6.3

WORKSHEET
Gas pressure

Gases have mass

As we look at the air surrounding us, we cannot see the gases that make it up. It is hard to believe that there are particles there. But if you use an electronic balance to measure the mass of an empty balloon, then inflate the balloon and remeasure its mass, you should find that the mass increases due to the presence of the extra gas particles in there. In fact, the reason that the balloon blows up is because the particles of air introduced into the balloon are gas particles with lots of energy that are moving in all directions and colliding with the inside wall of the balloon and pushing it out. As more particles are added, their collisions with the balloon wall exert an outward **pressure** causing it to stretch and inflate until it cannot stretch any more.

pressure
the amount of force exerted on a given area

Investigation 6.1

INVESTIGATION

Investigating diffusion

Aim

To design an investigation into how quickly particles can diffuse through water at different temperatures.

Materials

- aerosol deodorant/perfume
- food colouring
- 4 × 250 mL beakers
- eye dropper
- ice water, cold tap water and hot tap water
- thermometer
- stopwatch

Be careful
Check to ensure that no one suffers from any respiratory conditions before using the aerosol deodorant/perfume.

continued ...

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Procedure

1. Spray some aerosol deodorant/perfume in one corner of the room. Move to the opposite corner of the room and record the time it takes for the scent to reach you.
2. Put one drop of food colouring into a beaker of tap water. Observe how the colour spreads and record the time it takes for the colour to spread evenly in the water.
3. Design an experiment to determine if the diffusion of food colouring occurs faster in warm or cold water. Remember that in science experiments, every variable must be kept the same except for the one being investigated. What are the dependent, independent and controlled variables in this experiment? Consider what you will need to record and how you can do it.
4. Write a hypothesis about what you think might happen.
5. After checking your design with your teacher, carry out your experiment and record your results.

Results

1. Draw a diagram showing how the deodorant/perfume particles moved through the air.
2. Draw a diagram showing how the food colouring particles moved through the water.
3. Draw up a table that summarises the results from your self-designed experiment.

Discussion

1. How do you think the particles of the food colouring were able to spread through the water? Use the terms you have learned in class about the particle model and diffusion.
2. Explain why changing the temperature affected how fast diffusion occurred.
3. Many industries use diffusion to dispose of their waste products either as gases into the air or as liquids into rivers and the sea. Explain whether you think this is a suitable method in the long term.
4. Identify any sources of error present in your self-designed experiment and how you might prevent these from occurring again.

Conclusion

Draw a conclusion from this experiment on diffusion, supporting your statement with data.

Heating and cooling

expansion the process of substances getting larger: the particles of a substance move further apart as they heat up

contraction the process of substances getting smaller: the particles of a substance move closer together as they cool

The particle model suggests that if you heat up a substance, the particles will gain more energy and so they will begin to move more. As the particles start to move more, the distance between the particles increases, they begin to take up more space, and the attraction between the particles decreases. This process of the material (and not the particles) becoming larger is called **expansion**. When heat is applied, gases can usually expand more than solids and liquids because the particles are not held together by strong attractive forces and so are free to spread out.



Figure 6.10 In a hot air balloon, the heated air expands and becomes lighter than the air outside the balloon, so the balloon rises.

So how does it work when a substance is cooled? The reverse of the process of expansion occurs: the substance cools down, the particles lose energy, they slow down, and the distance between the particles gets smaller. The particles are more strongly attracted to one another, except in a gas, in which they are still relatively far apart. This process of the material (and not the particles) getting smaller is called **contraction**.

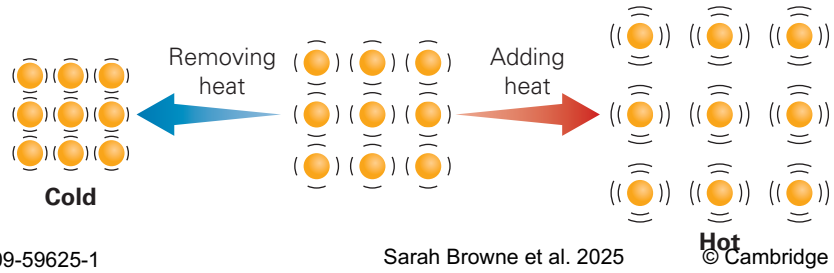


Figure 6.11 Diagram showing the changes experienced by particles with heating and cooling. Note that the size of the particles stays the same, while the space between the particles decreases or increases.

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Quick check 6.3

1. **Compare** the distance between particles in a gas, a liquid and a solid.
2. Use the particle model to **explain** what happens when a substance gains heat.
3. The particles of a substance in a sealed container are investigated at two different temperatures.
   - At temperature A, the particles are very close together but move about freely at moderate speed in the bottom of the container.
   - At temperature B, the particles are distant from one another and move about freely and very fast in all parts of the container.

   Determine the state of the substance at temperature A and at temperature B.

Practical skills 6.1

Expansion and contraction

Aim

To observe and explain the expansion and contraction of solids and gases.

Materials

- ball and ring apparatus
- Bunsen burner
- bimetallic strip (two different metals joined lengthwise)
- 1 balloon
- felt-tip pen
- ruler or tape measure
- bucket of ice water
- bucket of hot water



Figure 6.12 A ball and ring apparatus

Procedure

1. Examine the ball and ring apparatus. Does the ball fit through the ring when it is cold? What do you predict will happen when you heat the ball? Heat the ball using the Bunsen burner and see if it still fits through the ring. What happens if you heat the ring and not the ball?
2. Look at the bimetallic strip – predict or hypothesise what will happen when you heat it. Now, heat the bimetallic strip. Describe what happens.
3. Inflate a balloon. Draw two felt-tip pen lines exactly 10 cm apart on the balloon. Place the balloon in the bucket of ice water. What happens to the lines? Place the balloon in the bucket of warm water. What happens to the lines?

Results

Record all observations and descriptions from each step of the procedure.

Discussion

1. Write a sentence explaining your observations from each step of the method, referring to the particles, their energy, their movement, strength of their attraction etc.
2. Do you think a balloon can be used as a thermometer to measure temperature? Find out about how gas thermometers are made and used.

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Section 6.1 review

Online quiz

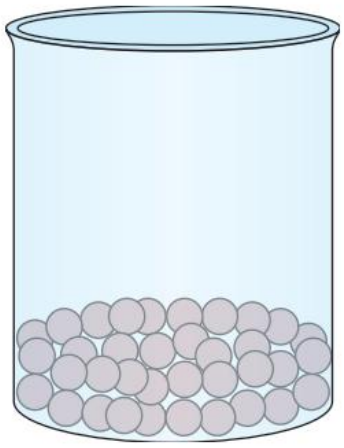
Section questions

Teachers can assign tasks and track results

Section 6.1 questions

Remembering

1. **Recall** the four key points of the particle model.
2. **Name** the state in which particles vibrate in a fixed position.
3. **Name** the state shown in the diagram below.



4. **Name** the state in which particles have the strongest attractions.
5. **Define** the term 'diffusion'.
6. **Identify** the word that describes the change you expect to see when a metal is heated.

Understanding

7. **Distinguish** between solids, liquids and gases. Include a diagram to model the different states using water as your substance. **Compare** the closeness of the particles, the speed at which they move and list some examples.
8. **Describe** what happens when you heat up and cool down particles.
9. **State** in which types of geographic features on Earth that the most water vapour, liquid water and ice are found.

Applying

10. At room temperature, in which state do the particles of a substance have the most energy? **Justify** your answer by providing evidence for your choice.

Analysing

11. Use the particle model to **explain** why food colouring and water mix together easily and quickly but food colouring and ice do not.

Evaluating

12. **Account** for how a liquid-in-glass thermometer such as a mercury thermometer works.

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6.2 Properties of solids, liquids and gases

Learning outcomes

At the end of this section, I will be able to:

1. describe and compare the physical properties of solids, liquids and gases.
2. explain differences in behaviours of the three states of matter and relate them to particle theory, including the relative strength of forces between particles.

WORKSHEET
Density

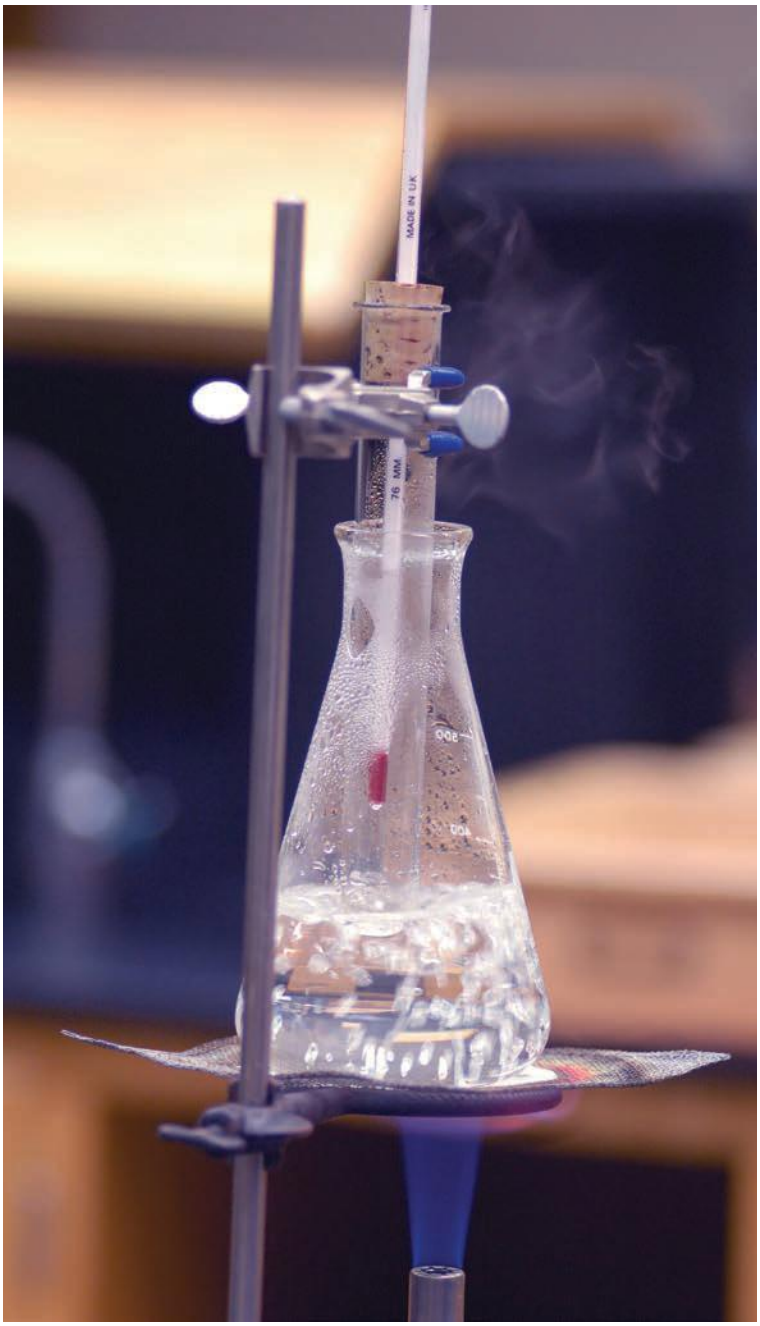


Figure 6.13 For comparing the physical properties of matter in different states, the boiling point, being measured here, and the melting point are important.

What are physical properties?

Scientists often refer to properties when they talk about the different states of matter, and in this chapter the type we will refer to are **physical properties**. Examples of physical properties are size, shape, **density**, hardness, strength, solubility, melting point, boiling point and conductivity.

physical property
the way a substance or object looks and behaves under different physical conditions; a characteristic of a substance that can be observed and/or measured without changing it chemically

density
how much matter (mass) is contained in a certain volume of a substance

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Practical skills 6.2

Investigating physical properties

Aim

To observe and compare some physical properties of solids, liquids and gases.

Materials

- beaker
- plastic syringe
- coin
- ice
- orange juice
- water
- air
- nitrogen dioxide (teacher demonstration)
- other samples of solids, liquids or gases

Procedure

1. For each sample (where possible), place in a beaker and record whether it has a fixed shape or takes the shape of the container.
2. Record whether each sample can be poured.
3. Try and compress the sample. For the coin and ice, can you squash it with your fingers? For the air sample, draw up some air into a plastic syringe, place your finger over the end and push in the stopper. Can you squash it? For the water sample, draw up a small amount into the plastic syringe. Place your finger over the end and push in the stopper. Can you squash it?

Results

Copy the table and complete it with your observations.

Sample	Solid, liquid or gas?	Fixed shape or takes the shape of the container?	Can it be poured?	Can it be compressed?
Coin				
Ice				
Water				
Orange juice				
Air				
Nitrogen dioxide				

Discussion

1. Can you find any trends from your observations? Are there properties that all the solids share? Or all the liquids? Or all the gases?
2. Can you think of any examples of solids, liquids or gases that do not seem to fit with your observations?
3. Try and use your understanding of the particle model to explain the observations you made.
4. What limitations were there with this experiment? How could it be improved?

If you had a chance to explore the properties of solids, liquids and gases in *Practical skills 6.2*, you would have identified a number of the key properties of solids, liquids and gases on your own. Let's review and explain them using what you already know from the particle model.

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Solids

Earlier in this chapter you learned that the particles in a solid are packed so tightly together and the forces of attraction between particles are so strong that the particles cannot move freely; they are fixed. This is why solids usually have a shape and volume that cannot be changed and why they are hard to break apart. This also explains why solids cannot easily be **compressed** (squashed) and cannot be poured.

compress
squeeze or press to make smaller

Property	Explanation
Solids have a fixed shape and cannot be poured.	The particles are closely packed and strongly attracted so solids keep a fixed shape.
Solids have a fixed volume.	The particles are strongly attracted to each other and cannot move away from each other.
Solids cannot be compressed.	The particles are already closely packed together and have no space to be squashed closer.

Table 6.1 The properties of solids can be explained by considering the particles within them.

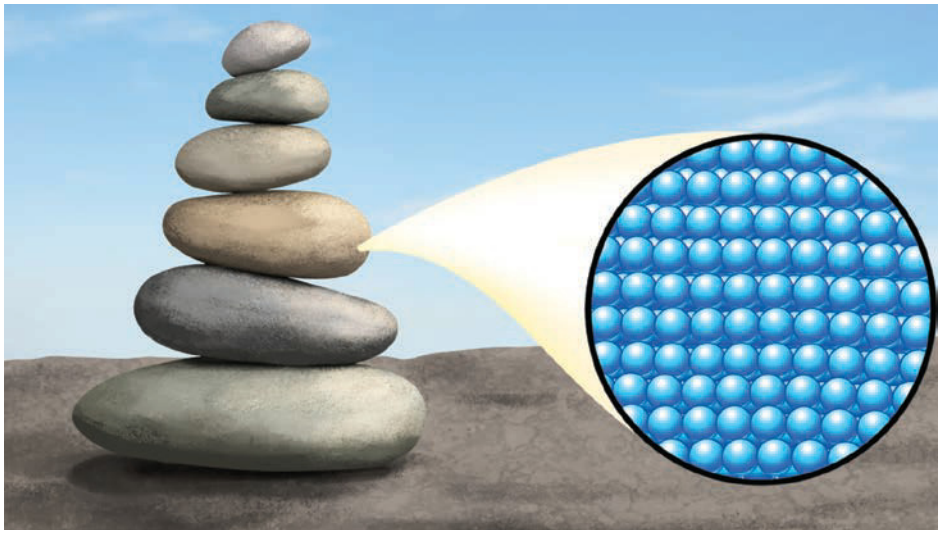


Figure 6.14 Consider these rocks and the arrangement of their particles shown in the diagram. Are their shapes fixed? Can they be compressed? Is their volume fixed? Can they flow?

Quick check 6.4

1. **List** some properties of a solid.
2. Copy and complete the table below.

Properties of a solid according to particle model	Behaviour of a solid as a result of property
Particles packed tightly together	
	Hard to break apart
Particles in solids cannot move freely; they vibrate in one spot, which is called a fixed position.	

3. A substance like sand can be poured and does not have a fixed shape. Is it a solid or a liquid? **Explain**.

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Liquids

Liquids are held together by the forces of attraction between particles, but these forces are not as strong as in solids. The particles of a liquid can move more freely and flow (be poured) and therefore take on the shape of the container they are in. Due to gravity, the shape the liquid takes on will always be at the bottom of the container into which it is placed. Although their shape can change, liquids have a fixed volume and mass. Like solids, they cannot be compressed into 'much' smaller spaces. The particles can be pushed a tiny bit closer together, but it takes a massive effort, and so we generally say that the particles in a liquid are so closely packed that they cannot be compressed.

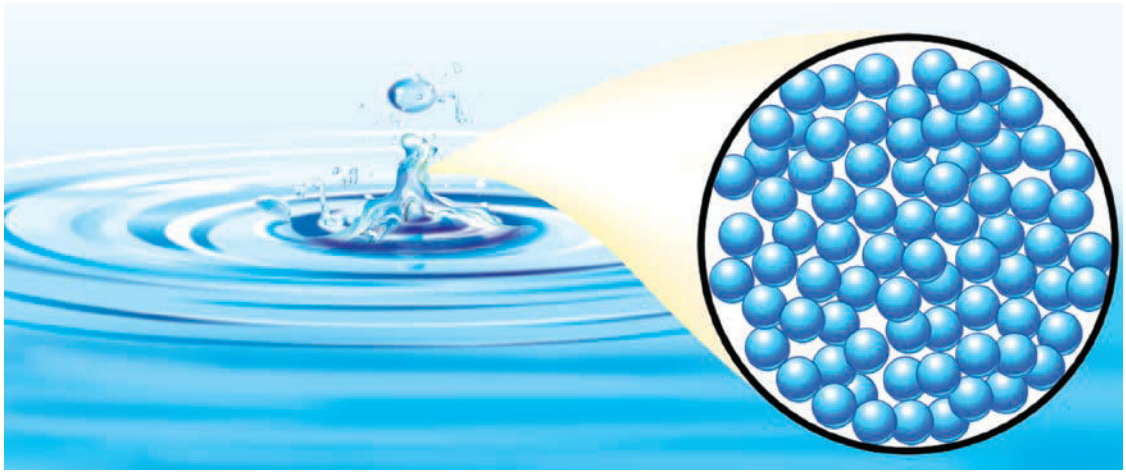


Figure 6.15 Consider the tap water and the arrangement of its particles shown in the diagram. Is its shape fixed? Can it be compressed? Is its volume fixed? Can it flow?

Property	Explanation
Liquids have a no fixed shape and can be poured.	The particles are close, but their attraction is less than in solids, so they can move and roll over each other.
Liquids take the shape of their container.	Since the particles are able to move and roll around each other, they have the ability to spread out in the bottom of a container.
Liquids have a fixed volume.	The particles are attracted to each other and remain in contact with each other.
Liquids cannot be compressed.	The particles are already close to each other and have no space to be squashed closer.

Table 6.2 The properties of liquids can be explained by considering the particles within them.

Gases

Scientists know the force of attraction between the particles in a gas is weak because the particles are far apart. This means that gases have no fixed shape or volume – they spread out to take up any space that is available. Keep in mind, though, that if the container you put a gas in does not have a lid, the gas particles will bounce off the walls and spread out by diffusion. Due to the large spaces between gas particles, there is plenty of space for the particles of a gas to be squashed together or compressed.

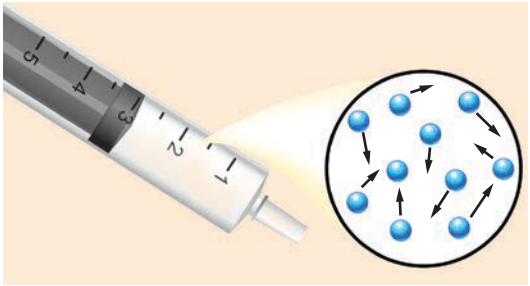


Figure 6.16 Consider the air in the first 3 cm of this syringe and the arrangement of the air particles shown in the diagram. If the nozzle is blocked by a finger or thumb, can it be compressed? Is its shape or volume fixed? Can it flow?

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Property	Explanation
Gases have a no fixed shape and can be poured.	The particles are far apart and have very weak forces of attraction.
Gases take the shape of their container.	Since the particles have only weak forces of attraction, they are moving fast in all directions. They will spread out to take up whatever space they are in.
Gases have no fixed volume.	You can change the size of the container, and the particles will spread out to fill it. This is because the particles are only weakly attracted and moving in all directions.
Gases can be compressed.	The particles are far apart, so there is a lot of space to allow you to squash the particles closer together.

Table 6.3 The properties of gases can be explained by considering the particles within them.

Quick check 6.5

1. **Define** the terms 'volume' and 'mass'.
2. **Compare** and contrast the shape and volume of solids, liquids and gases.
3. Copy and **complete** the following table to describe the particle structure and properties of solids, liquids and gases.

State	Examples	Describe particle structure	Properties
Solid			
Liquid			
Gas			

Explore! 6.2

Compression in gases

Gases can be compressed because there is a lot of space between the particles. There are lots of different places where you can see the result of such compression – for example, oxygen tanks for diving, air freshener sprays, deodorants and fire extinguishers that are filled with carbon dioxide.

1. Why is carbon dioxide a good choice for extinguishing fires?
2. Use the particle model to explain why gases can be compressed.
3. Explain why carbon dioxide in a fire extinguisher is under a lot of pressure.



Figure 6.17 You may find a common carbon dioxide fire extinguisher in the home and at school.

VIDEO
Aerosol cans and heat packs

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Try this 6.4

Making oobleck

Find a recipe on the internet for making oobleck (cornflour and water) and make some to play with. Ask yourself these questions.

- Can it be rolled into a ball? Can it be stretched? Does it flow and take the shape of its container? What happens when a ball of oobleck is dropped?
- What are the physical properties of oobleck?
- Based on its properties, is it a solid or liquid?

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Section 6.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.2 questions

Remembering

1. **Describe** how a liquid behaves in a container and what happens if it is put in a different container.
2. **Describe** how a gas behaves in a container and what happens if it is put in a different container.
3. **Describe** how particles in a solid behave. Use these terms in your answer: fixed, vibrate, shape, compressed, attraction.

Understanding

4. **Summarise** the properties of a gas in two sentences.
5. **Explain** why water vapour can be compressed but ice cannot.

Applying

6. **Organise** the following statements into the correct place to describe solids, liquids and gases. Some statements may apply to more than one state. You may use a Venn diagram.

Strong attraction between particles that are not as close	Particles that are free to move, no strong attraction	Strong attraction between close particles
Easy to compress	Definite shape	Can be poured
Expand to fill a container	Particles in a fixed position	Difficult to compress
Fixed volume	Not a fixed shape	

7. Imagine a single grain of sand. It is hard and has a definite shape. If you scoop up a handful of dry sand, you can pour it out of your hand, which makes it seem like it is a liquid, not a solid. It is very difficult to build a sandcastle with dry sand. However, if you wet the sand, you can shape it into a sandcastle.
   a. **Justify** why you might classify sand as a solid.
   b. **Justify** why you might also classify sand as a liquid.

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Figure 6.18 Sand seems to have different properties when it is wet and when it is dry.

Analysing

8. **Describe** two ways you could find out if a material is a solid.
9. The metal lid of a glass jar is stuck and cannot be undone. Kim runs the lid under hot water, and now the lid can be unscrewed. Using your understanding of the particle model and the properties of matter, **explain** why Kim used the hot tap.

Evaluating

10. **Discuss** how and why the properties of a liquid are different from the properties of a gas.
11. Office chairs, like the one shown in Figure 6.19, usually have a lever on the side for adjusting their height. The stand contains a cylinder and a piston that can move up and down inside it and consequently, the chairs often feel quite springy when you sit on them. Would the cylinder contain a solid, a liquid or a gas? **Justify** for your answer.



Figure 6.19 An office chair

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6.3 Changing states

WORKSHEET Changing states

Learning outcomes

At the end of this section, I will be able to:

1. explain how matter changes state in terms of particle arrangement and movement.
2. describe the processes of melting, freezing, boiling, evaporation, condensation, deposition and sublimation.
3. conduct an investigation to measure and graph the temperature of water over time to identify the changes of state.

Under the right conditions, all matter can change from one state to another: for example, from a solid to liquid, liquid to gas, or liquid to solid. This may occur because of a change in temperature or pressure, which may be naturally occurring or caused by humans.

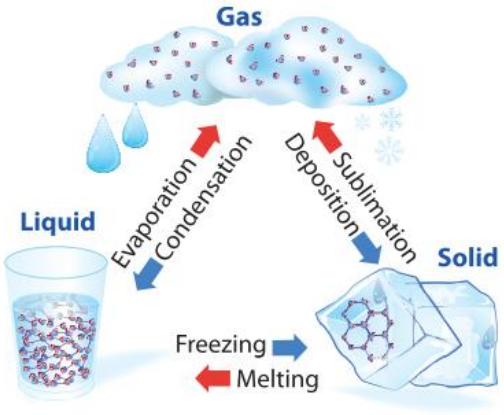


Figure 6.20 Changes in the state of water

Adding heat

You know that heating up a substance causes an increase in temperature, but did you know that if enough heat is added, the substance can actually change its state?

melting when heat causes a solid to become a liquid

melting point the temperature at which a specific solid melts

evaporation when heat causes liquid to become gas

Melting is when heat causes a solid to become a liquid. Remember that heating a substance gives the particles of that substance more energy and this makes the particles move or vibrate faster. If you add enough heat to the particles, the edge of the solid will eventually vibrate so much that the forces of attraction between the particles will be reduced slightly and some of them will break free. The temperature at which this occurs is called the **melting point** of the substance. Different substances respond to heat differently (their particles have different strengths of attraction) and therefore have different melting points. It is not surprising that when a substance changes from a solid to a liquid (by melting), its properties also change; however, the substance remains the same. For example, melting ice involves solid water forming a liquid form of water and the physical properties are very different (hardness, ability to be poured, shape), but they are both water.



Figure 6.21 Melting butter on a hot cob of corn involves a solid becoming a liquid. The physical properties may change but it is still butter.

WORKSHEET Heating curve

WIDGET Metals and melting points

Evaporation is where heat causes a liquid to become a gas. Adding heat to a liquid increases the energy of the particles and causes them to move faster and spread out. This increased distance decreases the attraction between particles. If enough heat is added to the liquid, the particles at the liquid's surface can vibrate or move so fast they break away from the rest of the particles and form a gas. For example, at a natural hot spring, water changes state from liquid to vapour. Some of it also then cools and changes back to liquid droplets forming clouds. Evaporation can, however, occur at a range of temperatures. Consider the clothes you hang on the line to dry. They will dry by the water evaporating from the surface of the clothes. Drying is faster when it is sunny and hot, but clothes still dry on cooler cloudy days.

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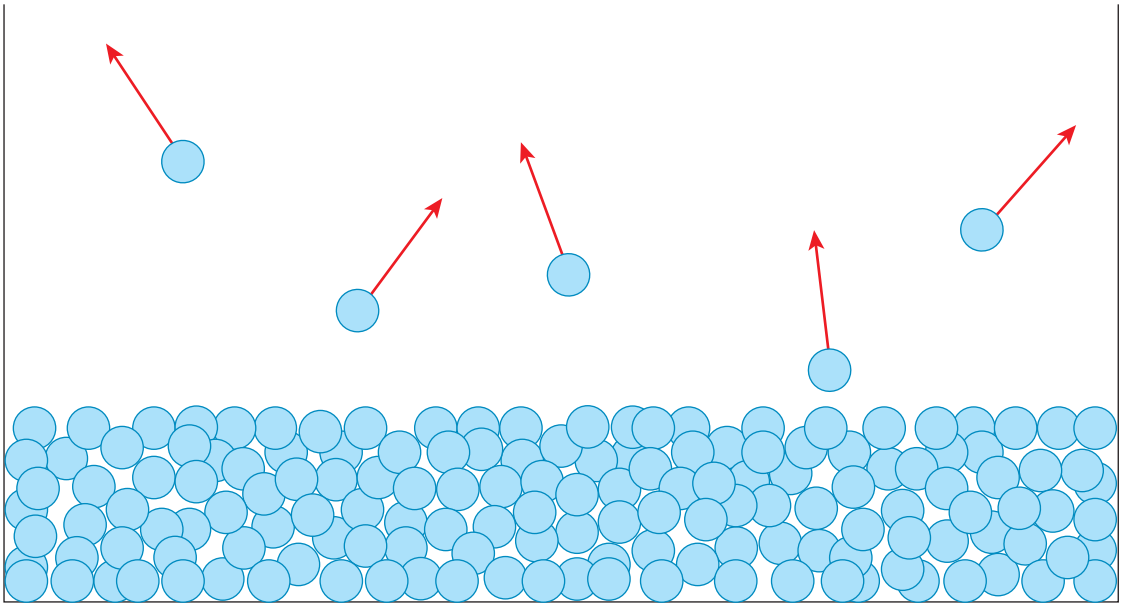


Figure 6.22 When heated, particles gain energy and spread out, allowing them to break free from the liquid and form a gas.

Boiling is the rapid vaporisation of a liquid which occurs when it is heated to a temperature called the boiling point. When a substance reaches this temperature, it is obvious that the substance is boiling. Vaporisation starts to occur not just on the exposed surface but at various points throughout the liquid where bubbles of vapour form. You may have watched water boil at 100°C in a transparent kettle or saucepan. Bubbles containing water vapour begin to form low down in the water, which then expand, rise and break at the surface.



Figure 6.23 The bubbles in boiling water form low down in the liquid, then expand and rise to the surface.

boiling
the rapid vaporisation of a liquid, which occurs when it is heated to a temperature called the boiling point

Investigation 6.2

Changes of state of water

Aim

To investigate and graph the changes of state of water as it is heated over time.

Planning

Write a risk assessment for this investigation.

Be careful

Take care when using the Bunsen burner, heatproof mat, tripod and glass thermometer. Be aware of the boiling water.

Materials

- ice
- 250 mL beaker
- Bunsen burner
- tripod
- gauze mat
- heatproof mat
- thermometer/temperature probe
- retort stand and clamp
- stopwatch
- matches
- safety glasses

INVESTIGATION

continued …

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Procedure

1. Wearing your safety glasses, set up the equipment as shown in Figure 6.24.
2. Add some ice to the beaker until it is approximately half full.
3. Heat the beaker on a tripod and gauze mat.
4. Record the temperature of the ice/water every 30 seconds until it has been boiling steadily for six data points. Make a note in your results table when the ice/water changes state.

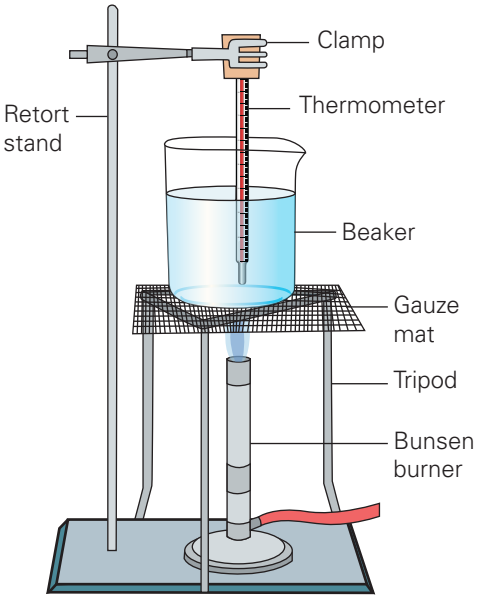


Figure 6.24 The equipment set-up

Results

1. Draw a suitable results table for this investigation.
2. Draw a line graph to show how the temperature of the ice/water changed over the total time you took measurements.
3. Note on your graph when changes of state occurred.

Discussion

1. Analyse your graph to deduce the freezing point of water.
2. Analyse your graph to deduce the boiling point of water. Using your knowledge of what the boiling point of water should be comment on how accurate your data is.
3. Explain why parts of the graph are horizontal lines. Think about what is happening. Shouldn't the temperature be increasing if the Bunsen burner is still on? Where is the energy going?
4. Identify any potential sources of error in this experiment.
5. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

Draw a conclusion from this investigation regarding the condensation and freezing points of water. Explain your conclusion.

Explore! 6.3

Melting and boiling points

As with melting points, different substances have different boiling points too.

1. Find out the melting and boiling points of some different substances. Try to include a variety of substances that are found in each state (solid, liquid, gas) at room temperature.
2. Draw up a table to record the melting point and boiling point of each of the substances you investigated.
3. Compare the melting points of the substances that are solid at room temperature with the substances that are liquid at room temperature. Can you use this information to estimate room temperature?

Did you know? 6.3

Melting and boiling points can change!

Melting and boiling points depend on how far above sea level you are. The higher up you are, the lower the melting and boiling points would be. Even in Bathurst, which is only around 650 m above sea level, the boiling point of water is around 97.7°C. Can you think why this is the case?

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Sublimation is where heat causes a solid to become a gas. Most substances go through the process of melting and evaporating when heated; however, there are a few rare substances that skip the liquid state at room temperature. Dry ice (solid carbon dioxide) is an example you may be familiar with.

Removing heat

You know that cooling a substance causes a decrease in temperature, and, if enough heat is lost, the substance can change its state.

Freezing (or solidification) is where heat is lost causing a liquid to become a solid. The process of freezing is the reverse of melting. As liquid cools, the particles lose energy and move or vibrate slower. If you remove enough energy, the particles will end up just vibrating in a fixed position, and due to their closeness, the particles will form stronger attractions with their neighbours than before, and a solid is formed. The point at which this occurs is called the freezing point. Different substances have different freezing points. For example, the freezing (and melting) point of pure water is 0°C, while the freezing (and melting) point of oxygen is –218.8°C.



Figure 6.25 Snowflakes form when the liquid water turns into the solid ice.



Figure 6.26 Condensation forms on a window as the air in contact with it cools.

sublimation
where heat causes a solid to become a gas, without passing through the liquid state

freezing
where heat is lost and a liquid becomes a solid

condensation
where heat is lost, causing a gas to become a liquid

Did you know? 6.4

How cold?

The lowest recorded temperature in Australia was –23°C, in the Snowy Mountains. Including our Antarctic territories, the lowest recorded temperature is –80°C. But this is nothing compared to the lowest temperatures achieved by scientists in a German lab. Scientists had developed a temperature scale called the Kelvin scale in which zero kelvin is considered absolute zero – the temperature at which particle energy is at its absolute lowest and even particle vibrations in solids virtually stop. No one has ever been able to reach absolute zero, which is equal to –273.15°C. However, in 2021 a team of German scientists managed to record a temperature of 38 trillionths of a degree above –273.15°C.

Condensation is where heat is lost causing a gas to become a liquid. As a gas cools, the particles of gas lose energy and slow down. When they have slowed down enough, the particles come close enough together that they begin to attract one another and consequently form a liquid. An example you may see every day is when the steam from your shower condenses on the mirror of the bathroom as the water vapour (gas) hits the cool mirror and forms a liquid.

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deposition where a reduction in heat causes a gas to become a solid, without passing through the liquid state

Deposition (also known as reverse sublimation or desublimation) is where a reduction in heat causes a gas to become a solid, without passing through the liquid state. Like sublimation, deposition is rare. However, it can be seen when, in sub-freezing air, water vapour changes directly to ice without first becoming a liquid.

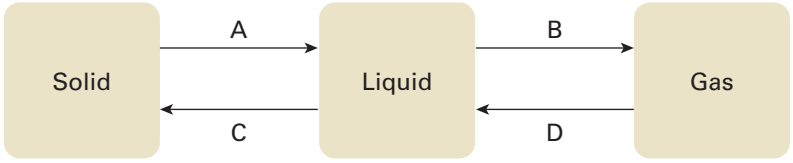
Try this 6.5

Changing state role-play

Working with your classmates, role-play what heating a solid (a change in state between a solid and a liquid, liquid and a gas) would look like. Make sure you can explain what the particles are doing. What would occur if you were to enact what happens when a gas cools down?

Quick check 6.6

1. In your own words, **define** the processes of: melting, evaporation, boiling, sublimation, freezing, condensation and deposition.
2. Solids, liquids and gases can change their state. In the diagram below, each arrow represents a change in state. **Answer** the following questions.



   a. Which letter represents melting?
   b. What is the name of the process represented by the letter B?
   c. What happens to the particles in a solid when it becomes a liquid?
   d. What is the name of the process represented by the letter C?
3. Use particle theory to **explain** the following.
   a. When you increase the temperature of a cube of frozen juice, it melts.
   b. When liquid water is heated, it starts to boil and then evaporates.

Advances in science 6.1

Is hot water different from cold water?

You have just been investigating the three states of water – solid ice, liquid water and water vapour (gas). However, our understanding of the states of water is changing! A study published in 2020 showed that water at very low temperatures exists in two different liquid states. They have different properties and differ in densities by 20%, and scientists believe that under the right conditions, they will be able to exist as liquids that will not mix, with an interface between them, similar to what you would see between oil and water. This is a very difficult area to research as it happens at very low temperatures with very little time to visualise before the water crystallises and becomes ice.

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Section 6.3 review

Online quiz

Section questions

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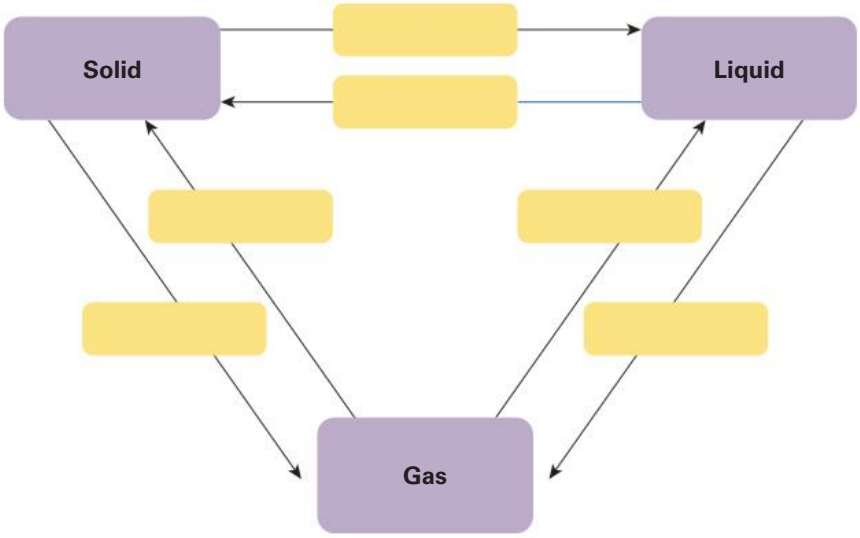
Section 6.3 questions

Remembering

1. **Recall** what happens to the closeness and energy of particles when you heat up something. What about cooling something instead?

Understanding

2. Copy this diagram and **label** the yellow boxes with the name of the process (for example, melting, evaporation). Then colour over the arrows with blue or red pen/pencil to indicate whether you add heat (red) or take it away (blue) to achieve that change of state.



Applying

3. For each of the following processes, **state** whether energy is added or taken away.
   - **a.** Sublimation
   - **b.** Evaporation
   - **c.** Freezing
   - **d.** Condensation
   - **e.** Deposition
   - **f.** Melting
4. **Describe** the process of ice melting and water boiling, using the following terms.

boil	boiling point	decrease
evaporate	gas	heat
increase	liquid	melt
melting point	particle	solid
space	speed	temperature

5. You get a can of cream soda out of the fridge and leave it on the bench while you run to get a glass from the cupboard. When you return to your can, it has beads of water on the outside. **Explain** where the water came from and what change of state occurred.

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Analysing

6. Answer the following questions using the information in Figure 6.27.

a. **Determine** which process is happening between 2 and 4 minutes.

b. **Determine** which state of matter is present at U.

c. **Determine** the temperature of the boiling point.

d. **Describe** the time period at which the whole substance is in liquid form.

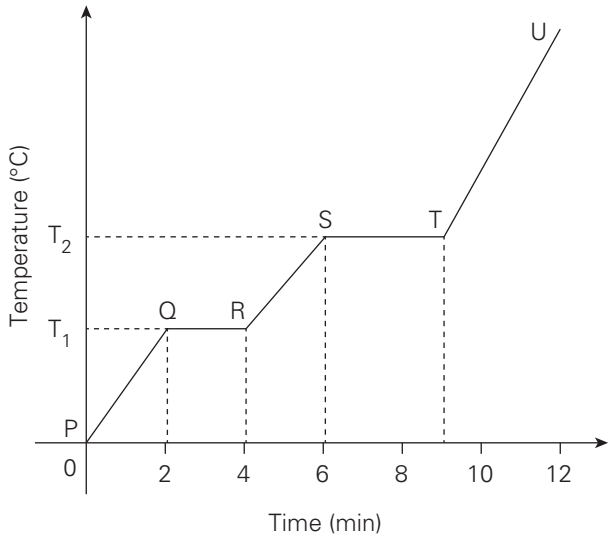


Figure 6.27 Heating curve of a substance that exists as a solid at time 0 minutes

7. Use the information in Table 6.4 to answer the following questions.

a. **Determine** which substance has the highest melting point.

b. **Determine** which substance has the lowest melting point.

c. **Order** the substances from lowest boiling point to highest boiling point.

d. **Name** one substance that is a gas at 20°C.

e. **Name** one substance that is a liquid at 20°C.

f. **Name** one substance that is a solid at 20°C.

Substance	Melting/freezing point (°C)	Boiling point (°C)
Water	0	100
Aluminium	660	2467
Iron	961	2212
Alcohol	–130	78
Helium	–272	–268

Table 6.4 Melting, freezing and boiling points of different substances

Evaluating

8. In cold countries, rock faces can sometimes have pockets of water trapped inside cracks after it rains. **Assess** what might happen if the trapped water freezes when the temperature drops.

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6.4 Properties of water

Learning outcomes

At the end of this section, I will be able to:

1. determine the volume and mass of regular-shaped and irregular-shaped objects to calculate their density using the formula $\rho = \frac{m}{v}$
2. investigate the density of different states of water.
3. describe some other physical properties of water: buoyancy and surface tension.

WORKSHEET
Properties of water

Density

Density is measure of how much matter is contained in a given volume of a substance. Density is an important physical property. For example, would you be happy to lift a normal-sized 7-litre bucket filled with osmium if you knew its density was about 23 grams per cubic centimetre? It would weigh about the same as two adults – 160 kg! Density also allows us to determine whether a solid object will float or sink. It describes how heavy or light something is for its size, but it is not the same as its weight or mass. For example, 1 kg of iron always weighs the same as 1 kg of feathers (they are both 1 kg), but the space they take up is very different. Density can therefore be defined as the measurement of how much matter (or mass) exists in a certain amount of space (or volume). So, the more dense an object is (like iron), the more mass there is in a particular volume. The relationship between density, mass and volume can be written as a scientific equation:

$$\rho = \frac{m}{V}$$

ρ = density
m = mass
V = volume

Worked example 6.1

Calculating density of a solid

A die measuring 16 mm in length has a mass of 4 g. What is the density of the die?



Working	Explanation
m = 4 g length of cube = 16 mm	Identify the values given in the question.
length of cube = 16 mm ÷ 10 = 1.6 cm	Convert units of length to cm.
$V = l \times b \times h$ $= 1.6 \times 1.6 \times 1.6$ $= 4.096\ \text{cm}^3$	Convert the length of the cube to volume.
$\rho = \frac{m}{V}$	Recall the equation for density.
$\rho = \frac{4\ \text{g}}{4.096\ \text{cm}^3}$	Substitute the relevant values into the equation.
$\rho = 0.98\ \text{g/cm}^3$	Solve the problem and give an answer with correct units.

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Quick check 6.7

1. **Identify** the two factors that affect the density of an object.
2. A cricket ball has a volume of 180 cm^3 and a mass of 160 g. **Calculate** the density of the ball.
3. A solid brick has the dimensions of 23 cm long, 11 cm wide and 8 cm high. It has a mass of 3 kg. **Calculate** the density of the brick in g/cm^3.

Practical skills 6.3

Calculating density

Aim

To design and conduct an investigation to measure the mass and volume of different objects, then use this information to calculate the density of the objects and determine whether they would float or sink in water.

Materials

- ruler
- large measuring cylinder
- 8 small random objects

Procedure

When you design your experiment, consider the following questions.

- What measurements do you need to be able to work out the density of an object?
- How will you measure the mass of the random objects you have chosen?
- How will you measure the volume of the random objects you have chosen? What will you do with objects of regular and irregular shape?
- How will you record your data? Would a table help?
- How will you calculate density?
- What is your prediction for the results? Which items do you expect will float and which will sink?

Before starting, your teacher will show you how to determine volume using the water displacement method. You will then write up your intended method step by step, as though it were going to be published in a textbook. Then check with your teacher that you can begin your investigation.

Results

1. Record your prediction.
2. Write your method step by step.
3. Record your measurements in a table using the headers below.

Object	Mass (g)	Volume (cm^3)	Float or sink?	Density (g/cm^3)

4. Using the equation for density, calculate the density of the objects you had access to.

Discussion

1. The density of water is 1.00 g/cm^3. If an object has a density of less than 1.00 g/cm^3, it should float in water. If an object has a density of greater than 1.00 g/cm^3, then the object should sink when placed in water. Did your results show these statements to be true?
2. Were your predictions correct?
3. Identify the advantages and disadvantages of using the water displacement method for determining volume.
4. Would your results be different if you used a different liquid to water? Explain your reasoning.
5. Were there any steps of the practical that you would do differently if you were to repeat the task? How would you improve them next time?

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We often think of density as being a physical property of solids. Density is also a physical property of liquids (and gases). What is interesting to note is that the density of a liquid is affected by temperature – the hotter a liquid is, the less dense it will be. Think about what you know about the particle model. How could you explain this?

Try this 6.6

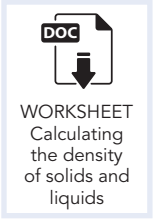
Make your own lava lamp!

Search the internet for instructions on how to make your own lava lamp at home. It is safe and easy to do. Begin by measuring the mass of a cup of oil and a cup of water (this is an equal volume). Which one is heavier? So, which one is more dense? How can you explain this using the particle model and your understanding of density? Think about how an effervescent (fizzy) tablet was used to power your lamp. What is used in the lava lamps you can buy in shops? Explain how temperature affects the density of substances.



Figure 6.28 A lava lamp demonstrates the behaviours of different density liquids. Density is one of the physical properties of liquids.

Measuring volume and mass



WORKSHEET Calculating the density of solids and liquids

For measuring volumes of solids when you can't use the water density method used in *Practical skills 6.3*, there are mathematical formulas for the volume of regular geometric shapes. For irregular shapes, a common approach is to estimate the volume by breaking the shape down in smaller regular shapes so you can roughly measure dimensions, use the geometric formulas and add up the parts.

Measuring the density of liquids is quite easy since the volume of a liquid can be measured in a measuring cylinder.

For solids and liquids, measuring mass is the easy part of density measurement, since it can be done with an electronic balance.

Note that the density of gases requires a different treatment. This is because the volume of a gas varies with the volume of the container it is in. Its density has to be measured in relation to its pressure, and this is not covered in this course.

Density of water

The density of pure water is 1.00 g/mL. This value is not a coincidence. The unit of mass, the gram, was originally defined in the eighteenth century as the mass of one cubic centimetre of water, and 1 cm^3 is equal to 1 mL. Strictly, this is at a temperature of 4°C, but it varies very little over typical environmental temperatures. You will remember that density is a measure of how much matter (mass) fits in a certain amount of space (volume). Density is a physical property of matter and changes between states of matter due to the different amount of space between particles. For most substances, as the particles are packed more closely in the solid state, this is the most dense state, but this is not the case with water! Think of an iceberg (solid state) floating on water (liquid state). This is a special property of water which comes about because water expands in a crystal structure as it freezes, instead of contracting.

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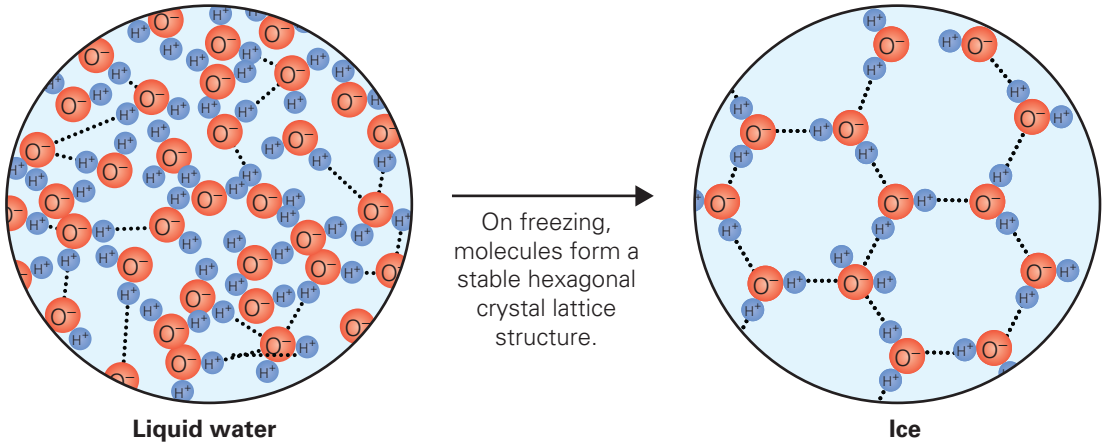


Figure 6.29 Water forms a crystal lattice structure on freezing and expands rather than contracting.

Density of water vapour

The density of water vapour at 1 atmosphere of pressure (i.e. at sea level) and 20°C is about 0.75 kg/m^3.

Investigation 6.3

The effect of state of matter and salinity on water density

INVESTIGATION

Aim

To investigate the density of water in different states of matter and compare the density of fresh water with salt water.

Materials

- large, coloured ice cubes made with fresh (tap) water and food colouring
- 2 × 500 mL beaker
- fresh water
- salt
- spatula
- stirring rod
- camera/phone/laptop

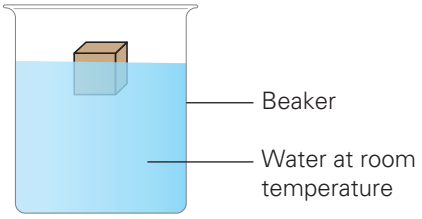


Figure 6.30 Equipment set-up

Procedure

1. Fill each beaker with approximately 300 mL of water.
2. Add 2–3 spatulas of salt (15 g if you would like to be more accurate) to one of the beakers.
3. Add a coloured ice cube to the top of each beaker of water. Watch what happens over time, take photographs and record your observations.
4. Continue until all of the ice has melted.

Results

Record your written observations next to photographs at different stages of the investigation.

Discussion

1. Compare your observations between the fresh water and salt water beakers. What differences did you notice?
2. Explain your observations in terms of the densities of fresh water, salt water and ice. Which is the most dense? How can you tell this from your observations?
3. How could you measure the densities of each state of water to confirm this?

Conclusion

Draw a conclusion from this investigation regarding the effect of temperature and salinity on the density of water.

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Quick check 6.8

1. **State** whether water is more dense when it is solid or liquid.
2. **State** whether water is more dense when it is liquid or gas.
3. **Compare** the density of water vapour (at sea level and at a temperature of 20°C) with the density of liquid water. How many times more dense is the denser one, than the less dense one?

Other properties of water

We have learned about some behaviours of water when it is in a liquid state, and we know it is crucial for life on Earth. However, water has some other fantastic properties. Have you ever noticed raindrops stuck on a window before they flow downwards in a storm? Or have you considered how a boat can float on water rather than sinking through it? These are due to physical properties of water: **buoyancy** and **surface tension.**



DEPTH STUDY IDEA
How has global heating affected the ocean currents?

buoyancy
the ability of an object to float on water or another liquid

surface tension
the ability of water or another liquid to be cohesive (sticky) and resist a force or hold together

Buoyancy

We have investigated the density of objects and learned that objects less dense than water float, while those that are more dense sink. So how do cruise ships made of steel with a density of around 7.8 g/cm^3 float? Well, density does affect an object's ability to be buoyant, but this relies on the overall density of the ship, including all the space below the waterline, not just the steel. You can learn more about buoyancy in Chapter 3.

Try this 6.7

Make a boat that floats!

Determine the density of a lump of plasticine. Does it sink in water when rolled into a ball? Is it possible to reshape this same lump of plasticine so that it floats?

Did you know? 6.5

Salt in water can mean objects are more buoyant!

The Dead Sea is about ten times saltier than the ocean. The high levels of salt increase the density of the water to around 1.24 g/mL, which means visitors to the sea (which is actually a lake) have higher buoyancy than usual and can easily float with heads out of the water!



Figure 6.31 A family floating in the Dead Sea

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Surface tension

You may have seen an insect like this walking on water and wondered, how is that possible?



Figure 6.32 Pond skaters use surface tension to walk on water!

The water particles are attracted to each other, and at the surface, they only have air above them, which means they are even more strongly attracted to their neighbouring water particles. This creates surface tension (a force in the surface) and allows some insects to walk on water without breaking the surface. The amount of surface tension a liquid has depends on the forces of attraction between the particles. Water has strong forces of attraction that give it these amazing properties.

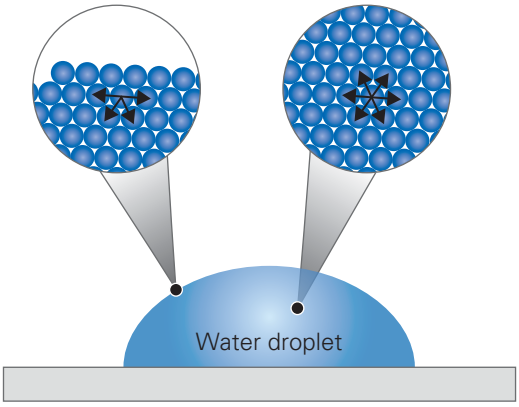


Figure 6.33 Water particles at the surface of a droplet pull strongly towards each other, creating surface tension.

Try this 6.8

Surface tension of water

Aim

To demonstrate the surface tension of different liquids.

Materials

- coin
- liquids to test including water, salty water, cooking oil, soapy water
- pipette dropper
- paper towel/tissues

Instructions

Carefully pipette droplets of each liquid onto the coin and record how many droplets are balanced before the liquid runs off. Be sure to clean and dry the coin between liquids and to record your findings as you go.

Evaluation

1. With which liquid were you able to drop the highest number of droplets onto the coin before it ran off? Therefore, which liquid had the highest surface tension?
2. Did your results surprise you? Explain why.
3. Can you think of everyday situations where you can see surface tension?

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Section 6.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

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Section 6.4 questions

Remembering

1. **State** how density is calculated.
2. **Describe** how water behaves if it is dropped carefully onto a coin.

Understanding

3. **Explain** why ice is less dense than water.
4. **Explain** why adding salt to water increases the ability of objects to float.

Applying

5. A plastic bowl with a mass of 30 g floats in a basin of water, but a teaspoon also with a mass of 30 g sinks to the bottom. **Explain** this observation using your knowledge of the properties of water.
6. Drops of rain often stick on windows for a short time before they run down. If drops of oil are splattered on a window, however, they run down quickly. **Justify** the differences in the time taken for drops to run down a window using your understanding of the properties of liquids.

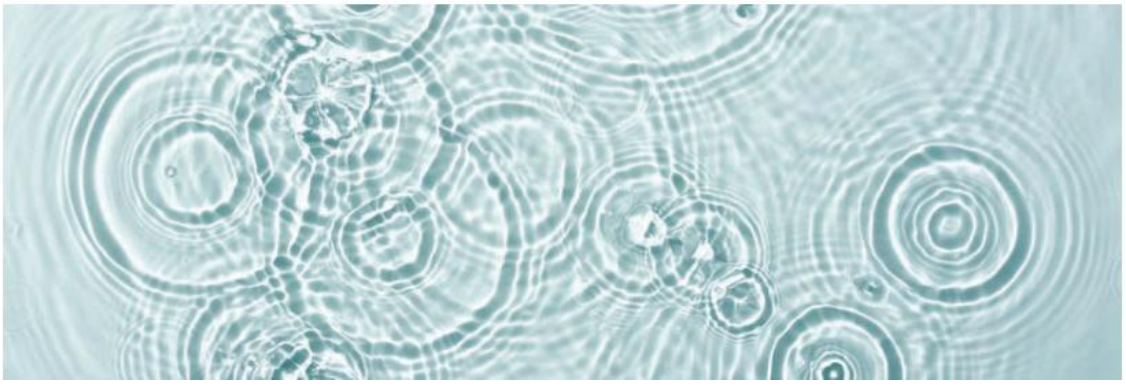
Analysing

7. The table below lists the densities of several materials. Which material will float in water? **Justify** your answer by referring to the information in the table as evidence.

Material	Density (g/mL)
Plastic	0.90
Water	1.00
Sulfur	2.07
Steel	7.80
Rubber	1.20

Evaluating

8. Dry ice is solid carbon dioxide. It changes from a solid to a gas at room temperature without becoming a liquid first and is quite dense. It is often used in filmmaking to make creepy horror cemetery scenes. **Propose** how dry ice is useful in this case. Include the state change involved.



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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
6.1	describe the different states of matter (solids, liquids and gases) using the particle model.	2, 9, 14
6.1	describe how the different states of matter are represented in the water cycle on Earth.	5
6.1	describe the effect of heating and cooling on matter using the particle model.	4, 5, 8
6.2	describe and compare the physical properties of solids, liquids and gases.	2, 4
6.2	explain differences in behaviours of the three states of matter and relate them to particle theory, including the relative strength of forces between particles.	6
6.3	explain how matter changes state in terms of particle arrangement and movement.	5, 8, 13
6.3	describe the processes of melting, freezing, boiling, evaporation, condensation, deposition and sublimation.	1, 8
6.3	conduct an investigation to measure and graph the temperature of water over time to identify the changes of state	1, 5, 8
6.4	determine the volume and mass of regular-shaped and irregular-shaped objects to calculate their density using the formula $\rho = \frac{m}{v}$.	3
6.4	investigate the density of different states of water.	15
6.4	describe some other physical properties of water: buoyancy and surface tension.	11



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Scorcher competition 

Review questions 

Data questions 

Go online to access the interactive chapter review!

Review questions

Remembering

1. **Identify** the correct words or terms to answer the questions or fill in the blanks below.
   - **a.** Something you can do if you want a metal to contract.
   - **b.** Hot air _____ because it expands and gets less dense.
   - **c.** This metal is a liquid at normal temperatures and, because of the way it contracts and expands, can be used to measure temperature.
   - **d.** A word that means the same as evaporation.
   - **e.** The process of turning a solid into a liquid by heating it.
   - **f.** When the water vapour in the air cools down overnight, it will often _____ and form dew.
   - **g.** Hot air balloons rise because the _____ of the air inside them increases.
2. **Recall** the correct properties of solids, liquids and gases to complete the following table.

	Solids	Liquids	Gases
Shape			
Volume			
Density			
Ability to flow			
Ability to be compressed			
Closeness of particles			

3. **Recall** the two measurements that you need to make to calculate the density of an object.

Understanding

4. **State** if each of the following statements is true or false. Rewrite the false statements so that they are true.
   - **a.** Toothpaste behaves only like a solid.
   - **b.** Oxygen can be compressed.
   - **c.** A wooden toy has a fixed shape.
   - **d.** Water vapour changes back to a liquid at the boiling point.
   - **e.** The particles in water are closer together than the particles in water vapour.
   - **f.** Solids and liquids have a fixed mass, while gases do not.
5. **Describe** the changes in state that occur as water cycles from bodies of water to clouds to snow and back to bodies of water.
6. **Compare** the relative strength of forces between particles in a gas, a solid and a liquid of the same substance and explain how this usually determines their relative densities.

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Applying

7. **Explain** why a solid is very difficult to compress when force is applied.

8. Use your knowledge of the particle model to **explain** what happens in the following situations.

a. The temperature of water vapour (gas) is decreased

b. The temperature of liquid water is decreased

9. Imagine a single grain of sand. It is hard and has a definite shape. If you scoop up a handful of dry sand, you can pour it out of your hand, which sounds like the behaviour of a liquid, not a solid. It is very difficult to build a sandcastle with dry sand. However, if you wet the sand, you can shape it into a sandcastle. **Explain** why you might classify sand as a solid.

10. Draw the expected graph of temperature over time for a substance being heated from –25°C to 200°C if its melting point is –10°C and its boiling point is 175°C. **Identify** the changes of state on the graph.

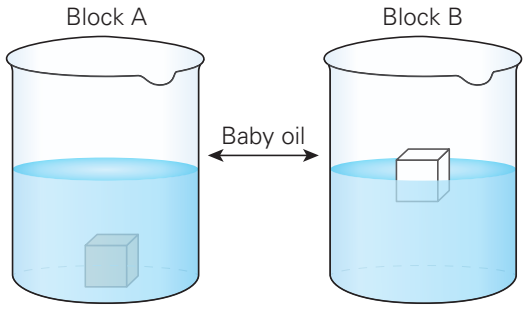
11. Water is a liquid with some unique properties. **Explain** the following properties, including an example of where the property is demonstrated in everyday life in your responses:

a. Surface tension

b. Buoyancy

Analysing

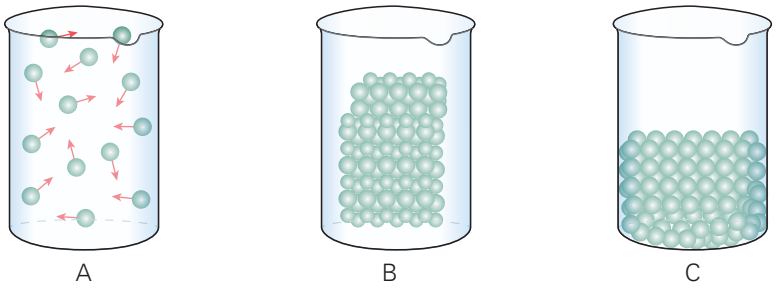
12. Block A and block B are made of different materials. Each block is in a beaker with baby oil, as shown below.



a **Explain** why block A sinks and block B floats. The density of baby oil is 0.82 g/mL.

b **Decide** whether warming up the baby oil in the beaker containing block B would give the same or different results.

13. Classify the following diagrams as a solid, liquid or gas. **Identify** the state of substance B, giving reasons for your choice.



Evaluating

14. The particle theory of matter states that there are attractive forces and spaces between particles. **Decide** whether the forces of attraction are greater or lesser for particles that are further apart from one another.

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15. When a full bottle of water is placed in the freezer, the bottle can sometimes split apart. **Propose** why this may happen, with reference to the difference in density between liquid water and ice.

Data questions

Water exists naturally on Earth in three states: solid (ice), liquid (water) and gas (water vapour). Figure 6.34 shows the point at which water changes between these states at different temperatures and pressures.

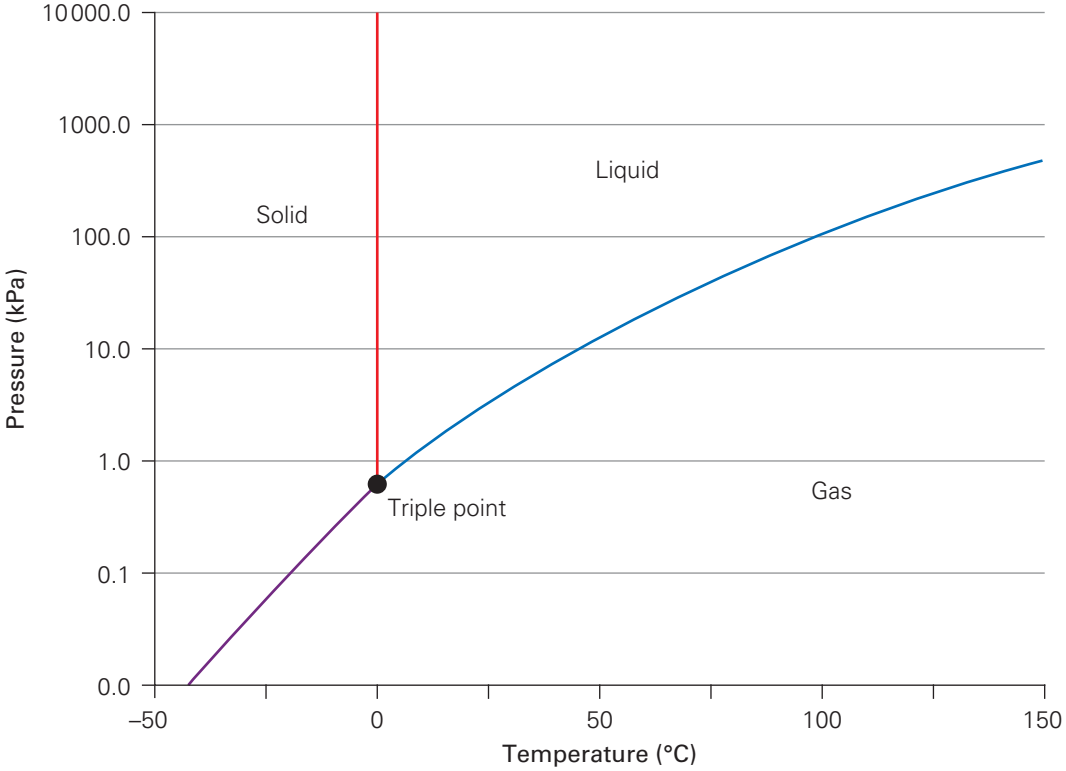


Figure 6.34 State changes of water at different temperatures and pressures. The purple line illustrates sublimation, the red line melting and the blue line evaporation.

1. **Identify** the state of water at 50°C and 100 kPa.
2. **Identify** the temperature of freezing at 1000 kPa.
3. **Contrast** the boiling point of liquid water at 10 kPa pressure and 100 kPa pressure.
4. **Infer** what is meant by the 'triple point'.
5. Given that atmospheric pressure (the pressure at sea level) is approximately 101 kPa, **explain** why we tend to encounter water in its liquid state in our daily lives (puddles, rain, rivers, lakes, coming out of taps etc.).
6. **Predict** at what temperature liquid water will freeze at 20 000 kPa pressure.
7. **Justify** that, at atmospheric pressure (101 kPa), snow should melt, and not sublime.
8. Starting at atmospheric pressure (101 kPa), **deduce** whether the pressure needs to be increased or decreased at 0°C for ice to sublime.
9. **Deduce** whether it is possible for water to exist as a liquid above 100°C.

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STEM activity: Prosthesis design

Background information

Your skeleton protects your organs and gives your body shape and structure. Your skeleton is necessary for you to move, make blood cells, store calcium and more! You would look very different without it. For various reasons, not everyone has all the bones that complete their skeleton. Biomedical engineers act to combine engineering principles and problem-solving strategies for healthcare purposes. In this case, a biomedical engineer would study the strength and durability of our bones so that they can replicate them to make prostheses (artificial devices that replace body parts).

DESIGN BRIEF

Construct a lower-leg prosthesis that can assist in movement.

Activity instructions

In teams, you will become a biomedical engineer and investigate the technology of prosthetics.



Figure 6.35 Components of an artificial lower leg

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Suggested materials

- ruler or tape measure
- scissors
- prosthetic structural materials from home, e.g. cardboard tubes, sponges, pants, shoes, rope
- roll of duct tape

Research and feasibility

1. Conduct research to find out what types of materials are used to manufacture prostheses, the physical properties of the materials and design considerations of the prosthesis.
2. Consider important design factors using the table below. You can also add other design considerations.

Design consideration	Why this is important	Rank of importance
Aesthetics (how it looks)		
Cost of materials		
Customisation of the prosthesis (socket that connects the prosthesis)		
Usability (how easy it is to use)		

Design

3. Design a lower-leg prosthesis and label all the design features. Consider the types of materials available, their durability and how the prosthesis attaches to the limb to allow movement.

Create

4. Construct the lower-leg prosthesis you have designed using the materials available.

Evaluate and modify

5. Create a reflection chart as shown below. Make sure you reflect on the strength, durability, usability, and comfort of the prototype.



Figure 6.36 An artificial limb restores functionality and independence.

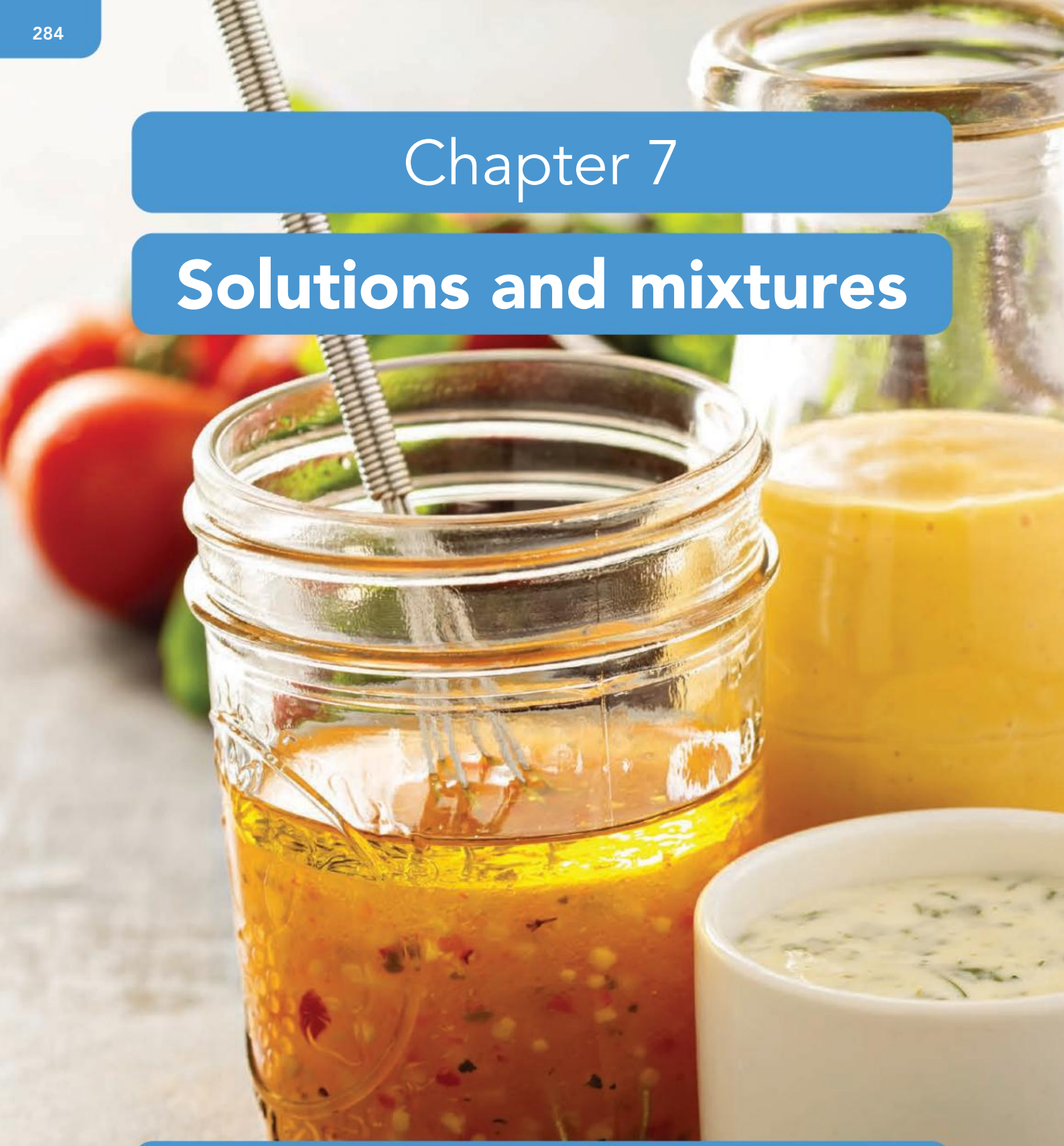
Positives	Negatives	Interesting
e.g. Ankle movement is realistic and the ankle has a 60° range.	e.g. Cardboard tubing used was not strong and broke when tested.	e.g. The foam used around the tubing was a strong support for the tubing.

6. Explain the improvements and modifications you would make to the prototype in a presentation to the class.

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Chapter 7

Solutions and mixtures

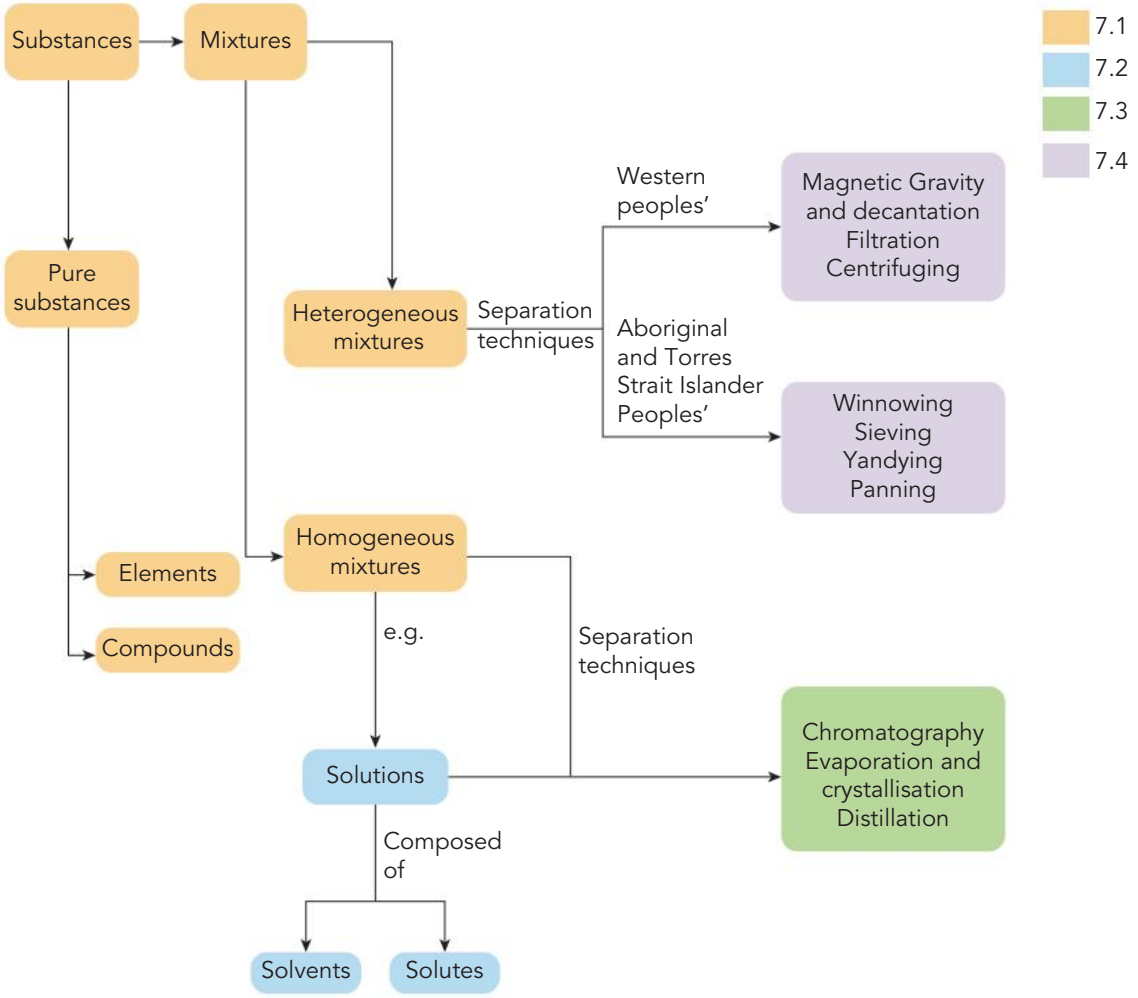


Chapter introduction

Our world is an amazing place. It is made up of many different substances like wood, food, metal, fibres, air, glass, plastic and ceramics. Some of these substances are pure substances, while others are mixtures. This chapter will help you understand how to identify pure substances and mixtures, understand the arrangement of particles in them and the differences between them. You will also look at the role of chemistry in helping us separate different mixtures into their parts and their separation in your home, as well as how people in different jobs use separation techniques.

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Chapter map



Glossary terms

aqueous solution
atom
centrifuge
chromatography
compound
concentrated
crystallisation
decantation
dilute
dissolve
distillation
element
evaporation
filtrate
filtration
flocculant
heterogeneous mixture
homogeneous mixture
insoluble
koolamon
mixture
molecule
pure substance
residue
saturated
solubility
soluble
solute
solution
solvent
supersaturated

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7.1 Pure substances and mixtures

WORKSHEET Separating heterogeneous mixtures

Learning outcomes

At the end of this section, I will be able to:

1. distinguish between atoms, compounds and mixtures and use particle theory to explain their properties.
2. classify matter as pure substances (elements and compounds) and impure substances (mixtures based on particle composition).
3. identify heterogeneous and homogeneous mixtures.

atom
the smallest possible piece of any substance; it makes up all matter

In the Chapter 6, you learned about the particle theory of matter, and the relationship between solids, liquids and gases. Scientists refer to some of these tiny particles using the scientific term '**atom**'. This word comes from an ancient Greek word that means 'indivisible'. You will learn more about atoms in Chapter 10, but we are going to keep it simple for now. If you want to imagine how small atoms are, there are about 10 000 000 000 000 000 atoms in the dot at the bottom of this exclamation mark!

Try this 7.1

The size of an atom

Cut a strip of paper 28 cm × 1 cm. Now cut it in half, and you will have two 14 cm lengths of paper. This is cut 1. Repeat this as many times as you can, counting your cuts as you go.

How many cuts were you able to make? Name one item that is the same size as the paper with 1 cut, 3 cuts, 5 cuts. How do you think you could keep cutting the paper smaller and smaller? Imagine this: it takes 31 cuts to get a piece of paper the size of an atom!

Pure substances: Elements and compounds

pure substance
material that is made up of either one type of atom or the same groups of atoms (molecules or compounds)

element
a substance made up of only one type of atom

compound
a substance made up of two or more different types of atoms

molecule
two or more atoms joined together by strong bonds

A **pure substance** is a substance that is made up of just one type of material or one type of particle, for example, pure water, pure gold and oxygen. Every pure substance has unique physical properties such as different states, densities, size, magnetism, colour, mass, melting points and texture. Scientists need an understanding of these different physical properties to be able to distinguish one type of material from another.

There are two types of pure substance that you will learn about here: **elements** and **compounds**. You will learn more about these, their properties and how they behave in Chapter 11, but we will start to use these terms here.

An element is a substance made up of only one type of atom. These can be single atoms or atoms that are bonded together (you will learn about bonds in Chapter 11), but they are all the same type of atom. For example, gold is an element and is made up of many single gold atoms joined by metallic bonds. A combination of atoms held together by strong bonds is called a **molecule**.

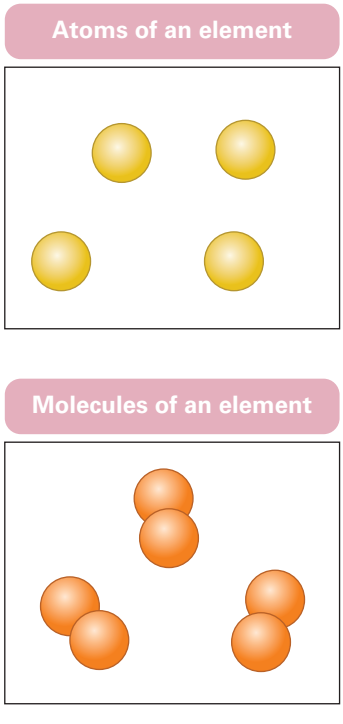


Figure 7.1 In an element, all the atoms are the same.

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Atoms of the element hydrogen tend to bind together to form molecules, each with two hydrogen atoms.

A compound is a substance made up of two or more different types of atoms bonded together. For example, water is a molecular compound as it is made up of two hydrogen atoms bonded to one oxygen atom, joined by strong bonds.

An atom is the smallest particle of an element that still has the properties of that element. For example, an atom of carbon can naturally decay (split up into smaller particles) but the resulting atoms will no longer be carbon.

A molecule is the smallest particle of a compound that still has the properties of the compound.

The properties of atoms and compounds are determined by such things as their mass and chemical reactivity – how likely they are to undergo chemical change – and how they respond to their physical environment, including heat and light.

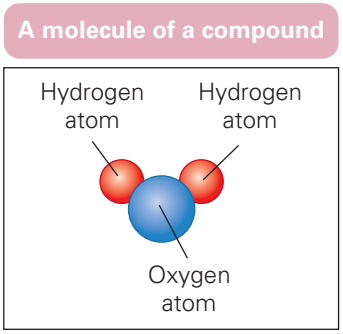


Figure 7.2 A water molecule is a compound because it has two different types of atoms: one oxygen atom bound together with two hydrogen atoms. Water is also a pure substance, as it is made up of only one type of molecule, the one shown here.

Quick check 7.1

1. Match the following terms with their correct definitions.

Molecule	The smallest piece of substance you can have; it makes up all matter
Compound	Substance made up of only one type of atom
Element	Two or more atoms (same or different) joined together by bonds
Atom	Substance made from two or more different types of atoms

Did you know? 7.1

Scanning tunnelling microscopes

You cannot see an atom with a light microscope, which is the type of microscope you may have at school. In 1981, a type of microscope called a scanning tunnelling microscope (STM) was developed that allowed scientists to finally see atoms. Since then, the technology has improved further, and in 2018, the world record for the highest-resolution microscope was achieved by researchers at Cornell University in the United States. Their transmission electron microscope (TEM) measures down to an impressively small one billionth of a metre.

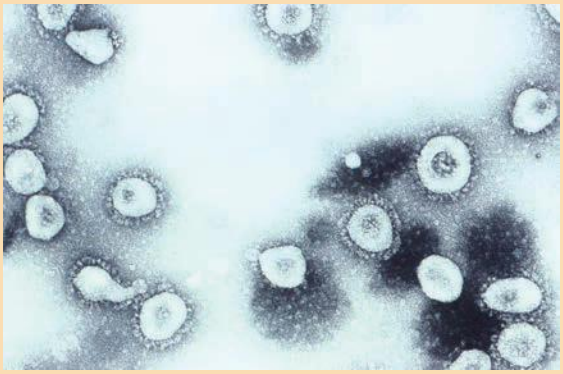


Figure 7.3 Transmission electron microscopic (TEM) image of coronavirus OC43, a member of the same family of viruses that causes SARS-CoV-2 (the novel coronavirus that causes coronavirus disease 2019, or COVID-19).



Figure 7.4 This scanning transmission electron microscope in the United States is able to see single atoms.

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Mixtures

mixture
a material made up of two or more different pure substances (compounds or elements) that are not bonded together

dissolve
cause to become mixed in a liquid so that it cannot be seen

Almost everything around you is a **mixture** of different pure substances. Mixtures are substances made from two or more different substances mixed together that can be physically separated. Mixtures can be separated because they have not combined in a chemical way through a chemical reaction. Some examples of mixtures that you may be familiar with include soft drinks (a mixture of sugar, water, carbon dioxide, flavours and colouring), a cup of tea (a mixture of tea leaves and water), tap water (a mixture of water, fluoride salts, salts **dissolved** from ground water and chlorine), spaghetti bolognese (a mixture of pasta, tomatoes, beef, garlic and thyme) and fruit salad (a mixture of kiwi fruit, apples, bananas and raspberries).

VIDEO
Types of mixtures



Figure 7.5 Spaghetti bolognese sauce is a mixture you may love to eat.

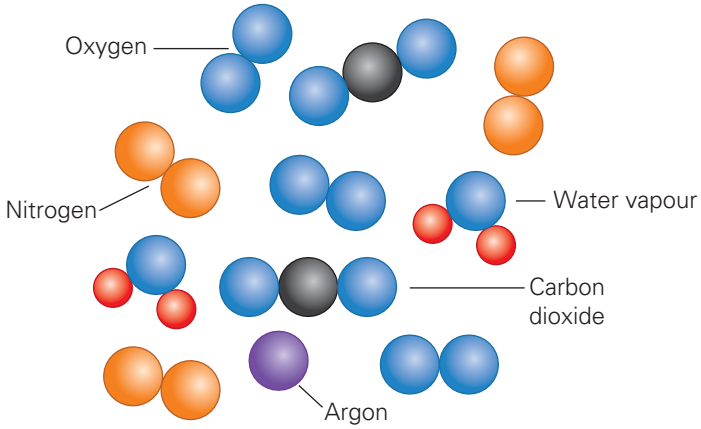


Figure 7.6 Air is a mixture of several different elements and compounds: nitrogen, oxygen, argon, carbon dioxide, water vapour and very small amounts of other gases. Note that this diagram does not show the relative amounts of these components.

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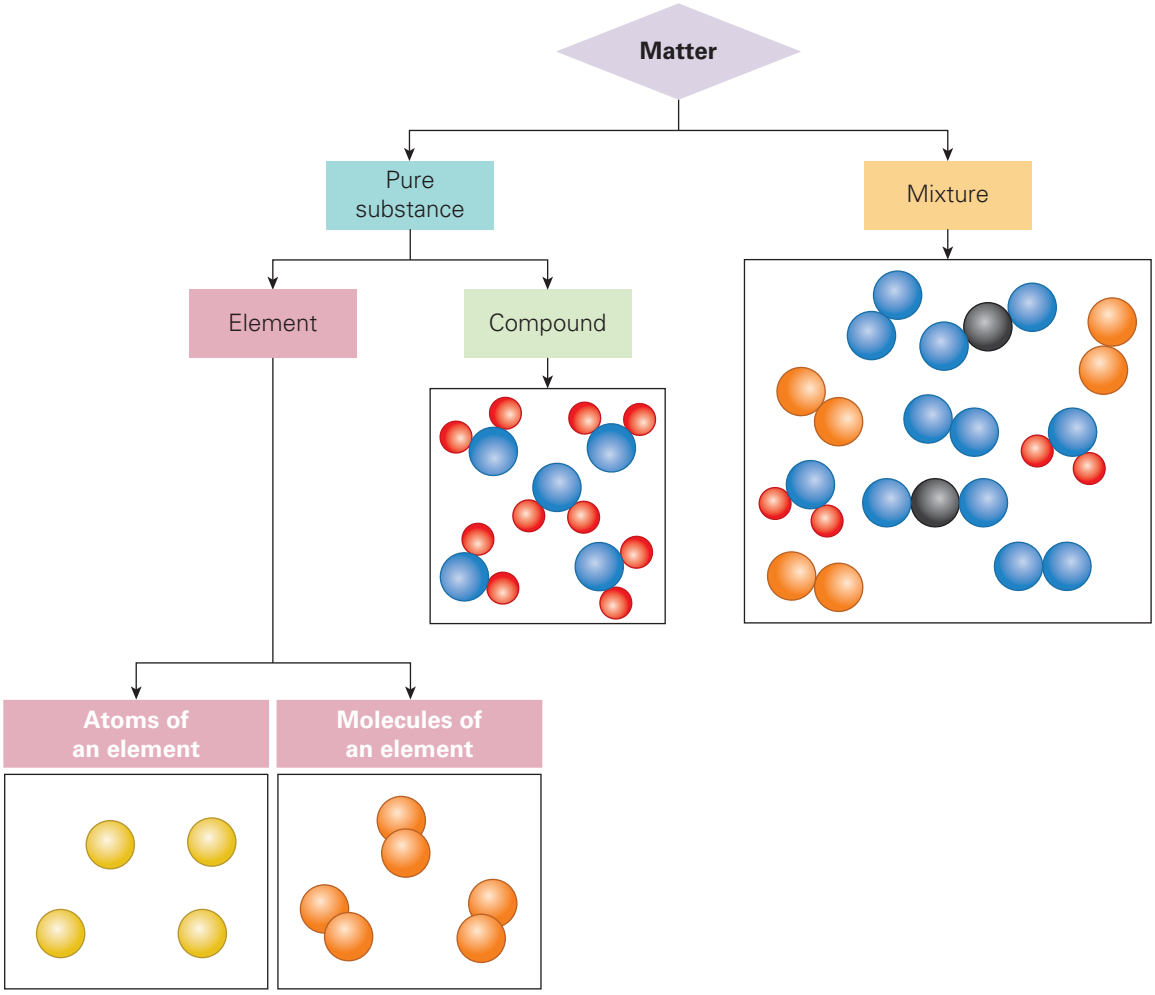


Figure 7.7 Putting it all together: matter is made up of pure substances (elements and compounds) and mixtures.

Quick check 7.2

1. Draw up a table with the headings 'pure substances' and 'mixtures' and classify the names of the following substances by writing them into the correct column.

smoke	pen ink	iron
soft drink	aluminium foil	cough medicine
trail mix	margarine	filtered water
hand cream	chocolate milk	jelly
salt water	ice cream	cheese
oxygen	carbon dioxide	blood

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Classifying mixtures

homogeneous mixture
a mixture where components are evenly distributed and all parts have the same properties

heterogeneous mixture
a mixture that can be easily separated into its parts, and those parts keep their original properties

Mixtures can be broadly classified into two categories: **homogeneous mixtures** and **heterogeneous mixtures** (see Figure 7.8). You need to understand these terms because they help you determine the properties of mixtures, and you need to know these before you can attempt to separate a mixture into its components.

Homogeneous mixtures are mixtures where you cannot tell that two or more substances have been mixed together as they don't settle or separate out when left to stand. The components of the mixture are all evenly distributed, and the entire mixture has the same properties. For example, air, tap water and soft drinks are all homogeneous mixtures, because wherever you take a sample from, the properties of the samples will be the same.

Heterogeneous mixtures are mixtures that can be easily separated into their parts, and those parts retain their original properties. The mixture is not blended together evenly and is not the same consistency throughout, so if you were to take a sample from different parts of the mixture, you would find all of your samples have different properties. Examples include trail mix, fruit salad, pizza, choc chip cookies and salad dressing.

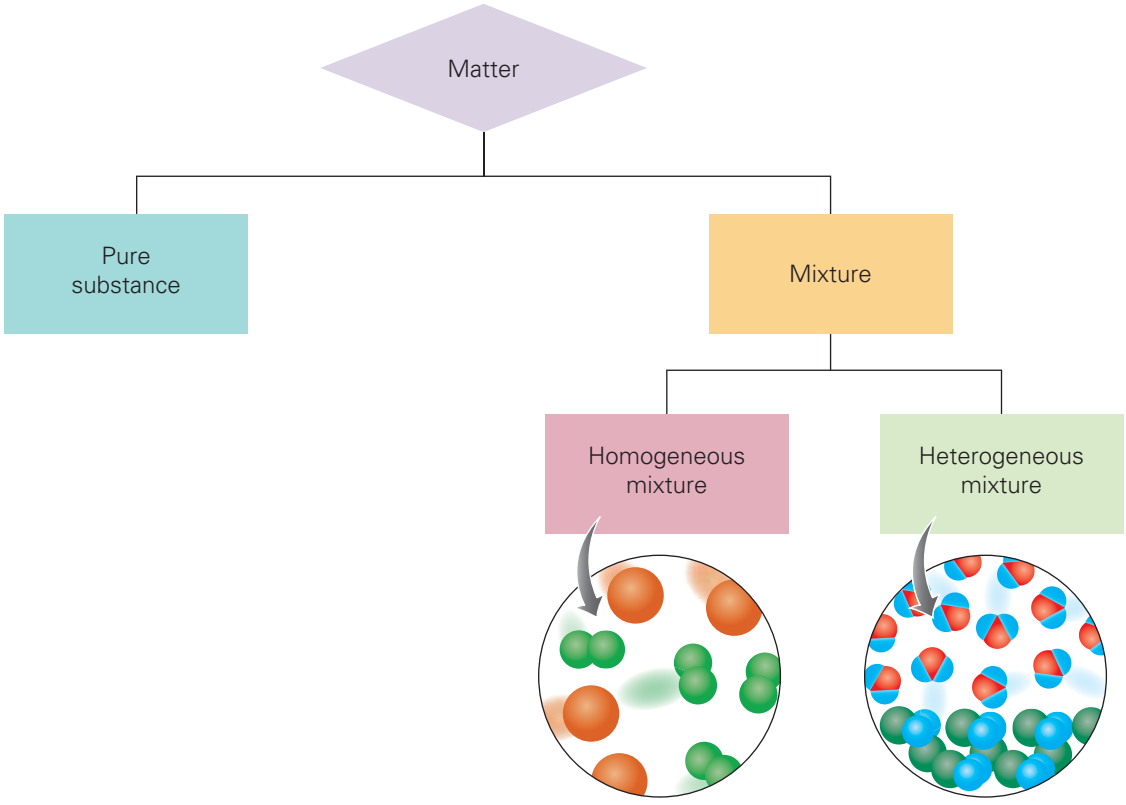


Figure 7.8 How particles may be organised in a heterogeneous mixture and a homogeneous mixture

Quick check 7.3

1. **Define** the term 'heterogeneous'.
2. **Recall** the characteristics that allow you to identify if a mixture is heterogeneous.
3. **Define** the term 'homogeneous'.
4. **Recall** the characteristics that allow you to identify if a mixture is homogeneous.
5. Research online to find out about your local recycling process and then **describe** the properties of the different components of the recycling that allow the parts to be separated.

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Section 7.1 review

Online quiz

Section questions

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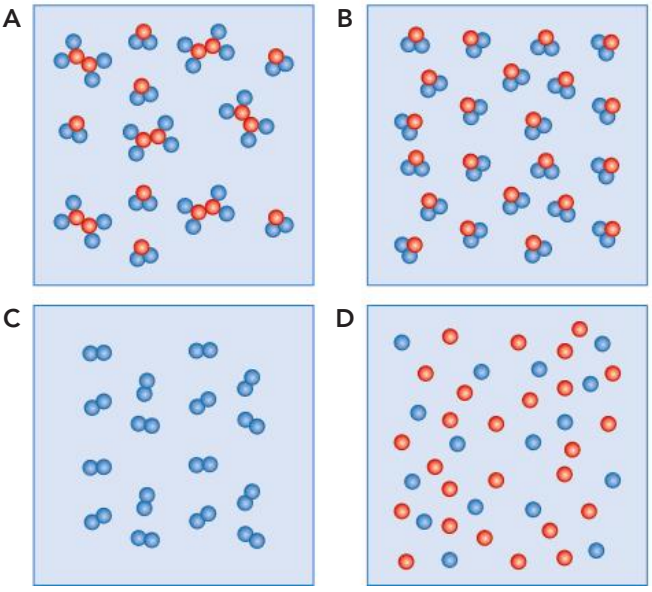
Section 7.1 questions

Remembering

1. **Name** the smallest part of an element.
2. **Define** the terms 'pure substance' and 'mixture', providing examples of each.
3. **Identify** which of the following would be described as a pure substance: smoke, air, water, hair gel

Understanding

4. Look at diagrams A to D below.



Select which diagram is:

   a. an element
   b. a compound
   c. a mixture of elements
   d. a mixture of compounds.

5. **Summarise** the differences between pure substances and mixtures. Give two examples of each.
6. **Outline** the differences between heterogeneous mixtures and homogeneous mixtures. Give two examples of each.

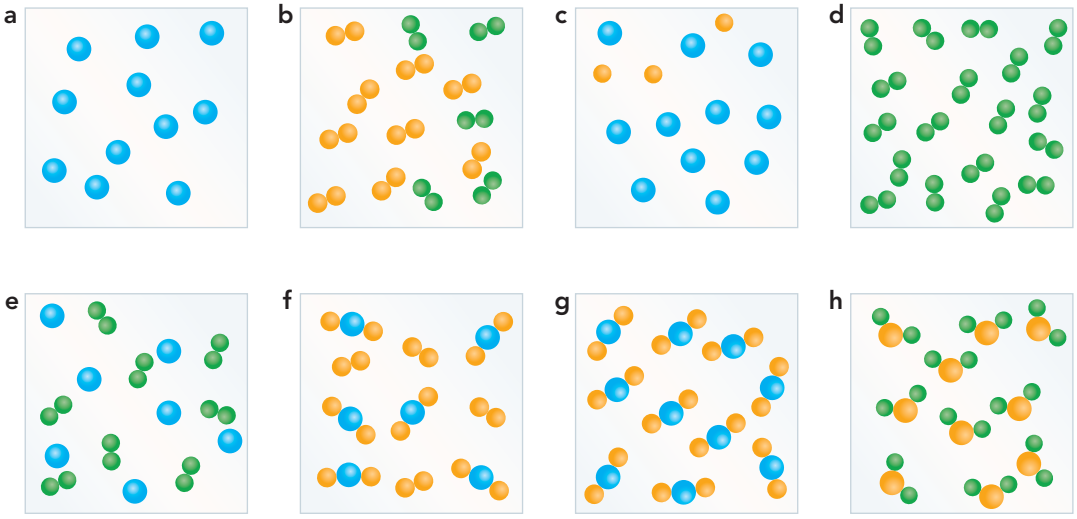
Applying

7. Is 100% pure carrot juice a pure substance? **Explain** using the definitions you have learned.
8. You add a powdered substance to a liquid in a container and shake the container. You then place the container on a table and observe it over time. **Outline** how you can tell if it is a homogeneous mixture or a heterogeneous mixture.

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Analysing

9. **Classify** the following substances as a homogeneous mixture, a heterogeneous mixture or a pure substance. Substances: pure water, cola, iron nails, green paint, chunky salsa, silver ring, chocolate chip cookies, concrete, orange juice with pulp, table salt.
10. **Select** one or two words from the following list that best describe each of the following particle diagrams: mixture, pure substance, heterogeneous, homogeneous.



Evaluating

11. **Justify** the saying 'oil and water don't mix', referring to vegetable oil and vinegar poured into a bowl to make a salad dressing, before and after it is whipped up with a fork, and then if it is left to stand for a while. Is it a heterogeneous or homogeneous mixture?



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7.2 Solutes, solvents and solutions

Learning outcomes

At the end of this section, I will be able to:

1. identify substances that dissolve in water and use the terms soluble, insoluble, solubility, solute, solvent and solution.
2. describe how particle theory can be used to model solutions.
3. measure solubility of different solutes in water, and present data using tables and relevant graphs.
4. describe the effect of temperature on solubility.
5. compare the properties of dilute, concentrated, saturated and supersaturated solutions.
6. calculate the concentration of dilutions using grams per litre (g/L) or percentage volume per volume (% v/v).

WORKSHEET Solutions, solutes and solvents

VIDEO Dissolving solutes in a solvent

Solutions

A **solution** is a type of mixture that is formed when the particles of one substance separate and spread out evenly into another substance. This act of separating and spreading out is called dissolving. Recall that the solute is the name given to the substance that dissolves, and the solvent is the name given to the substance it dissolves into. A solution is therefore the name given to a mixture of a **solute** dissolved in a **solvent**.



Figure 7.9 Tap water is a solution because various trace elements from the ground water, plus chlorine and fluorine added by water treatment, are dissolved evenly in pure water.

solution
a mixture where one substance is evenly dissolved in another

solute
the component of a solution being dissolved

solvent
the component in a solution capable of dissolving another substance

Try this 7.2

Particle theory

Put a sugar cube in a glass of water. Describe what is happening using the terminology you have been learning. What happens in terms of particles? Where are the particles? What are the particles doing?

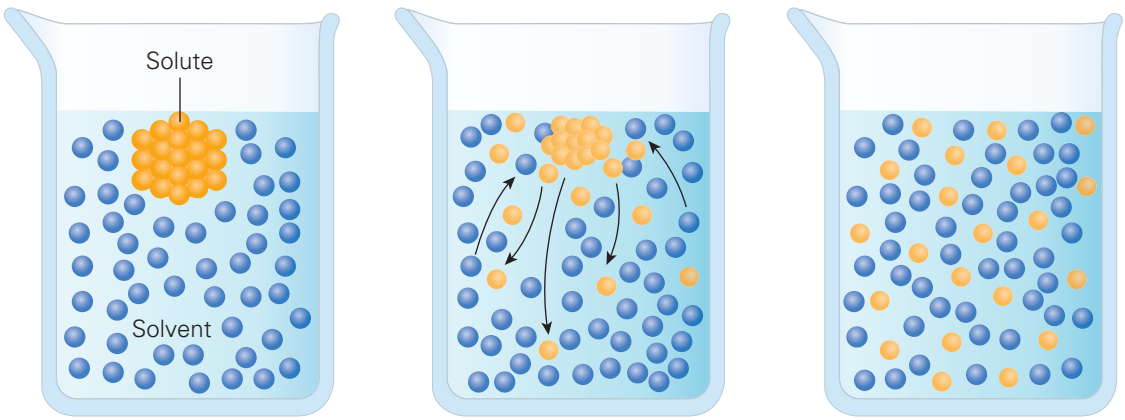


Figure 7.10 Particle diagram of a solid solute dissolving into a liquid solvent to form a solution. Note that only representative particles of solvent are shown in this kind of diagram – there would be negligible space between them.

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Figure 7.11 Oxygen is a solute that is dissolved in the solvent water to form the solution that organisms like fish and plants live in.

Examples of solutions

An everyday example of a solution is the oxygen dissolved in fish tank water, where the oxygen is the solute, and the water is the solvent. Other examples include the cordial (solute) dissolved in a glass of water (solvent) and the carbon dioxide (solute) dissolved in a fizzy drink water (solvent). You will notice that many of the solutions mentioned so far are made of solutes dissolved in the solvent water. Water is sometimes called the 'universal solvent' due to its versatility to dissolve a wide variety of different solutes. Solutions using water as a solvent are called **aqueous solutions**.

Not everything is able to dissolve to form a solution. Substances that can dissolve are called **soluble** and those that are unable to dissolve are called **insoluble**. Substances that are insoluble have very strong forces of attraction between their particles. The solvent cannot break apart those particles, and so the substance remains undissolved.

aqueous solution a solution where the solvent is water

soluble substances that can dissolve

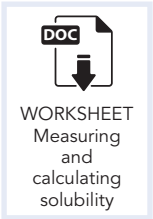
insoluble substances that cannot dissolve

solubility the ability of a solute to dissolve in a solvent to form a solution

The ability of a substance to dissolve in a solvent is called its **solubility** (in that solvent). The maximum amount of a solute that can dissolve in a given amount of solvent varies by temperature and in some cases pressure.

Measuring solubility

Solubility can be measured and expressed in units when we know the mass or volume of the solute that has been added to or is in a known volume of the solute. A variety of units are used, but the common ones are grams per litre (g/L) or percentage volume per volume (% v/v).



WORKSHEET Measuring and calculating solubility

Solution concentrations

A solution that has very little of a substance (solute) added to the solvent is said to be **dilute**. It is also described as a solution with a low concentration. For example, a friend asks you to make a weak glass of cordial. You would need to add only a little of the cordial (solute) and a lot of water (solvent) to make a weak or dilute solution.

A solution that has a lot of a substance (solute) added to the solvent is called **concentrated**. It is also described as a solution with a high concentration. How would you make your friend's cordial drink in this case?

dilute a solution with only a small amount of the solute

concentrated a solution with a large amount of the solute



Figure 7.12 The more dilute solutions are on the left, while the more concentrated solutions are on the right.

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Quick check 7.4

1. Copy and **complete** each incomplete sentence using the correct word from the following list: aqueous solution, dissolves, soluble, solute, solution, solvent
   When sugar is mixed with water, it _____, and this shows that sugar is _____ in water. When it dissolves, it forms a _____.
   The sugar is called the _____. This type of solution, where water is the _____, is called an _____.
2. **Define** these terms and give a named example of each: solution, solvent, solute, aqueous solution.

Try this 7.3

Investigating solubility



WORKSHEET
Dissolving solutes

Investigate the solubility of household substances in water, at home or in class.

1. Collect seven containers of the same size. (Alternatively, use test tubes in a rack from your science laboratory.)
2. Add a teaspoon of one of seven common household substances to each container and label the container. Typical substances are sugar, salt, bicarbonate of soda, flour, coffee, sand and jelly crystals.
3. Add a couple of tablespoons of cold water from the tap and mix the substances together using a spoon or by carefully swirling or jiggling the test tube.
4. Record your observations of each substance as soluble, partly soluble or insoluble in a results table.
5. Why is it that some substances dissolve in the water but others do not? Can you ever put too much solute in a solvent so it stops dissolving? Try adding more and more solute to one of the containers to find out. Measure (in grams or teaspoons) the amount of solute you can add before it stops dissolving. Notice how some substances are more soluble than others.

Saturation

saturated
a solution with the maximum amount of solute dissolved

supersaturated
a solution with more than the maximum amount of solute that is possible to dissolve; undissolved solute will be visible

Did you try adding more and more solute to one of your containers in *Try this 7.3*? When you do this, you will notice that the solution reaches a point where no more solute can dissolve. The solution is now called a **saturated** solution. This is like having a towel saturated with water after you drop it in the pool – the towel just cannot take in any more water. A saturated solution is so concentrated that no more solute will dissolve into the solvent. If you continue adding solute after this point, undissolved solute will settle at the bottom of the container. At this point, the solution is called a **supersaturated** solution.



Figure 7.13 If you add enough solute to a solution, eventually the solute will no longer dissolve.

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INVESTIGATION

Investigation 7.1

The effect of temperature on solubility

Background information

Water is a 'universal solvent', and many substances will dissolve in water. Every solute has a different ability to dissolve, depending on their physical properties.

Be careful

Take care with hot water and no food should be consumed in the lab, so do not eat the M&Ms used in this experiment.

Materials

- M&Ms or similar sugar-coated chocolates
- 3 glass beakers
- hot water
- room temperature water
- cold (iced) water
- white paper

Procedure

1. Pour hot water, cold water and room temperature water into the three glass beakers, enough to cover an M&M.
2. Place the beakers on white paper and label each.
3. Place a single M&M of the same colour in each beaker at the same time.
4. Observe what happens over a few minutes and record your observations.

Results

Record your observations, including photographs if you wish.

Discussion

1. Does the temperature of the water affect the amount of coloured coating that dissolves from an M&M? How do you know?
2. The particle model explains what happens to liquid particles when they are heated. What happens to the water molecules as the temperature is increased? Can you use this to explain the results you saw?
3. This investigation compared your observations of solubility at different temperatures. Can you think of how you might carry out a quantitative investigation, where measurements are recorded for more accurate comparisons?

Conclusion

Write a short conclusion on the effect of temperature on the solubility of sugar in water from your results.



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Section 7.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

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Section 7.2 questions

Remembering

1. **Define** these terms: saturated solution, aqueous solution, dilute solution, concentrated solution.

Understanding

2. **Rewrite** each statement to make it true.
   - **a.** Soluble is when a substance cannot be dissolved in a solvent.
   - **b.** The solvent dissolves to form a solution.
   - **c.** A mixture is when different substances are chemically combined.
   - **d.** A saturated solution is a solution in which the minimum amount of solute has been dissolved.
   - **e.** In a solution, it is the solute that is unable to dissolve into the solvent.
   - **f.** Concentrated solutions have a lot of solvent compared to the amount of solute.

Applying

3. **Explain** why it is possible to see solid salt crystals added to water but not possible to see the dissolved salt particles.
4. **Determine** which is the solvent, solute and solution in the following situations.
   - **a.** Fizzy water
   - **b.** Vinegar
   - **c.** Syrup
5. You were given a diluted mug of cordial and a concentrated mug of cordial and asked to work out which was which without looking in the mug. **Determine** how you would achieve this.
6. **Justify** whether a supersaturated solution is a homogeneous or heterogeneous mixture.
7. **Describe** how the properties of colour, density and taste change as more and more red cordial is added to a glass of water.
8. A saturated solution of sugar in 150mL of water is evaporated, leaving behind 300g of sugar. **Calculate** the solubility of sugar in g/L.

Analysing

9. **Compare** and **contrast** solutions and mixtures. You may like to use a Venn diagram.
10. Are all solutions mixtures? Or are all mixtures solutions? **Justify** your choice.

Evaluating

11. Look at the diagram of a test tube on the right containing a liquid substance and a soluble solid substance. **Redraw** and **label** the diagram as many times as needed to **illustrate** the following key terms. You may be able to include several terms on one diagram.



dilute solution	concentrated solution
dissolve	aqueous solution
insoluble	soluble
solution	saturated solution

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7.3 Separating heterogeneous mixtures

WORKSHEET
Separation

Learning outcomes

At the end of this section, I will be able to:

1. explain how methods such as magnetic separation, decantation, flocculation, filtration and centrifuging can be used to separate heterogeneous mixtures.

Heterogeneous mixtures like fruit salad can be separated into their parts using their physical properties such as size of pieces, colour, texture, hardness, smell and so on, and those parts retain their original properties. To actually separate them, though, you need to use hand-sorting, that is, using your fingers to get your favourite lollies out of a lolly bowl, or pulling the strawberries out of a fruit salad. But there are other ways of sorting using their physical properties.

Magnetic separation

Magnetic separation is another technique that is easy to use, based on the magnetic properties of materials – some are magnetic while most aren't. Imagine you are building a skateboard in woodwork class and you drop some screws on the sawdust-covered floor. Magnets attract iron, nickel and cobalt-containing substances (ferromagnetic) like screws, and so you would be able to pull the screws out from under the sawdust as wood does not contain iron. This is how steel cans (containing iron) are separated from the rest of your non-ferromagnetic recycling at the Materials Recovery Facility.



Figure 7.14 Magnets can be used to separate magnetic substances from non-magnetic substances.

Decantation

decantation the process of separating by using gravity, pouring the liquid off the bottom layer of solids

flocculant a substance that causes particles to clump together

filtration separating a mixture by passing through a filter

If you have dropped a piece of fruit in your drink at a birthday party, the fruit will sink to the bottom of your glass. The process of **decantation** can help you separate your drink from the piece of fruit. Decantation is a technique where you carefully pour the liquid off the top of a solid–liquid mixture or a liquid–liquid mixture, to separate the two components. You may have done this when pouring water off the top of your vegetables once they have been boiled for dinner. Decantation uses the flow properties of a liquid.

Flocculation

A **flocculant** is a chemical that causes suspended particles to clump together so that they sink (forming sediment). They can be separated from the liquid they were suspended in by decantation or sometimes by filtration. For example, you collect muddy water from a river and while some particles settle to the bottom, the water is still cloudy. A flocculant would help clear the water by causing the smaller particles to clump and sink. It is also used to clarify water in swimming pools.

Filtration

Filtration is a technique used to separate the components of a mixture based on their size and solubility by passing them through a filter. You may have heard of filter baskets in pools that catch the leaves, or filters used in your vacuum cleaner so that the air pumped out is cleaned, or perhaps the filters used in cafes when making coffees.

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The holes in the filter will be different sizes depending on what is being filtered. For example, a filter basket in a pool has holes that you can see as leaves are not microscopic; however, the holes in a coffee filter are much smaller as the coffee granules are smaller.

Sieving is another name for filtration and is perhaps a lot more familiar to you – watching your fish and chips being pulled out of hot oil using a wire basket, sifting flour when baking a cake or straining your spaghetti by pouring it through a colander.



Figure 7.15 Coffee at a cafe is produced by pouring or forcing hot water through coffee grounds in a paper, plastic or metal filter. The filter allows the water to pass through but not the coffee grounds as they are too big to pass through the holes.

Quick check 7.5

1. **Recall** what you could use to separate a mixture of sand and iron.
2. **Explain** what might prevent a magnet from being useful to separate the components of a mixture.
3. **Identify** a situation when hand-picking would be the most appropriate way to separate a mixture.
4. **Explain** the separation technique of decantation.



Figure 7.16 Flocculants can be used to help clean pool water.

Did you know? 7.2

Filtration in cars

Combustion engines in cars have very fine filters that can trap extremely small carbon particles and stop them from polluting the atmosphere.

Filtrate and residue

When you talk about the process of filtration, you use words like **filtrate** and **residue**. The filtrate is the name of the substance that passes through the filter – for example, the clean air coming out of an air conditioner. The residue is the name of the substance left behind in the filter after the process of filtration. In this example, it is the dust in the air that enters the air conditioner from outside.

filtrate
the substance that passes through the filter

residue
the substance that is left in the filter

Did you know? 7.3

Toothless whales have filters

The humpback whale, and other toothless whales, possess a unique feeding adaptation called baleen. The baleen is a wide plate in the whale's mouth, made up of hundreds of long, fringed blades that are composed of the same substance in our hair and nails. The blades filter small animals such as krill, plankton and small fish out of the sea water.



Figure 7.17 The mouth of a humpback whale contains baleen, which allows them to filter the ocean water for krill.

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Try this 7.4

Drawing a filter

Draw a cartoon strip, make an animation using PowerPoint or make a stop-motion short film demonstrating the movement of different-sized particles through a filter with fixed-sized holes.

Practical skills 7.1

Separating heterogeneous mixtures

Be careful
Do not test water by consuming it.



Aim

To compare the effectiveness of different separation techniques for cleaning contaminated water.

Background information

Separation of heterogeneous mixtures relies on each different substance having a unique set of physical properties. Each difference in property (e.g. one substance is magnetic and the others are not) is used to remove one substance from a mixture while the other substances are left behind.

Real-life example: an excellent application of this can be seen by researching the winner of the 2019 Google Science Fair, who was a school student who discovered a way to remove microplastics from sea water safely using a ferrofluid.

Materials

- alum (potassium aluminium sulfate) or equivalent
- contaminated creek water (simulated) – water from a fish tank (water left over from cleaning the filter is ideal), sand, clay, mud
- 3 glass beakers
- 2 glass cylinders
- metal spoon
- stirring rod or spoon
- funnel
- filter paper
- retort stand and clamp and optional: microscope with dropper, slide and coverslip to observe water

Procedure

Use each of the following methods separately to identify which substances are removed by the process and the physical or chemical property that was used to isolate one substance from another.

1. Draw the table shown in the results section in your science book.
2. Test each of the following methods and record the results in the table for comparison.

Decantation

3. Measure 100 mL of water into a cylinder.
4. Stir the water until it appears cloudy.
5. Leave the mixture undisturbed for five to 10 minutes so that solid substances can settle on the bottom.
6. Very carefully, pour the liquid off the top of the solid substances into a beaker so that they remain in the cylinder.
7. Record your observations in the results table.

Flocculation

8. Measure 100 mL of water into a cylinder.
9. Transfer into a beaker.
10. Stir the water until it appears cloudy.
11. Measure 3 mL of alum solution and stir the mixture for two minutes.
12. Leave the mixture undisturbed for 15 minutes.
13. Record your observations in the results table.

continued …

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Filtration

14. Fold your filter paper as shown in Figure 7.18.
15. Set up your equipment as shown in Figure 7.19.
16. Measure 100 mL of water into a cylinder.
17. Stir the water until it appears cloudy.
18. Pour the mixture through the funnel and let it filter through the paper.
19. Record your observations in the table.

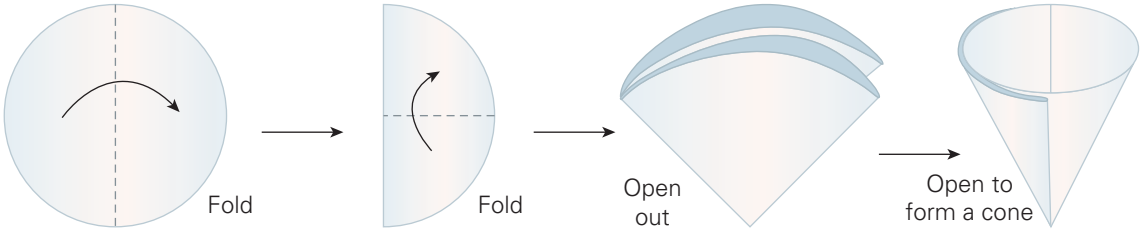


Figure 7.18 How to fold your filter paper

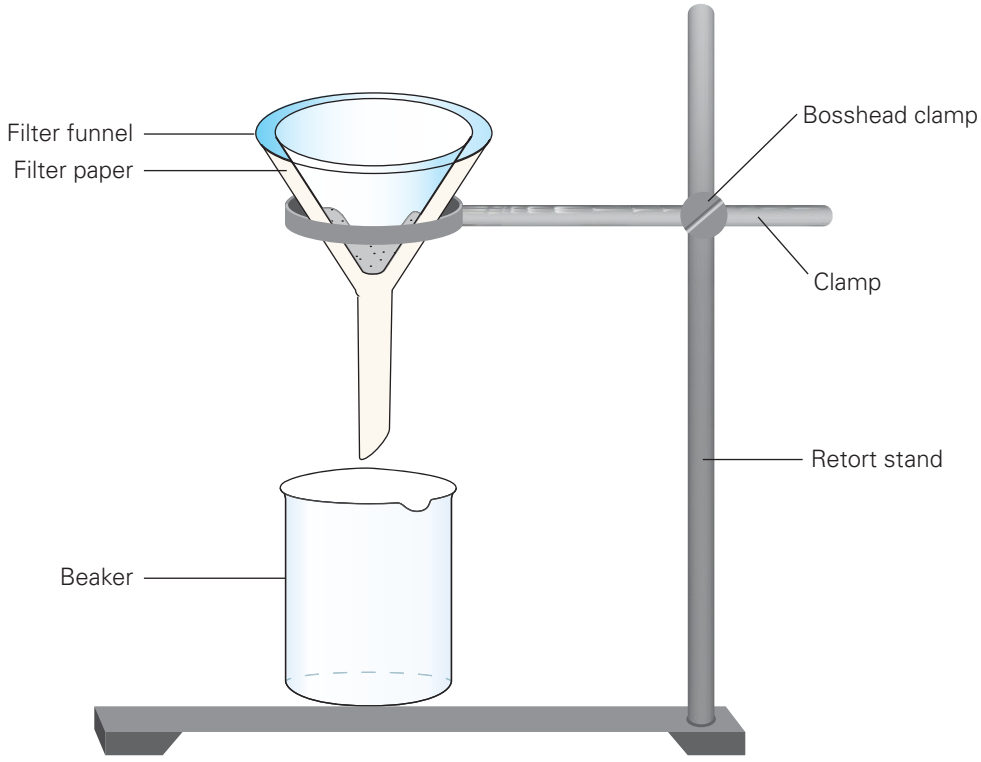


Figure 7.19 Experimental set-up

Results

Independent variable: Separation technique	Dependent variable: Water quality		
	Describe the initial condition of the water	Number of contaminants removed	Issues that may have affected the results e.g. speed, incomplete removal of substance
Decantation			
Flocculation			
Filtration			

continued …

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Discussion

1. Critique the effectiveness of each method by considering the number of contaminants removed and any issues that were found when testing it.
2. Describe how you could use these three methods in combination to remove contaminants from water.
3. Compare the results with other class groups. Determine how much variation was found in the results.
4. Identify the method which was the most reliable at separating out a contaminant based on the response in the previous question.
5. Discuss whether these three methods effectively clean the water so that it could be consumed by humans.
6. Optional: Place a drop of the contaminated water under a microscope and observe it. Review the answer to Question **3** above.
7. Propose any changes that could be made to the method to improve the quality of the data in future experiments.

Did you know? 7.4

Our kidneys have filters

After your body has processed the nutrients you consume, waste products are formed. One of the main jobs of the kidneys is to filter this waste out of the blood. Your blood supply circulates through the kidneys about 12 times every hour. Each day, your kidneys process around 200 litres of blood. Each of your kidneys has more than a million mini filters called nephrons.

If, for any reason, your kidneys cannot remove enough waste from your blood, haemodialysis can be used to clean it. The machine filters the blood, acting like an artificial kidney. This is not a permanent cure and must be done regularly.



Figure 7.20 This haemodialysis machine filters blood by trying to mimic what your kidneys do.

Quick check 7.6

1. **Use** the following information to answer the questions or to complete the sentences.
   Charcoal and salt are accidentally mixed together. The mixture is placed in water and stirred before being passed through filter paper.
   - **a.** What will remain in the filter paper?
   - **b.** What will pass through the filter paper?
   - **c.** The filtrate is the _____.
   - **d.** The residue is the _____.
   - **e.** The residue is found in the _____.
   - **f.** The filter paper can separate the two substances in the mixture because those two substances have different _____.

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Centrifuging

A **centrifuge** is a device that can separate substances based on their density by spinning the mixture very fast. Denser solids in a liquid, like blood cells in blood, or denser liquid droplets in a liquid, like cream in milk, move to the outside circumference of the spin. This is the same principle as whirling a ball around on a string. High-speed centrifuges can spin up to 100 000 times a minute!

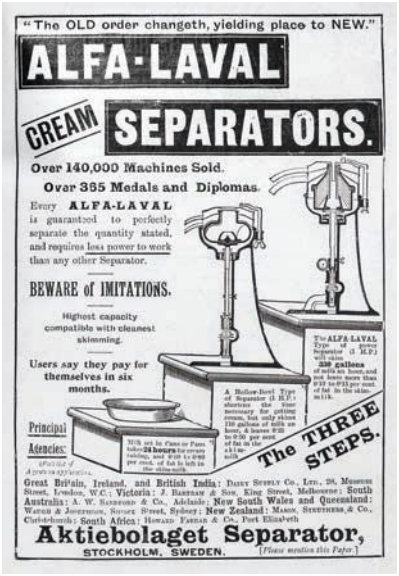
centrifuge
a device that uses fast circular motion to separate substances based on mass

Explore! 7.1

INVESTIGATION

History of the centrifuge

The first centrifuge-like machine was invented in 1864 and used in the dairy industry to separate cream from milk. Research the history of the centrifuge online and construct a timeline of the key developments in this incredibly useful technology.



Did you know? 7.5

VIDEO
Centrifuging blood

Blood has different components

Blood fractionation is the process of separating the blood from your body into its components, using centrifugation. When you spin blood, the heaviest components (red blood cells) move to the bottom and the lightest components (plasma) move to the top. White blood cells and platelets are often found in the middle. What does that suggest about their mass?

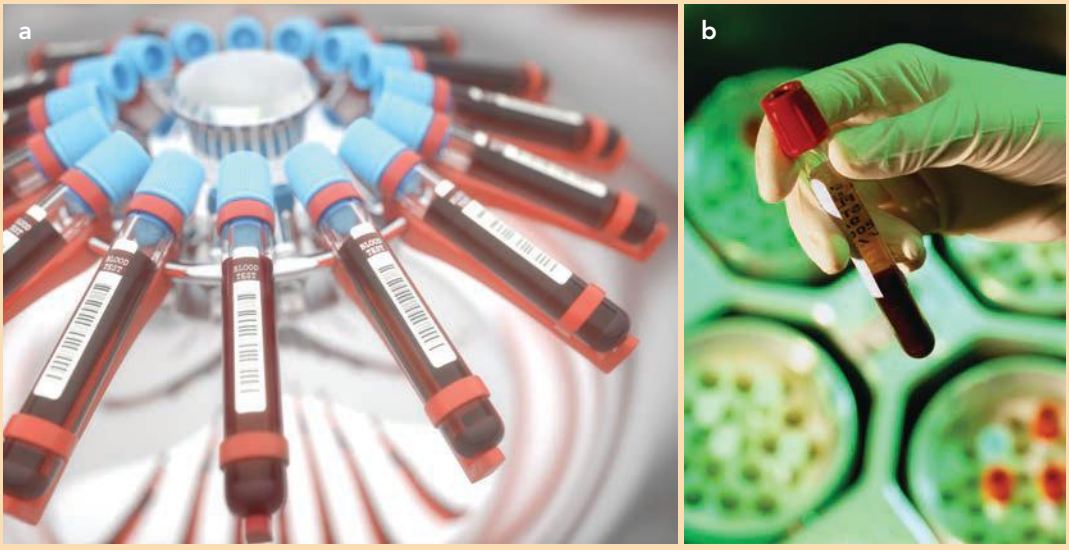


Figure 7.21 Whole blood being centrifuged to separate the components **(a)**, and the resulting separation of components within the tube **(b)**

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Separation techniques used by Aboriginal and Torres Strait Islander Peoples

Aboriginal and Torres Strait Islander Peoples have been separating heterogeneous mixtures for centuries. Below are a few examples. You should research more specific examples from local communities using the culturally safe and respectful guidelines provided with this resource.

koolamon also spelled coolamon, a carrying vessel, widely used by Aboriginal and Torres Strait Islander Peoples across Australia

- Winnowing involves tossing seeds and husks and husks into the air using a **koolamon** to allow the wind to blow away the lighter husks, separating them from the heavier seeds that fall back into the koolamon.
- Sieving uses woven or bark tools to sift fine materials, like sand, from larger particles, ensuring only the desired resource is collected.
- Yandying is a specific technique where a shallow dish is rocked back and forth to separate seeds from sand, relying on differences in density and size.
- Additionally, simple gravitational methods, like panning, are used to extract heavier materials, such as ochre (a natural pigment used in paint), from sediments.

These practices demonstrate a deep understanding of the physical properties of materials, leading to sustainable resource use.

INVESTIGATION

Explore! 7.2

Filtering liquids

Research and identify ways that Aboriginal and Torres Strait Islander Peoples filter water to make it drinkable.

Go online to access the interactive section review and more!

Section 7.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 7.3 questions

Remembering

1. **State** which of the following cannot be separated using a centrifuge: components of blood, soil particles from muddy river water, salt from sea water.

Understanding

2. Does filtering always work? **Explain** why you may sometimes find flies in your house despite having flyscreens on the windows.
3. **Explain** why filtering water doesn't mean that it is pure.

Applying

4. **Explain** why you cannot filter dissolved sugar out of water. Include the terms you have learned earlier in this chapter in your answer.
5. **Explain** which physical properties are being used in the following separation techniques: filtration, centrifuging, magnetic separation, hand-sorting a box of Lego bricks and parts.

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Analysing

6. a. All of the filters (**A–F**) shown below are used in the home. For each, consider its role and **identify** the:

- components of the mixture
- residue
- filtrate.



Figure 7.22 Filters

b. Each of the filters has a different mixture to separate. **Explain** how this affects the different-sized holes of each of the filters, and the different-shaped holes of each of the filters.

c. **Order** the filters from largest holes to smallest holes.

Evaluating

7. Gas masks are becoming more and more sophisticated to combat the development of dangerous nerve gases. Nerve gases interfere with the nervous system. This means you may lose your ability to move your muscles, including those muscles that help you breathe. **Propose** why a paper-filter mask will not work with nerve gases.



Figure 7.23 A modern-day gas mask

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7.4 Separating homogeneous mixtures

WORKSHEET
Chromatography

VIDEO
Paper chromatography of food colourings

VIDEO
Paper chromatography of inks

Learning outcome

At the end of this section, I will be able to:

1. explain how techniques such as chromatography, evaporation, crystallisation and distillation can be used to separate homogeneous mixtures.

Physical properties of homogeneous mixtures

What physical properties of the components of a homogeneous mixture can be used to separate them? Think back: what does 'homogeneous' mean? The definition says that compared to a heterogeneous mixture a homogeneous mixture is evenly distributed and everywhere the same. It also stays the same – the substances don't separate. What keeps them mixed up together?

If each substance is present as very small particles – molecules, for example – then from particle theory you know that molecules in a liquid move randomly, sliding past each other with constant Brownian motion. This constantly mixes up the different molecules of solute and solvent in solution.

As you go through the techniques in this section, consider the properties of different substances, such as boiling point or solubility, that enable them to be separated.

Chromatography

chromatography a technique to separate substances based on movement at different rates due to solubility

Chromatography is a technique used to separate the substances in a mixture based on their solubility, which is their ability to dissolve in a solvent (and their attraction to a solid material, for example, paper). Look at Figure 7.24. This is the common set-up for carrying out paper chromatography, in this example, to separate the colours that make up the ink in felt-tip marker pens. The mixture (components of ink) is made to move by a solvent (often water or methylated spirits), through another substance that stays still (filter paper) until the components separate. The more soluble the components of the ink are in the solvent, the more quickly they will move up the filter paper in the solvent.

The 'mobile phase' is the name given to the solvent moving with the soluble parts of the mixture in it. The substance that stays still is called the 'stationary phase' (filter paper).

Chromatography is used a lot in various industries. These are some examples.

- In forensics, chromatography allows you to analyse and separate the components of ink in pens to catch the forger or the writer of a ransom note.
- In toxicology, gas chromatography is used to separate the components of a poison so that it can be identified and neutralised.



Figure 7.24 Paper chromatography: the separation of the components of ink. Note that the green ink is made up of yellow (less soluble) and blue (more soluble) components.

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- In pharmacology, chromatography allows for the testing of the purity of medicines and drugs.
- In fashion, chromatography helps break down the different components of the dyes in clothing.
- In athletics and other sports, gas chromatography is used to check if the sportsperson has been using any banned substances.
- In archaeology, chromatography allows for organic materials to be separated from inorganic materials. This can help experts learn more about how people lived in the past, e.g. identifying what kind of diet ancient people had or what clothes they wore.

Investigation 7.2

Separating the pigments in water-soluble colour marker pens

INVESTIGATION

Aim

To separate the pigments from water-soluble marker pen ink using chromatography.

Materials

- water
- large beaker
- long strips of filter paper
- wooden skewer
- stapler and staples
- ruler
- water-soluble colour marker pens

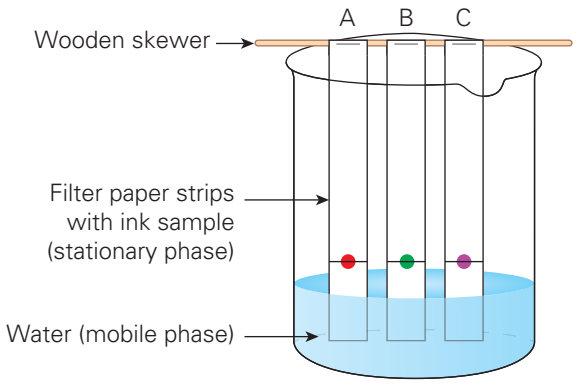


Figure 7.25 Experimental set-up

Procedure

1. Use a pencil to draw a line across each filter paper strip 1.5 cm from the bottom. Label the wooden skewer A, B and C – one position for each of three strips of filter paper.
2. Add enough water to the beaker so that the pencil lines will sit above the water line.
3. Using the water-soluble colour marker pen, draw a small dot on the filter paper in the middle of your pencil line.
4. Fold the paper strip over the wooden skewer, as shown, and staple it on.
5. Repeat the first four steps, this time using different coloured marker pens.
6. Lower the three samples into the water in the beaker, making sure the ink spot is above the water and the end of the paper stays in the water.
7. Leave the strips for about 10 to 20 minutes after placing them into the water.
8. Remove the paper strips (called chromatograms) from the beaker when the water has reached approximately 2 cm from the top of the paper and leave them to dry somewhere safe.
9. Label the solvent front on each of your chromatograms (this is where the solvent has reached on the filter paper).

Results

Stick your dried chromatograms into your science book (or take a photo and upload it to your practical report file).

Discussion

1. The chromatogram formed is unique for each type of pigment. Discuss what you found out about the different pigments in the ink of the different coloured pens.
2. Identify possible sources of error when using this separation technique.
3. Discuss how you could minimise the impact of these sources of error in the future.

Conclusion

Copy and complete this statement in your science book. From this activity we can claim that pen ink _____. This is supported through observations that _____. Therefore, it can be concluded that _____.

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Did you know? 7.6

Drug screening

Gas chromatography is one of the most common methods of testing urine and blood samples for drugs. In gas chromatography, the sample is converted into a vapour in the presence of a gaseous solvent and placed into a special machine. Each component of the sample will dissolve differently in the gas and will only stay in the gas phase for a unique time, called the retention time. When the sample is analysed, it is compared to known samples of different drugs, so that specific drugs can be identified in the urine or blood samples.



Figure 7.26 Samples being prepared for analysis using gas chromatography

Evaporation and crystallisation

evaporation when heat causes liquid to become gas

crystallisation solidification of a substance into a highly structured form

You have learned that **evaporation** is a change in state from a liquid to a gas, but it can also be used as a separation technique. Evaporation can be used to separate a dissolved substance (solute) from its solvent in a solution by heating the mixture up so the liquid solvent turns into gas and boils off. For example, the water in salt water will evaporate when heated, leaving behind salt crystals – the water and the salt are separated by evaporation. Can you think of some examples where evaporation has been used in your home to separate substances? Examples could include wet clothes drying in the sun on the clothesline.



Figure 7.27 Crystals of salt can be formed and harvested by slow evaporation of water from a salt crystallisation pond.

Crystallisation

Often when you use the process of evaporation to separate a mixture, crystals form after the solvent has nearly all evaporated. This is called **crystallisation** and occurs because as the solvent evaporates, the solution left behind becomes more and more concentrated. Eventually the solution is so concentrated that it becomes supersaturated; that is, not all of the solute can remain in solution. Consequently, some of the solute will start to come out of the solution in the form of crystals. The crystals grow as the solvent continues to evaporate. Crystals come in amazing shapes and sizes depending on the solute and how quickly evaporation occurs.

Have you seen salt crystals forming on your skin as you dry off after a swim in the ocean? Very slow evaporation of the solvent, like the water in a crystallisation pond, can form even bigger crystals of salt.

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Did you know? 7.7

Painting uses evaporation as a separation technique

Paints, you may recall, are a type of mixture. Wet paint is a mixture of colour pigments suspended in a binding medium (allows the paint to stick to surfaces and remain solid once it dries) and a solvent. Sometimes, other additives are used to make the paint dry quicker, to allow it to be used on sailing boats or on railings prone to rust, or to resist being broken down by sunlight. When the solvent dries and evaporates, only the colour pigment is left behind, suspended in the binding medium. It is the evaporation of the solvents that creates the distinctive smell of paint drying.



Figure 7.28 Gum arabic is a common binding agent used in paints.

Quick check 7.7

1. **Select** the correct term from the list to complete the sentences: filter, pigments, solvent, water.
   Chromatography is a technique that can separate different components of a mixture, such as different _____ in ink or in a leaf. Samples of different mixtures are put on a piece of _____ paper, and the paper is put into a solvent. If the mixture dissolves in water, then _____ can be used for the solvent. If the mixture does not dissolve in water, then a different _____, such as methylated spirits, must be used.
2. **Number** the following statements to indicate the order they occur in the process of paper chromatography.
   _____ Place your sample in the centre of the pencil line.
   _____ Place a small volume of water into a beaker (about 1 cm deep).
   _____ Make sure the sample dot does not go below the surface of the liquid in your beaker.
   _____ Leave for 20 minutes until the solvent reaches the top of the filter paper.
   _____ Draw a line using a pencil across a filter strip 1 cm from the bottom.
   _____ Fold the paper strips over the ice block stick, clip them, and lower them into the water in the beaker.
3. **Define** the key terms 'evaporation' and 'crystallisation'.
4. **Develop** a method that would allow you to separate salt and ground pepper (which can float) when they are all mixed together. Include the concepts of 'evaporation' and 'crystallisation' in your explanation.

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Investigation 7.3

Using evaporation to separate mixtures

Be careful
Observe general fire safety.
Wear safety equipment.

Aim

To analyse the mass of salt contained in a concentrated salt solution.

Background information

INVESTIGATION

Homogeneous mixtures contain particles too small to be seen with the naked eye. Solutions are mixtures where one substance is dissolved into another. Separation of substances in a solution relies on each substance having a unique set of physical or chemical properties. One unique property of substances is their boiling point. When a mixture is heated, each substance will evaporate at different temperatures, leaving the other substances behind.

Materials

- concentrated salt water
- measuring cylinder
- 250 mL beaker
- Bunsen burner
- tripod
- matches
- heatproof mat
- gauze mat
- safety glasses
- scales

Procedure

1. Copy the results table into your science book.
2. Weigh the mass of the beaker using the scales. Record the mass in the table.
3. Measure 100 mL of concentrated salt water into the beaker.
4. Set up the tripod and gauze over the Bunsen burner.
5. Place the beaker on the gauze.
6. Light the Bunsen burner as described in *Practical skills 1.2* in Chapter 1.
7. Allow the mixture to boil until there is 25 mL of water left in the beaker.
8. Turn off the gas.
9. Leave the beaker on the tripod to cool.
10. When cool, pack up the equipment and leave the beaker in a warm place to allow the remainder of the liquid to evaporate for a few days.

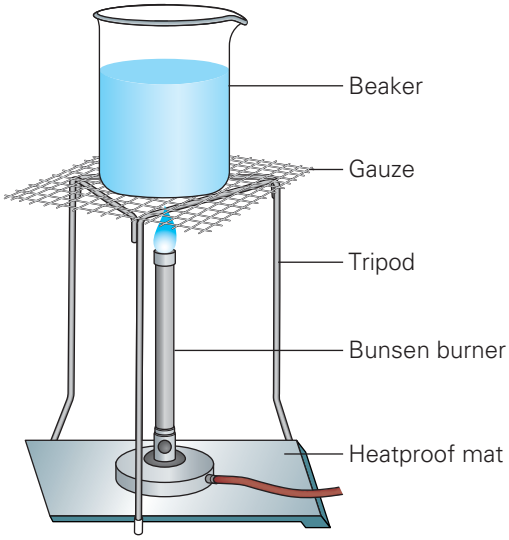


Figure 7.29 Experimental set-up

Next lesson

11. Weigh the beaker and record the mass.
12. Calculate the change in mass.

Results

Mass (grams)	Group result	Class mean
Empty beaker		
Beaker + salt		
Salt in beaker (= mass of salt in beaker)		

Draw a labelled diagram that clearly shows how to set up the equipment for this separation method.

continued …

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- Follow the rules for drawing scientifically.
- Use a sharp pencil.

Peer review

1. Swap experimental diagrams with another group and give each other feedback on how clearly the diagram communicates how to set up the separation method. Your feedback should discuss the following:
   - how well the diagram follows the rules for scientific drawing
   - any other suggestions to improve the quality of communication.
2. After receiving feedback, make alterations to the diagram to address the identified issues and write up a final copy to present to the class.

Discussion

1. Compare your result with the actual mass of salt that was dissolved in the water (your teacher has this information).
2. Compare your result with other groups. How much variation was observed between the final results for the mass of the salt?
3. Calculate a class mean for the mass of salt that was dissolved in 100 mL of water.
4. Determine if a reliable conclusion could have been drawn about the mass of salt per 100 mL based on the mean class results.
   Most natural water sources contain a variety of dissolved salts.
5. Discuss how this would affect the validity of the conclusion drawn about the mass of salt that was dissolved into the water to make the test solution.
6. Propose changes to the method to improve the quality of the data in future experiments.

Distillation

distillation
a technique to separate substances in a liquid using evaporation through boiling and condensation

You may have thought about the process of evaporation and how when you separate salt from salty water, all the water is lost into the atmosphere as water vapour. But what if you could catch it so that you could use it? This is where **distillation** comes in. It is a technique that uses evaporation (heating) and condensation (cooling) to separate the components of a liquid mixture according to their boiling temperatures. All components of the mixture are retained. The solute remains in the flask, while the solvent evaporates and is caught as it forms the distillate in the beaker at the end. In order for the distillate to make its way into the beaker, it must first go through the condenser. A condenser is an important piece of equipment that has an outer 'jacket' through which cool water flows. This helps to cool and condense the solvent vapour back into its liquid form.

VIDEO
Distillation

WIDGET
Choosing the best method for separating mixtures



Figure 7.30 Distillation equipment used in the food and beverage industry

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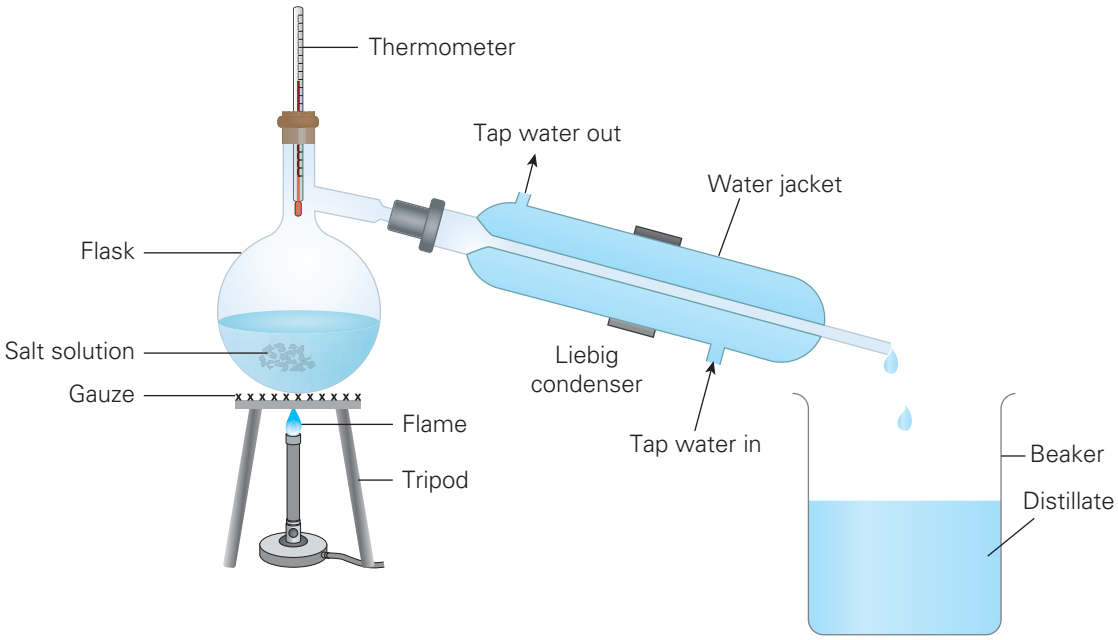


Figure 7.31 A Liebig condenser is used for the process of simple distillation.

INVESTIGATION

Explore! 7.3

Essential oils

The formation of essential oils and perfume relies on the separation technique of distillation.

1. Investigate the role of distillation in the creation of essential oils and perfume.
2. Investigate Aboriginal Peoples' use of steam distillation to obtain aromatics from plant material.
3. Compare these two distillation process and their uses.
4. Summarise how and why three other industries use distillation.

Practical skills 7.2: Teacher demonstration

Distillation

Be careful

The distillation apparatus can become extremely hot during the experiment. Ensure water pressure is slowly increased so as not to introduce internal stress to the condenser.

Aim

To observe the process of distillation.

Materials

- water
- table salt
- 2 × 250 mL beakers
- Bunsen burner
- distillation apparatus
- spatula
- tripod
- safety glasses

Procedure

1. Set up the equipment for distillation as shown in Figure 7.32.
2. Wear safety glasses.
3. Put 100 mL of water into one of the beakers. (The other one will collect the distilled water.)
4. Use the spatula to add salt and stir.

continued …

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5. Continue adding salt until the solution is very concentrated but not saturated. Pour the concentrated salt solution into the round-bottomed flask of the distillation apparatus.
6. Turn on the water that circulates in the condenser.
7. Heat the salt solution.

Results

Describe your observations of this process. How did the original solution look? What substance was left behind in the round-bottomed flask?

Discussion

1. Why was it necessary to heat the salty water solution?
2. Explain how the condenser works.
3. Which part is the distillate?
4. What were possible sources of error when using the different separation techniques?
5. How could you minimise the impact of these sources of error in the future?

Advances in science 7.1

The Sydney Desalination Plant – an example of industrial separation

The Sydney Desalination Plant, in Kurnell, annually provides relief to the water supply of Sydney. When needed, it can supply over 1.5 million people a day with drinking water. The plant provides a source of water which is unaffected in times of drought or flooding and has been filtered over several steps of purification. After sea water has been drawn in through an underground pipe, the water is first filtered to remove any sand and other solid substances. The second filtration technique, called reverse osmosis, then starts. This is where the filtered sea water is forced through an ultra-fine membrane that contains extremely small pores, which only let water particles through. The salt particles are too large to pass through and so are returned to the sea as a concentrate, and fresh water continues on in the process to be treated and then distributed.

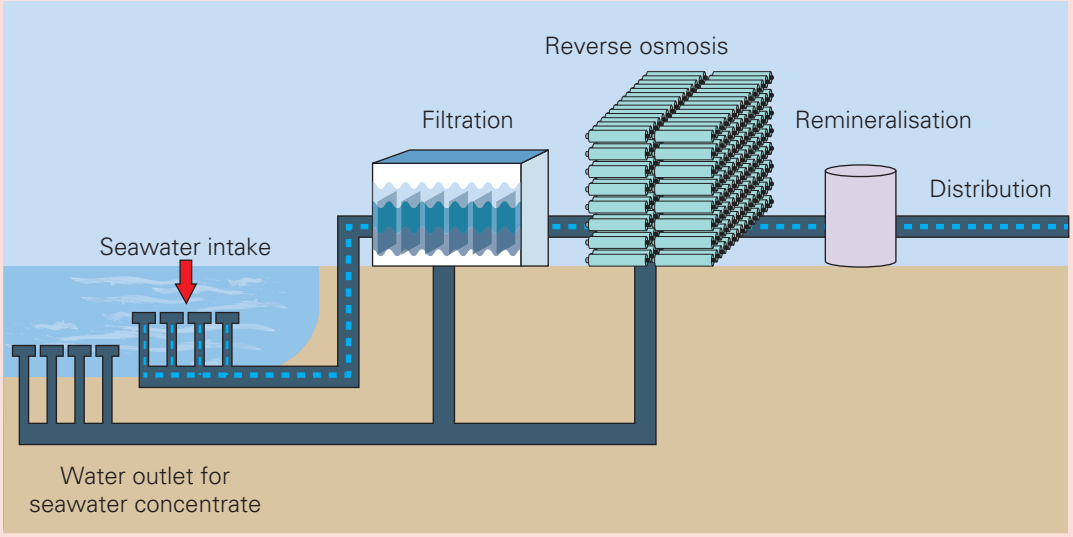


Figure 7.32 Desalination process

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Section 7.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.4 questions

Remembering

1. Copy and **label** the parts of the Liebig condenser and other equipment indicated in Figure 7.33.

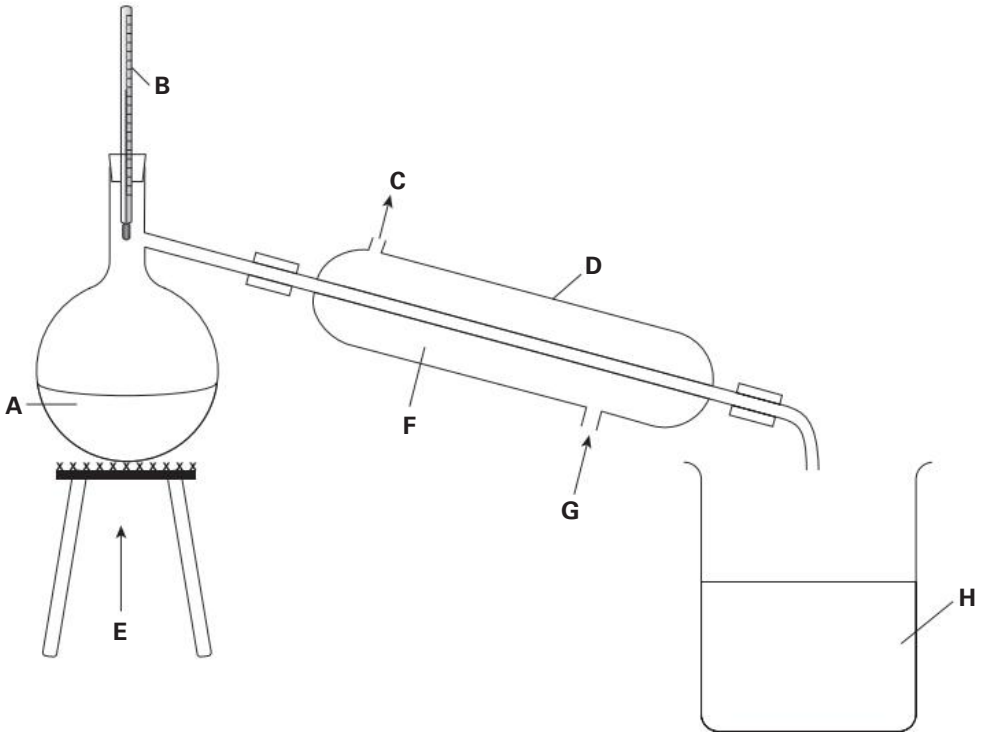


Figure 7.33 Liebig condenser and other equipment

Understanding

2. **Define** the terms 'distillation' and 'evaporation'.
3. **Describe** the difference between distillation and evaporation.

Applying

4. **Explain** what happens to particles during the process of evaporation and the process of condensation. Draw pictures of the particles to help in your explanation.

Analysing

5. **Compare** and **contrast** evaporation and crystallisation.

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Evaluating

6. **a.** Copy and **label** the diagram shown in Figure 7.34.
   b. **Explain** what is meant by 'mobile phase' and 'stationary phase'.
   c. **Sequence** the colours from least to most soluble in the solvent.
   d. **Explain** why the bottom line should be marked in pencil and not in pen.

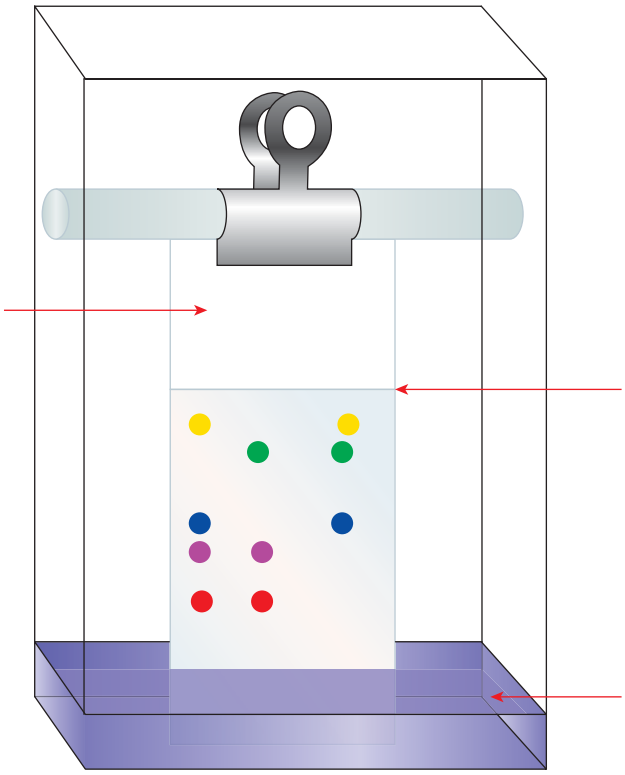


Figure 7.34 Chromatography

7. Substances X, Y, Z, W and sugar were mixed in water. The properties of each substance are listed below.

Substance	Solubility in water	State at room temperature	Boiling temperature (°C)
Sugar	Soluble	Solid	> 110
X	Soluble	Liquid	86
Y	Soluble	Liquid	68
Z	Insoluble	Solid	> 800
W	Insoluble	Solid	86

Determine the steps you would use to separate the mixtures.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
7.1	distinguish between atoms, compounds and mixtures, and use particle theory to explain their properties.	2
7.1	classify matter as pure substances (elements and compounds) and impure substances (mixtures based on particle composition).	7
7.1	identify homogeneous and heterogeneous mixtures.	4
7.2	identify substances that dissolve in water and use the terms soluble, insoluble, solubility, solute, solvent and solution.	4, 13, 16
7.2	describe how particle theory can be used to model solutions.	11, 12, 13
7.2	measure solubility of different solutes in water, and present data using tables and relevant graphs.	16
7.2	describe the effect of temperature on solubility.	12
7.2	compare the properties of dilute, concentrated, saturated and supersaturated solutions.	4, 6, 13
7.2	calculate the concentration of solutions using grams per litre (g/L) or percentage volume per volume (% v/v).	6
7.3	explain how the physical properties of substances are used to separate heterogeneous mixtures.	1, 18, 19
7.3	give examples of physical properties used to separate heterogeneous mixtures, including particle size, density and volatility.	9, 18, 19
7.3	explain and apply separation techniques for heterogeneous mixtures including magnetic separation, decantation, flocculation, filtration and centrifuging.	9
7.3	describe separation techniques for heterogeneous mixtures used by Aboriginal and Torres Strait Islander Peoples.	8
7.4	explain how techniques such as chromatography, evaporation, crystallisation and distillation can be used to separate homogeneous mixtures.	3, 5, 10, 16

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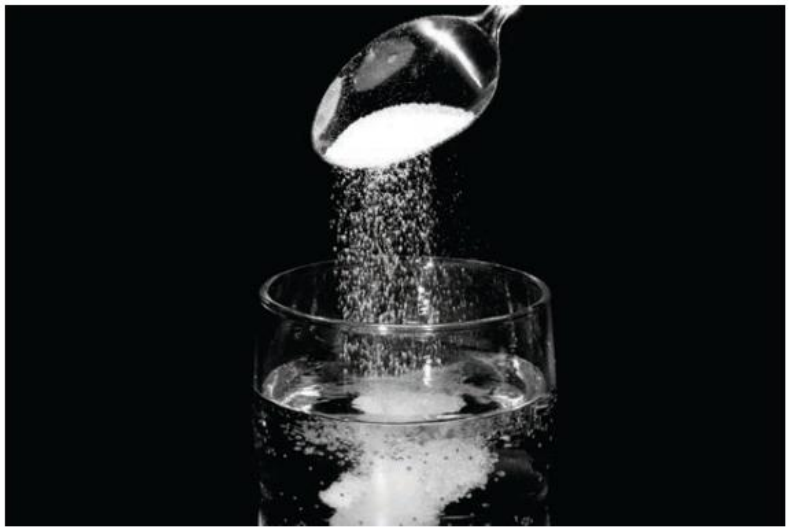
Scorcher competition	Review questions	Data questions

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Review questions

Remembering

1. **Define** the following key words:
   - **a.** Solvent
   - **b.** Solute
   - **c.** Solution
2. **Identify** the difference between a compound and an element.
3. **Recall** the name of the piece of paper at the end of a chromatography experiment.
4. **Complete** the sentences below using the word list: aqueous, solute, solvent, solution, soluble, insoluble, supersaturated, saturated, dissolve, dilute.
   Cordial is an example of an _____ solution because the _____ is water.
   Many substances can dissolve in water to form a _____.
   However, for example, soil is _____ in water because it does not _____, compared to salt, which is _____ in water because it dissolves completely.
   A solution with the maximum amount of dissolved _____ is called a _____ solution. If more solute is added, the solution will become _____, but if more solvent is added, the solution will become more _____.



Understanding

5. **Select** words from this list to complete the following paragraph: boiling temperatures, mixtures, condensed, solvent, evaporated.
   Distillation is a method used to separate _____ according to their _____.
   The liquid is _____ at a certain temperature, the vapour is collected, and then it is _____ to form a liquid again. The liquid collected during this process is called the _____. The residue is the mixture that remains in the original container.
6. **Explain** what the concentration of a solution means and a unit in which it might be measured.
7. **Identify** which of the following are pure substances and which are impure substances (mixtures): smog, distilled water, oxygen gas, carbon.

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8. **List** three examples of techniques used by Aboriginal and Torres Strait Islander Peoples to separate mixtures.
9. **Determine** whether the following separation techniques are of a solid, liquid or a gas, and describe the physical property that this separation is based on. Give an example. You may choose to use a table format as shown in the example.

Method of separation	Separation of solid/liquid/gas?	Physical property or principle on which it is based	Example
Decanting			
Flocculation			
Filtration			
Crystallisation			
Magnetism			
Centrifuge			

Applying

10. **Provide** an example of a mixture you would separate using evaporation. Explain why no other method would work better.
11. **Describe** how the following mixtures could be separated into their components:
    - **a.** Copper sulfate from copper sulfate solution
    - **b.** Water from wet clothes
    - **c.** Peas out of a mixture of peas and water
    - **d.** Oil out of a mixture of water and oil
    - **e.** Sand from a mixture of sand and iron filings
    - **f.** Red dye from a blue dye
12. Use particle theory to **explain** how the solubility of a substance in water might increase with temperature.

Analysing

13. Lottie prepared two glasses of salt solution but forgot which was which. She thought one was a saturated solution and one was not. She put a crystal of salt in each glass and then left it overnight. What she saw in the morning is shown in Figure 7.35.

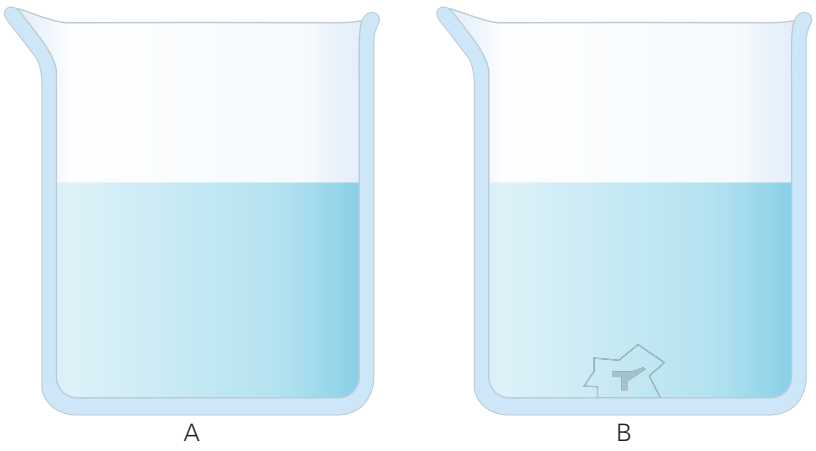


Figure 7.35 Salt solutions

- **a.** **Determine** which glass contained the saturated solution.
- **b.** **Justify** your response to part **a**.

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14. a. **Draw** and label a diagram of a heterogeneous mixture showing how the particles are distributed.

b. **Draw** and label a diagram of a homogeneous mixture showing how the particles are distributed.

15. Explain why soluble nutrients can be absorbed by the roots of plants through microscopic holes, but insoluble nutrients cannot.



16. Draw a graph using the following data. What does the trendline of the graph suggest?

Temperature of 100 mL water (°C)	20	40	60	80	100
Mass of sugar dissolved (g)	200	238	287	362	485

17. You have been doing a graphic design course and have created an awesome poster. However, you have forgotten which ink pen you used to create the main heading. Figure 7.36 shows the results of a chromatography experiment you carried out to identify the ink. Five inks were compared: A, B, C, D and E.

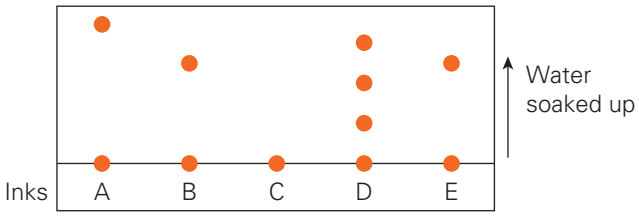


Figure 7.36 Chromatography experiment

a. You know your ink is just one colour. **Identify** which ink sample is a mixture of different colours.

b. **Determine** which two inks are the same.

c. Given your ink is not soluble in water, **identify** which ink sample is yours.

Evaluating

18. Sieving is a useful separation technique for varying-sized solid particles. **Describe** how sieving could be used in a recycling centre.

19. Propose the separation processes you would use to separate a mixture of pebbles, sand, salt and water. You can choose to use a flow chart. Clearly show what was separated at each step.

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Data questions

Recycling centres separate mixtures of recyclable material on a very large scale. The relative mass of paper and packaging components of the recyclable material sent for processing in a particular area is shown in Figure 7.37.

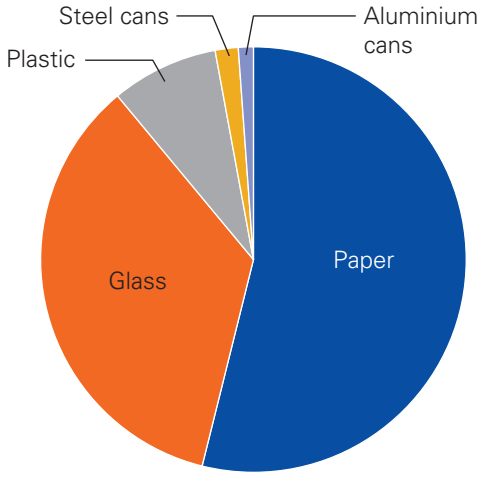


Figure 7.37 Relative mass of paper and packaging materials collected for recycling in a particular area

Questions 1–3 refer to Figure 7.37.

1. **Determine** which component of the paper and packaging mixture accounts for the smallest mass.
2. **Calculate** the percentage of mass made up of paper if the glass component accounts for 35% of the overall mass, plastic 8% and cans (steel and aluminium) 3%.
3. **Sequence** the components of the paper and packaging mixture in order of decreasing relative mass.



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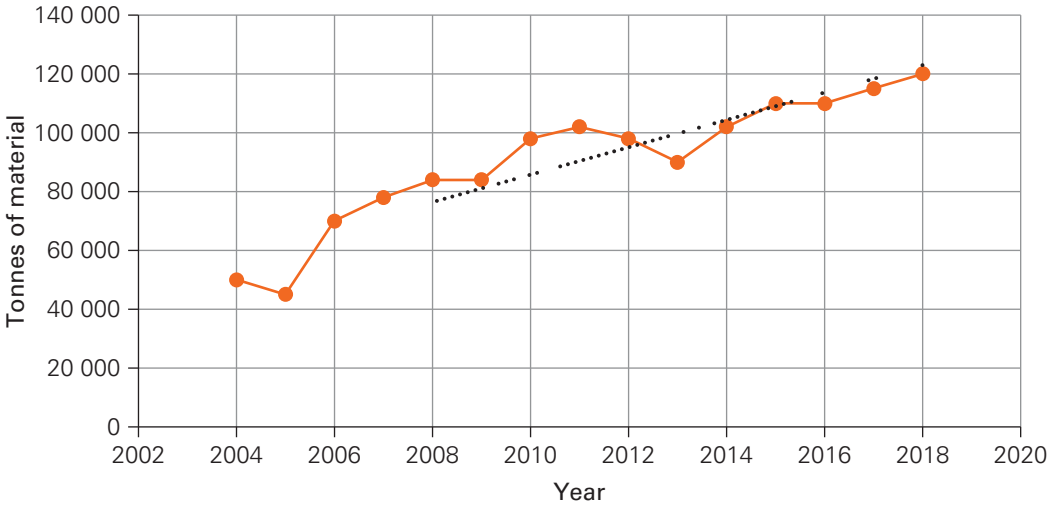


Figure 7.38 Approximate mass of glass collected (orange) for recycling (the trendline is the black dotted line)

The mass of glass materials collected for recycling is shown in Figure 7.38.

Questions 4–8 refer to Figure 7.38.

4. **Identify** the trend in the mass of glass collected for recycling between 2004 and 2018.
5. **Distinguish** between the information provided by the orange line and the black dotted line.
6. **Predict** how the trend in mass of glass collected for recycling will progress over the next ten years.
7. **Justify** why the trend would progress in the way you have predicted in Question **6**.
8. **Extrapolate** the trendline to the year 2020. What mass of glass was estimated to be collected for recycling in that year?



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STEM activity: Cleaning up an oil spill

Background information

The Great Barrier Reef is a Natural Wonder of the World. It is home to thousands of different types of fish, soft and hard coral, sharks, rays, turtles and marine mammals. This vulnerable ecosystem is threatened by many external factors, one being oil spills.

In 2010 a cargo ship struck the reef, which not only caused large damage to the reef, but also caused approximately 3 to 4 tonnes of oil to be released into the ocean. This oil slicked on the surface, and although chemical dispersants were used to break up the oil, oil tar balls were found washed up on islands nearby. It was impossible to physically collect the oil using booms and skimmers as the weather had caused large waves.

Oil is a low-density substance, which means it floats on water and never mixes into it. Although this is a convenient property, oil also has the property of clinging to anything that is not water, and this is what makes it tricky to clean up – it clings to plants, animals and land, and impacts on marine ecosystems. Oil spills therefore need to be cleaned up very quickly and effectively to lessen their impact. Clean-up strategies used by environmental engineers include first using booms (inflatable barriers to contain the spill), skimming (scooping the oil off the surface using a vacuum), absorbing (soaking up the oil using sponges and absorbent rope) and dispersing the oil (breaking it into smaller droplets). Some of these methods are more effective than others.



Figure 7.39 A dolphin swims next to an oil spill

DESIGN BRIEF

Determine the most effective way to clean an oil spill from the Great Barrier Reef.

Activity instructions

In this task you will play the role of an environmental engineer and work together in your group to determine the most effective way of cleaning oil from the Great Barrier Reef. You will carry out a simulation of an oil spill and how it can be cleaned up. You will collect data about the oil removal and consider the effectiveness and cost of each method. You will present your findings in either a report or a presentation for the local government, which includes the perspective of the oil company.



Figure 7.40 Booms and skimmers helping to contain and clean up an oil spill

Research and feasibility

1. Copy and complete the table by listing all the possible ways of cleaning up an oil spill and what materials you have access to that could do the job. For each material, consider whether they are a skimmer, absorber or dispersant. Find out how much each unit or packet of material costs at the supermarket. Estimate how much of it you need and the total cost to clean one cup of an oil spill.

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Material	Effect on oil spill	Skimmer, absorber or dispersant (and cost)
Detergent		
Cotton balls		
Plastic spoon		
Small sponge		
Paper towel		

2. Consider how you will record your data on effectiveness of oil removal and cost.
3. Predict which material will be most effective at removing oil.

Design

4. Design a method in your group for the three different techniques of oil spill clean-up:
   a. using a skimmer **b.** using an absorber **c.** using a dispersant.

Note: You may want to pour your oil from a beaker into the tray and then as you collect the oil, place it back into the beaker to help you measure before and after amounts to compare how effective the removal was. You should try to collect all the oil before it reaches the coastline.

Create

5. Using your set-up reef, place the ship in an agreed location (group consensus), and pour your oil mixture onto the water slowly. Try to completely remove the oil mixture using the skimmer technique. Spill the oil back into the water, then repeat for the absorber, and then the dispersant. Record your results in the table you designed in Step **2**.

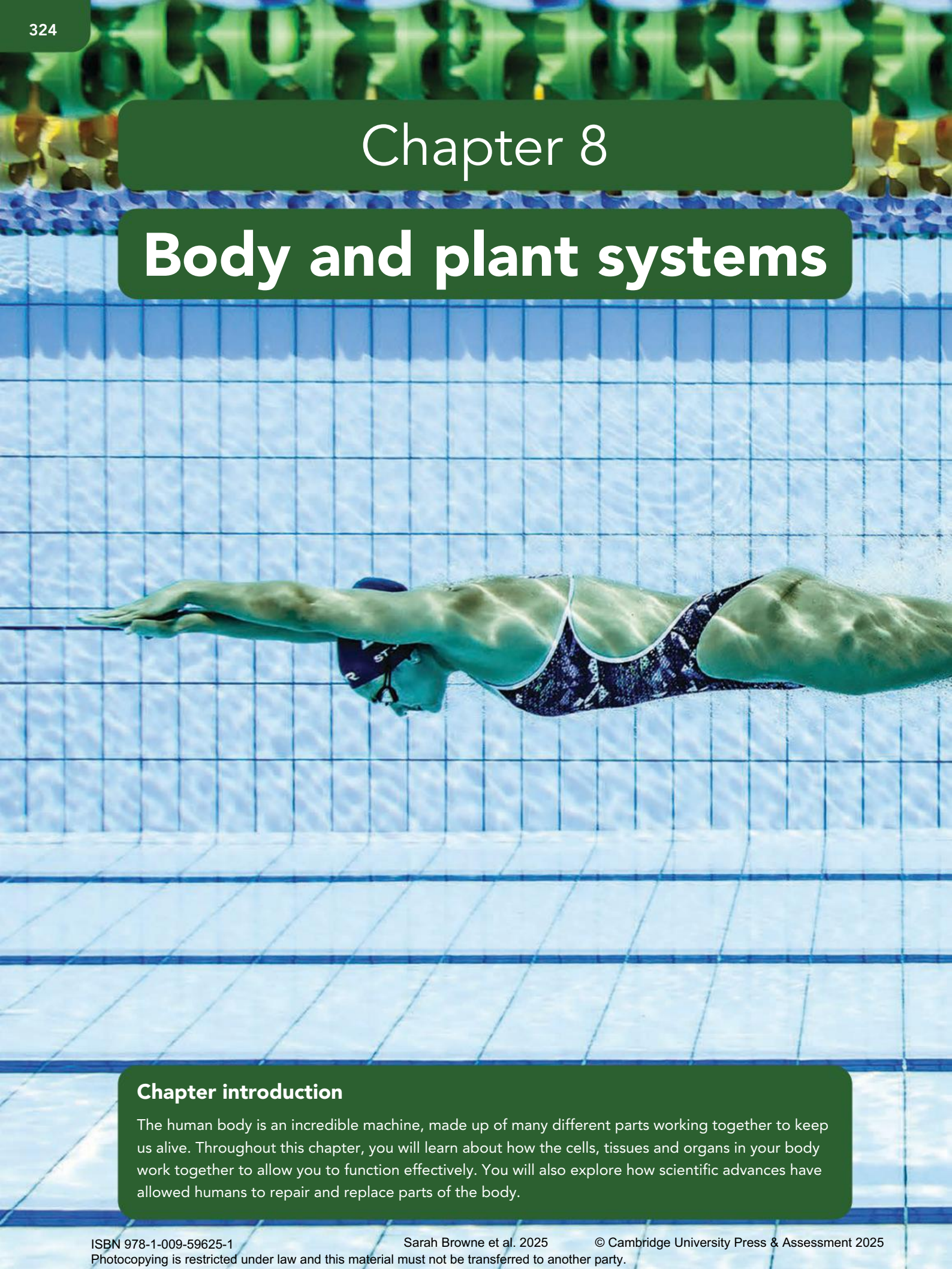
Evaluate and modify

6. Analyse your results. Begin by drawing a graph showing the effectiveness of each clean-up method, and another showing the cost of each clean-up method.
7. Discuss the effectiveness of each method of cleaning up an oil spill. Did your findings support your hypothesis or not? Were there any sources of error in your experiment? How could you work to prevent these errors from occurring in the future?
8. Consider skimming as a clean-up technique. Hypothesise what impact the ocean waves might have on the effectiveness of this technique. Is it cost-effective when you need to have boats with specialised equipment for the task?
9. Consider an absorber as a clean-up technique. Reflect on how you would dispose of absorbers that have soaked up the oil after the clean-up. Have you considered that the oil removed from the ocean must be stored elsewhere? Hypothesise on how effective absorbers would be to remove oil in the ocean.
10. Consider dispersants as a clean-up technique. Explain what the dispersant does to the oil on water. Is it appropriate to be putting more chemicals in the water? Discuss with your group three possible impacts of the dispersants on the marine ecosystem.
11. Compare the measured volume of crude oil spilt into your ocean with the volume of crude oil you removed. What percentage of crude oil did you successfully remove from the ocean? Did one technique prove to be more effective? Explain the possible causes of any differences between the two volumes.
12. You now have enough information to write your report. Prepare a report for local government that summarises your simulation findings. Include:
    a. the different methods, their effectiveness and their costs
    b. both points of view: the environmental engineer and the oil company
    c. which method/s you think should be utilised by environmental engineers in the future when cleaning up an oil spill in a local waterway.

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Chapter 8

Body and plant systems

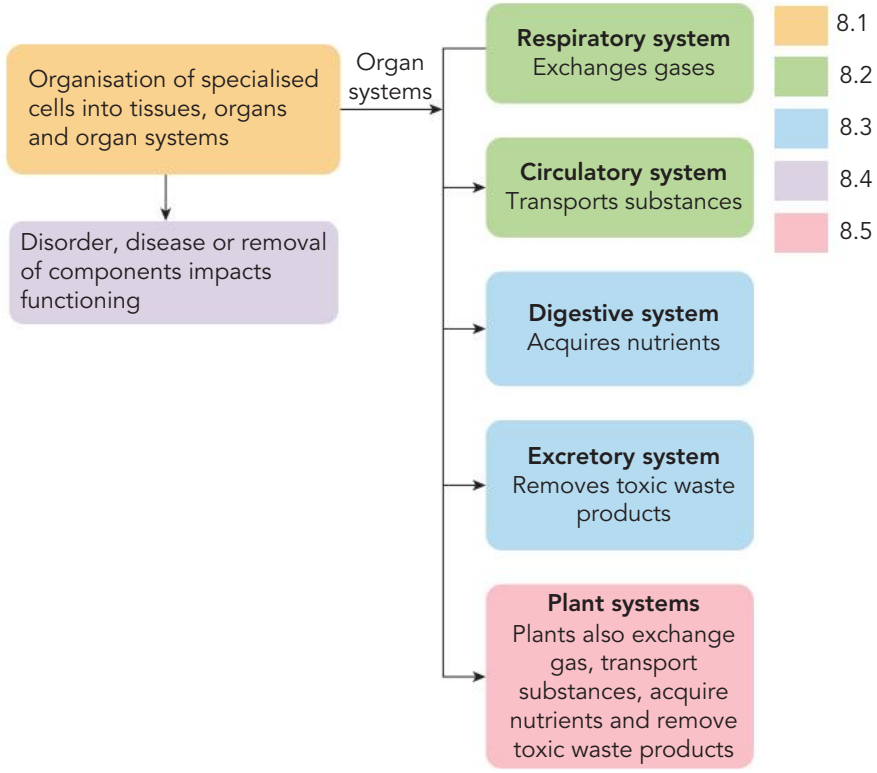


Chapter introduction

The human body is an incredible machine, made up of many different parts working together to keep us alive. Throughout this chapter, you will learn about how the cells, tissues and organs in your body work together to allow you to function effectively. You will also explore how scientific advances have allowed humans to repair and replace parts of the body.

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Chapter map



Glossary terms

alveoli
ammonia
anus
aorta
atrium
bile
bladder
bolus
bronchiole
bronchus
caecum
capillaries
carbon dioxide
cellular respiration
chemical digestion
chyme
diaphragm
diffusion
duodenum
enzyme
epiglottis
ethical
excretion
excretory system
gall bladder
guard cells
haemoglobin
heterotroph
ileum
intolerance
jejunum
kidneys
large intestine
lenticels
liver
mechanical digestion
metabolic
microvilli
nectar
nephron
organ
organ rejection
organ transplantation
organism
pancreas
peristalsis
pharynx
phloem
plasma
platelets
pollination
rectum
saliva
skin
sphincter
stomata
tissue
tissue engineering
trachea
transpiration
urea
ureter
urine
vascular bundles
vena cava
ventricle
villi
xenotransplantation
xylem

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8.1 Cells to systems

Learning outcomes

At the end of this section, I will be able to:

1. explain the interrelationship between cells, tissues and organs.
2. identify the levels of organisation in a multicellular organism.

Levels of organisation

The cells in your body work together in a complex and highly coordinated manner to carry out essential functions like nutrient uptake and waste removal. This is where tissues, organs and organ systems come into play.

Tissues are groups of similar cells that work together to perform a specific function. They are the building blocks of organs, which are structures made up of two or more types of tissues that work together for a common purpose. Organs, in turn, work together to form organ systems, with each system fulfilling a different role in the body. An example is shown in Figure 8.1.

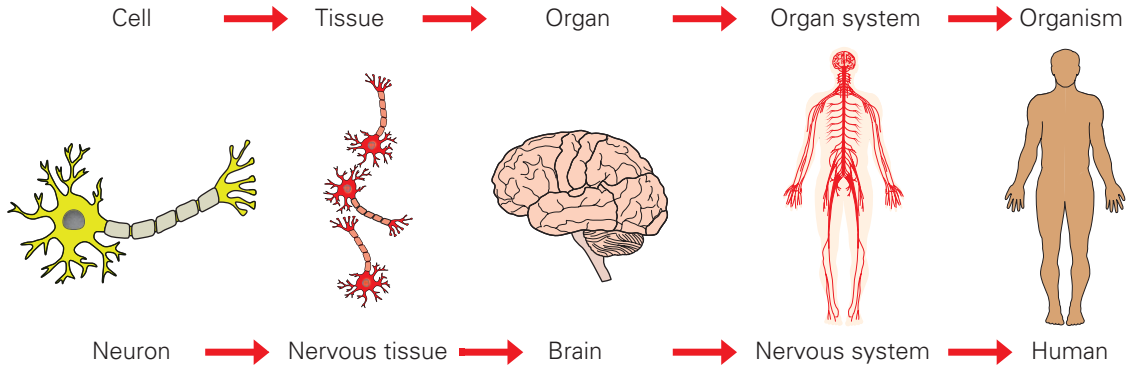


Figure 8.1 The nervous system is an example of cells being organised into an organ system.

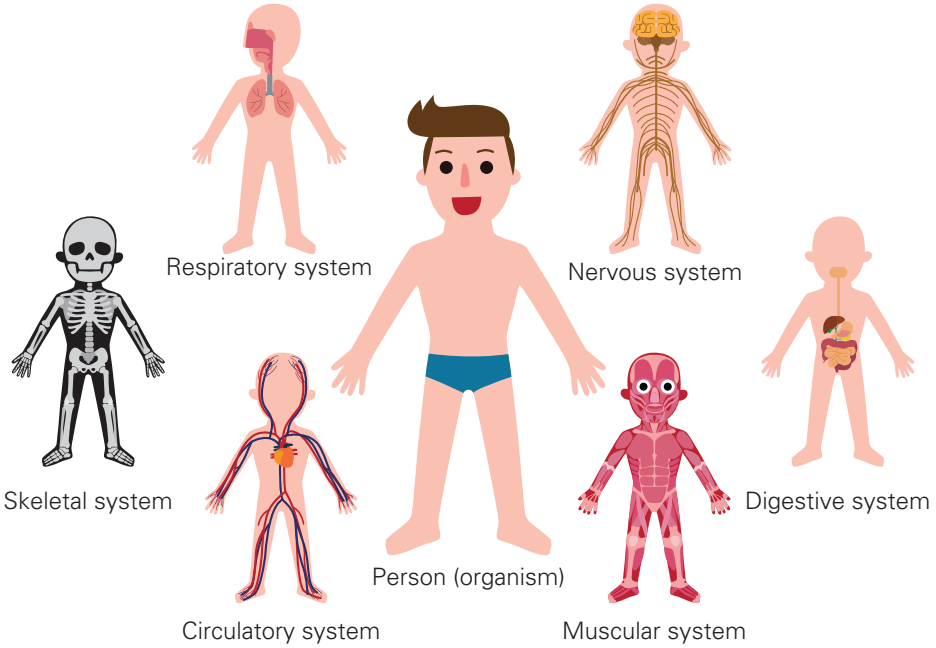


Figure 8.2 A multicellular organism, such as a human, is composed of many specialised cells, which are organised into tissues, organs and organ systems.

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Tissues

When a group of cells of the same type work together in a body, we call them a **tissue**. One of the most obvious tissues in animals is muscle tissue. These groups of cells contract and relax to generate movement by the animal. Muscle tissues require lots of energy, and so each cell has many mitochondria to carry out **cellular respiration** and provide that energy. Muscle cells also have a good supply of blood to deliver oxygen and glucose for cellular respiration and to remove waste products such as carbon dioxide. Other types of tissue include lung tissue, liver tissue and connective tissues, such as tendons and ligaments. Even blood is considered a tissue.

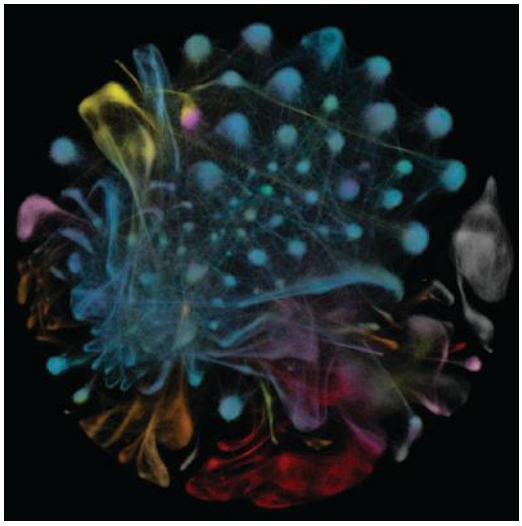


Figure 8.3 The image shows roughly 100 000 cells from a rhesus macaque monkey. Similar cells are clustered together, with every dot representing a single cell. The lines connecting the dots reflect how similar they are. Each colour represents cells from a different tissue. For example, brain cells are shown in grey, lung cells in pink and liver cells in green.

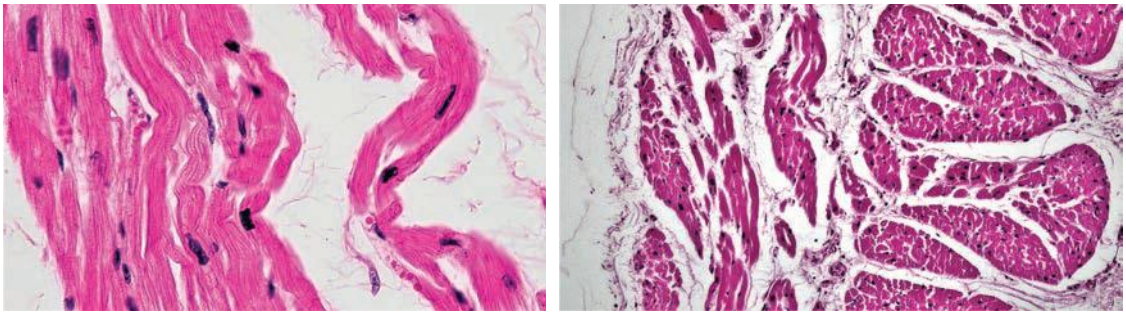


Figure 8.4 A high-magnification photograph of human smooth muscle (left) and cardiac (heart) muscle (right), seen through a light microscope. Each of the cells has a purple nucleus. Note that a stain has been added to the tissue to make it more visible.

tissue
a group of similar specialised cells that work together to carry out a specific function; different tissues make up organs

cellular respiration
a process that occurs inside the mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

organ
two or more types of tissue acting together to perform a specific role

Organs

An **organ** is a structure formed by various tissues that work together to carry out specific functions. The brain, one of the most crucial organs in the human body, serves as the control centre for all bodily activities. It is primarily composed of nerve tissues, which are organised into two main types:

- grey matter, which is responsible for processing information and controlling muscle activity
- white matter, which transmits signals between different parts of the brain and the rest of the nervous system.

Alongside these nerve tissues, the brain is well supplied by blood that flows through many blood vessels.

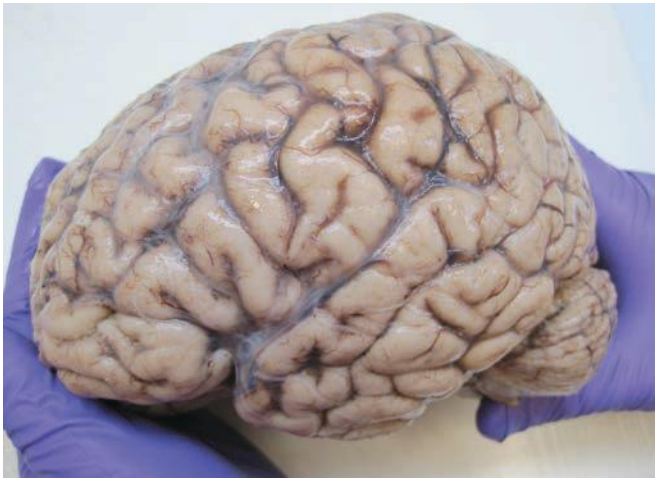


Figure 8.5 The human brain is a complex organ composed of neurons, blood vessels and other cells.

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Did you know? 8.1

A new human organ

In 2020, scientists conducting cancer research discovered a new human organ. When using CT and PET scans with radioactive glucose to highlight tumours, researchers from the Netherlands Cancer Institute noticed unexpected glowing spots in the head.

Further investigation revealed a previously unknown organ, the tubarial salivary gland, located behind the nasal passage near the throat. This gland is believed to moisten the upper throat, and after examining 100 patients, the scientists confirmed the presence of this gland in each one.

The human body has three other major salivary glands, all of which keep the mouth lubricated for chewing and swallowing: the parotid glands (below and in front of the ear), the submandibular glands (under the lower jaw, providing most of the saliva), and the sublingual glands (under the tongue).

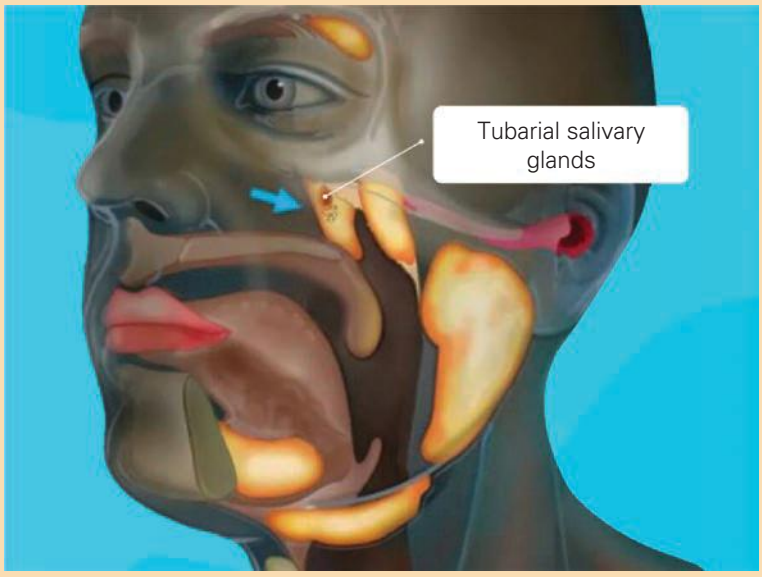


Figure 8.6 A model of the human head with salivary glands highlighted. The tubarial salivary glands were unknown before 2020.

Organ systems

A group of different organs working together is called an organ system (or body system). The structures of the system each perform distinct processes or functions. There are eleven organ systems in humans.

Did you know? 8.2

Organs systems and mental health

Your organ systems don't just keep your body working – they also affect your brain and mental health! Scientists have discovered that when organs like the heart, liver, lungs and muscles aren't functioning well, they can cause changes in brain structure, increasing the risk of depression and anxiety. For example, poor heart health can reduce blood flow to the brain, while liver problems can lead to harmful toxins building up in the body. Even the immune system plays a role, as chronic inflammation has been linked to mood disorders. By looking after your organ systems with regular exercise, a balanced diet, good sleep and avoiding smoking or excessive alcohol, you can help protect both your body and mind!

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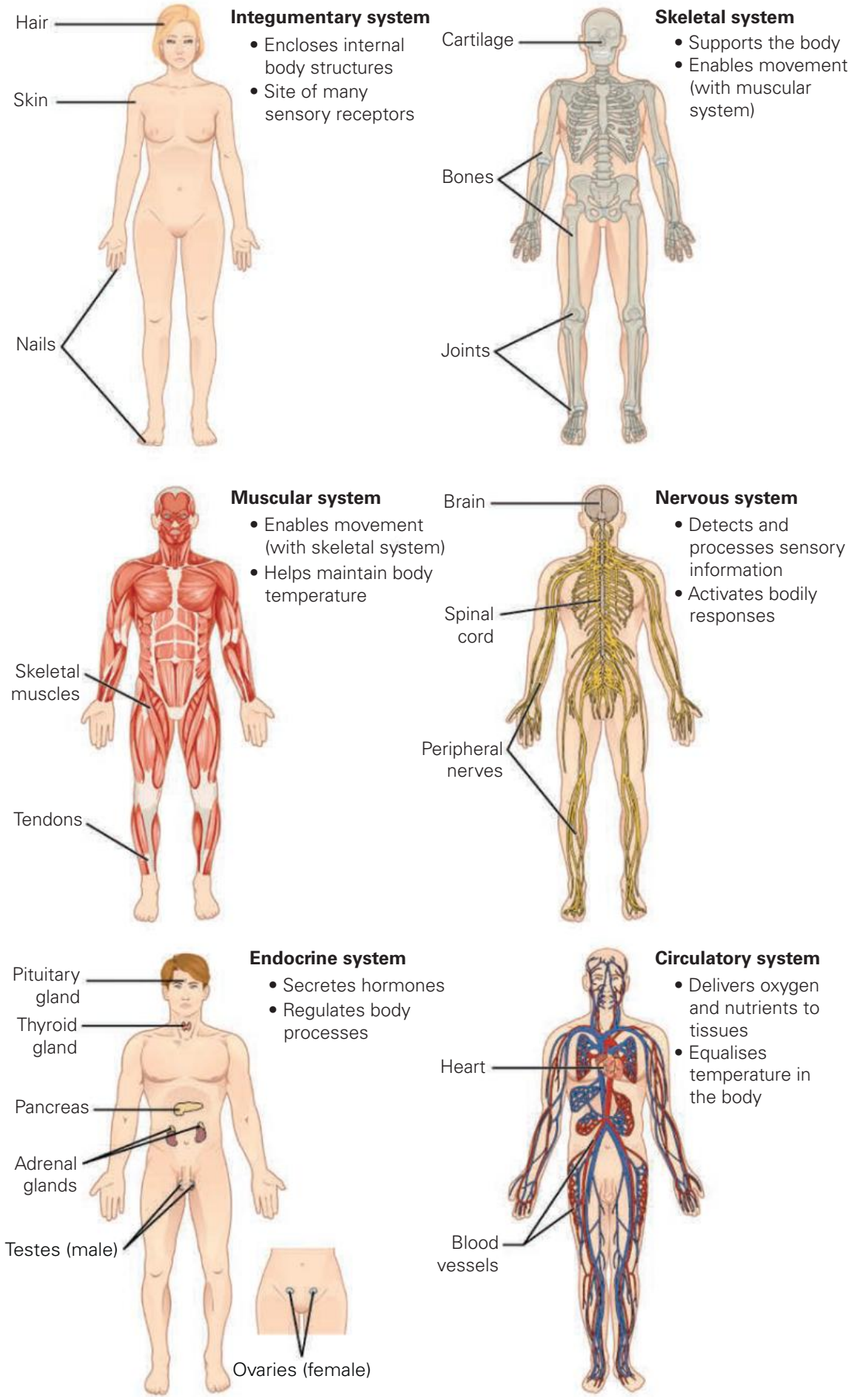
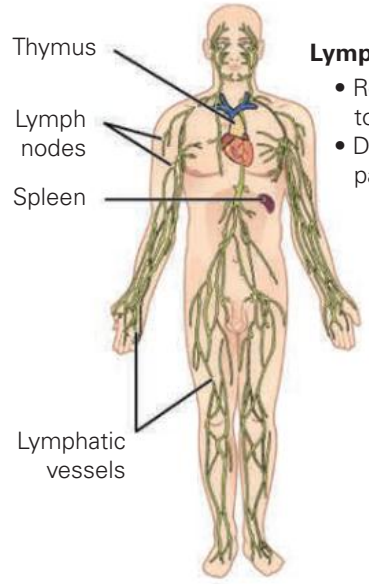
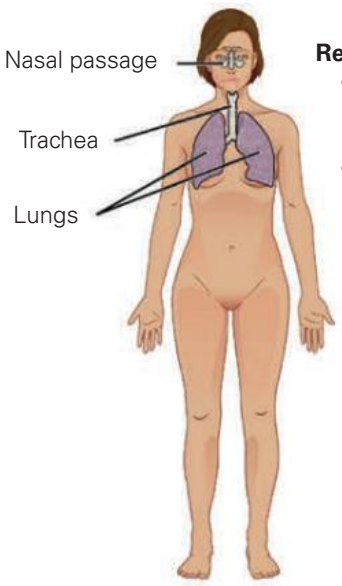


Figure 8.7 The 11 human organ systems (continued on the following page)

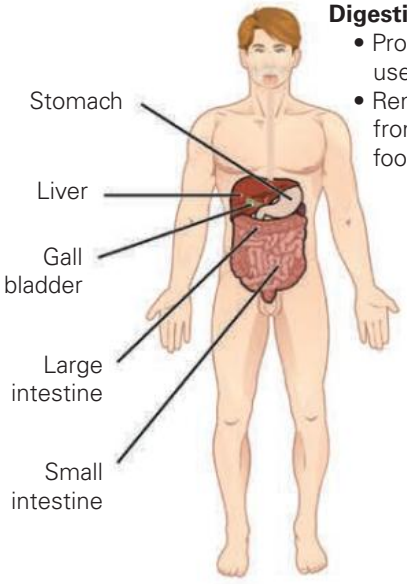
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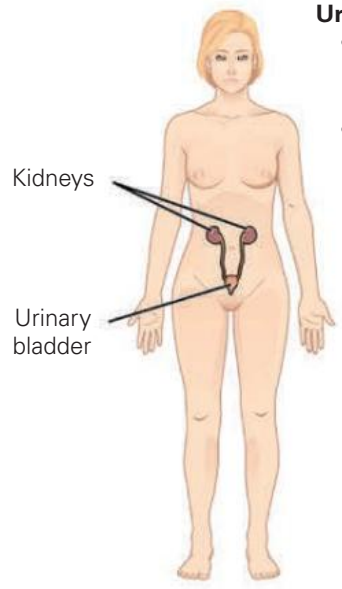
Lymphatic system
- Returns fluid to the blood
- Defends against pathogens



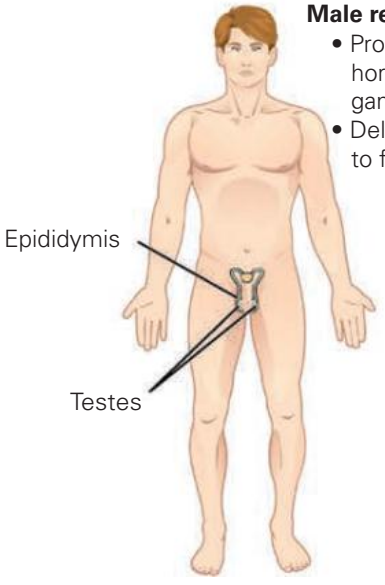
Respiratory system
- Removes carbon dioxide from the body
- Delivers oxygen to the blood



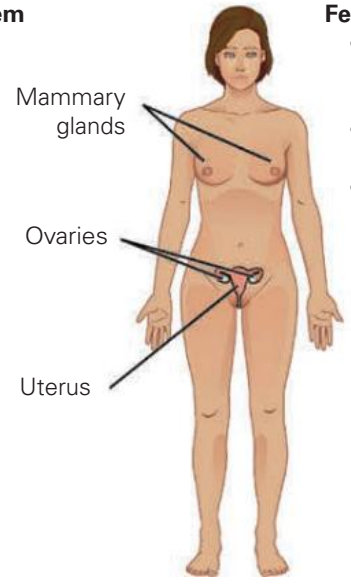
Digestive system
- Processes food for use by the body
- Removes wastes from undigested food



Urinary system
- Controls water balance in the body
- Removes wastes from blood and excretes them



Male reproductive system
- Produces sex hormones and gametes
- Delivers gametes to female



Female reproductive system
- Produces sex hormones and gametes
- Supports an embryo/foetus until birth
- Produces milk for an infant

Figure 8.7 The 11 human organ systems *(continued)*

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Advances in science 8.1

Practice makes perfect

Haptic feedback gloves are gloves that provide sensory feedback to the wearer through vibrations or other means. They are being used in surgical training to provide a realistic and immersive experience for trainee surgeons. The gloves allow trainees to practise procedures in a simulated environment, where they can experience haptic feedback as they perform virtual reality surgeries. This allows the trainees to get a more realistic sense of the physical aspects of surgery, such as the resistance and movement of tissues, or how the tissue of a baby would differ from that of an older person. This can help to build trainees' surgical skills and improve their confidence before they perform procedures on real patients.



Figure 8.8 The HaptX Gloves DK2 system being used in 2019 with FundamentalVR's surgeon simulator software. This technology allows trainee surgeons to build their skills before performing a real operation.

Try this 8.1

Three-dimensional organ systems

Use the internet to find an online 3D anatomy site such as ZygoteBody. You should compare the two-dimensional representations in this book with the three-dimensional representations of organ systems online to understand how organs are positioned within the body.



Figure 8.9 A couple show an ultrasound image of their unborn baby. It is amazing to think that inside this tiny organism (within another organism!), all the body's essential organ systems are developing.

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Organisms

organism
a living creature, such as a plant or an animal

A group of organ systems working together supports a living being called an **organism**. Each day, we eat food, breathe air and excrete waste products from our bodies. The many organ systems in our bodies work together in integrated ways to detect and respond to changes and complete the processes required to keep us alive.

Explore! 8.1

Plants are complex

Plants are eukaryotic organisms, just like us. This means their cells have complex membrane-bound organelles, such as the nucleus. We tend to think that because plants are usually sessile (stationary), they are less complicated than animals, but plants also have specialised cells that are organised into tissues, organs and organ systems.

Research one plant of your choice and list one example of each of the levels of organisation:

Cell: Tissue: Organ: Organ system: Organism:

Quick check 8.1

1. **Sequence** the following structures into the correct level of organisation, from largest to smallest: cell, organ system, organism, organ, tissue.
2. **Propose** why unicellular organisms don't have organs.
3. **Distinguish** between a tissue and an organ.

Did you know? 8.3

Traditional knowledge of internal systems

Aboriginal and Torres Strait Islander Peoples have unique ways of communicating their understanding of the internal systems of organisms. Various Peoples often depict the internal features of animals through mediums like X-ray paintings, sculptures or head dresses.



Figure 8.10 Consider what internal systems are being shown in these pieces of art.

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Try this 8.2

Levels of organisation study mate

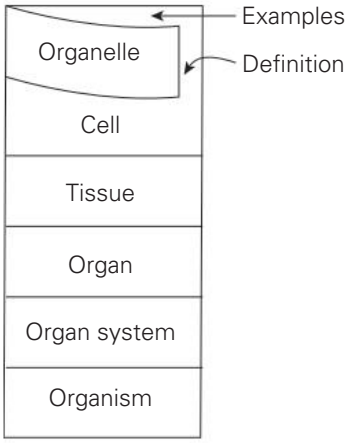
Step 1 Hold a piece of A4 paper in 'portrait' (upright) orientation.

Step 2 Fold it in half vertically – from left to right. You have formed a brochure with four sides or pages.

Step 3 Cut the front page only into six horizontal sections and label the front of these six flaps 'organelle, cell, tissue, organ, organ system, organism' from the top down.

Step 4 On the back of each flap, add the definition of each of the six levels of organisation.

Step 5 On the third page of the brochure, add some examples of each of the six levels of organisation.



When you look at the front of the brochure, you should see the names of the levels of organisation. As you open each flap, you should see the definition and examples.

Section 8.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 8.1 questions

Remembering

1. **Define** the term 'tissue'.
2. **Recall** the number of different organ systems in a human.

Understanding

3. **Explain** the interrelationship between cells, tissues and organs.

Applying

4. **Sketch** some simple diagrams that model the difference between a cell, a tissue, an organ and an organ system.
5. **Choose** which of the following statements are correct. Hint: there may be more than one correct answer.
   - **A.** An organ is composed of different types of tissue.
   - **B.** A tissue is composed of only one type of cell.
   - **C.** If you look at a tissue under the microscope, you will see many different organs.

Analysing

6 **Categorise** the following terms as either cells, tissues, organs, organ systems or organisms: liver, neuron, sperm, dog, digestive, human, eucalyptus, brain, muscle, blood.

Evaluating

7. A newly discovered organism ingests food through an opening. The food travels through a long tube to a storage area and any waste products eventually excreted through a sphincter. Based on this description, **justify** whether the observed structures constitute evidence of a tissue, an organ or an organ system.

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8.2 The human respiratory and circulatory systems

WORKSHEET
Human respiratory system

Learning outcomes

At the end of this section, I will be able to:

1. identify the role of the respiratory and circulatory systems of humans, and name the major organs.
2. draw or annotate representations of models of the respiratory and circulatory systems of humans to describe their processes and functions.
3. describe how the structures of the respiratory and circulatory systems of humans, and the specialised cells within these systems, enable them to carry out their functions.
4. describe examples of how the components of the respiratory and circulatory systems interact to allow the efficient functioning of an organism.



Figure 8.11 When you breathe out on a cold day, you can see your warm breath start to condense in the cold air.

The respiratory system

The main function of the organs in the respiratory system is to get oxygen into your body tissues and release the waste product carbon dioxide into the air. The respiratory system works very closely with the circulatory system, which transports oxygen in the blood from the lungs to the body tissues, and transports carbon dioxide from body tissues back to the lungs, where it is then breathed out.

Breathing versus respiration

You can probably hold your breath for about a minute, maybe two, but after that your body forces you to take a huge gulp of air. This is because the cells in our bodies need a constant supply of fresh oxygen to produce energy and function efficiently. Cellular respiration is the process that happens inside the mitochondria in our cells, which turns glucose and oxygen into useable energy. The process also produces the waste products of carbon dioxide and water. Breathing, the physical process of inhaling and exhaling, provides your body with oxygen to undertake cellular respiration. If you stop breathing, you are preventing oxygen from entering your body and therefore depriving your cells of oxygen, meaning energy cannot be made.

KEY IDEA

To summarise: breathing is a physical process; cellular respiration is a chemical process.

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Structures in the respiratory system

The lungs are the largest and principal organ of the respiratory system, where oxygen enters the blood and carbon dioxide takes the reverse path (called gas exchange). Figure 8.12 shows features and describe the main roles.

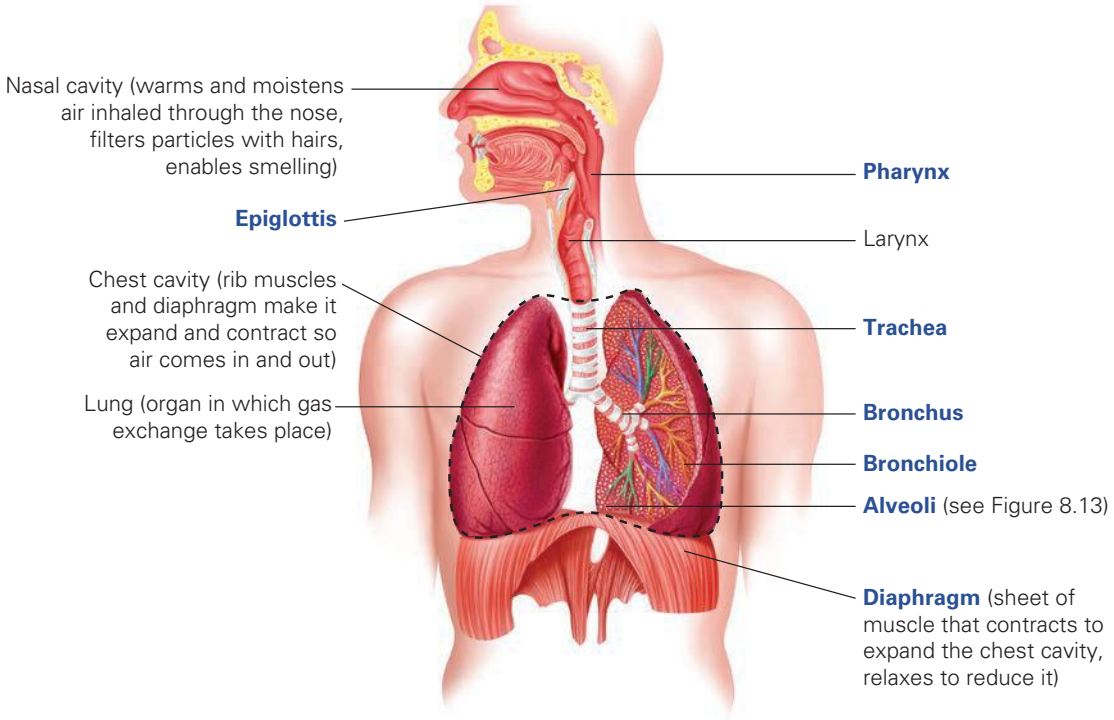


Figure 8.12 Structure of the human respiratory system. Note how the airways are like an upside-down tree; the nasal cavity and mouth are like the roots, the trachea is like the trunk and bronchi and bronchioles are the branches, while the alveoli are like the leaves.

epiglottis
a flap of elastic cartilage that covers the opening of the trachea during swallowing, preventing food and liquids from entering the airways

pharynx
the throat region where the nasal cavity and oral cavity meet, leading into the trachea

trachea
the tube (reinforced with rings of cartilage, lined with cilia to remove foreign particles and mucus) that carries air down to the lungs; also known as the windpipe

bronchus
(plural bronchi) the large airways of the lung; two primary bronchi branch off the trachea, one main left bronchus to the left lung and one main right bronchus to the right lung

bronchiole
a smaller tube that branches off a bronchus and leads to the alveoli

alveoli
the tiny sacs at the end of bronchioles in the lungs; the site of gas exchange with the capillaries

Quick check 8.2

1. **Define** the main function of the respiratory system.
2. **Describe** what happens to air as it passes through the nose.
3. **Sequence** these terms in order so that they represent the direction of airflow during inhalation: alveoli, pharynx, nose/mouth, bronchus, trachea, bronchiole



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capillaries
the smallest blood vessels, one cell thick, and the site of gas exchange with cells

diaphragm
a dome-shaped muscle that separates the chest and abdominal cavities; it contracts to draw air into the lungs

VIDEO
Gas exchange in an alveolus

Alveoli

When the air gets to the end of the smallest bronchiole, it enters small sac-like structures called alveoli. The alveoli are only one cell thick and are surrounded by a net of very small blood vessels called **capillaries**. This is where gas exchange occurs: inhaled oxygen diffuses out of the alveoli and into the capillaries (into the bloodstream) for transport around the body. Carbon dioxide moves in the opposite direction, from the capillary into the alveoli. As the diaphragm and intercostal muscles relax, the carbon dioxide-rich air is exhaled out through your nose and mouth.

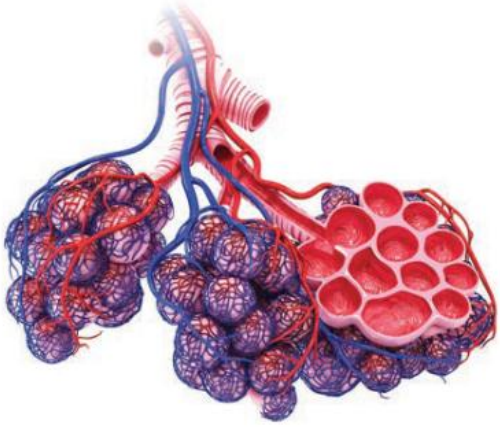


Figure 8.13 Gas exchange occurs between the alveoli and the capillaries. The oxygenated blood is returned to the heart, and the carbon dioxide-rich air is exhaled.

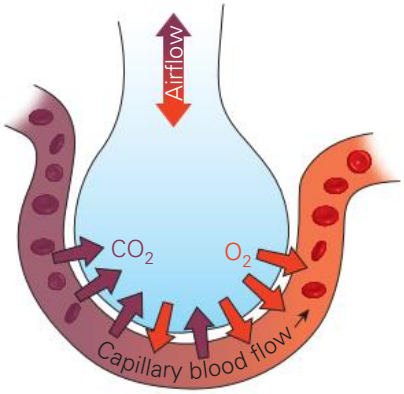


Figure 8.14 Gas exchange between the alveolus and the capillary. Note the direction of diffusion as oxygen enters by dissolving in the bloodstream and carbon dioxide leaves by evaporating from the bloodstream.

Big breath in!

When you breathe in (inhale), a large muscle at the base of your ribs, called the diaphragm, contracts and pulls down. At the same time, the intercostal muscles between your ribs contract, moving the ribs upwards and outwards. This increases the volume in your chest, drawing air in through your mouth and nose by decreasing the pressure in your lungs compared with the outside. As you breathe out (exhale), the diaphragm relaxes, and air is passively released through your nose and mouth because the pressure has increased in the lungs.

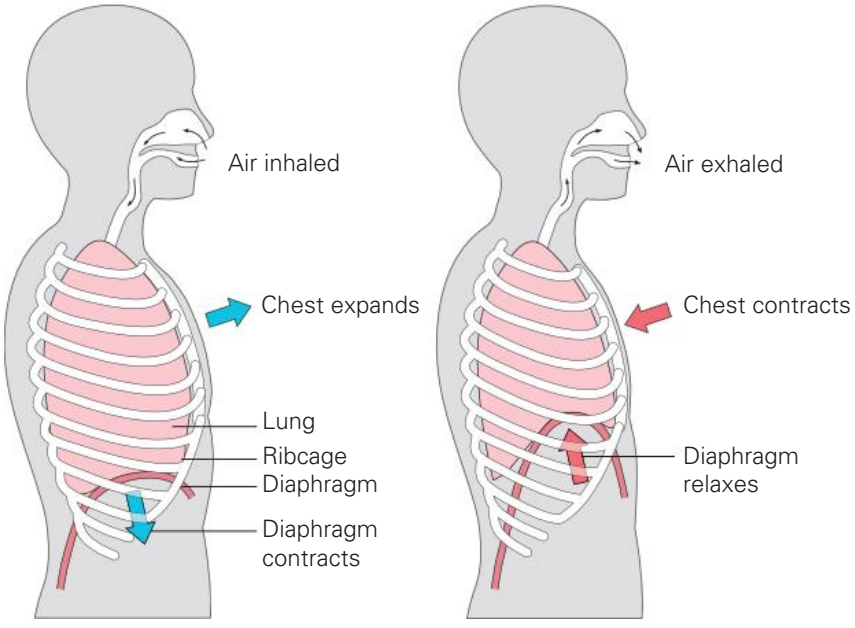


Figure 8.15 The movements of the chest during inhalation and exhalation

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Practical skills 8.1

Modelling the pressure changes in the lung

Aim

To model how contraction of the diaphragm creates negative pressure inside the lungs.

Materials

- plastic bottle, 500 mL or 1 L
- straw
- 2 elastic bands
- 2 balloons
- putty
- scissors
- sticky tape

Procedure

1. Tie a knot in one of the balloons and then cut off about a quarter of the other end.
2. Cut the bottle in half and only use the top half.
3. Put sticky tape around the cut edge of the bottle.
4. Stretch the cut balloon over the cut bottle opening and secure in place with an elastic band and sticky tape.
5. Put a straw into the second balloon and use an elastic band to hold them together.
6. Place the straw with balloon attached through the neck of the bottle and seal the hole with putty.
7. Pull down on the bottom balloon covering to mimic the diaphragm contracting and describe what you observe.

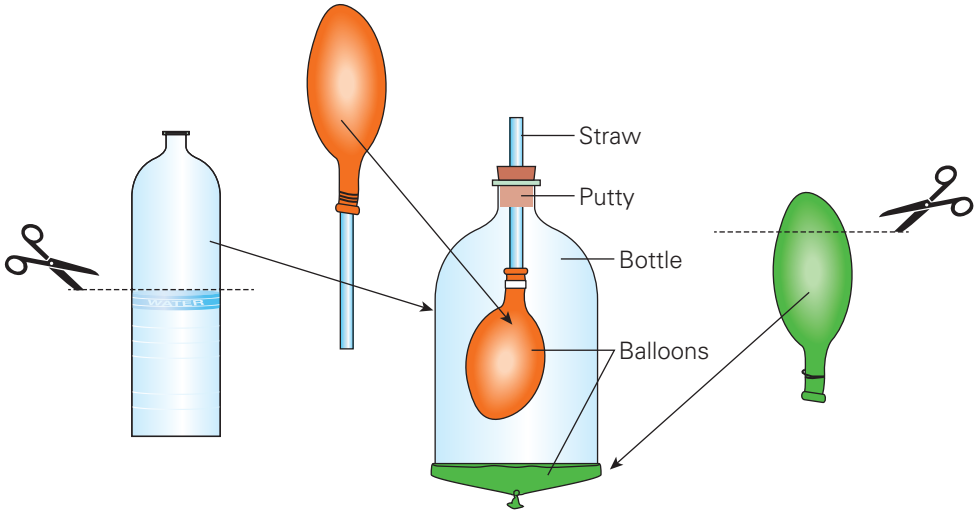


Figure 8.16 Experiment set-up. Breathing in: pressure in the lungs is lower than the atmosphere, so air flows in. Breathing out: pressure in the lungs is greater than the atmosphere, so air flows out.

Results

Draw your model of the lung in your book and label each of the parts that represent the following structures: lungs, ribs, diaphragm, trachea, mouth.

Discussion

1. What similarities can you draw between your model and the actual human respiratory system?
2. Describe the flow of air when you pull down on the balloon at the bottom of your model.
3. Explain what happens to the balloon lung when you push the balloon at the bottom of your model upwards.
4. Think about where the force acts that make the air move. Although you apply a force to the balloon, the balloon does not apply a force to the incoming air. What does?

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Did you know? 8.4

Your lungs float!

Each of your lungs contains around 300 million alveoli, which you can imagine as tiny balloons. When 'inflated', the lungs are the only organ in the human body that can float on water.

Quick check 8.3

1. **Explain** how the diaphragm is involved in breathing in and out.
2. **Recall** the site of gas exchange in the lungs.

WORKSHEET Human circulatory system

VIDEO Contraction of heart chambers

The human circulatory system

When oxygen dissolves in the blood in the alveoli, it's just the first step in its journey through the body. The next stage is delivering it to every part of the body, and that's where the circulatory system comes in.

The circulatory system, often called the cardiovascular system, is the essential transport network for the body. It moves oxygen, nutrients, hormones, immune cells, waste and heat throughout the body in a continuous loop. Without the circulatory system, the other organ systems wouldn't be able to function properly.

Heart

The heart is a powerful muscular pump. It has one job: to maintain pressure in your circulatory system, which moves the blood around your body. Once in your heart, blood is ready for recirculation. Your heart does this by contracting and relaxing about 60–90 times per minute. Your heart is located near the centre of your chest, and it is about the same size as your fist. It is made up of four main sections: the right **atrium** and left atrium (top parts of the heart) and the right and left **ventricles** (bottom parts of the heart).

atrium one of the two upper chambers of the heart, the left atrium and right atrium

ventricle one of the two lower chambers of the heart, the left and right ventricles

vena cava the large vessel that returns deoxygenated blood from the body to the heart, emptying into the right atrium

aorta the largest vessel leaving the heart, from the left ventricle, carrying oxygenated blood to the body

It generates high pressure, which pushes blood out of your heart into the arteries. Blood is pushed towards the heart because valves in the veins prevent back-flow, and it continues moving because of muscles around the veins applying pressure.

The human heart is like a double pump: the left side sends blood out to the body, and the right side sends blood to the lungs. Let's follow the path of a red blood cell through the circulatory system, using Figure 8.17.

Blood returning to the heart from the body enters the heart though the **vena cava** and goes into the right atrium. This blood has low levels of oxygen and high levels of carbon dioxide.

The blood then passes into the right ventricle and is prevented from travelling backwards by a valve between the atrium and the ventricle. Once in the ventricle, the blood is then pumped out of the heart and travels via the pulmonary artery to the lungs.

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As the blood passes through the lungs, it releases the carbon dioxide it has stored within it and gains oxygen from the alveoli of the lungs.

The oxygenated blood then returns from the lungs through the pulmonary veins into the left atrium. From there, it passes into the left ventricle. The left ventricle pumps the blood out via the **aorta** to all the different parts of the body. This process delivers oxygen to the cells and picks up the waste carbon dioxide.

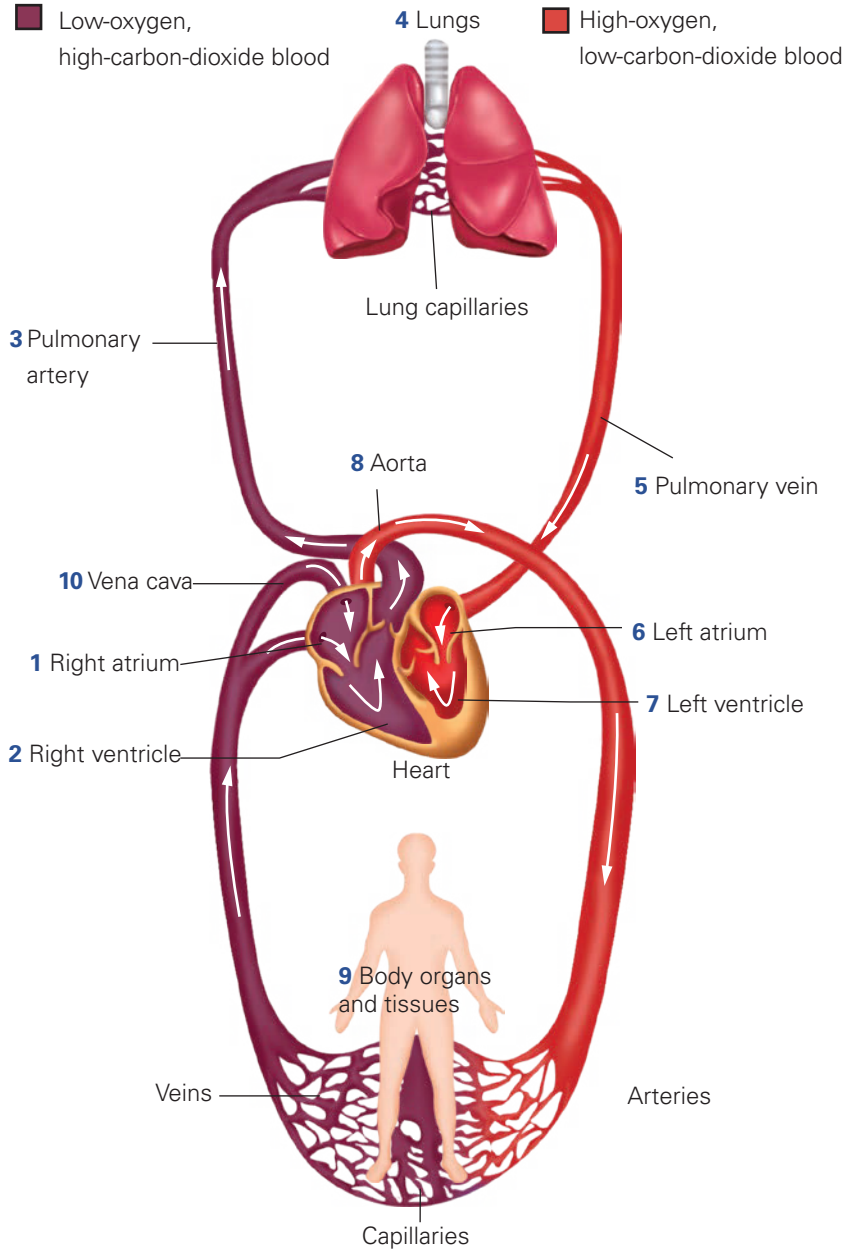


Figure 8.17 The human circulatory system operates in a continuous loop, with blood flowing in the sequence indicated by the blue numbers. It starts in the right atrium **(1)**, then moves to the vena cava **(10)**, before returning to the right atrium **(1)** and circulating around the loop again.

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Try this 8.3

Testing your heart rate

Your heart rate responds to the oxygen requirements of your body. For each of the following test conditions, follow the procedure below and record your heart rate (in beats per minute) in the table. You will need a stopwatch.

Find your pulse by gently pressing two fingers over your radial artery (on the soft side of your wrist, slightly off-centre towards the thumb). Count the number of beats you feel in 15 seconds, using the stopwatch, and then multiply by four to find your heart rate in beats per minute (bpm).

Test your pulse under the following conditions, then copy and complete the table.

Test condition	Heart rate (bpm)
Lying down	
Sitting	
After jogging for three minutes	



Figure 8.18 Feeling for the radial pulse

Graph your data as a bar chart and answer the following questions.

1. During which test condition was your heart rate:
   - **a.** at its highest
   - **b.** at its lowest?
2. For each answer you gave to Question **1**, propose a reason why this was the case.

Did you know? 8.5

Red or blue?

When you look at your wrist, you might be tempted to think that your veins are blue or green, depending on your skin tone. The light passing through our skin makes our veins look blue or green, but this is just an illusion! The appearance of blue veins is due to the interaction of light with the veins and the layers of skin above them.



Figure 8.19 Bright red oxygenated blood (left) and darker deoxygenated blood (right)

The colours you perceive are determined by the wavelength of light that reaches your eye. Different layers of skin cause the wavelengths to scatter in various ways. In individuals with darker skin tones, veins often appear green, rather than the blue seen in individuals with lighter skin tones. This is because green and blue light have shorter wavelengths compared to red light. Red light can penetrate human tissue better than blue light. As a result, our skin absorbs red wavelengths, while green and blue wavelengths are reflected and scattered back to us, contributing to the colour we observe in veins.

Quick check 8.4

1. **Name** the four chambers of the heart.
2. For each of the vessels listed below, **state** whether it carries oxygenated or deoxygenated blood.
   - **a.** Vena cava
   - **b.** Pulmonary artery
   - **c.** Pulmonary vein
   - **d.** Aorta

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Practical skills 8.2

Sheep heart dissection

Aim

To identify the path of blood flow through the heart and become familiar with the structures.

Materials

- lamb heart, preferably with aorta and vena cava attached
- dissecting scissors
- disposable gloves
- two blue and two red pipe cleaners (or straws)
- wash bottle
- dissecting tray

Procedure

1. Place the heart on the dissecting tray and identify the front (anterior) and back (posterior).
2. Before cutting into the heart, identify:
   - the vena cava – Place a blue pipe cleaner into the vena cava (representing deoxygenated blood).
   - aorta – Place a red pipe cleaner into the aorta (representing oxygenated blood).
   - pulmonary artery – Place a blue pipe cleaner here (representing deoxygenated blood. Note that this connects to the same side as the vena cava).
   - pulmonary vein – Place a red pipe cleaner here (representing oxygenated blood. Note that this connects to the same side as the aorta).
   - right/left side (Remember, these will be opposite – your left and right).

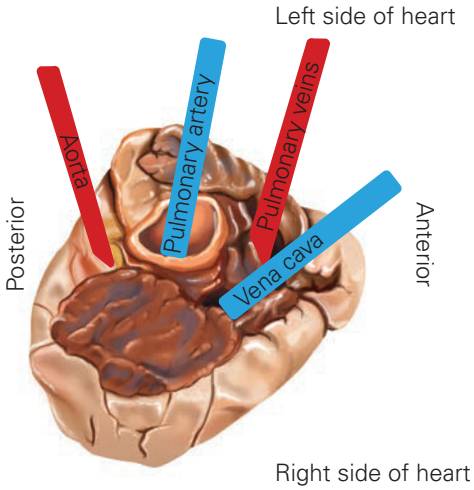


Figure 8.20 Diagram of where you will place the pipe cleaners in the lamb heart

3. Place your finger into the vena cava and then into the aorta. Notice the difference in strength and thickness of the walls of the blood vessels.

Right atrium

4. To open the right side of the heart, place the dissecting scissors into the vena cava and cut down the wall of the heart, stopping about a quarter of the way down the heart.
5. Open the atrium chamber and locate the valve joining the right atrium to the right ventricle.
6. Using water from a wash bottle, fill the right ventricle through the valve.
7. Gently squeeze the heart and observe as the water moves up and tries to re-enter the atrium.

Right ventricle

8. Continue to cut down the same line you made earlier to expose the right ventricle.
9. Locate the 'heart strings' within the ventricle.

Left side of the heart

10. Repeat the process above to expose the left side of the heart.
11. Compare the thickness of the walls of the heart on the left and right sides.

Discussion

1. Identify which chambers of the heart receive the blood and which pump the blood.
2. Describe the action of the valves in the heart.
3. Compare the wall thickness of the right and left sides of the heart. Suggest a reason why they differ.
4. Describe how the vena cava and aorta feel on your finger.

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DEPTH STUDY IDEA
Investigate remote or robotic surgery

Vessels of the circulatory system

Blood vessels are the pipes of the circulatory system. There are three main types of blood vessels in the body: arteries, veins and capillaries, as shown in Table 8.1.

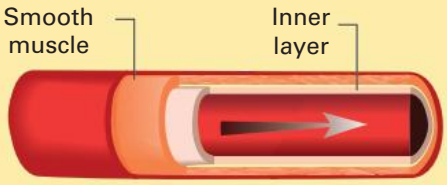
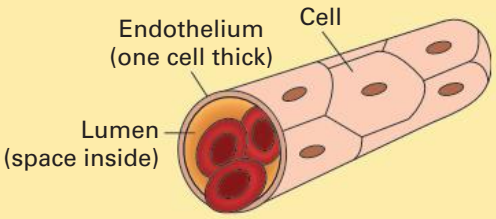
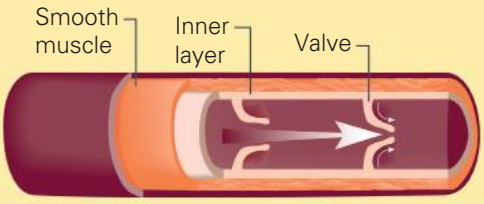
Type and diagram	Description	Role
Artery 	Thick, muscular, and elastic walls	Carries oxygenated blood away from the heart to organs and muscles under high pressure. The pulmonary artery is an exception, carrying deoxygenated blood to the lungs under low pressure.
Capillary  Not to same scale	Very thin-walled vessel (one cell thick), smallest in the circulatory system; barely wide enough for red blood cells to pass through	Facilitates the exchange of nutrients, gases, waste products and chemical messengers between blood and surrounding cells
Vein 	Thin walls with valves to prevent backflow	Carries deoxygenated blood from organs and muscles back to the heart at low pressure. The pulmonary vein is an exception, transporting oxygenated blood to the heart.

Table 8.1 Types of blood vessels

Try this 8.4

Examining vessel types

Your teacher can provide some prepared slides showing cross-sections of arteries, veins and capillaries. Observe these vessel types under the microscope and try to identify all the features discussed in this section.

Blood

The human circulatory system is structured around a pumping heart and connected vessels, but the third part is the tissue that is actually circulated: blood. You have around five litres of blood circulating around your body all the time. This blood contains dissolved nutrients, gases and several types of cells.



Figure 8.21 Blood plasma

Plasma

plasma
the yellow liquid component that makes up 55% of blood; it carries water, dissolved gases and chemicals

Most of your blood is made up of a liquid called **plasma**. Plasma is yellowish in colour, made up mainly of water, and contains all the dissolved nutrients and chemicals that are travelling to the tissues around your body.

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Red blood cells



Figure 8.22 Red blood cells

The second-largest component of blood is the red blood cells. These cells contain a molecule called **haemoglobin**, which gives blood its red colour. Haemoglobin molecules contain iron and can bind with oxygen molecules. Red blood cells are unusual, as they expel their nucleus as they mature. This gives them more space for haemoglobin, which allows them to carry more oxygen molecules. The biconcave shape provides a greater surface area for gas exchange and allows the cells to be extremely flexible so that they can fit through small capillaries easily.

haemoglobin the red pigment in blood that binds to oxygen, allowing red blood cells to carry oxygen

platelets tiny cell fragments that assist with blood clotting

White blood cells

White blood cells make up about one per cent of the overall volume of blood. This varies depending on whether you are sick, because white blood cells are part of the immune system. White blood cells are generally much bigger than red blood cells. They help the body fight infection by foreign organisms by engulfing these organisms and breaking them down or by using special molecules known as antibodies to destroy the invaders.

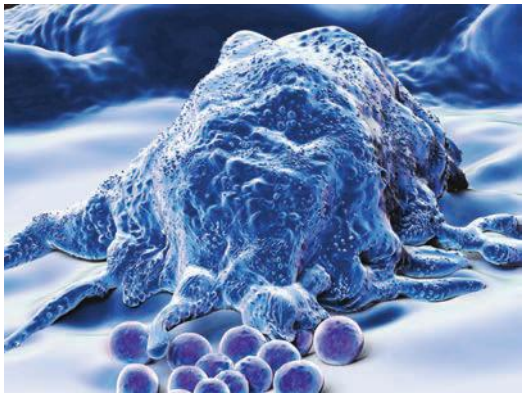


Figure 8.23 A large white blood cell (called a macrophage) engulfing and destroying bacteria

Platelets

Another component of your blood is the **platelets**. These tiny cell fragments help blood to clot and help scabs form. Platelets are much smaller than red blood cells. If platelets encounter any punctures along the blood vessels, they become activated and change shape. They then bind to a thread-like protein called fibrin and form a plug. This allows them to seal the puncture. If your body has too few platelets, then you won't be able to stop bleeding if you have an injury. On the other hand, if you have too many platelets, clots can form inside the blood vessels and stop the blood from flowing properly. These internal clots can lead to heart attacks or strokes.

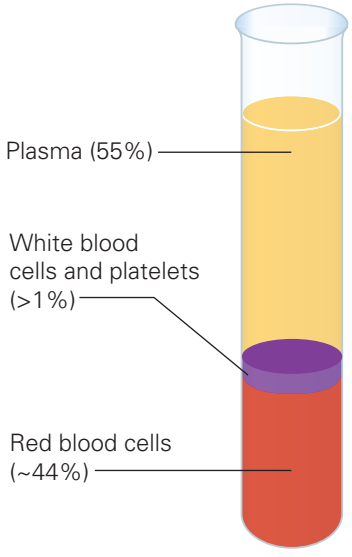


Figure 8.24 The components of blood, separated into layers using a centrifuge

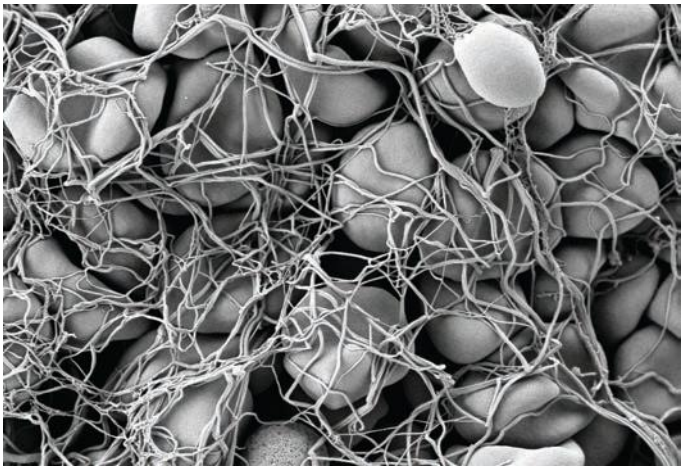


Figure 8.25 Red blood cells trapped in fibrin threads

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Quick check 8.5

1. **State** the vessel type that matches each feature listed below.
   a. Thick, muscular walls
   b. Walls that are one cell thick
   c. Valves to prevent backflow of blood
2. **Explain** why arteries carry blood at high pressure.
3. **Explain** why capillary walls need to be only one cell thick.
4. **Name** three components found in the blood and state their approximate percentage composition in the blood.
5. **Recall** what is contained in the plasma.

Go online to access the interactive section review and more!

Section 8.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 8.2 questions

Remembering

1. **Name** the gases that are absorbed into and removed from the body by the respiratory system.
2. **State** the function of the lungs.
3. **State** the function of the heart.
4. **State** the components of blood.

Understanding

5. **Explain** how the parts of the respiratory system are similar to a tree.
6. **Summarise** the functions of each of the following parts of the respiratory system:

Structure	Function
Alveolus	
Trachea	
Nose	
Bronchiole	

7. **Explain** the function of a platelet.
8. **Explain** how the structure of a capillary allows it to exchange nutrients and gases with cells.

Applying

9. **Summarise** the movement of the diaphragm during inhalation and exhalation.
10. **Construct** a flow chart showing the route taken by an oxygen molecule, starting from the air in your classroom and finishing with a body cell.
11. **Determine** the point in your circulatory system where your blood pressure would be the highest.
12. **Determine** the point in your circulatory system where your blood pressure would be the lowest.

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Analysing

13. Contrast the term 'breathing' with the term 'respiration'.

14. The graph in Figure 8.26 shows a person's respiration rate when resting and when exercising.

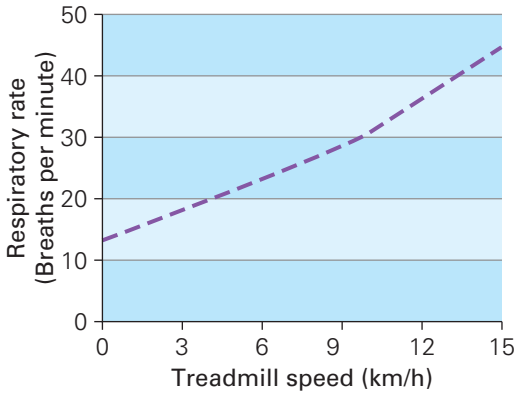


Figure 8.26 Respiration rate for a person resting and exercising

a. Identify the person's respiration rate at rest.

b. Identify their respiration rate at the maximum treadmill speed.

c. Infer why their respiration rate increased during exercise.



15. A baby is diagnosed with 'patent foramen ovale', a condition distinguished by a hole in the wall of the heart, between the left and right atria. **Infer** what effect this hole would have on the blood that is being pumped out the aorta.

Evaluating

16. Cystic fibrosis is a disease that causes the production of thick and sticky mucus, which builds up in the airways and can be life-threatening if the person catches a cold or the flu, resulting in a chest infection. **Propose** a reason why a build-up of mucus in the lungs can be harmful, and why the person may experience shortness of breath.

17. Suggest a problem that would be faced by someone who has too few platelets in their blood.

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8.3 The human digestive and excretory systems

WORKSHEET Human digestive system

Learning outcomes

At the end of this section, I will be able to:

1. identify the role of the digestive and excretory systems of humans, and name the major organs.
2. draw or annotate representations of models of the digestive and excretory systems of humans to describe their processes and functions.
3. describe how the structures of the digestive and excretory systems of humans, and the specialised cells within these systems, enable them to carry out their functions.
4. describe examples of how the components of the digestive and excretory systems interact to allow the efficient functioning of an organism.

The human digestive system

The role of the digestive system is to acquire and process all the nutrients the body needs. Through chemical and mechanical digestion, food is broken down into its smallest components, and the nutrients are absorbed into the bloodstream to be transported to the cells that require them.

The excretory system works alongside the digestive system by removing waste materials produced during digestion and nutrient utilisation. The circulatory system also supports the digestive system by transporting the absorbed nutrients to where they are needed, while carrying some waste products to the excretory system for removal.

The nutrients we need

heterotroph any organism that obtains its nutrients by consuming other organisms

Humans are **heterotrophs**, which means we cannot produce our own food as plants can. We need to obtain nutrients from the environment around us by eating other living organisms. The types of nutrients that humans need can be grouped into four main categories:

- carbohydrates – the main source of energy in the human diet. Bread, pasta, rice and oats are all great sources of carbohydrates. The simplest carbohydrate is glucose.
- proteins – the building blocks of life and the main structural component of most of the living parts of your body. Proteins are needed for growth and repair. Meat, cheese, eggs, seeds, nuts and legumes are great sources of protein.
- lipids – also called fats and oils. Fats transport some vitamins around our bodies, are a good energy source and help protect the delicate organs inside our bodies from shock or impact. Good sources of lipids include butter, oils, avocados and fatty fish.
- vitamins and minerals – essential for the efficient functioning of our body. There are many vitamins and minerals that we can't make ourselves, so we must consume them in the food we eat. Good sources of vitamins and minerals include fruits, vegetables, dairy and whole grains.

Quick check 8.6

1. **Recall** the simplest carbohydrate.
2. **Recall** another name for lipids.
3. **Name** some sources of protein.

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Did you know? 8.6

Where does vitamin C come from?

Vitamin C helps the body to absorb more iron, which is required for oxygen-carrying haemoglobin in the blood. It also aids in the production of collagen, which helps heal cuts in your skin. You would get most of your vitamin C from vegetables and citrus fruits. Dogs and many other carnivores can synthesise their own vitamin C inside their bodies. This adaptation could come in handy if you do not like eating vegetables!



Figure 8.27 New lime varieties such as blood lime (red), sunrise lime (yellow) and outback lime (green), bred from native limes such as the finger and desert limes, have been developed by CSIRO.

Parts of the human digestive system

The process of digestion can be divided into two aspects:

- **Mechanical digestion** involves physical changes – that is, physically breaking food into smaller components but not changing the chemical structure of the food. Examples include breaking food apart with your teeth and tongue when you chew, and bile acting to emulsify (break up) fats.
- **Chemical digestion** involves chemical changes that occur when enzymes break the food down into its most basic chemical components.

The human digestive system primarily consists of a long, continuous tube that runs from the mouth to the anus, known as the alimentary canal. The space through which food travels is called the lumen, a term also used to describe the space in blood vessels. Let's take a closer look at the structure and function of this essential organ system.

mechanical digestion a series of mechanical processes that break food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

chemical digestion a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

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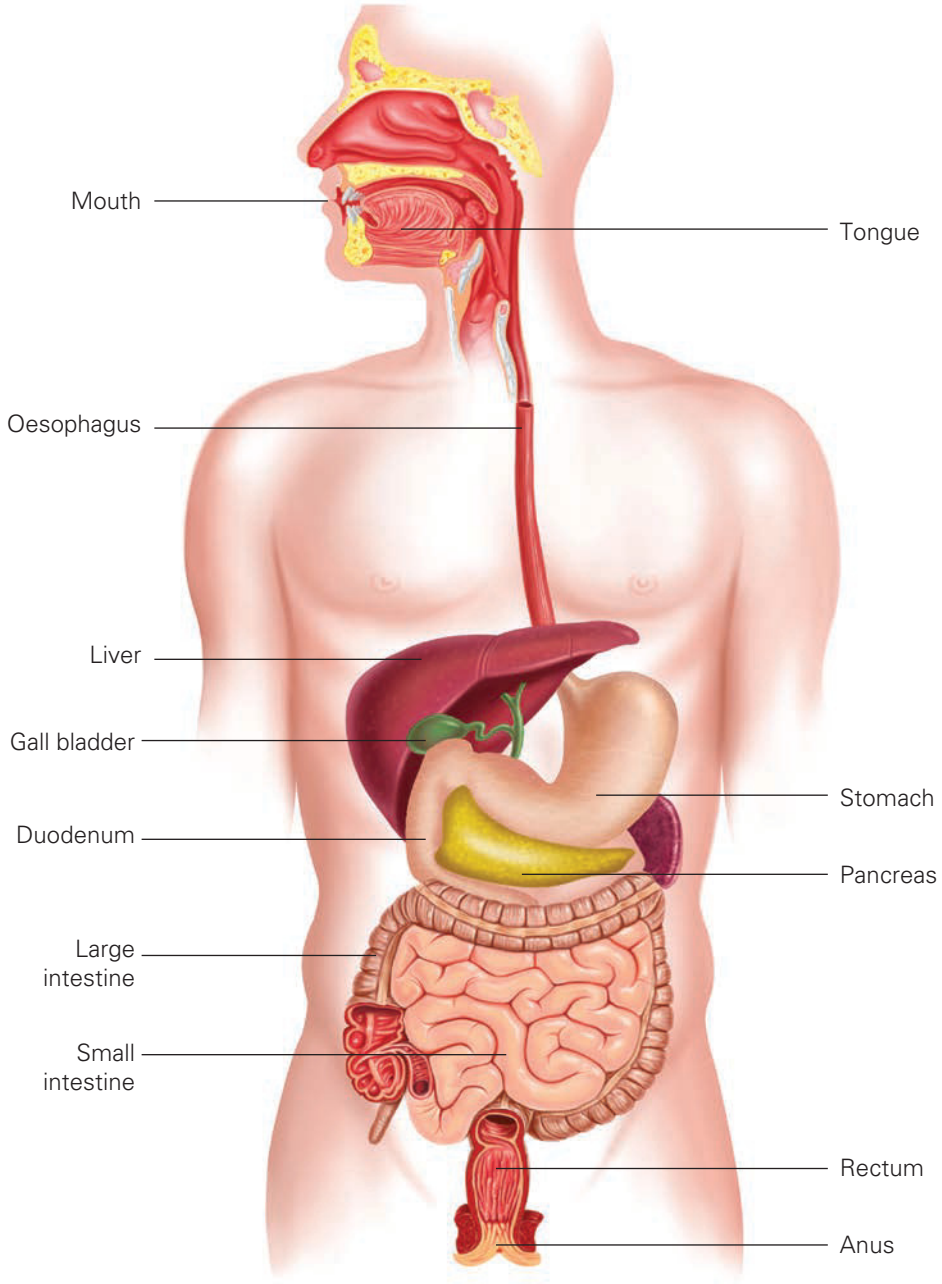


Figure 8.28 The human digestive system

Mouth and tongue

The mouth has many specialised structures that start the digestive process. First, your teeth cut, tear and grind the food, breaking it into smaller pieces (mechanical digestion). This increases the surface area of the food, which helps with chemical digestion later. The tongue moves the chewed food around the mouth and coats it in saliva. It forms a lump of partially broken-down food called a **bolus**.

bolus
a lump of partially digested food

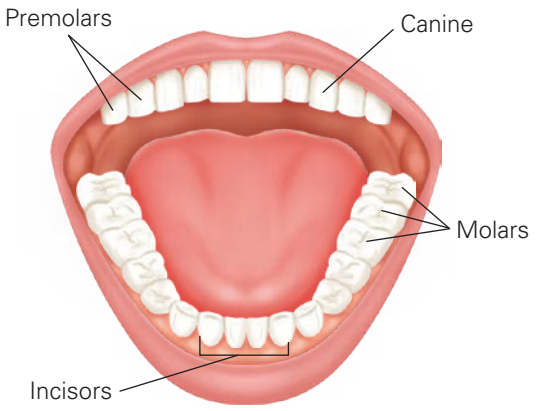


Figure 8.29 The different kinds of adult teeth: incisors for cutting, canines for tearing and molars for grinding

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Saliva lubricates the food to make its movement through your body smoother. It also has a role in chemical digestion because it contains special proteins, called **enzymes**, that begin to break down the food at a molecular level.

The main enzyme found in your saliva is called *amylase*, and it begins to break down carbohydrates, such as starch, into maltose in your mouth. Many more enzymes are found along the digestive tract, and each is designed to break down a particular food type.

saliva
liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

enzyme
a protein that speeds up chemical reactions in living organisms

peristalsis
a wave-like contraction of the muscles of the digestive tract that pushes the food along

Try this 8.5

Thanks, enzymes!

Place a small piece of bread or a dry savoury cracker on your tongue and leave it to sit there for a while. As the amylase in your saliva begins to break down the carbohydrates, you should be able to taste the sweeter maltose subunits.

Oesophagus

The oesophagus is a tube that connects the throat to the stomach. When you swallow food, a wave-like contraction of your oesophagus pushes the food down towards your stomach. This movement is known as **peristalsis**, and it continues all the way along your digestive tract to constantly keep the food moving along. Peristalsis is so effective that you could eat upside down and the food would still be pushed against gravity, up your oesophagus!

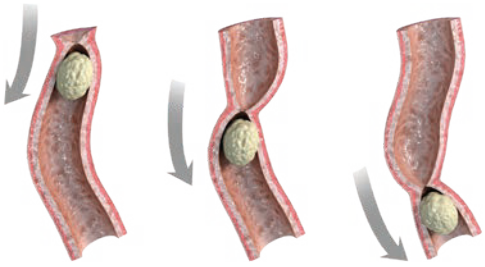


Figure 8.30 Peristalsis moves the bolus of food down the oesophagus.

Try this 8.6

Modelling peristalsis

Find an old nylon stocking and cut off the toe end of the leg. Place a tennis ball at the toe end and gently squeeze behind the tennis ball to move it along the length of the stocking. This is how the muscles of the oesophagus push a bolus of food along.

VIDEO
Peristalsis

Quick check 8.7

1. **Describe** the function of saliva.
2. **Name** the enzyme found in saliva.
3. **State** if chewing food is an example of mechanical or chemical digestion.
4. **Define** 'peristalsis'.

Stomach

At the bottom of your oesophagus is a **sphincter** that opens to allow food to enter your stomach. The stomach contains many types of enzymes, along with very strong hydrochloric acid – together, these are known as the gastric juices. The sphincter at the opening of the stomach is very important, as it prevents these enzymes and acids from entering the oesophagus and irritating the tube. This irritation causes a burning sensation in the chest that is commonly known as 'heartburn'.

sphincter
a muscle that surrounds an opening in the body and can tighten to close it, e.g. at the bottom of the oesophagus, leading into the stomach

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Food stays in your stomach for two to six hours, depending on the size, amount and type of food. During this time, the stomach contracts and churns the food (mechanical digestion), helping to further break up the large particles, while mixing the bolus with the gastric juices (chemical digestion). The acid in your stomach also performs some important functions: it kills many of the harmful bacteria that might be found on the food you eat and provides an optimum pH for digestive enzymes to work. The stomach wall is a mucosal membrane, which produces mucus to protect the stomach tissue from the strong acid.

The main enzyme in your gastric juices is called *pepsin*, and its role is to begin the digestion of protein. Each enzyme has a specific shape that fits only one type of molecule, and therefore each food type has a special enzyme dedicated to breaking it down in the body. For example, pepsin can only break down protein while amylase can only break down starch.

The stomach absorbs some substances into the bloodstream, such as water, medicines and alcohol. The digested bolus is now called **chyme**, and it leaves the stomach by passing through the pyloric sphincter, at the base of the stomach, into the small intestine.

chyme
a partially digested mass of food after it leaves the stomach

duodenum
the first section of the small intestine, where many enzymes are secreted

jejunum
the second section of the small intestine, where food breakdown and nutrient absorption occur

ileum
the third section of the small intestine, where further food breakdown and nutrient absorption occur

villi
finger-like structures in the digestive system that have a high surface area and rich blood supply for absorption of nutrients

microvilli
tiny projections on the surface of villi cells that increase surface area to enhance nutrient absorption

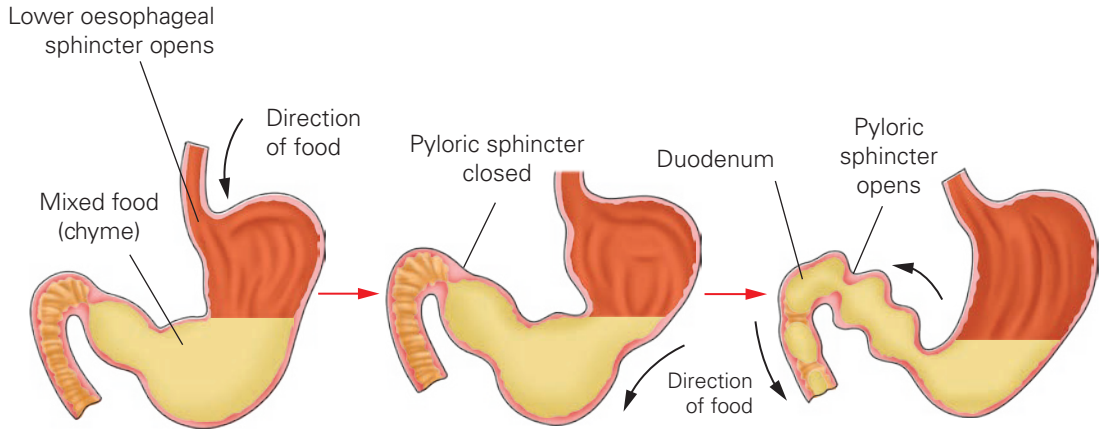


Figure 8.31 The pyloric sphincter controls the flow of chyme out of the stomach and into a region of the small intestine called the duodenum.

Quick check 8.8

1. **State** two sites of mechanical digestion.
2. **Define** 'chyme'.
3. **Name** the enzyme that catalyses the digestion of protein.
4. **Explain** why the stomach wall is lined with mucus.

Small intestine

The small intestine is only called 'small' because it is narrower in diameter than the large intestine. It is actually very long, measuring, on average, nearly six metres. Because it is so long, the small intestine is divided into three main parts: **duodenum**, **jejunum** and **ileum**.

The duodenum is the first part of the small intestine. Many digestive enzymes are secreted into it, which help to continue digestion of the chyme. Peristalsis also occurs in the small intestine, and it propels the chyme forwards and continues all the way along the digestive tract.

Most nutrient absorption takes place in the middle section of the small intestine, the jejunum. This section is lined with millions of finger-like structures called **villi**, which are covered in specialised cells that have **microvilli**. The villi and microvilli together provide a large surface area and have a good blood supply, increasing the efficiency of nutrient absorption into the bloodstream.

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The end section of the small intestine is the ileum. The main function of this portion of the intestine is to finish off any absorption of nutrients and to compact the remaining digested food and pass it through into the large intestine.

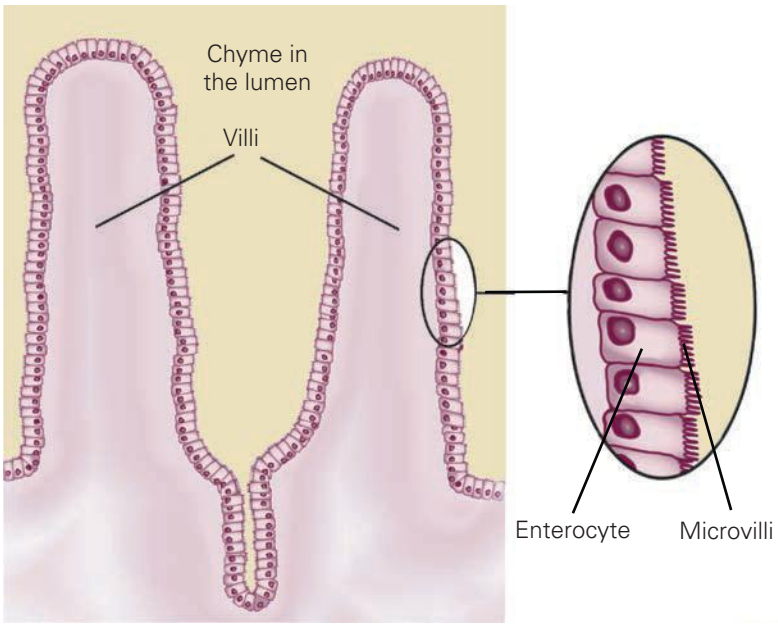


Figure 8.32 A cross-section through the wall of the small intestine. Microvilli are tiny projections on the surface of specialised cells (enterocytes) located on the villi. They significantly increase the surface area for nutrient absorption.

Liver, gall bladder and pancreas

The **liver** produces **bile**, which helps to mechanically break down fats or lipids. The bile is stored in the **gall bladder** and is excreted into the duodenum if you eat a fatty meal.

Bile acts like a detergent – it emulsifies or breaks big globs of fats and oils into smaller ones that can be easily moved and broken down further. Bile has the second job of neutralising the harmful acids from the stomach and preventing damage to the intestines. The **pancreas** secretes pancreatic juices, which also help to neutralise the acids from the stomach and contain more enzymes to keep chemically digesting the different food types.

liver
a large organ that has many functions, including the production of bile

bile
a substance that helps break down fats; it is produced in the liver and stored in the gall bladder

gall bladder
a small organ near the liver that stores bile and secretes it into the duodenum

pancreas
an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

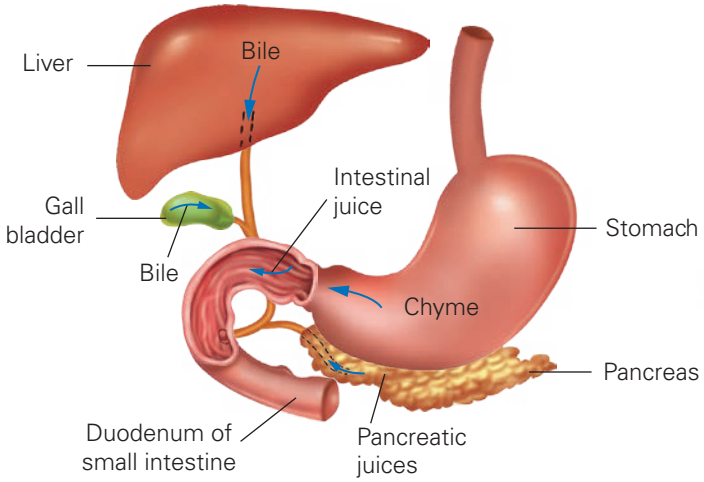


Figure 8.33 The liver, gall bladder and pancreas all contribute to the digestion of food and are connected to the duodenum.

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Large intestine

large intestine the organ that is connected to the small intestine at one end and the anus at the other

caecum a pouch that forms the first part of the large intestine

rectum the second-last section of the large intestine; stores faeces

anus the opening at the end of the digestive tract, through which solid waste leaves the body

The **large intestine** is one to two metres long and has five parts: caecum, appendix, colon, rectum and anus. Its main function is to absorb water from the material left over from digestion. The large intestine also has large numbers of helpful bacteria that can produce vitamin K and vitamin B for your body to use. In humans, the **caecum** is a pouch at the start of the large intestine, where it joins the small intestine. The caecum helps digest and absorb nutrients, especially plant materials, with the assistance of bacteria. The appendix has long been considered a useless organ that is a remnant of evolution, but there is ongoing debate about what its actual role is. As waste enters the large intestine and passes through the colon, water leaves the waste and is absorbed back into the bloodstream, resulting in a solid mass called faeces remaining in the colon. Faeces are stored in the **rectum**, and when the rectum is full, it sends a signal to your brain to tell you to go to the toilet. The faeces then pass out through a sphincter called the **anus**.

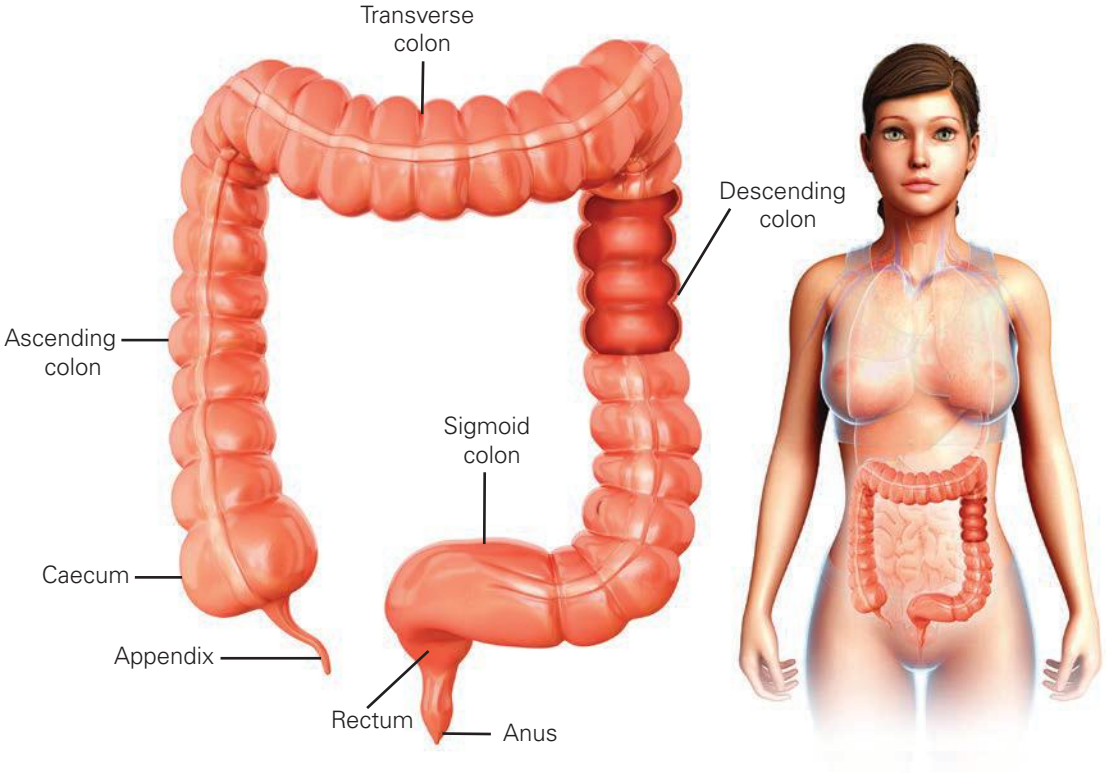


Figure 8.34 The five sections of the large intestine. Note that the colon is subdivided into the ascending, transverse, descending and sigmoid colon.

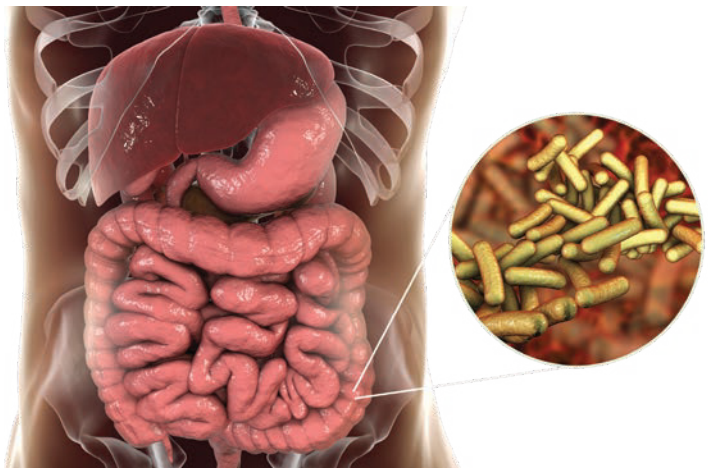


Figure 8.35 Most bacteria in your body are in the intestine. It is thought that the appendix could be a safe haven for good bacteria that can repopulate the gut after sickness and diarrhoea.

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Try this 8.7

Model digestive system

Sketch a simple layout of the digestive system on paper and label each part. Decide which materials you will use for each organ. For example, you could use a sandwich bag for the stomach or tights for the intestines. Prepare a short presentation explaining your model to the class. Discuss the function of each part of the digestive system and why you chose the materials for that particular organ.

Quick check 8.9

1. **State** the three sections of the small intestine.
2. The liver produces bile, which is stored in the gall bladder. **Recall** the type of food that bile helps to mechanically digest.
3. **Explain** how villi improve the absorption of nutrients.
4. **Organise** the following sections of the large intestine in the correct order that faeces pass through: rectum, colon, anus, caecum, appendix.

Did you know? 8.7

Is your stomach rumbling?

Ever heard those gurgling stomach noises when you are hungry? Well, they are the sounds of hyperactive peristalsis in the intestines and are named *borborygmi*. When the muscles in your stomach and small intestine are pushing everything along, all the food packed inside muffles the sound. But if it's been a while since you've eaten, most of that food is gone (hence why you equate it with being hungry!) and all those gurgling gases are easier to hear.

WORKSHEET
Human excretory system

The human excretory system

Each cell in our body functions like a miniature factory, producing essential substances like energy and proteins while also generating waste products such as ammonia and carbon dioxide. To prevent these waste products from accumulating and causing harm, our bodies rely on the **excretory system**. This system includes four main organs: the liver, kidneys, lungs and skin, all of which work together to efficiently remove waste from our bodies. **Excretion** is the mechanism through which the body eliminates **metabolic** waste products and excess substances.



Figure 8.36 Jaundice is a condition characterised by yellowing of the skin and eyes, often caused by a build-up of bilirubin in the blood. The liver is responsible for processing bilirubin, a pigment formed from the breakdown of red blood cells. When the liver is unable to effectively metabolise bilirubin or if there is an excess production of bilirubin, it can accumulate in the body, leading to jaundice.

Metabolic waste

Mammals, being active and warm-blooded, have high metabolic rates that leads to the production of large amounts of metabolic waste. These wastes include carbon dioxide, **ammonia**, **urea** and bile pigments produced from the breakdown of haemoglobin.

With the exception of carbon dioxide, the liver plays an important role in producing most of these excretory substances. When protein is broken down, it produces a toxic substance called ammonia. Liver cells can convert ammonia into urea, which is much less harmful to the body. The liver also detoxifies substances that are not needed or toxic, such as alcohol or medicinal drugs.

excretory system
the body system that is responsible for filtering the blood and removing cellular waste products

excretion
the process of removing metabolic waste from the blood via liver, kidneys, lungs and skin

metabolic
the chemical processes that occur within a living organism to maintain life, including breaking down substances to produce energy and building new molecules for growth and repair

ammonia
a poisonous substance that is produced when protein is broken down

urea
a substance that is produced by the liver by breaking down ammonia

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Excretion through the urinary system

kidneys a pair of organs that filter waste products from the blood and excrete them as urine

nephrons small filtering structures found in the kidney

urine a waste product from the body made of water, urea and other excreted wastes

ureter the tube that leads from the kidneys to the bladder

bladder the organ that stores urine

carbon dioxide a waste product produced in cellular respiration

Urea passes from the liver into the blood and is carried to the **kidneys**, a pair of bean-shaped organs that filter the blood for waste through millions of tiny structures called **nephrons**. Excess water, urea and other waste materials then pass into the collecting ducts, forming **urine**. The urine then travels down the **ureter** and is stored in the **bladder** until it is expelled from the body during urination.

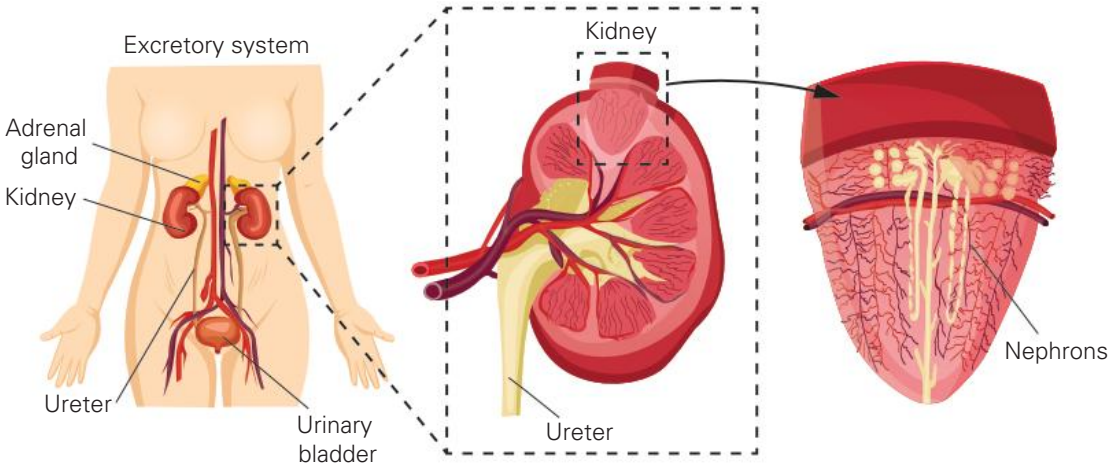


Figure 8.37 The human urinary system

Excretion through the respiratory system

One of the primary waste products our bodies produce is **carbon dioxide**, a by-product of the cellular respiration process that generates energy for our cells. We excrete carbon dioxide by exhaling it from our lungs.

During exercise, the muscles produce more waste products, such as lactic acid and carbon dioxide. The increased production of carbon dioxide leads to a build-up in the blood, which can make the blood more acidic. This can have negative effects on the body's function, including impaired muscle contraction and fatigue.

To prevent this build-up of carbon dioxide, the body increases its breathing rate and depth during exercise. This increased ventilation means carbon dioxide is removed at a faster rate.



Figure 8.38 Steph Catley and Clare Wheeler are exhaling more carbon dioxide than the rest of the Matildas.

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Excretion through the skin

The **skin**, the body's largest organ, also plays a role in excretion. It removes waste products through sweat glands.

skin
the biggest organ in the body, which forms a protective outer layer on a person

The skin is made of three main layers:

- **Epidermis**: The outermost layer, which forms a protective barrier against environmental factors.
- **Dermis**: Beneath the epidermis. This layer contains sweat glands, blood vessels and nerves.
- **Hypodermis**: The deepest layer, made primarily of fat, helps insulate the body and contains larger blood vessels.

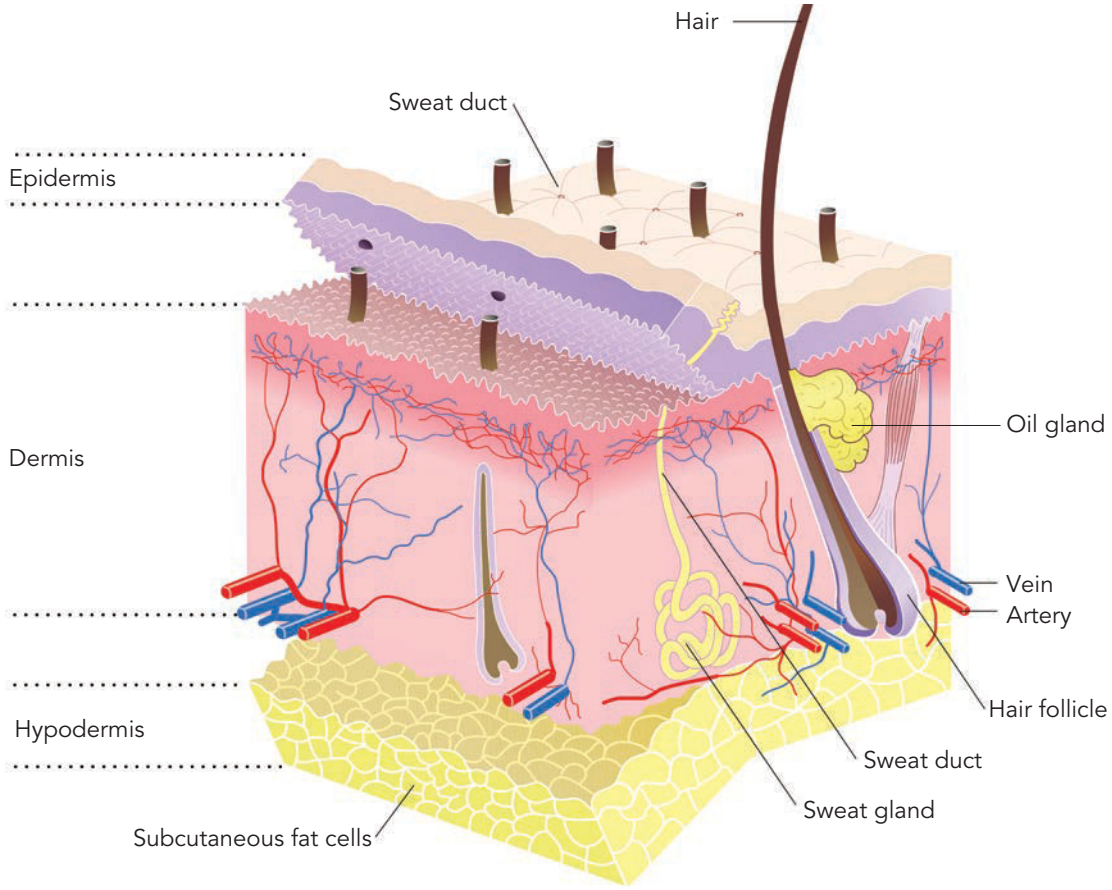


Figure 8.39 The different layers of the skin

Excretion occurs when sweat glands in the dermis produce sweat, which is mainly composed of water, salts and small amounts of urea. As sweat is excreted through the pores, it helps rid the body of excess salts and waste products. The process of sweating allows the skin to act as a secondary route for excretion, helping to maintain the body's balance of water and salts.

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Practical skills 8.3

The products of respiration

Aim

To demonstrate the products found in exhaled air.

Materials

- air pump
- straw
- conical flask
- glass Petri dish
- bromothymol blue
- water

Procedure

Bromothymol blue solution

1. Add 50 mL of water to a conical flask.
2. Add 2–3 drops of bromothymol blue and record the colour in the 'Observations before' column of your results table.
3. Using a pump and a straw, blow air slowly through the solution for 30 seconds.
4. Record your observations in the 'Observations after' column.
5. Using your breath and the same straw, blow air slowly through the bromothymol blue solution for 30 seconds, being careful not to suck up any of the solution.
6. Record your results in the 'Observations after' column.

Petri dish

7. Using a pump, blow air directly over the Petri dish.
8. Record any changes in the results table.

Air source	Bromothymol blue solution		Petri dish	
	Observations before	Observations after	Observations before	Observations after
Pump				
Exhaled				

9. Using your breath, exhale directly over the Petri dish.
10. Record any changes in the results table.

Discussion

When carbon dioxide is dissolved in water, it becomes acidic. Bromothymol blue turns from blue to green/yellow when it is exposed to acid.

1. Using the information above and the results you collected, explain your bromothymol blue before and after results.
2. Discuss your observations of the Petri dish portion of the practical and relate your findings to the products of respiration.

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Section 8.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Go online to access the interactive section review and more!

Section 8.3 questions

Remembering

1. **Name** two waste products produced by the body.
2. **Recall** the route that food waste/faeces takes after it leaves the stomach. List the three sections of the small intestine and the five sections of the large intestine it passes through.
3. **State** the organ that converts ammonia to urea.
4. **State** the type of acid that is found in the human stomach.

Understanding

5. **Describe** the role of the stomach in food digestion.
6. **Explain** how food is transported along the digestive tract.
7. **Explain** why ammonia is changed into urea.
8. **Explain** why your breathing rate increases when you exercise.

Applying

9. **Develop** a hypothesis about what might happen if the large intestine was removed from the digestive tract.
10. If a person breathes in 500 cm^3 of air containing 0.04% carbon dioxide and exhales air containing 4% carbon dioxide, **calculate** the volume of carbon dioxide they exhale in one breath.

Analysing

11. **Compare** the duodenum to the jejunum.
12. **Classify** the processes listed in the table as mechanical or chemical digestion.

Process	Mechanical or chemical?
Stomach churning and contracting	
Chewing food	
Bile released from the gall bladder into the duodenum to break down fats	
Lactase breaking down lactose	

13. **Create** a flow diagram to describe the processes that occur between the production of ammonia and the excretion of urine.

Evaluating

14. **Evaluate** whether digestion in the lumen of the stomach and intestines takes place within the body or a space enclosed and surrounded by the body.
15. **Discuss** whether defecation is excretion. Consider if the waste expelled has entered the cells or tissues of the body or if it has been metabolised. Consider also if anything is excreted from any organs into the lumen of the intestines and expelled with the faeces.

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8.4 Disorders and diseases in human body systems

WORKSHEET Organ replacement and repair

Learning outcome

At the end of this section, I will be able to:

1. explain how a disorder or disease affecting a body system, including removal of any component in the body system, impacts on the overall functioning of the system and the organism as a whole.

Each of the organ systems in your body relies on the specialised function of different components working together to keep you healthy. But when components become diseased or dysfunctional, they can impact the overall functioning of the system. The treatment of the component that is not functioning properly depends on the specific type of dysfunction and the underlying cause. Common treatments for less severe dysfunction may include medication or lifestyle changes. A variety of examples are given in this section. However, treatment is sometimes not enough, and as discussed later in this section, an organ may need to be completely replaced.



Figure 8.40 Most of us have two healthy kidneys. If they are damaged, one option is a kidney transplant.

In this section, some examples are given for the digestive system, followed by guidance on researching issues affecting the functioning of other body systems.

Digestive disorders and diseases

Food poisoning

Your body can detect hazardous substances in the food you eat. Sometimes food can be contaminated with toxins or microorganisms that could do harm to your body. If your body senses the presence of these harmful substances, it signals to your digestive system to empty quickly. This causes the stomach to contract violently, causing vomiting, and it also causes the intestines to contract, causing diarrhoea. Even though getting sick is never fun, it is your body's way of protecting you by removing the harmful substances.

Treatment for food poisoning generally focuses on alleviating symptoms and rehydrating the body. Since the main symptoms – vomiting and diarrhoea – can cause dehydration, it is essential to drink plenty of fluids, such as water, oral rehydration solutions or clear broths, to replace lost fluids and electrolytes. In most cases, food poisoning resolves on its own within a few days, but severe cases may require medication to manage symptoms or treat bacterial infections.

Food intolerance

intolerance an inability to eat a food without experiencing adverse effects

Many people cannot eat certain foods, because of **intolerance** or allergy. An intolerance is when a food cannot be properly broken down by the body and results in an adverse reaction.

One of the most common intolerances in humans is lactose intolerance. Lactose-intolerant people are unable to digest the sugar in milk and dairy products, called lactose. Normally, when somebody eats food containing lactose, the enzyme lactase is released in the small intestine to break down the sugar into more simple sugars. People who are lactose intolerant do not have lactase, and this means that the sugars do not get digested and absorbed.

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Instead, the bacteria in the intestines break down these sugars, leading to bloating, lots of gas and diarrhoea.

Because humans are mammals, we all drink milk as infants. This means that the enzyme lactase, which breaks down lactose, is found in everybody when we are young. As we grow older and start to eat solid foods, some of us may lose the lactase enzyme. Anyone can become lactose intolerant at any stage in their life, although there are certain groups of people who are more likely to become lactose intolerant. Here are some examples:

- People of Asian, African, Indigenous and South American backgrounds are more likely to develop lactose intolerance at a young age.
- People who already have problems with their digestive system caused by disorders such as coeliac disease or Crohn's disease are more likely to develop lactose intolerance.
- Certain antibiotics can trigger temporary lactose intolerance by interfering with the small intestine's ability to produce the lactase enzyme.
- As people get older, their bodies can stop producing lactase.
- If you go for a long period of time without eating dairy, your body may stop producing lactase.



Figure 8.41 All mammals produce milk, but not all adult humans can digest it.

While lactose intolerance is not curable, its symptoms can be managed. People with lactose intolerance can avoid or limit their intake of foods containing lactose, or opt for lactose-free dairy products. Over-the-counter lactase enzyme supplements are also available, which can help individuals digest lactose-containing foods more easily.

Explore! 8.2

INVESTIGATION

Coeliac disease

Coeliac disease is a condition where a person's immune system damages the lining of the small intestine when they eat gluten. Gluten is a protein in wheat, rye and barley-based products such as bread, pasta, pastry, cakes and biscuits. Bread has been a stable part of the human diet for thousands of years, and so many people view gluten intolerance and coeliac disease as new phenomena, but humans have been affected by these conditions throughout history. However, it was not until about 100 years ago that doctors began to diagnose and treat coeliac disease. In coeliac disease, the immune response to gluten causes inflammation that damages the villi, making them blunted or flattened. This leads to a decrease in the surface area available for absorption of nutrients, which can result in malabsorption and malnutrition.

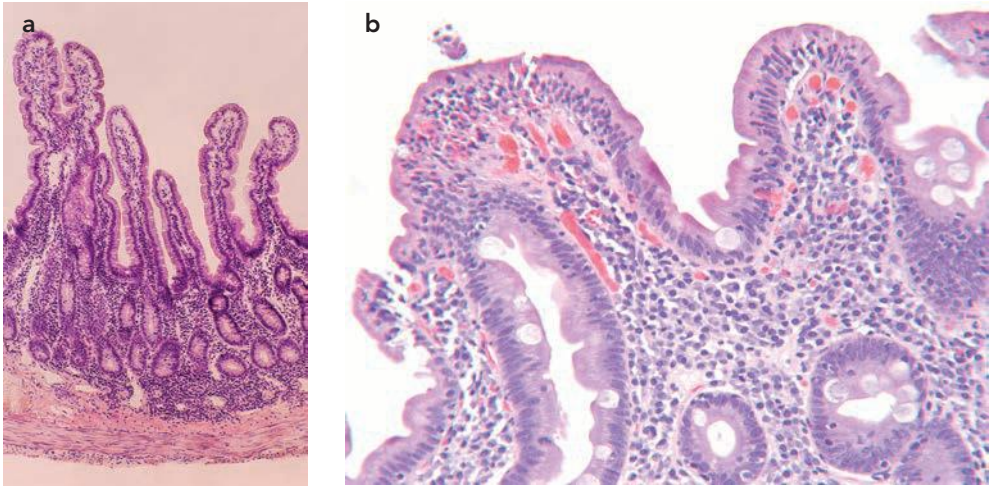


Figure 8.42 Villi in the small intestine of a healthy person **(a)** compared with blunted villi in a person with coeliac disease **(b)**

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1. Find out how many people suffer from coeliac disease and how many people have gluten intolerance. You may like to find out the statistics for the world or investigate different countries.
2. Outline the symptoms of coeliac disease.
3. Research and then summarise what it is about gluten that makes people sick. Include an explanation of how the body of a person with coeliac disease responds to gluten.

Explore! 8.3

Disorders and diseases

Carry out some research on disorders and diseases that affect the functioning of body systems and write a report outlining the issue, typical treatments and new advances being made in treating or overcoming the issue.



VIDEO
Organ transplants

Organ transplants

Damaged organs can sometimes be given the chance to repair through certain medications, diet and lifestyle changes. However, if an organ becomes so damaged that it can no longer work at all, the only option may be to completely replace it. This is done through a medical procedure known as **organ transplantation**, in which a healthy organ from one body is used to replace the damaged organ in another.

organ transplantation the process of removing a donor organ and then surgically implanting it into a recipient to improve their organ function or replace a diseased organ

organ rejection when an organ transplant recipient's immune system recognises the organ as foreign and attacks it

The first successful human organ transplant was a kidney transplant performed in 1954 by Dr Joseph Murray and Dr David Hume in Boston, using a kidney from the patient's identical twin. Kidneys filter waste products out of your blood and produce urine. Diseases and environmental factors that can damage your kidneys include medications, alcohol and diabetes. We have two kidneys in our body, but we can manage with only one. Therefore, some people volunteer to donate one of their healthy kidneys to a friend or family member who needs a replacement one.

For an organ transplant to be successful, the donor (person giving the organ) and the recipient (person receiving the organ) must have similar matching markers on their cells. If these markers are not matched, the body will recognise the new organ as a foreign invader and attack the organ using the immune system. This is known as **organ rejection**. Unfortunately, the chances of two people being a match is extremely low, even within families. This means that there is a high demand for organs but a very low supply available.



WORKSHEET
Organ donation

Organ donation is sometimes possible when a person dies and has previously indicated that they would like to donate their organs. This donation can save multiple lives, as organs such as the heart, lungs, kidneys, liver, large intestine, pancreas and some tissues, such as skin and corneas from the eye, can all be donated. In 2024, 1328 Australians received an organ, donated from 527 deceased and 253 living organ donors and their families.

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Not many deaths occur in a way that allows organ donation. In Australia, organ donation typically occurs when a person dies in a hospital setting. This is because the organs need to be removed as soon as possible after death to ensure their viability for transplantation. Sometimes the families of registered organ donors refuse to give consent, which is why it is very important that people discuss their wishes with their families and consider registering their intentions on the Organ Donor Register.



Figure 8.43 A heart being transported, ready for transplantation

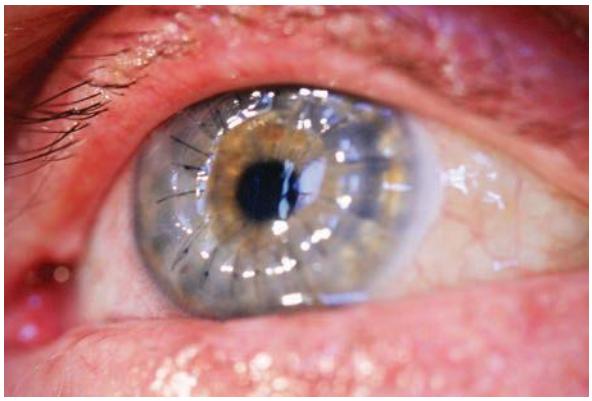


Figure 8.44 A corneal transplant, two weeks after surgery. The sutures are 0.00381 cm thick.

Quick check 8.10

1. If an organ is damaged, **recall** the first treatment options before a transplant is considered.
2. **Name** some of the organs and tissues that can be donated in Australia.
3. **Describe** what would happen if a transplanted organ came from a donor who was not a good match for the recipient.

Explore! 8.4

INVESTIGATION

Downsizing dialysis

Dialysis is a medical treatment used to remove waste products and excess fluid from the blood of people with kidney failure. The treatment involves patients travelling to a clinic, where they are connected to a large 100 kg machine that filters the blood outside of the body and returns it to the patient. Usually, each treatment lasts about four hours and is done three times per week. This leads to some significant environmental impacts, particularly with regard to water waste, as each four-hour session uses 120–180 litres of water.



Figure 8.45 An artificial kidney could replace the need for large dialysis machines.

Many companies are developing alternatives to clinic-based dialysis.

Research the benefits of the following new innovations:

- KidneyX
- NextKidney
- automated wearable artificial kidney (AWAK) device
- artificial kidney.

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Organ replacement

xenotransplantation transplanting organs from one species into another

Because of the high demand but low supply of organs available for transplantation, scientists are developing new ways to overcome this problem. One method is **xenotransplantation**. This is the process of transplanting organs from a different species than the recipient.

Doctors have been transplanting porcine (pig) heart valves into humans since 1965, as pig organs are a similar size and shape to human organs. However, there are two main biological challenges that scientists face with any pig–human transplant procedure:

- The biological markers on pigs' cells and organs do not match those in humans, and so the human recipient's body can reject the organ.
- There are viruses in pigs' genetic material that could infect and harm humans who receive a pig organ.

In 2022, doctors successfully transplanted a pig heart into an American man, but he sadly died two months after the procedure, possibly due to an infection from the heart. Later in the year, surgeons successfully transplanted genetically engineered pig hearts into two brain-dead patients in New York. Over three days of monitoring, the new hearts functioned perfectly, and neither body caught any diseases. The hearts were sourced from pigs that had 10 genetic modifications, including four that blocked pig DNA from triggering the immune system to prevent rejection and abnormal organ growth, as well as six human transgenes to improve pig–human compatibility.



Figure 8.46 Pig–human transplants will become increasingly common within the next few years.

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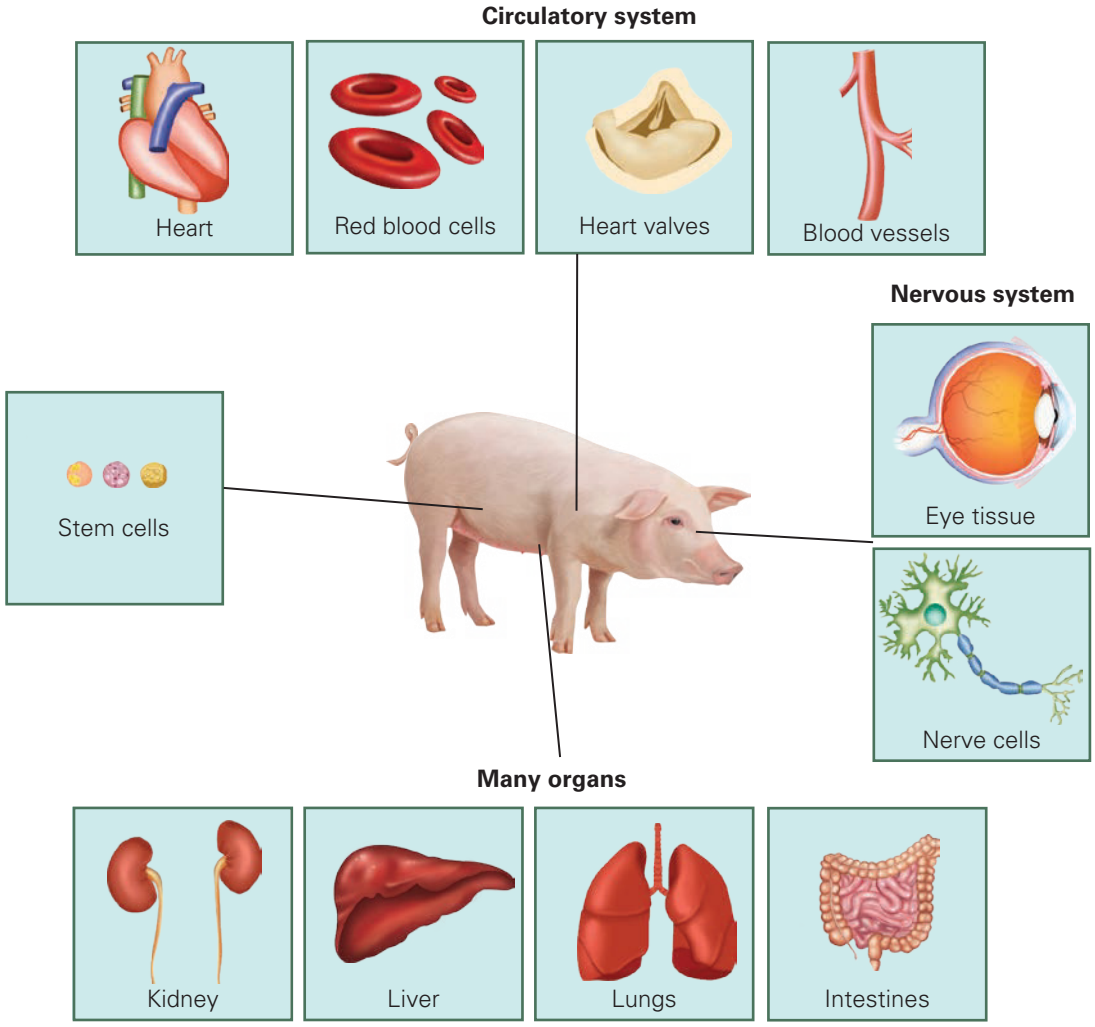


Figure 8.47 Some of the possible transplanted tissues and organs we could get from pigs

Explore! 8.5

INVESTIGATION

Ethical organs

Organoids are tiny clusters of cells that organise themselves into miniature and rudimentary versions of our organs. They present biomedical researchers with an opportunity to study organ development and experiment with drug technologies. Organoids develop from stem cells that have been grown in tiny 'wells' and made to differentiate into specialised cells, such as neurons. These neurons then make connections and begin to behave in a similar way to how they do in a patient's actual brain.

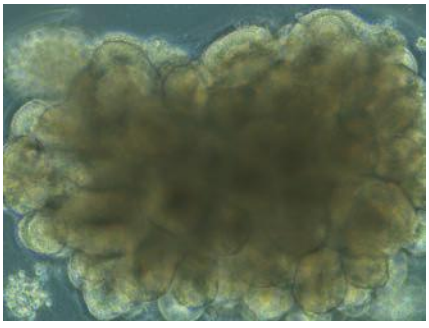


Figure 8.48 Developing human cerebral organoid, made from human brain cells. The organisation, structure and nervous signalling are similar to brain tissue. Organoids are used to study diseases of the nervous system.

The development of organoids has had a significant impact on using live animals in laboratory research. Many people object to the use of live animals in research, and the use of organoids has the potential to reduce the number of animals used.

Complete some research and discuss how the use of organoids has impacted the ethical, environmental, social and economic issues associated with using live animals in laboratory research.

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Organ regeneration

The liver is the largest internal organ in your body and the only human organ that can not only repair itself but can regrow dead or damaged areas. It is located just below your ribs, on the right side of your body. The liver is involved in many important processes, such as producing enzymes for digestion, storing vitamins and removing toxins from your blood. If the liver is exposed to too many toxins over a long period of time, it can become damaged and not perform its job properly.

Alcohol is a toxin that the liver filters out of the blood. People who regularly drink too much alcohol can permanently damage their liver. Fatty liver is the earliest stage of liver damage caused by excessive alcohol consumption, occurring when the liver begins to accumulate excess fat.

If the person continues to drink, they can develop alcoholic hepatitis, a condition in which the liver becomes inflamed and damaged, and then fibrosis, where the liver becomes scarred. Cirrhosis is the final stage of liver damage from alcohol consumption, where healthy liver tissue is replaced with fibrous tissue. Cirrhosis can lead to several serious health problems, including liver failure. If caught early enough, a change in lifestyle habits can reverse or limit the damage done to the liver. In severe cases, however, liver transplantation surgery may be necessary.

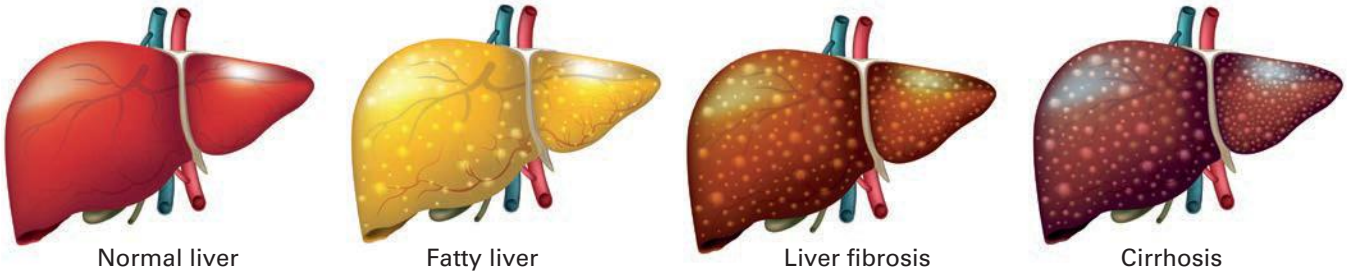


Figure 8.49 The stages of liver disease

tissue engineering the combined use of cells and engineering to improve or replace biological tissues

As you learned earlier in this section, organ transplants come with many risks, and matching donors are hard to find. That is why scientists are working on the ability to regenerate or grow organs from living healthy tissues. This process is called **tissue engineering**, and it is a fast-growing area of research. This means that healthy living organ donors can donate part of their liver, and their liver can grow back to nearly the same size over time. Because of the regenerative properties of the liver, scientists can grow whole new organs from as little as a quarter of an original liver.

If scientists could grow and regenerate organs using the patient's own tissue, then the body would not reject the transplanted organ.

VIDEO Artificial organs

Artificial organs

Advances in technologies have enabled the repair and replacement of organs using synthetic materials. An artificial organ can mimic or enhance the function of a real organ in several different ways.

Regardless of their design, artificial organs are constructed using materials that are compatible with the human body. Some artificial organs are also equipped with sensors and other devices that can monitor and adjust their function in real time.

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Purpose	Description
Replacement	Some artificial organs are designed to replace a damaged or failing organ.
Supplementation	Artificial organs can supplement the function of a real organ.
Enhancement	Artificial organs can enhance the function of a real organ.
Control	Artificial organs can control the function of a real organ.



Figure 8.50 An artificial heart can be implanted in a patient with heart failure to help pump blood.



Figure 8.51 Dialysis machines and artificial kidneys can be used to filter the blood and remove waste products in patients with kidney failure.



Figure 8.52 A cochlear implant can be surgically implanted in the ear to enhance hearing in individuals with hearing loss.



Figure 8.53 A pacemaker can be used to control the heartbeat and regulate the electrical activity of the heart.

Table 8.2 Different purposes of artificial organs



DEPTH STUDY IDEA
Investigate the latest artificial organ technology

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Try this 8.8

The benefits of artificial organs

Research the benefits of using artificial organs and create a persuasive text that influences a specified audience regarding their use. You may want to think about their cost effectiveness, their medical outcomes and the impact on organ donor waiting times.

Quick check 8.11

1. **Contrast** organ replacement and organ regeneration.
2. **Define** 'xenotransplantation'.
3. **Summarise** two potential problems with xenotransplantation.
4. **Name** two toxins that are removed by the liver.
5. **Recall** the size of liver that the organ can regrow from.

Investigation 8.1

Investigating the impact of salt on liver function

Be careful
Safety glasses and gloves must be worn.





INVESTIGATION

Background information

The liver breaks down hydrogen peroxide, a toxic substance that is produced as a by-product of various metabolic processes in the body. Hydrogen peroxide can cause damage to cells, so it must be quickly broken down into non-toxic products. The liver does this by using the enzyme catalase, which converts hydrogen peroxide into water and oxygen. Some research has suggested that a high-salt diet may lead to a high risk of liver damage and fibrosis.

Aim

During this experiment you will add hydrogen peroxide to blended cow liver. If the hydrogen peroxide is broken down, then oxygen bubbles will be produced. You will add different amounts of salt solution to test the effect of salt on liver function.

Planning

1. Write a rationale about the role of the liver and factors that can affect liver function.
2. Write a specific and relevant research question for your investigation.
3. Identify the following variables in your experiment: independent, dependent and three controlled variables.
4. Construct a hypothesis for your experiment: predict what effect the different concentrations of salt solution will have on the number of oxygen bubbles being created.
5. Write a risk assessment for your investigation.

Materials

- 5 large test tubes
- liver solution (100 g of cow liver blended with 100 mL water)
- 10 mL measuring cylinder
- 0%, 10%, 20%, 30%, 40% salt solutions
- 3% hydrogen peroxide solution
- test-tube rack
- disposable gloves
- marker
- stopwatch

Procedure

1. Place the test tubes in a rack and label them 0%, 10%, 20%, 30%, 40%.
2. Add 3 mL of liver solution and 3 mL of the first salt solution and allow them to combine for three minutes.

continued ...

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3. Mark the level of the solution with a marker.
4. Add 2 mL of hydrogen peroxide to the test tube and time until the bubbles stop being produced.
5. When the bubbles stop being produced, record the time in the results table.
6. Repeat steps **3–5** after combining liver solution and a different salt solution in each of the remaining tubes.

Results

1. Draw a results table for your experiment.
2. Produce a suitable graph for your experiment.

Discussion

1. Describe any patterns, trends or relationships in your results.
2. Explain any trends you have identified.
3. Identify any limitations in your investigation.
4. Using your results, suggest a range of salt percentage that you would test in a follow-up investigation.
5. Explain the reason that a test tube containing no salt was included in the experiment.

Conclusion

Draw a conclusion from this experiment regarding the effect of salt on liver function, using data to support your statement.

Ethics of organ transplants

When we discuss organ transplants, we must think about the **ethical** implications of taking an organ from one person and using it in another. 'Ethics' is the term we use to discuss what is right and wrong in society. As there are many different beliefs, cultures and people around the world, ethics can vary from country to country or from person to person. When something is considered right, we say it is ethical, and if it is considered wrong, we say it is unethical.

ethical relating to ethics, the field of considering what is right and wrong

Our laws are linked to the ethical beliefs of a nation and can change over time as people's perception of ethics evolves. However, just because something is considered unethical does not necessarily mean that it is illegal.



Figure 8.54 Judges make decisions based on law, but ethics may also be a consideration in the decision-making process.

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Some donated organs, such as kidneys and partial livers, come from living donors. This creates an ethical dilemma for the doctor who is performing the surgery. Should they risk the life of a healthy person to save or improve the life of a patient? Some questions they must consider are:

- Does the living donor know and understand all the risks?
- What if something goes wrong during surgery and puts the donor's life at risk?
- What if the transplant is rejected by the patient and the organ goes to waste?
- What happens if the donor is left with long-term pain, infection or impaired health after the surgery?

The donor may be under a lot of pressure from friends or family, which can make them feel forced into donating.

At any one time, there are around 1600 people on the Australian organ transplant waiting list. There are many rules in place to ensure that organs are allocated to patients in a fair process that is not affected by race, religion, gender, disability, social status or age, unless an adult organ is too large for a child, or a child's organ is too small for an adult, for example.

There is a very limited number of organs available at any one time, and so the wait for an organ could be anywhere from six months to more than four years. As a result of this, several factors are used to decide who gets an organ, such as:

- how long the person has been waiting for a transplant
- how well the organ matches the patient
- how urgent the transplant is for the patient's health
- whether the organ can be brought to the person in time.

Try this 8.9

The pros and cons of organ donation

Create a table showing the possible advantages and disadvantages (risks) for both an organ donor and a recipient.



INVESTIGATION

Explore! 8.6

Opt in or opt out?

In some countries, such as Wales and Spain, all adults are automatically registered as organ donors. These adults can 'opt out' of the registration if they do not wish to be an organ donor. Many do not opt out. Spain consequently has one of the shortest waiting times for organ transplants in the world.

Research the current percentage of Australians who are registered organ donors and our average waiting list times and compare these with Spain's.

Answer the following questions and justify your opinion with evidence.

1. Do you think Australia would benefit from an 'opt out' organ donation system?
2. What are some of the advantages and disadvantages of an 'opt out' system?
3. Discuss the ethical issues that arise from organ transplantation.

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Section 8.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

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Section 8.4 questions

Remembering

1. **State** the function of the kidneys.
2. **Name** two factors that can damage the kidneys.
3. **List** the two main challenges that scientists face with xenotransplantation.
4. **Name** the largest organ inside a human.

Understanding

5. **Define** 'organ donor'.
6. **Define** 'organ transplant'.
7. **Explain** why organs are rejected.

Applying

8. **Summarise** how too much salt can be harmful to a person.
9. **Identify** one organ that can regenerate.
10. **Identify** how Australian rules keep organ donation fair.

Analysing

11. **Compare** ethics to laws.
12. Patients who are waiting for a kidney transplant might undergo daily or weekly dialysis treatment. Dialysis involves attending a hospital and being connected to a machine that filters your blood, and then returns it to your circulation. The graph in Figure 8.55 shows percentage survival rates for patients on dialysis versus patients who receive a kidney transplant. Use the graph to answer the following questions.
    a. **Determine** the difference in survival rates at the one-year mark for dialysis patients versus transplant recipients.
    b. **Determine** the difference in survival rates at the five-year mark for dialysis patients versus transplant recipients.
    c. Using your knowledge of organ transplantation, **account** for the difference in survival rates for these two patient populations. (What advantages does transplantation offer?)

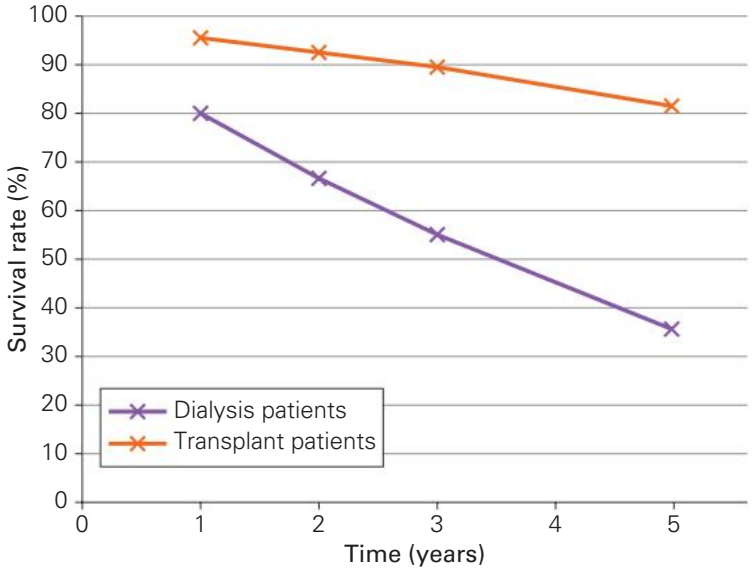


Figure 8.55 Survival rate of patients on dialysis versus patients who have received a kidney transplant

Evaluating

13. **Justify** why liver regeneration would be more beneficial than a liver transplant.

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8.5 Plant systems

WORKSHEET
Plant systems

Learning outcomes

At the end of this section, I will be able to:

1. determine the role, structure and function of the components of a plant.
2. observe and describe the specialised cells and tissues involved in the structure and function of plants.

Roots

The part of a plant that is underground and absorbs water and nutrients from the soil is known as the root system. It serves two main purposes. Firstly, it provides structural support, anchoring the plant in place and enabling its above-ground parts to grow tall, allowing them to compete effectively for sunlight. Secondly, the root system absorbs water and essential nutrients from the soil, supplying the plant with the resources necessary for photosynthesis and overall growth.

diffusion
the movement of particles from an area of a high concentration of particles to an area of a low concentration of particles

To maximise their effectiveness, roots have a large surface area due to tiny structures called root hairs. These hair-like extensions, which are specialised cells, both increase the root's surface area and reduce the distance for the **diffusion** of water and nutrients, increasing the plant's ability to absorb these important substances.

Practical skills 8.4

Observing root hair cells under the microscope

Aim

To observe and identify root hair cells and understand their structure and function.

Materials

- microscope
- glass slides
- coverslips
- water
- onion bulb or other plant with visible root hairs
- scalpel or razor blade
- paper towels
- microscope slide with a prepared onion root tip (optional, for comparison)

Procedure

Preparing the slide

1. Take a small section of the root of an onion bulb and use a scalpel or razor blade to carefully slice the root section into thin slices.
2. Place a small drop of water on a clean glass slide.
3. Gently place the thin slice of the onion root onto the water drop.
4. Cover the slice with a coverslip, avoiding air bubbles.

Observations

1. Place the slide on the stage of the microscope.
2. Start with the lowest-magnification objective lens and focus on the slice using the coarse and fine focus knobs.

continued …

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3. Once the slice is in focus, increase the magnification to observe the root hair cells in more detail.
4. Observe the shape and structure of the root hair cells. Note the presence of the elongated tubular structure extending from the root surface (root hair).
5. Look for any other structures within the cells, such as nuclei or cell walls.
6. If available, observe a prepared slide of an onion root tip to compare the root hair cells with other cells in the root tip.

Results

1. Sketch the observed root hair cells, noting their shape and any other observed structures.
2. Label the sketch with any relevant structures.

Discussion

1. What is the function of root hair cells?
2. How do the root hair cells differ from other cells in the root tip?
3. How do root hair cells help a plant absorb water and nutrients from the soil?

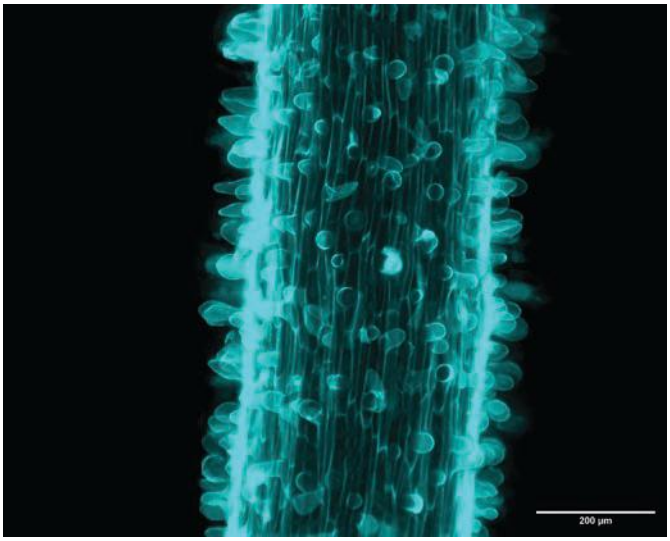


Figure 8.56 An image showing the root hairs on a tomato plant's root, made using a special fluorescent technique

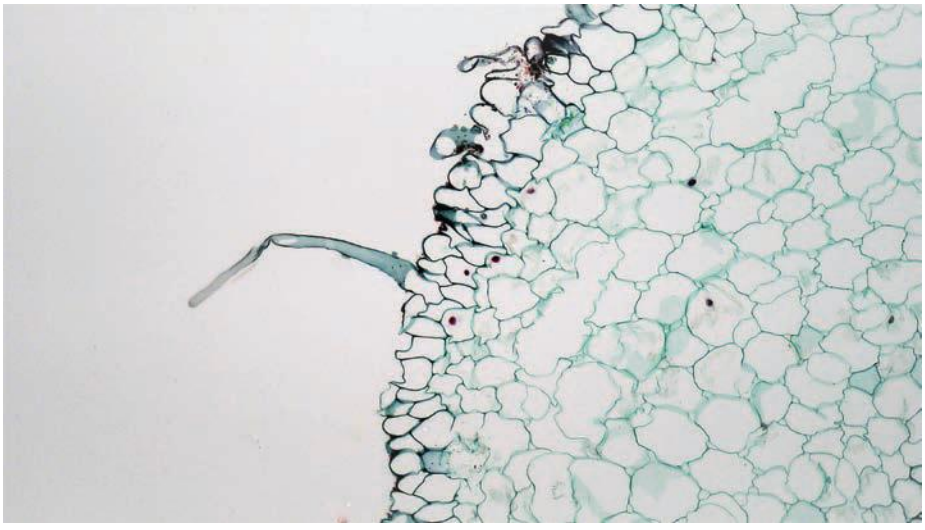


Figure 8.57 Root hairs are elongated specialised cells that increase the surface area of roots, helping plants absorb water and nutrients more efficiently.

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Shoots

vascular bundles a transport system in plants, made of xylem and phloem

xylem vascular tubes that transport water in one direction through the plant

phloem vascular tubes that transport sugars and nutrients throughout the plant

The shoot system represents the portion of a plant that extends above the soil surface, made up of all visible parts such as leaves, flowers and the stem. This system is important for photosynthesis, reproduction and structural support.

The stem of a plant provides support for the plant and transports water, minerals and sugars. Within the stem are **vascular bundles**: specialised tissue made of **xylem** and **phloem** cells.

- Xylem is responsible for transporting water and minerals from the roots to the leaves. Xylem cells are arranged end-to-end, forming long tubes that extend throughout the plant. These vessels also provide structural support to the plant, helping it to stand upright.
- Phloem transports sugars produced during photosynthesis to various parts of the plant. It consists of sieve tube elements and companion cells, which work together to allow the movement of these substances throughout the plant.

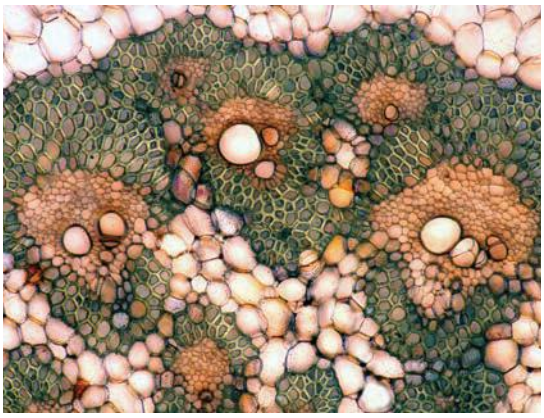


Figure 8.58 Vascular bundles in a banana plant stem

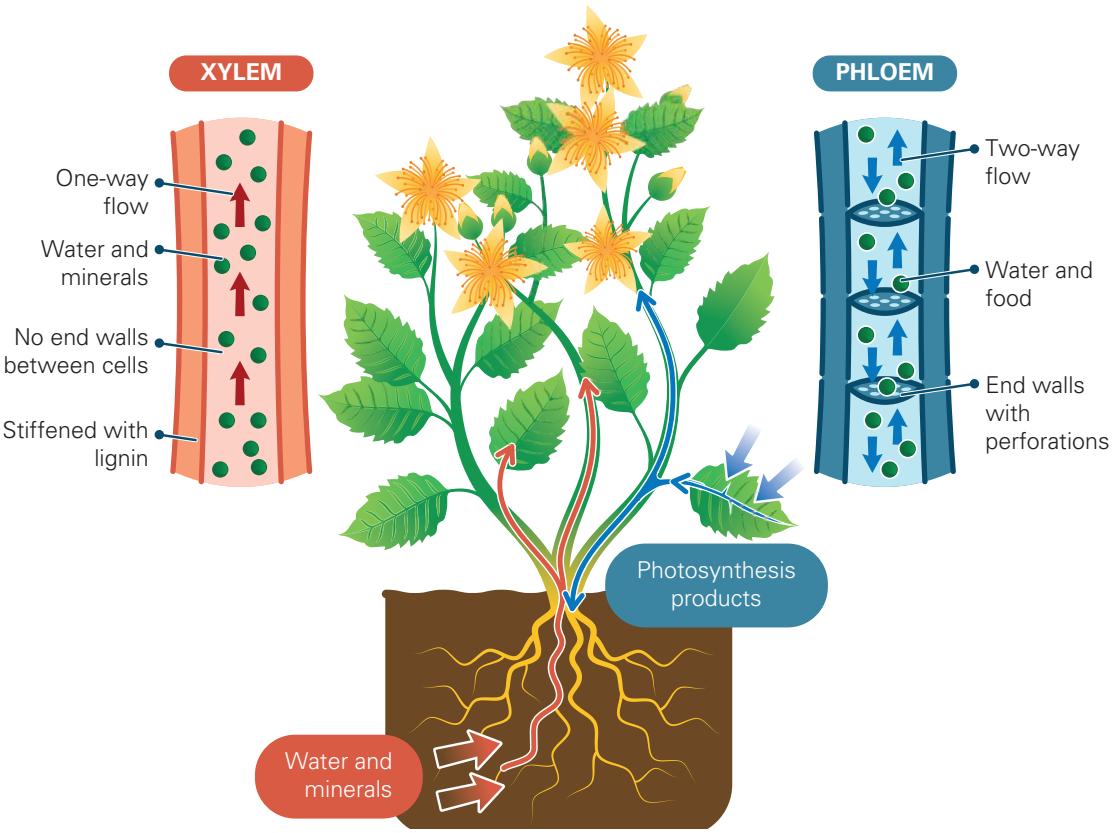


Figure 8.59 Xylem and phloem transport water, minerals and nutrients through the shoots of plants.

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Try this 8.10

Colourful carnations

You can use white carnations and food colouring to observe the vascular bundles. Fill glasses with water and add a few drops of different food colours. Trim the carnation stems diagonally and place one in each glass. Over the next day, you will see how the colour moves up the xylem into the petals, demonstrating how plants transport water and nutrients. You can even split stems to make multicoloured flowers.



Figure 8.60 Carnations will change colour when placed in food colouring.

Reproductive system of flowering plants

On a warm summer day, if you sit near a patch of flowers, you might see bees or butterflies visiting the flowers. Many flowers rely on these insects to help them reproduce and create seeds. The parts of a flower are shown in Figure 8.61.

Pollination is the process where pollen from one flower reaches another flower, allowing the plant to produce seeds. Bees and other insects are attracted to the bright colours, sweet scents, and **nectar** of flowers. While they feed on the nectar, they pick up pollen on their bodies.

When a bee moves to another flower, some of the pollen on the bee sticks to the new flower's stigma. The pollen then travels down the style to reach the ovule, where seeds start to develop.

pollination
the process by which pollen, containing the male reproductive cells of a plant, is transferred from the male part of a flower to the female part of a flower

nectar
a sweet liquid produced by flowers to attract pollinators

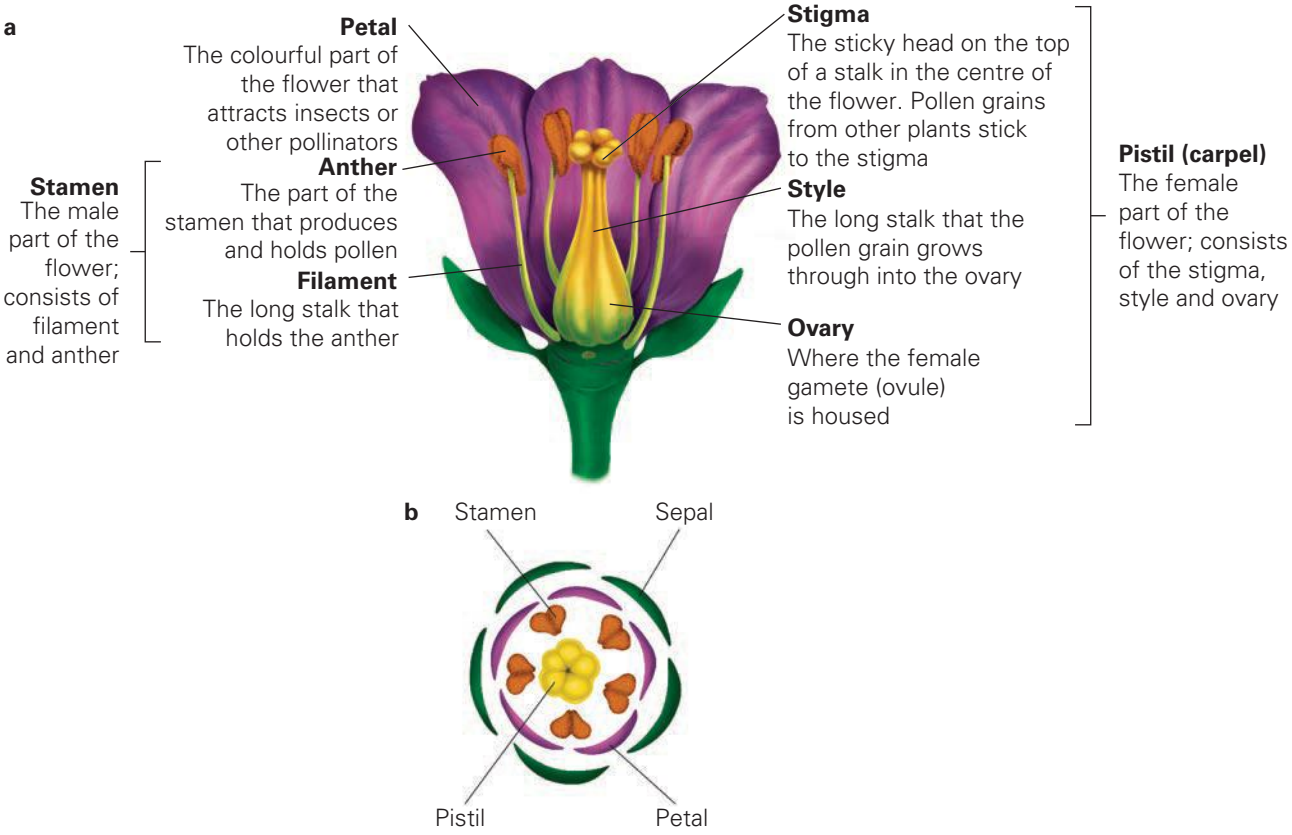


Figure 8.61 (a) A vertical section showing the reproductive parts of a flower. **(b)** A cross-section of the reproductive parts

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Practical skills 8.5

Flower dissection

Be careful
Take extreme care when handling the razor blade.



Aim
To identify the parts of a flower.

Materials
- a variety of flowers for dissection
- hand lens
- stereomicroscope
- tweezers
- single-sided razor blade
- chopping board

Procedure
1. Refer to Figure 8.61 to help you to identify the parts of your flower. Draw a diagram of your first flower. Note the number of petals and sepals, and label these on your diagram.
2. Holding the flower carefully with tweezers on the chopping board, cut the flower in half vertically. This means you should now be looking at a vertical section of the flower, similar to the top picture in Figure 8.61.
3. Draw a diagram of the flower and label all the parts of the flower you can recognise.
4. Gently remove the sepals and petals by pulling them down towards the stem. Use a microscope to look at the tip of the petal at low magnification. Record your observations of the petal's texture in your results.
5. Remove the flower's stamens by breaking or gently cutting them off the stem. Examine the pollen with your microscope. Record your observations of the pollen's shape and texture in your results.
6. Gently remove all parts except the pistil, so that it remains alone on the stem. Carefully cut the pistil in half lengthwise and use your hand lens to look at the inside of it. Record your observations of the style, ovary and ovules in your results.
7. Repeat steps **1–6** with the other flowers.

Results
Your results should consist of:
- labelled diagrams of the whole flower and vertical section of the flower
- observations made during the dissection.

Discussion
1. Consider the different flowers you looked at. List the similarities and differences between them.
2. Explain why these differences between flowers might exist.



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Explore! 8.7

Citizen science

Bees pollinate most of our crops, but bee numbers are decreasing rapidly. Bees can fly between flowers at about 25 km/h and visit up to 5000 flowers in one day. In fact, bees are so important that artificial hives are moved all around the country to help pollinate new crops.

With the bee industry facing challenges such as invasive pests and extreme weather, bee experts are urging citizen scientists to help count various species of insects to assess the health of pollinators. The Australian Pollinator Count is a long-term citizen science project to monitor the status of pollinator populations, including more than 2000 species of bees, along with thousands of species of flies, butterflies, moths and wasps.

Suggest why people want to be involved in citizen science projects.



Figure 8.62 The Australian Pollinator Count takes place every year around November, and anyone can get involved!

Leaves

Gas exchange is important for all living organisms, including plants. Plants perform both cellular respiration and photosynthesis, requiring organs that facilitate gas exchange with the environment. The main organ for this in plants is the leaf. Most photosynthesis occurs in the palisade cells, a layer near the top of the leaf. During photosynthesis, leaves take in carbon dioxide and release oxygen. Like our lungs, which have many alveoli, plants have many leaves to increase surface area for gas exchange and light absorption.

Leaves have tiny pores called **stomata** (singular: stoma), mainly on their underside, which control gas exchange. Each stoma is surrounded by **guard cells** that open and close the pore.

The guard cells of stomata have large vacuoles that open the pores when filled with water. This happens in strong sunlight or high carbon dioxide levels, as the stomata need to be open to allow the carbon dioxide to enter for photosynthesis.

However, when stomata are open, this allows water vapour to escape, so plants need to balance gas exchange with minimising water loss. The loss of water through the stomata of leaves is called **transpiration**.

When the plant faces dry conditions, high temperatures or low humidity, the vacuoles lose water, causing the guard cells to become flaccid and close the stomata. At night, stomata also close because the low light levels are insufficient for photosynthesis.

stomata
tiny pores (holes) in leaves that facilitate the entry and exit of gases such as oxygen and carbon dioxide

guard cells
specialised cells located on either side of a plant stoma that regulate gas exchange by opening and closing the stoma

transpiration
a plant's loss of water through the stomata of its leaves

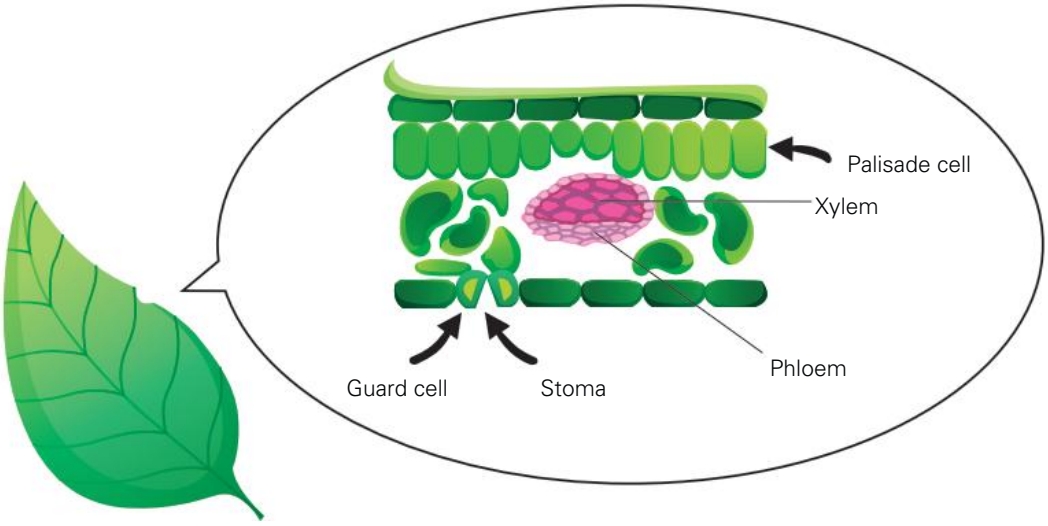


Figure 8.63 Cross-section showing gas exchange occuring in the leaves of plants

WORKSHEET
Plant respiration

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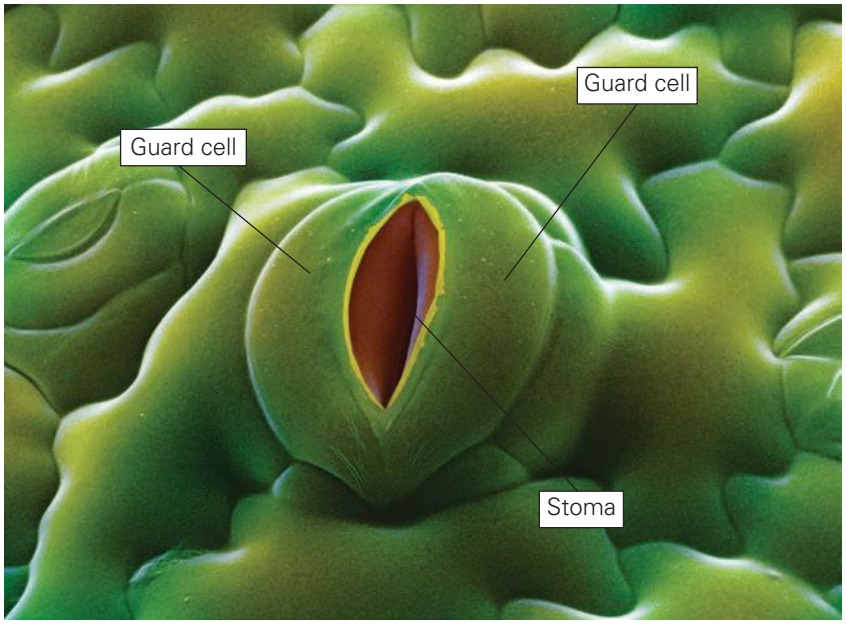


Figure 8.64 Swollen guard cells have forced open this stoma, allowing gases to enter and exit the leaf.

Did you know? 8.8

Trichomes

Plant hairs, also known as trichomes, can help to prevent water loss in plants. They break up the flow of air across the plant surface in windy regions, reducing water loss. When trichomes are dense, they reflect sunlight, and in areas where plants obtain their water from fog, the trichomes allow water droplets to accumulate.



Figure 8.65 Scanning electron micrographs showing a variety of trichomes on different leaves

Try this 8.11

Modelling stomata with a balloon

1. Blow up a twist balloon and fold it in half, but do not tie a knot in the end.
2. Keeping the balloon folded, allow some air to escape slowly from the balloon.
3. Notice how the two sides of the balloon begin to come together. This is like what happens in the stomata as it loses water. By closing the stomata, the plant can limit water loss.

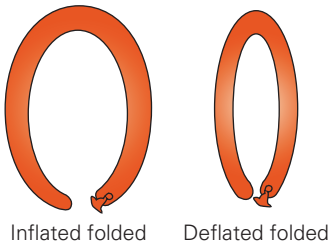


Figure 8.66 Model of set-up

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Practical skills 8.6

Stomata lab

Aim

To observe and compare stomata in desert and non-desert plants using a compound microscope.

Materials

- leaves from desert and non-desert plants
- compound microscope
- transparent ruler
- sticky tape
- glass slide
- transparent nail polish

Be careful



Carry the microscope appropriately, with one hand holding the arm and one hand under the base. Do not make big changes in magnification, so that the glass slide does not get damaged.

Procedure

1. Choose leaves from desert and non-desert plants.
2. Identify the top and bottom of the leaf.
3. Use the nail polish to paint a thin layer of varnish on a small section of the bottom side of each leaf.
4. Allow the polish to dry completely.
5. Place the sticky tape over the dry polish and pull it off.
6. Place the sticky tape with the polish impression onto a microscope slide.
7. Use the compound microscope to focus on the stomata impression, noting how many stomata you can see.
8. Focus on the highest possible magnification and sketch an image of a stoma.
9. Repeat for each leaf.

Results

Plant	Source (desert/non-desert)	Number of stomata you can see

Discussion

1. Compare the estimated number of stomata in desert and non-desert plants.
2. Explain why different plants are likely to have a different number of stomata. Consider the environments in which these plants grow.
3. Suggest a reason why some stomata are open while others are closed.

Advances in science 8.2

Thirsty plants

At present, agriculture consumes 90% of the world's fresh water to irrigate (water) crops. Scientists have found a way to genetically alter crops so that they are only able to partially open their stomata. This means the plants lose less water vapour when they open their stomata to gain the carbon dioxide they need to carry out photosynthesis. In a study conducted on tobacco plants, the modification improved crop water use by 25% but did not affect the yield of the crops – that is, the same amount of tobacco was produced. Now, the research team hope to apply their discoveries to food crops, which are more difficult to genetically modify than tobacco plants.



DEPTH STUDY IDEA
Research genetically modified plants

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Although the stomata on leaves do a great job of providing gases for the leaves, other parts of the plant need to respire, using oxygen. The thick woody parts of trees, such as the branches, stems and trunks, have structures called **lenticels**. You can often see these in the bark – they look like small dots or stripes. Lenticels allow the thick woody parts of the plant to exchange gases with the air.

lenticels
small slits on the trunks or branches of trees that allow gas exchange



Figure 8.67 The small horizontal slits in this tree trunk are lenticels.

Quick check 8.12

1. **Name** the structures that allow gas exchange to occur in leaves.
2. **Recall** three environmental factors that could cause stomata to close.
3. **Describe** the need for lenticels on a tree.
4. **Compare** xylem and phloem.
5. **Name** a structure that can be found in the shoot system.

Go online to access the interactive section review and more!

Section 8.5 review

Online quiz | Section questions | Teachers can assign tasks and track results

Section 8.5 questions

Remembering

1. **Define** the term 'gas exchange'.
2. **State** the location of stomata.
3. **Define** 'lenticels'.

Understanding

4. **Explain** how stomata open and close.
5. **Explain** why the stomata also close at night.

Applying

6. **Describe** the two primary functions of the root system.
7. **Compare** the structure of the lungs to the structure of a tree.

Analysing

8. **Distinguish** between the two types of vascular tissue in plants: xylem and phloem.

Evaluating

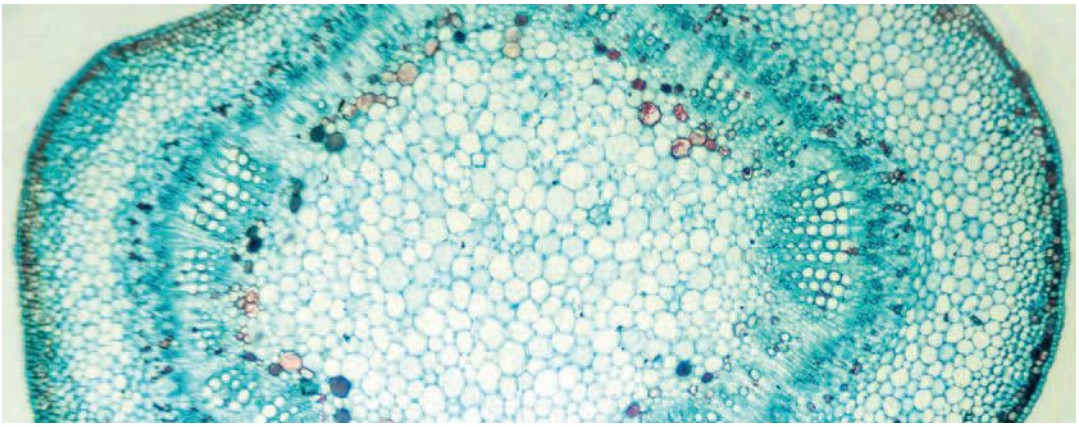
9. **Discuss** why plants in the desert have fewer stomata.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
8.1	explain the interrelationship between cells, tissues and organs.	9
8.1	identify the levels of organisation in a multicellular organism.	9
8.2	identify the role of the respiratory and circulatory systems of humans, and name the major organs.	1
8.2	draw or annotate representations of models of the respiratory and circulatory systems of humans to describe their processes and functions.	15
8.2	describe how the structures of the respiratory and circulatory systems of humans, and the specialised cells within these systems, enable them to carry out their functions.	6, 12, 13, 16
8.2	describe how the components of the respiratory and circulatory systems interact to allow the efficient functioning of an organism.	8
8.3	identify the role of the digestive and excretory systems of humans, and name the major organs.	2, 5, 8
8.3	draw or annotate representations of models of the digestive and excretory systems of humans to describe their processes and functions.	3
8.3	describe how the structures of the digestive and excretory systems of humans, and the specialised cells within these systems, enable them to carry out their functions.	10, 14, 16
8.3	describe how the components of the digestive and excretory systems interact to allow the efficient functioning of an organism.	17
8.4	explain how a disorder or disease affecting a body system, including removal of any component in the body system, impacts the overall functioning of the system and the organism as a whole.	7
8.5	determine the role, structure and function of the components of a plant.	10, 17
8.5	observe and describe the specialised cells and tissues involved in the structure and function of plants.	4



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Scorcher competition

Review questions

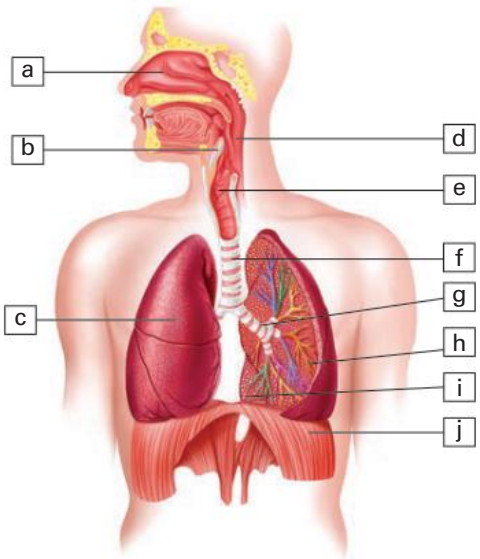
Data questions

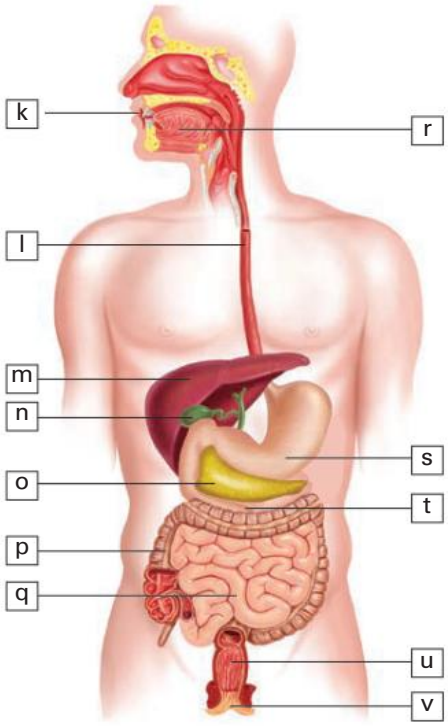
Review questions

Remembering

1. **Name** the blood vessel that:
   - **a.** carries blood away from the heart to the lungs to become oxygenated
   - **b.** carries oxygen-rich blood out of the heart
   - **c.** returns blood to the heart from the body.
2. **State** the key roles of the small intestine and the large intestine in humans.
3. Using the words from the list below, **identify** the components and organs labelled with letters in the following diagrams.

alveoli	large intestine	pharynx
anus	larynx	rectum
bronchiole	liver	small intestine
bronchus	lung	stomach
diaphragm	mouth	tongue
duodenum	nasal cavity	trachea
epiglottis	oesophagus	
gall bladder	pancreas	





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4. **Draw** and label a cross-section through the vascular bundle of a plant and state the functions of the labelled components.

Understanding

5. **Name** three organs from the excretory system and describe their functions.
6. **Describe** the different components of blood including the percentage of the blood that they comprise.
7. **Describe** why a disorder in cells or tissues can affect how an organ functions.
8. **Explain** the function of the liver.
9. **Sequence** these terms in order of increasing size/complexity: organ, organism, tissue, cell, organ system
10. **Distinguish** between mechanical digestion and chemical digestion.
11. **Describe** how guard cells control the opening and closing of stomata.

Applying

12. Complete the table to **distinguish** between an artery, a capillary and a vein in terms of both their structure and function.

	Structure	Function
Artery		
Capillary		
Vein		

13. Complete the table to **compare** the structure and function of villi and alveoli.

	Villi	Both	Alveoli
Structure			
Function			

Analysing

14. **Describe** what happens if nephrons in the kidneys stop removing urea from the blood and outline possible remedies.
15. **Propose** why masks covering the mouth and nose are effective in preventing the spread of infectious lung diseases such as COVID-19.
16. **State** which organ is a part of both the respiratory and excretory systems, and explain how its structure can serve a role in both systems.

Evaluating

17. Other than helping enzymes to break down food, **propose** another function of stomach acid.
18. **Discuss** how the petals, scent and nectar of flowers attract the most effective pollinators.

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Data questions

Biathlon is a winter sport whereby an athlete competes by completing three legs of cross-country skiing and two legs of shooting at a target, followed by a final sprint. In each phase of the race, the biathlon athlete's heart rate will change as the athlete uses energy to ski and then calms themselves for a shooting phase. The heart rate of a biathlon competitor is plotted over the various phases of the race in Figure 8.68. The relationship between maximum heart rate (HR_{max}) and age of the athlete is shown in Figure 8.69.

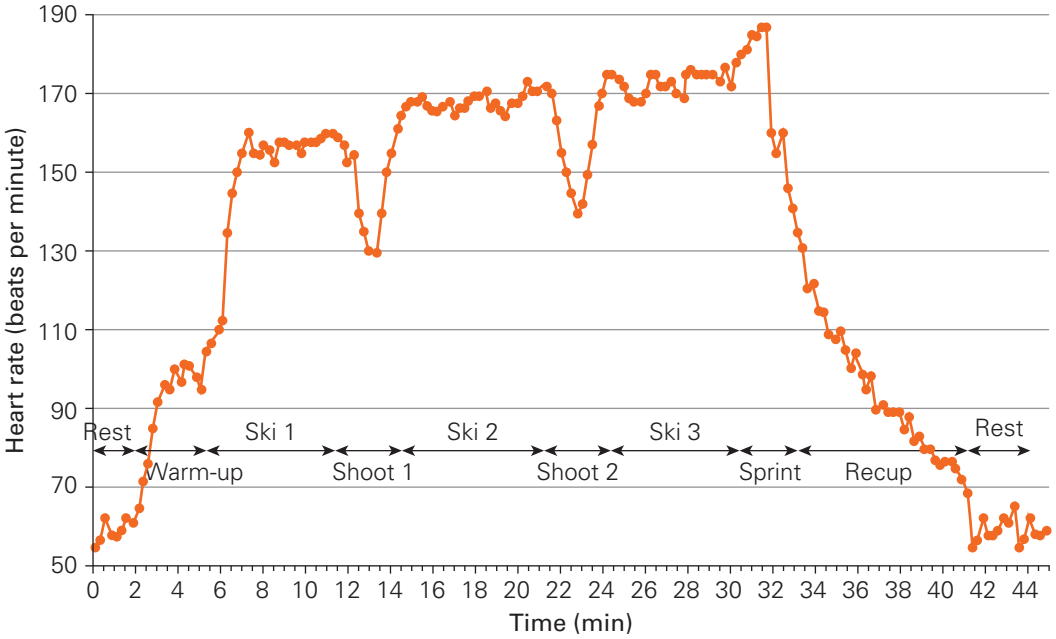


Figure 8.68 Heart rate of an athlete during a biathlon race including warm-up, three ski phases, two shootings, a final sprint and a recuperation phase.

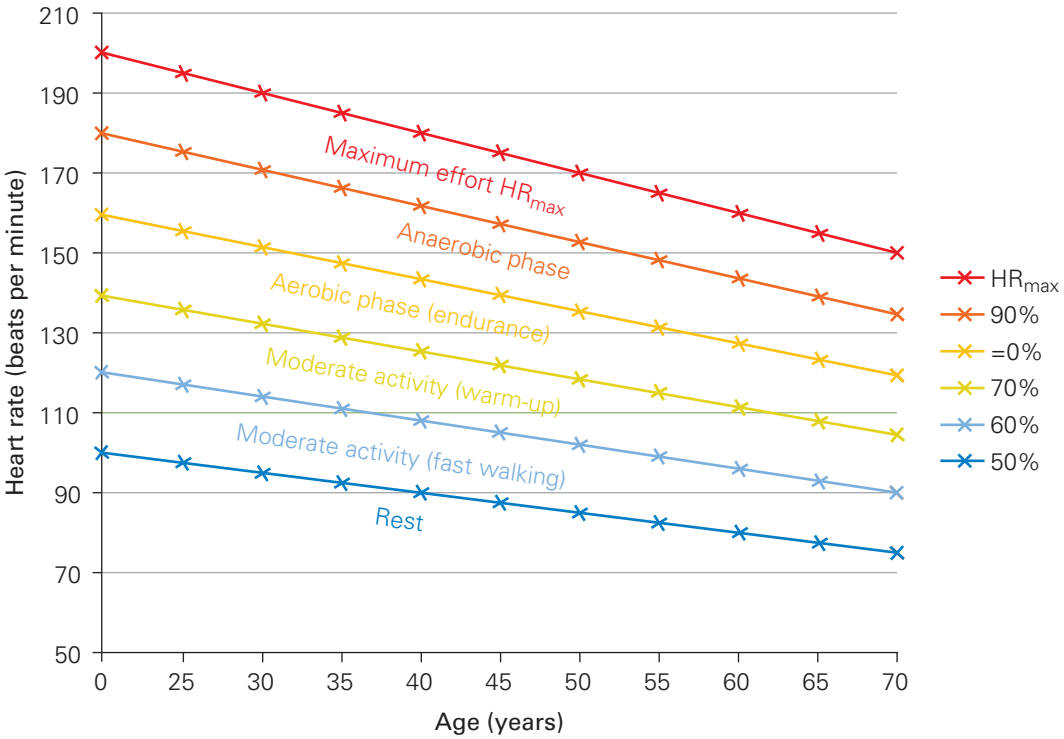


Figure 8.69 Activity intensity linked to the average human heart rate as a function of age. (Following the commonly accepted relation HR_{max} = 220 – age)

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1. With knowledge that the heart rate is higher during the ski periods and lower for the shooting periods, **identify** the time range for each of the three ski periods and the two shooting periods.
2. **Identify** when the athlete's heart is beating at its lowest rate.
3. **Calculate** the duration of the athlete's recuperation phase, when the heart rate goes from its highest, back to the resting pace.
4. Using the graph in Figure 8.69, **identify** the potential age of the athlete knowing their HR_{max} is 190, and that HR_{max} = 220 – age.
5. **Identify** the relationship between the heart rate during the successive ski periods and the fatigue of the athlete across the race.
6. **Contrast** the heart rate between 24 and 30 minutes (third ski phase), and between 30 and 32 minutes (final sprint).
7. Another athlete in the race was 40 years old and had a heart rate of 150 beats per minute during the second shooting phase. **Deduce** the activity intensity for this athlete during this phase.
8. **Infer** whether or not the heart rate of the athlete during the ski phase would be identical on a longer race with five ski periods and four shootings.
9. **Predict** the maximum heart rate of a 70-year-old athlete running a marathon if the athlete was using the maximum effort.



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STEM activity: Clearing a blocked artery

Background information

The heart is responsible for pumping oxygen and nutrients around your body and to every cell. It continues to pump for your entire lifetime, and you can't live without it. Unfortunately, many people around the world experience heart conditions that are life threatening. An example is coronary artery disease (CAD), a major cause of death in Australia. Many heart conditions can be treated with medication, and some require surgery. Other conditions, such as dilated cardiomyopathy, CAD and heart-related birth defects, can only be treated with a heart transplant. A donor heart can be used from a person who has died and has consented to being an organ donor. However, sadly, the number of people on waiting lists for heart transplants is far greater than the number of donor hearts available, and many people die while they are waiting for a transplant.

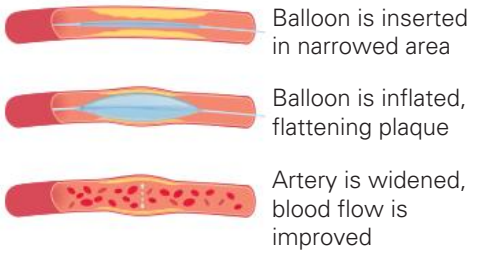


Figure 8.70 In angioplasty, a small 'balloon' is inflated inside the artery, which pushes the plaque aside and widens the vessel.

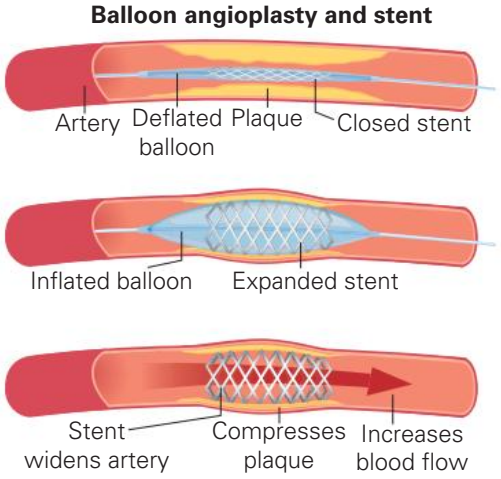


Figure 8.71 Many people also have a stent inserted inside the artery after the artery has been widened by angioplasty. A stent is a small tube made of plastic or metal that is inserted into the artery to prevent it from narrowing again.

Like all our organs, the heart requires oxygen and nutrients. These are supplied to the heart in blood that travels via the coronary arteries. When a person has CAD, substances including cholesterol, calcium and fat deposit on the walls of their coronary arteries. These deposits make the coronary arteries narrower, reducing the blood supply to the heart and therefore reducing the supply of oxygen to the heart muscle.

Two ways of using surgery to overcome this problem of blocked coronary arteries are shown in Figures 8.70 and 8.71.

It is important to note that neither of these methods actually cleans the plaque away. This is because blood vessels are fragile, and cleaning the plaque would cause it to dislodge, which is dangerous because it might then completely block a narrower blood vessel, causing a heart attack.

DESIGN BRIEF

Design a device and a procedure to clear blocked arteries while trapping the dislodged plaque.

Activity instructions

In groups of three or four, you will design a device along with the procedure to unblock an artery. As part of the design brief, your device and procedure will also need to trap any of the plaque that is cleared out.

You can only insert any devices from the top end of the 'artery' tube (see Figure 8.72).

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Suggested materials

- model of a blocked artery, created using a tube or a toilet roll tube and play dough
- paper clips
- string
- popsicle sticks
- cloth
- glue
- tape
- cardboard
- paper

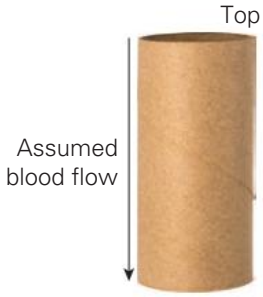


Figure 8.72 A model of an artery

Research and feasibility

1. Together as a group, discuss your understanding of the problem. Discuss the materials you have available and any constraints you may have in your design.
2. As a group, research methods of filtration and reflect on their suitability for trapping dislodged plaque.

Method of filtration	How it works?	Usability of filtration method for trapping plaque
e.g. Mesh/ sieve	The mesh stops things that are larger than the hole from passing through.	Mesh would stop plaque of a certain size; the mesh size and material would need to be thought of.

Design and sustainability

3. Research materials used in surgery, and as a group, think about the sustainability of these materials. Use this information when considering your design.
4. As individuals, sketch your own solution/s to the design brief and then share as a group. Annotate each group member's sketches, and together sketch your preferred model, making note of annotations for your design.

Create

5. As a group, build the model agreed upon by the group and then test it for effectiveness. You may wish to create a table such as the one below.

	Prototype 1	Prototype 2
Time taken for removing plaque		
Difficulty of procedure		
Percentage estimate of dislodged plaque caught in trap		

6. Modify your model and test again. You can test as many prototypes as you have time for.

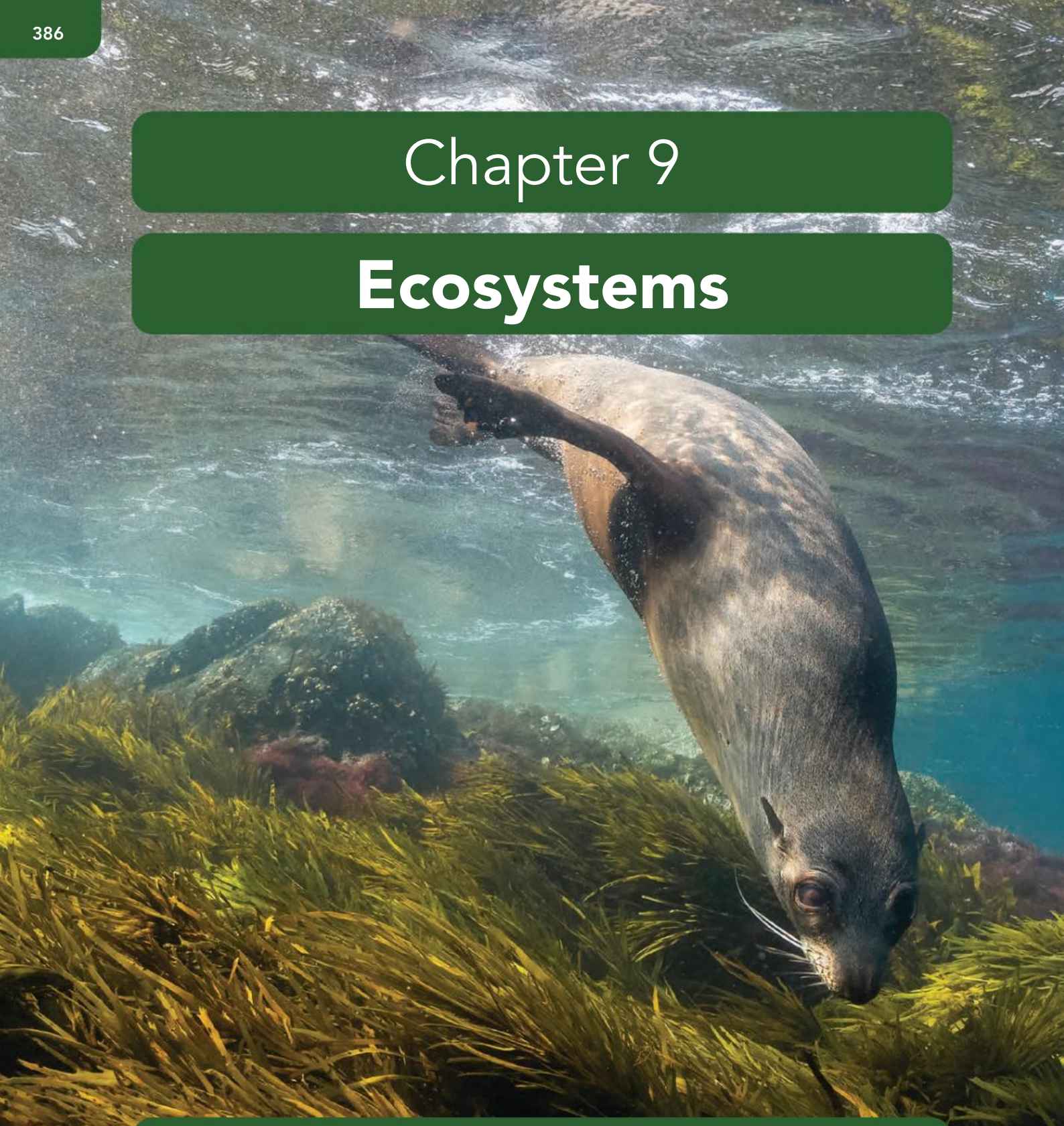
Evaluate and modify

7. For each model that you created, discuss how effectively the model performed. Consider how long the procedure was and how difficult it was to carry out. Evaluate how effective the 'trap' was at catching the dislodged pieces – how much of the plaque did it catch?
8. Imagine you had to do this procedure on a real patient. Discuss the limitations of your model of a blocked artery and how your device and procedure might need to be modified to better reflect real life.

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Chapter 9

Ecosystems

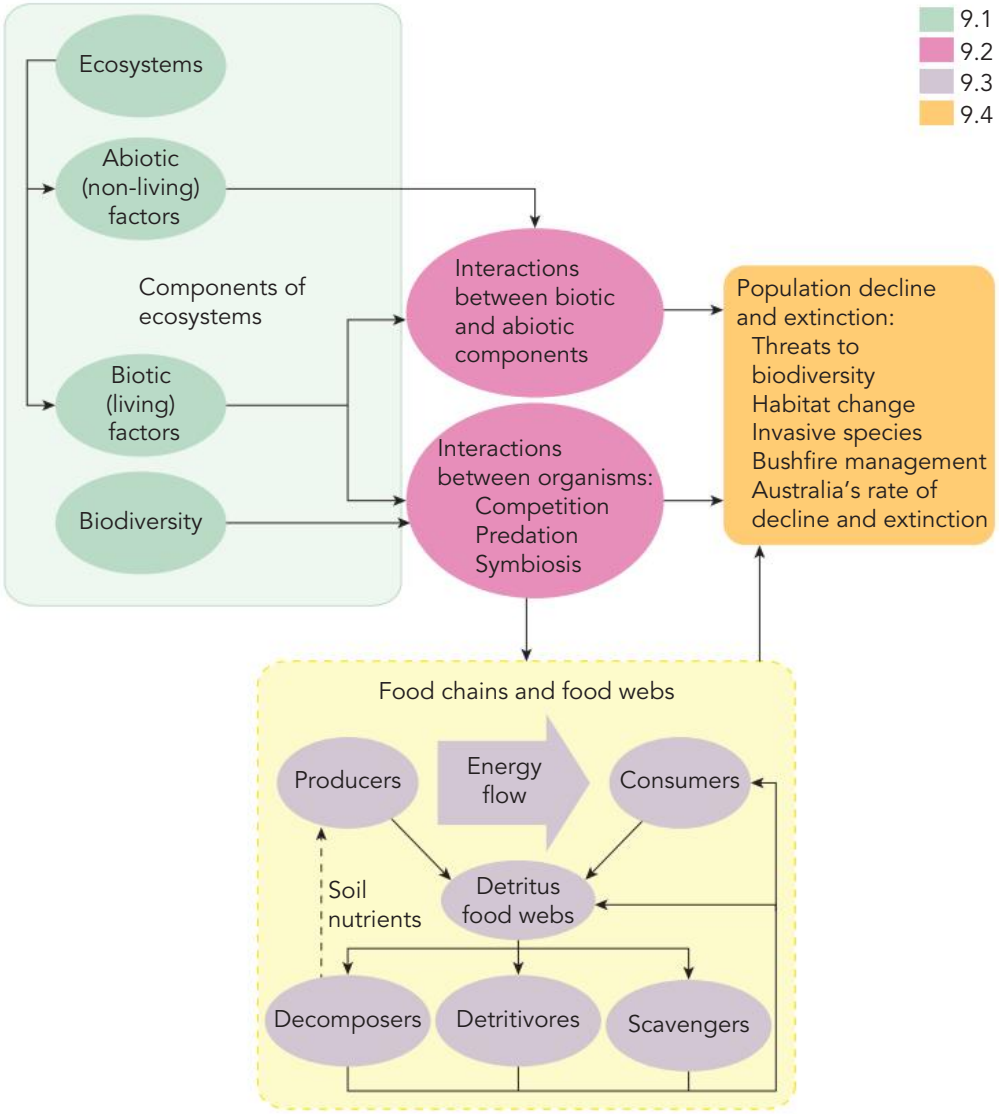


Chapter introduction

Despite now being in secondary school, you are not as independent as you might think. You are part of a global ecosystem that is made up of several smaller ecosystems. In fact, you are an ecosystem yourself, supporting many trillions of microorganisms who live on or in your body! You play a small role in a larger interdependent system where organisms depend on each other and the physical aspects of their environment to provide them with what they need to survive. In this chapter, you will look at the interaction of organisms and their environment. You will also explore how any activity that disturbs the interconnectedness will affect ecosystems.

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Chapter map



Glossary terms

10% rule
abiotic
abundance
apex predator
biodiversity
biological control
biomass
biotic
calicivirus
carnivore
cellular respiration
citizen scientist
commensalism
community
consumer
decomposer
detritivore
ecological niche
ecosystem
egestion
energy
energy pyramid
environment
excretion
extinction
firestick farming
food chain
food web
habitat
herbivore
herbivory
interdependence
interspecific
intraspecific
invasive species
mesopredator
microorganism
omnivore
parasitism
photosynthesis
population
predator
prey
primary consumer
producer
pyramid of biomass
pyramid of numbers
rewilding
scavenger
secondary consumer
species
symbiosis
tertiary consumer
tolerance
trophic level

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9.1 Components of ecosystems

WORKSHEET
Biotic and abiotic features

Learning outcome

At the end of this section, I will be able to:

1. identify the components that make up an ecosystem.

Describing ecosystems

ecosystem the interrelationship between living and non-living components of a specific area

biotic relating to the living things in an ecosystem

environment the physical conditions in which an organism lives

abiotic relating to the non-living things in an ecosystem

An **ecosystem** can be described as an area where living organisms (**biotic** factors) interact with each other and the surrounding non-living **environment** (**abiotic** factors). All parts of an ecosystem are linked, and even the smallest of changes can produce large effects. The important aspects of an ecosystem are the interrelationships and interactions between living things, and between living things and non-living things.

Biotic and abiotic components of ecosystems

Biotic components consist of populations of different organisms plus the organic matter produced by them. Even though waste material such as faeces and bones is not living, it is considered biotic because it came from living things. Abiotic components include not only physical things such as sunlight, rocks and sand, but also things that can be measured, such as temperature, wind speed and pH.

Some examples of biotic and abiotic features are listed below. These are the potential components of any ecosystem.

VIDEO
Biotic and abiotic features

Biotic	Abiotic
Animals	Temperature
Plants	Sunlight
Fungi	Water
Protists	Salinity
Bacteria	Humidity

Table 9.1 Examples of biotic and abiotic features in ecosystems

If you are trying to decide if a feature of an environment is biotic or abiotic, you can remind yourself of the life processes displayed by all living things (Figure 9.1).

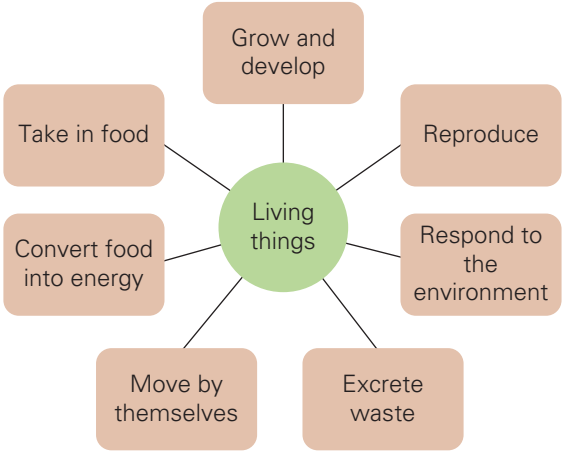


Figure 9.1 All living things demonstrate these processes.

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Try this 9.1

Distinguishing biotic and abiotic components

Sturt National Park, located in the far northwest of New South Wales, is a remote and diverse park that includes part of the Strzelecki Desert. Named after the explorer Charles Sturt, who ventured through the area in the 1840s, the park spans over 340 000 hectares. List as many biotic (living) and abiotic (non-living) features of this type of ecosystem as you can. The images in Figure 9.2 may help to inspire you. After you have tried on your own, chat with your classmates to see what other ideas they had that you can add to your two lists.



Figure 9.2 Sturt National Park

Examples of ecosystems

Ecosystems may be named by location or by the type of component, biotic or abiotic. In addition to the hot desert ecosystem of Sturt National Park in *Try this 9.1*, here are more examples:

- Coastal ecosystem – Jervis Bay Marine Park
- Rainforest ecosystem – Nightcap National Park
- Alpine ecosystem – Kosciuszko National Park
- Box-gum woodland ecosystem – around Wagga Wagga
- Wetland ecosystem – Macquarie Marshes

Try this 9.2

Ecosystems

In small groups, come up with five different ecosystems and write them down. Then, as a class, list them on the board, avoiding any duplications. Discuss whether some areas can be further broken down into several habitats.



Figure 9.3 The Mann River, seen from Cangai. This is an example of many habitats in one area.

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Habitats within ecosystems

habitat
the place where an organism lives

All organisms have a specific set of needs that they require to survive and reproduce, and the area where they live that provides these needs is called their **habitat**. Each ecosystem is made up of many individual habitats that are the perfect places for specific organisms to survive. If you consider an ecosystem as a suburb where an organism lives, then the habitat is the organism's address in that suburb.

Some of the biotic and abiotic requirements that an organism needs to survive are:

- food
- water
- shelter
- space to live
- other similar organisms for reproduction.

Every organism has its own habitat requirements. Some animals can survive in more than one habitat. Other animals are limited to specific habitats and may have adaptations that allow them to survive there. Although they prefer to live by the edges of forests next to grasslands, dingoes can be found in every habitat across every state of Australia except Tasmania. They are only limited by their access to water. However, the koala has adaptations that allow it to only eat toxic eucalyptus leaves, so it will only be found in habitats that support eucalyptus trees.




Figure 9.4 The dingo can survive in a wider range of habitats than the koala.



Figure 9.5 Habitats can range in size from a single skin pore to huge forests. After studying human skin, scientists have discovered that each pore contains a single variety of *Cutibacterium acnes* bacteria.



Figure 9.6 How many different habitats can you spot at Kanangra Walls?

Quick check 9.1

1. **Define** these terms: ecosystem, biotic, abiotic, habitat.
2. **Name** four different types of ecosystems.
3. **Name** three examples of biotic and abiotic factors in an ecosystem.
4. **Discuss** what makes a habitat a home for a particular organism.

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Levels in an ecosystem

When scientists discuss the biotic aspects of an ecosystem, they can be described at different levels from large to small: **community**, **population** and individual. Table 9.2 summarises each level.

community a group of animals or plants that live or grow together

population all organisms of a particular species or group who live in one area

species the most specific taxonomic ranking of a group of organisms

abundance the number of individuals of a species within a community or ecosystem

Level of organisation	Description
Community	A group of different organisms that live in the same area. For example, a community that is found on the Myall River consists of mangrove trees, which provide shelter for the young and adults of many fish **species**. They also provide roosting and feeding opportunities for birds and bats. Their root network provides a habitat for crabs, snails, worms and insects.
Population	A group of the same species of an organism living in the same area. For example, there is a population of the red-tailed phascogale living in Mallee Cliffs National Park. Their total number is called their **abundance**.
Individual	One living organism

Table 9.2 The levels of organisation in an ecosystem

Explore! 9.1

INVESTIGATION

Threatened communities in New South Wales

In New South Wales, there are ten threatened ecological communities. In 2023, the New South Wales government acquired Comeroo, Muttawary and Maranoa stations (collectively known as Comeroo), adding over 37 000 hectares of threatened communities to the NSW national park estate.

Managed by the NSW National Parks and Wildlife Service, Comeroo includes diverse habitats such as floodplains, swamps, wetlands, grasslands, woodlands and shrublands, with more than a quarter of the new park covering Yantabulla Swamp.

Research the three ecological communities listed as endangered that cover one-third of Comeroo, and which species will benefit from protecting this area.



Figure 9.7 The stripe-faced dunnart (*Sminthopsis macroura*) is one of the species found at Comeroo.

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Try this 9.3

Demonstrating the organisation of ecosystems

Select an organism native to New South Wales that you find interesting. Some endangered examples are the eastern fat-tailed gecko, the squirrel glider and the rufous bettong. On a piece of A3 paper, put the name of this organism in a small circle in the centre of your page – this is your individual. You may like to include a picture of your organism. Now draw a larger circle around your individual. This will be your population. Continue to add examples of each level of organisation as you work all the way up to ecosystem. See Figure 9.8 for an example. This diagram also includes higher levels of organisation: a biome is a large region comprising similar ecosystems, and a biosphere consists of all the ecosystems on a planet. The focus in this course is on ecosystems.

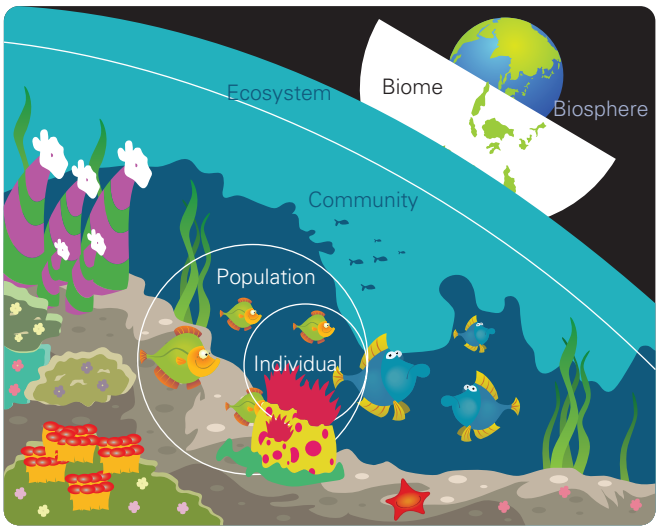


Figure 9.8 Levels of organisation

Investigation 9.1

Investigating ecosystems

Be careful
Ensure safety measures are taken when conducting fieldwork, including wearing appropriate clothing and footwear for outdoor conditions, and following any guidelines provided by the school or local authorities.

Aim

To conduct a practical investigation to collect a dataset on biotic and abiotic features, focusing on observing and tracking changes in vegetation type and distribution, temperature, humidity and light intensity.

Time period

Over a semester or year, depending on the complexity of the investigation and the availability of the study area.

Background information

Changes in these abiotic and biotic factors can impact ecosystems and the organisms within them.

Materials

INVESTIGATION

- field notebook or data collection sheets
- map of the area
- measuring tape
- thermometer
- hygrometer (to measure humidity)
- light meter or lux meter
- species identification sheets
- camera (optional, for documenting observations)

Procedure

1. Select a suitable outdoor location for fieldwork, such as a park, bushland or school grounds.
2. Use the measuring tape or the map to measure the size of the study area.
3. Use the thermometer to record the temperature at various points in the study area.
4. Use the hygrometer to measure humidity levels.
5. Use the light meter to measure light intensity at different locations.

continued ...

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6. Record observations of vegetation type and distribution in different areas of the study site.
7. Repeat the data collection again at different points throughout the year.

Results

Record all data in your field notebook or data collection sheets, including the date, time and location of each observation.

Discussion

Analyse your data to identify any trends or patterns in temperature, humidity and light intensity and how they can affect vegetation type and distribution.

Extension

If available, compare your findings with data from previous years to identify any long-term trends or changes in the study area.

Biodiversity

When scientists look at all life on Earth, they start to talk about **biodiversity**. Biodiversity refers to the variety of all living things found in a specific area or an ecosystem and is normally considered at three levels.

biodiversity the variety of life that exists in an area

- Genetic diversity: This is the variation in the genes of one species in the area. It is better if a species is very genetically diverse, as it improves its chance of survival.
- Species diversity: This is the variety and abundance (total number) of different species found in an area. Places like coral reefs and rainforests are considered extremely biodiverse because of the many different species that live in those ecosystems.
- Ecosystem diversity: This is the variety of ecosystem types found in an area.

Chapter 4 introduced the classification of all life on Earth into six kingdoms. These kingdoms indicate the species diversity on our planet, which is constantly being updated as new species are discovered. About 76% of all species have been classified into the animal kingdom, meaning this is the most diverse of all the kingdoms. Within the animal kingdom, the phylum Arthropoda is by far the most diverse, with the class Insecta making up about 75% of all animal species.

For a number of reasons, greater biodiversity in an area generally means greater stability and resilience in its ecosystems.

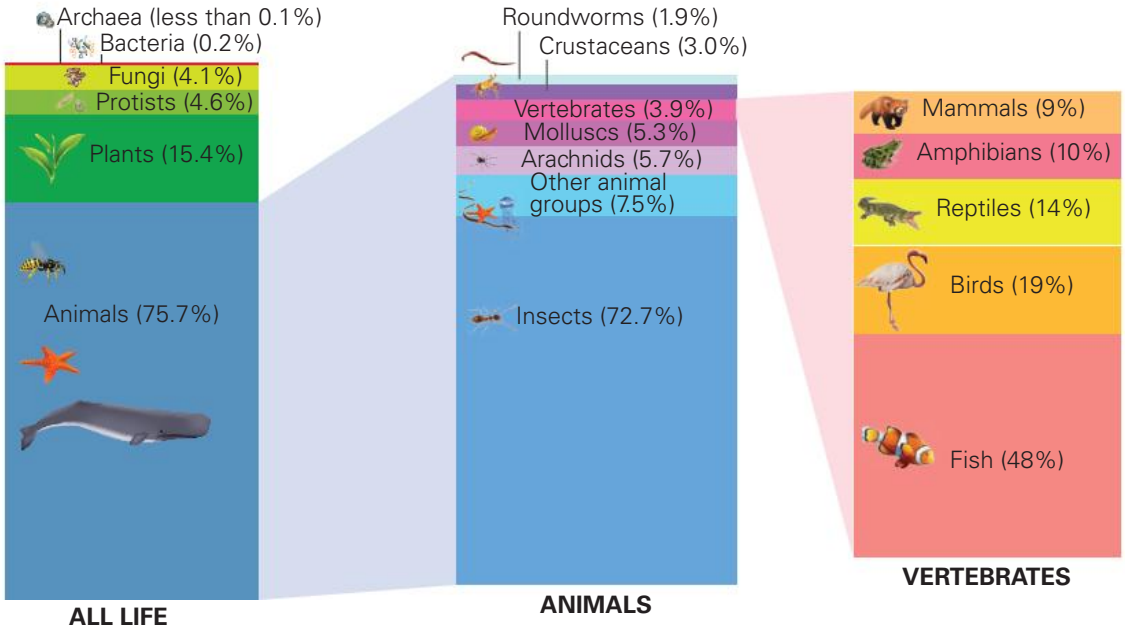


Figure 9.9 Species biodiversity on our planet (approximate percentages shown)

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Quick check 9.2

1. **Define** the terms 'environment', 'community' and 'population' in your own words.
2. **Name** a specific habitat and propose a community, population and individual that would be found in that habitat.
3. **Sequence** the following terms to demonstrate the levels of organisation: individual, ecosystem, population, community.

Go online to access the interactive section review and more!

Section 9.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 9.1 questions

Remembering

1. **Identify** the levels of an ecosystem, from largest to smallest.
2. **Identify** some abiotic features found at a chosen location.
3. **Identify** three biotic features found at the same location you chose in Question **2**.

Understanding

4. **Give** examples of two biotic or abiotic components important to the following types of organism in their ecosystem:
   - **a.** a kangaroo
   - **b.** a flowing plant
   - **c.** a yabby
   - **d.** a shark
5. **Define** the term 'habitat' and compare it to 'ecosystem'.



Figure 9.10 Grose Valley

Applying

6. Imagine you are dropped into the middle of the wilderness. **Construct** a detailed list of all the features you would require in your ideal habitat to survive. Remember to be very specific.
7. Make a **judgement** about the following statement and **explain** your reasoning: 'The changes in the abiotic components of an ecosystem will affect the biotic components of an ecosystem'.
8. Look at Figure 9.10 and **identify** parts of the ecosystem such as communities, abiotic and biotic factors, and habitats.

Analysing

9. **Compare** the terms 'ecosystem' and 'environment'.
10. Using a Venn diagram, **compare** abiotic and biotic factors in an ecosystem. Give an example of each.

Evaluating

11. Environmental conditions are changing in ecosystems every day. **Propose** the changes in abiotic factors that occur in a desert ecosystem over the course of a day and how these changes would affect the biotic parts of the ecosystem.
12. 'All populations living together within a community interact with one another and with their environment to survive and maintain a balanced ecosystem.' **Decide** if you agree with this statement. Give reasons for your decision.

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9.2 Interactions in ecosystems

Learning outcomes

At the end of this section, I will be able to:

1. describe factors that change populations.
2. describe interactions in an ecosystem between biotic and abiotic components, as well as between different biotic components.
3. examine examples of factors that change populations.



WORKSHEET Interactions between organisms and abiotic components



VIDEO Relationships between organisms

Interactions between biotic and abiotic components

Abiotic components or factors affect the overall distribution and abundance of organisms within an ecosystem. Most organisms have a **tolerance** range for a certain abiotic factor, such as temperature, and this will determine where they can live. Sometimes the range is very narrow. Seasonal changes in temperature and precipitation can impact the availability of food and shelter for organisms, affecting their distribution and population size. Habitat destruction, such as deforestation or urbanisation, can lead to the loss of suitable habitats for many species, resulting in population decline.

tolerance the range of conditions that an organism can survive and function within

Examples of biotic/abiotic interactions are given in Table 9.3.

Abiotic component	Examples of interactions
Temperature	• Enzymes in organisms work best at certain temperatures, which affects how organisms adapt to different climates. • Fruit trees like cherry trees need a cold period in winter to help them reproduce. • Mammals must keep their body temperature around 37°C. They cool down by sweating or panting and seek shade in hot weather. In the cold, they eat more food or use fur, fat, or shelter to stay warm. • Reptiles, like the Central Bearded Dragon, rely on their environment to control their body temperature. They bask in the sun in the morning to warm up and move to shade or burrows in the afternoon to cool down. At night, they stay inactive when it is cold.
Sunlight	• The amount and intensity of sunlight affect where photosynthetic plants, algae and bacteria can live. • Forest plants are adapted to specific light levels. • Sunlight controls how deep corals with symbiotic algae can grow on a reef. • Water clarity (turbidity) affects how much sunlight reaches aquatic plants and corals with symbiotic algae, influencing where they can survive.
Water and humidity	• The amount of water available is the main factor affecting where most organisms live. • Plants need water for support, transpiration and photosynthesis. • Humidity is important for plant pollination and seed or spore dispersal. • Fungi grow best in humid or moist environments, and most decomposers also thrive in damp conditions. • Animals either live in water or need it for their metabolism and breeding. • Many invertebrates rely on water to reproduce.
Salinity	• Most plants and animals need either freshwater or saltwater, but some can tolerate changing salinity in estuaries. • Vertebrates rely on their kidneys to control blood salinity, which affects where they can live and what they eat.

Table 9.3 Examples of interactions between some biotic and abiotic components of ecosystems

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Explore! 9.2

Investigating interactions between biotic and abiotic components of ecosystems

Choose a species that interacts closely with an abiotic component of its ecosystem. Investigate and explain this interaction, including its impact on the species's survival and population. Describe how the species detects and responds to changes in the abiotic component and discuss how human activities might affect this interaction. Consider the future of the abiotic component and whether human management is needed to protect the species.



Investigation 9.2

The effects of ocean acidification on marine organisms

Aim

To observe and understand how ocean acidification affects the growth and health of marine organisms.

Time period

Approximately one week.

Background information

Ocean acidification is the ongoing decrease in the pH of Earth's oceans, caused by the uptake of carbon dioxide from the atmosphere. Marine organisms such as corals, shellfish and plankton are sensitive to changes in pH levels.

Materials

- 2 beakers
- seawater
- pH meter or pH test strips
- vinegar (acetic acid)
- small pieces of coral (can be obtained from a pet store or aquarium supplier)
- shells (e.g. collected from the beach or mussel/clam shells from a seafood market)

Procedure

1. Fill both beakers with seawater.
2. Add a small amount of vinegar (acetic acid) to one beaker to simulate ocean acidification.
3. Measure and record the initial pH of the seawater in each aquarium using the pH meter or test strips.
4. Carefully place the pieces of coral and shellfish into each beaker.
5. Leave the beakers for one week.
6. Note any visible effects of ocean acidification on the shells and coral.

Discussion

Analyse your data to determine the effects of ocean acidification on marine organisms.

Conclusion

Draw conclusions about the impact of ocean acidification on marine ecosystems. Discuss the importance of mitigating ocean acidification to protect marine life.

ecological niche the role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment

Interactions between different organisms (species interactions)

The role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment, is known as its **ecological niche**. This includes its habitat, feeding relationships and interactions with other organisms.

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Species interactions within the community may help, harm or have no effect on the organisms involved. For example, the introduction of a new species to an ecosystem can have significant impacts on the existing populations by competition for resources, predation or the introduction of new diseases. All of these impacts can influence the distribution and abundance of organisms within the ecosystem.

In some cases, organisms may require other organisms to survive. This is known as **interdependence.** Competition, predation and **symbiosis** are the three main types of species interactions.



Figure 9.11 An example of interdependence between a New Holland honeyeater and a *Grevillea* plant. The honeyeater depends on nectar for food, and the *Grevillea* depends on birds (some on insects) to pollinate it.

interdependence the dependence between different species in a community

symbiosis a long-term close interaction between two organisms of different species

Try this 9.4

Koala populations

Abiotic and biotic factors can influence the distribution and health of koala populations in different parts of Australia.

Explore how the availability of eucalyptus leaves affects koala populations. Consider factors such as:

- types of eucalyptus trees preferred by koalas
- seasonal variations in eucalyptus leaf availability
- the impact of deforestation and habitat loss on food sources.

Examine the impact of climate on koala populations. Focus on:

- the effects of extreme temperatures (both hot and cold) on koala health and behaviour, including the impact of bushfires
- changes in Australian climate patterns and their impact on koala habitats
- how koalas cope with temperature extremes (e.g. seeking shade, changing activity patterns).

Analyse the data you have collected to identify patterns and correlations between biotic and abiotic factors and koala populations. You should prepare a presentation to share your findings with the class.

WORKSHEET Interactions between organisms

Competition

Organisms occupying the same ecological niche will compete with one another for resources that are in limited supply. This occurs when different organisms require the same resources – such as food, space, shelter and mates – to survive. **Interspecific** competition is competition for resources between members of different species. For example, kangaroos and sheep compete for grass as their major food source. In contrast, **intraspecific** competition occurs between members of the same species.

VIDEO Interspecific and intraspecific relationships

Quick check 9.3

1. **Define** the terms 'interspecific competition' and 'intraspecific competition'.
2. **Describe** what happens when two species are competing for food, and one species is better adapted or stronger.

interspecific occurring between members of different species

intraspecific occurring between members of the same species

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predator
an organism that obtains food by killing and consuming other organisms

prey
an organism hunted and killed by another organism for food

herbivory
the consumption of plants

Predation

A predator–prey relationship occurs when one organism, known as the **predator**, kills and eats another organism, known as the **prey**. **Herbivory** is a type of predation where the prey is a plant. It is unusual for predators to depend upon one species of prey, so if one prey species reduces in supply, the predator can prey upon other species. For example, dingoes prey on rabbits but can also eat other small mammals. The relationship between predator and prey is usually balanced, but occasionally, this can change. For example, favourable conditions may lead to an increase in the prey population, which in turn can lead to an increase in the number of predators. If a period of adverse conditions occurs to reduce the prey population, predators will turn to another prey species, and there may be an increase in intraspecific competition among the predators.

WORKSHEET
Predator–prey relationships

Try this 9.5

Predator–prey relationships

Feral rabbits do have natural predators such as the red fox; however, their ability to reproduce quickly has seen rabbits continue to thrive within Australia. Generally, if there is a shortage of prey, then there will be fewer predators surviving in that environment. Another predator and prey relationship occurring in the deserts of Australia is that of the red kangaroo and the dingo. The dingo is the apex predator in this biome, and although they do not usually prey on kangaroos, they will hunt and kill them when food is scarce.

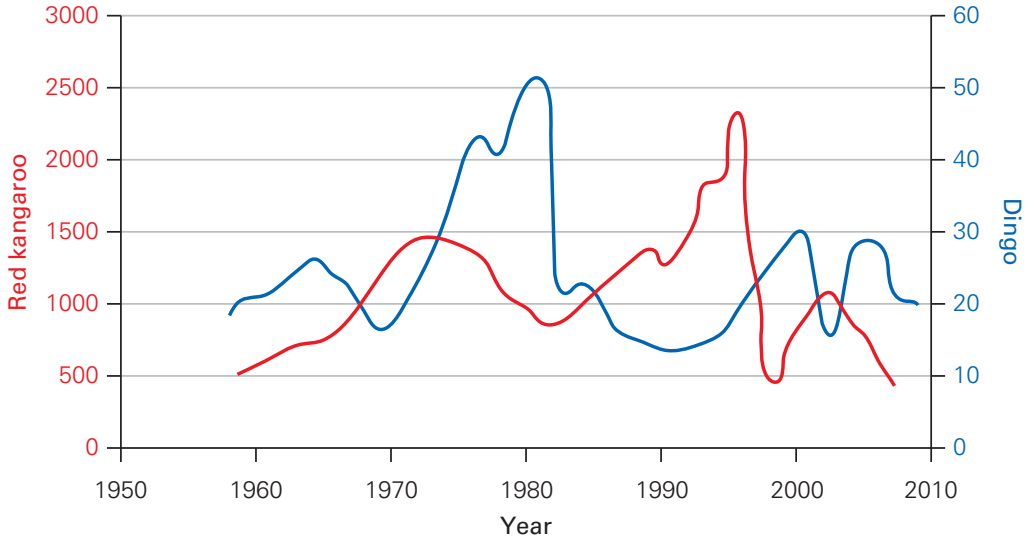


Figure 9.12 Population sizes over time for the dingo (in blue) and the red kangaroo (in red)

Using Figure 9.12, answer the following questions.

1. Identify the year with the greatest abundance of red kangaroos.
2. Explain what happens to the dingo population as red kangaroo numbers increase.
3. Examine what happens to the dingo population size when the red kangaroo population size decreases.
4. Describe the pattern of the predator–prey relationship shown in the graph.
5. Identify and discuss a factor, other than the red kangaroo population, that may influence the size of the dingo population.
6. Identify and discuss a factor, other than the dingo population, that may influence the size of the red kangaroo population.

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Symbiosis

Symbiosis is an interaction where individuals from two different species share a close and long-term relationship with each other. There are three major types of symbiosis: mutualism, **commensalism** and **parasitism**.

commensalism a symbiotic relationship where one organism benefits and the other neither benefits nor is harmed

parasitism a symbiotic relationship where a parasite benefits from living on or in a host (which is harmed)



Mutualism

Mutualism is a symbiotic relationship between two organisms in which both benefit from the association. For example, plants have a mutualistic relationship with pollinators. Some plants, like grasses, are pollinated by wind, but many flowering plants rely on insects, birds or small mammals to transfer pollen from one plant to another. In a plant–pollinator relationship, the pollinator benefits as it feeds on the nectar provided by the flower. In return, the plant benefits as the pollinator transferring pollen allows the plant to reproduce.

Another example is the alpheid shrimp and goby fish. Alpheid shrimps are near-blind, so they dig burrows to stay safe. However, when above ground, they are vulnerable to predators. When foraging or excavating outside of their burrows, a goby fish will stand guard at the entrance to the burrow. The shrimp will always be in antennal contact with the goby fish tail, which the fish will flick whenever there is danger. Both members of the relationship benefit: the goby fish gets a burrow to live in, while the shrimp is warned of predators.



Figure 9.13 The relationship between the goby fish and the alpheid shrimp is mutualistic.

Commensalism

Commensalism is a symbiotic relationship in which one organism benefits, while the other organism is not affected (neither is harmed nor benefits). These types of relationships are much rarer than mutualism or parasitism.

One example is that of the pearl fish and sea cucumber. The pearl fish spends its day in the intestines of the sea cucumber, emerging at night to feed on small crustaceans. The pearl fish is protected from predators while inside the sea cucumber, which does not appear to be harmed. Other examples include birds following army ants when they raid forest floors. During the raid, birds will feed on the flying insects that are stirred up by the ants walking past.



Figure 9.14 Army ant raids are a coordinated hunting swarm of thousands and sometimes millions of ants. The ants spontaneously move out of their nest, moving together across the forest floor to hunt for food.

Parasitism

Parasitism is a symbiotic relationship in which one species benefits and the other is harmed. The species that benefits is called the parasite and the one that is harmed is the host. The host is harmed, but rarely killed, as then the parasite would die too! Instead, the parasite survives on or in the host, taking nutrients or growing and reproducing in organ systems, causing disease.

There are two main types of parasites: ectoparasites and endoparasites. 'Ecto' means outer or external, so ectoparasites live on the surface of other organisms. Lice and ticks are examples of ectoparasites. 'Endo' means inner or internal, so endoparasites are found living inside other organisms. Worms and protozoans are examples of endoparasites.

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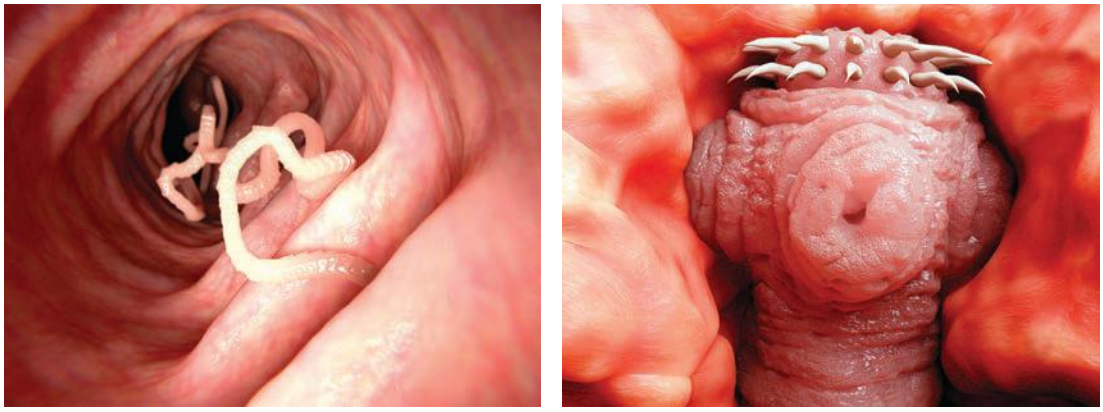


Figure 9.15 These tapeworms are endoparasites that inhabit the digestive tracts of animals (including humans). Tapeworms use their specialised hooks to anchor themselves in the intestine and absorb nutrients through their body wall. Disturbingly, they can grow to several metres in length, but they do not necessarily cause symptoms.

The main types of interactions are summarised in Table 9.4.

Interaction	Species 1	Species 2	Example
Competition	Harm	Harm	Kangaroos and sheep both compete for grass.
Predation	Benefit	Harm	Crocodiles prey upon insects, fish, frogs, lizards, crustaceans and small mammals.
Herbivory	Benefit	Harm	A koala eating eucalyptus leaves
Parasitism	Benefit	Harm	The mange mite burrows into the skin of wombats where it lays its eggs and causes irritation.
Mutualism	Benefit	Benefit	The boxer crab carries a pair of small anemones in its claws. When a predator approaches, the crab waves the anemones around, deterring the predator due to the stinging tentacles. The anemones benefit as they get small particles of food from the crab during feeding.
Commensalism	Benefit	No effect	Cattle egrets walk close to where cattle are grazing because the cattle stir up insects from the vegetation that the egrets can eat.

Table 9.4 Summary of some of the different interactions that occur in an ecosystem. Parasitism, mutualism and commensalism are symbiotic interactions.



Figure 9.16 Examples of **(a)** parasitism, **(b)** mutualism and **(c)** commensalism

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Quick check 9.4

1. **Complete** the following table, describing the types of relationships between organisms. Use a smiley face, sad face or neutral face to represent how each organism is affected.

Relationship	Definition	Organism 1	Organism 2
Competition			
Mutualism			
Commensalism			
Parasitism			

2. **Contrast** an ectoparasite and an endoparasite.

Try this 9.6

What is the interaction?

Look at each of the following images and, with a little research, decide which type of interaction is being demonstrated.



Figure 9.17 Examples of different types of interactions between organisms: **(a)** a leech on human skin, **(b)** two kangaroos fighting and **(c)** a lemon shark with a remora fish on its back

Section 9.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

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Section 9.2 questions

Remembering

1. **Define** the terms 'parasitism', 'mutualism' and 'commensalism'.
2. Using what you have learned about interactions in ecosystems, **name** an example of each of the following interactions in which humans are involved.
   - **a.** Mutualism
   - **b.** Parasitism
   - **c.** Commensalism
   - **d.** Predator–prey
   - **e.** Interspecific competition
   - **f.** Intraspecific competition
3. When there is a large increase in the population size of a prey species, **recall** what tends to happen to the population size of the predators.

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Understanding

4. **Explain** what kind of interaction is shown when a species of plant survives only in wet soil.
5. **Explain** what is meant by an organism's 'ecological niche'.
6. A bee feeds on the nectar from a flower. **Explain** why this is an example of mutualism.

Applying

7. **Give** an example of an interaction between a reptile and sunlight.
8. Look at the graph and answer the following questions.

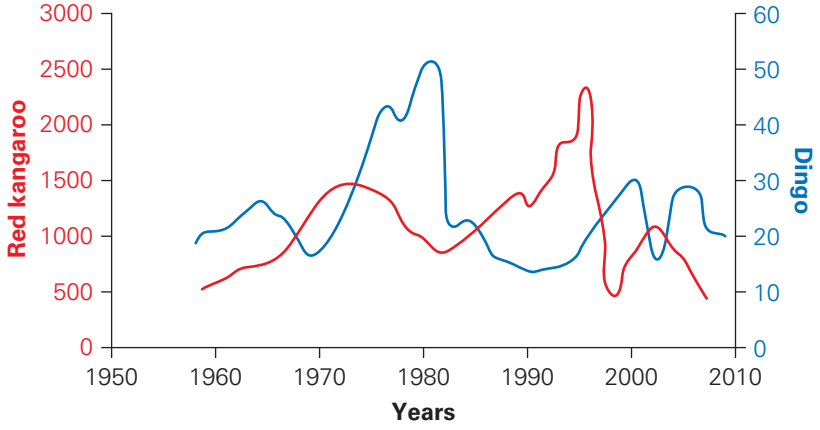


Figure 9.18 Red kangaroo and dingo populations from 1950 to 2010

   a. **Identify** which line colour represents the population of dingoes over time.
   b. **Determine** the population of dingoes in the year 2000.
   c. **Identify** the year that had the largest dingo population.
   d. **Identify** the pattern between the two populations with reference to the terms 'predator' and 'prey'.
   e. **Deduce** the population of red kangaroos when the population of dingoes was at its peak.
   f. **Infer** why the red kangaroo population was greatest in the mid-1990s.
   g. In the year 2015 the red kangaroo population fell to a trough of approximately 300 in this region. **Predict** how the dingo population might have changed in this time.
   h. **Predict** the populations of red kangaroos and dingoes in 2030 given the data in the graph.

Analysing

9. **Compare** an ectoparasite and an endoparasite, providing examples for each.
10. **Examine** the role of mutualistic relationships within ecosystems, using examples not already used in this chapter.
11. A species of oyster is adapted to a salinity of about half that of seawater. **Explain** where it is likely to be distributed.

Evaluating

12. **Decide** whether the following descriptions are examples of mutualism, commensalism or parasitism.
   a. A man has tinea (a fungus) growing between his toes.
   b. A woman notices her cat looks very bloated. She takes it to the vet, and they suggest deworming the cat, as it probably has tapeworm.
   c. Small fish swim around on the back of whale sharks for protection from predators.
   d. Birds stand close to wild buffalo and eat the insects that are stirred up as the buffalo graze.
13. If all the predators from an area were removed, **discuss** the positive and negative effects on the ecosystem.

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9.3 Food chains and food webs

Learning outcomes

At the end of this section, I will be able to:

1. describe how matter and energy are cycled through an ecosystem.
2. create and analyse food webs to show feeding relationships.
3. create an ecological energy pyramid.
4. describe how energy pyramids show energy or matter at each level.

WORKSHEET
Food webs

Energy

When it comes to **energy**, ecosystems are not closed (you will learn more about closed systems in Chapter 12). They need a constant input of energy, and the ultimate source of energy for most ecosystems is sunlight. Plants convert this light energy into chemical energy, which they use as food. Animals cannot produce energy directly from the Sun. Instead, they must eat plants or other animals that eat plants to gain the chemical energy trapped in food. Once an organism has acquired its food, it can release the energy trapped at a cellular level in a process called **cellular respiration**.

energy the ability or capacity to do work

cellular respiration a process that occurs inside the mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

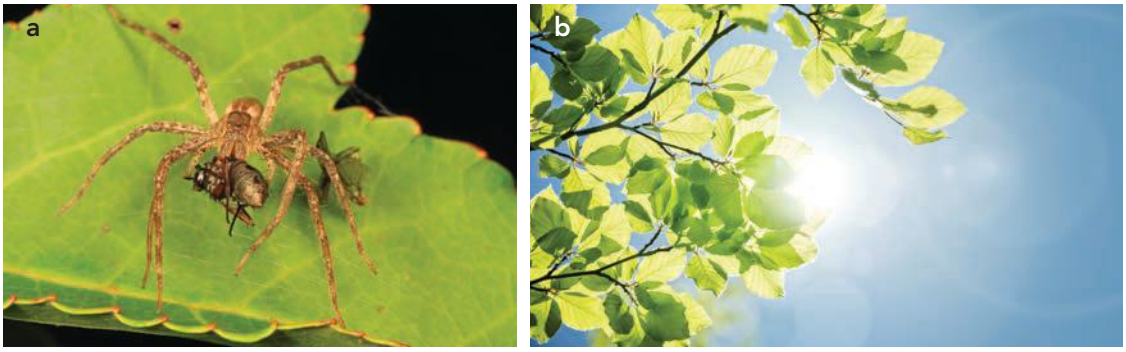


Figure 9.19 (a) The plant can convert light energy into its own food, but the spider must hunt for its own food. **(b)** All the energy in an ecosystem originally came from sunlight.

This is the cellular respiration word equation:

glucose + oxygen → energy + carbon dioxide + water

The energy produced in cellular respiration is used for all the processes in each living organism. Organisms use the energy to grow and reproduce, repair and replace their structures, and respond to their environment. A common mistake is to think that plants do not perform cellular respiration because they make their own food. In fact, they must do cellular respiration, otherwise the chemical energy in the food they produce would never get released.

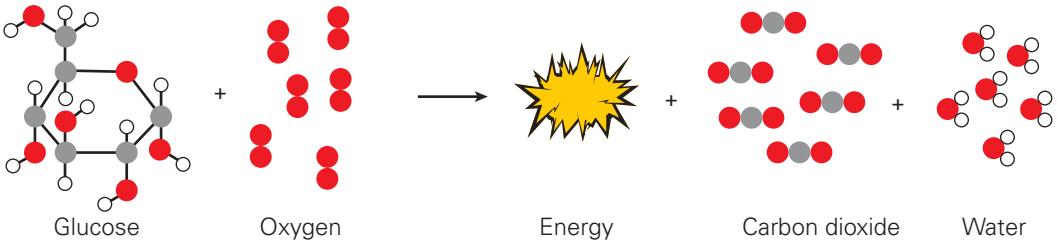


Figure 9.20 The process of cellular respiration

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Quick check 9.5

1. **Define** the term 'energy'.
2. **Explain** what energy is needed for.
3. **Explain** why cellular respiration is a necessary process carried out by all living things.
4. **Name** the inputs and outputs of the process of cellular respiration.

Producers

photosynthesis the process by which green plants, some protists and bacteria convert light energy into chemical energy in the form of sugars using carbon dioxide and water, and releasing oxygen

producer an organism capable of producing food from photosynthesis

Plants make their own food through **photosynthesis**. You will learn more about this in Chapters 5 and 8. Using the light energy from the Sun, water and carbon dioxide from the atmosphere and nutrients from the soil, plants chemically make their own food. Since they make their own food, they are called **producers**.

This is the word equation for photosynthesis:

carbon dioxide + water → glucose + oxygen

Plants then break down the sugars they produce to produce energy, which they use to grow, reproduce and repair themselves.



Figure 9.21 Plants will bend towards the light to increase the rate of photosynthesis.

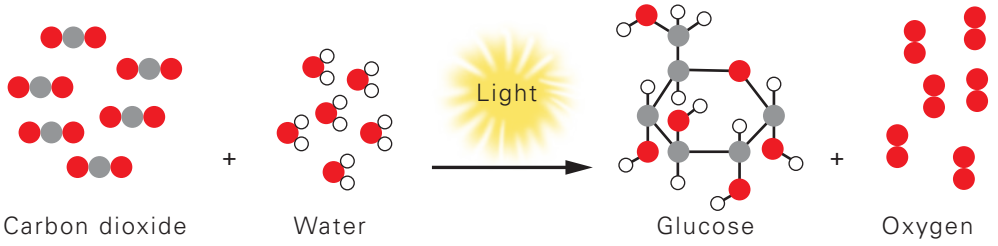


Figure 9.22 Photosynthesis

Quick check 9.6

1. **Discuss** why plants are called producers.
2. **Explain** why plants must carry out photosynthesis.
3. **Name** the inputs and outputs of the process of photosynthesis.

Consumers

consumer an organism that obtains food from consuming other organic material

herbivore an organism that eats only plants

omnivore an organism that is naturally able to eat both plants and animals

carnivore an organism that eats only meat

Organisms which cannot create their own food from sunlight must eat either plants or animals for energy. These organisms are called **consumers**. Some organisms get their energy from directly eating plants, while others will eat other animals that have already eaten plants. Organisms that eat only plants are called **herbivores**. Organisms that eat both plants and other animals are called **omnivores**. Organisms that eat only other animals are called **carnivores**.

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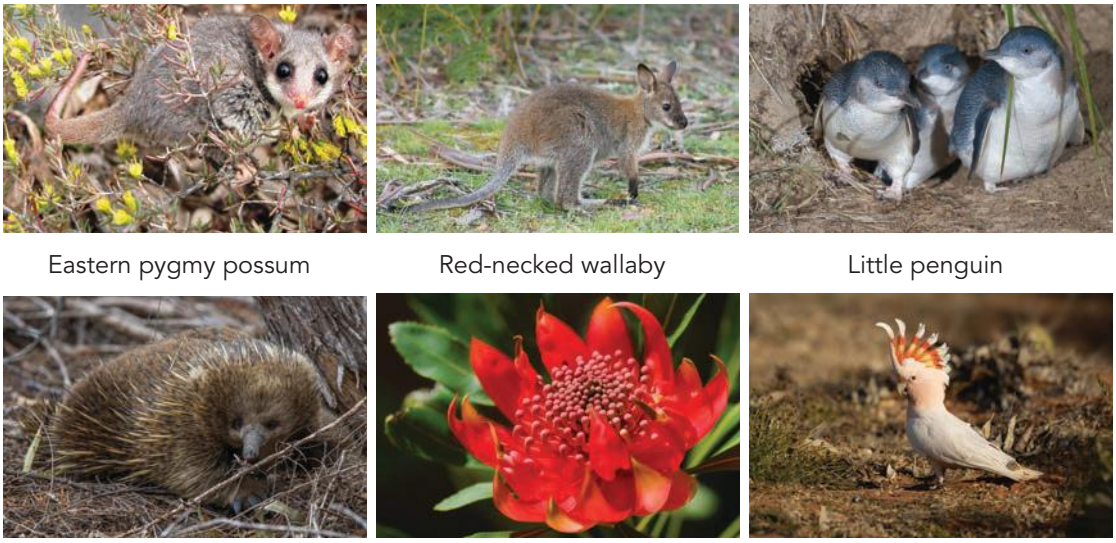


Figure 9.23 (a) Pademelons are herbivores. **(b)** Brush-tailed possums are omnivores. **(c)** Kookaburras are carnivores.

Try this 9.7

How do I get my food?

Complete some research and organise the organisms native to New South Wales in Figure 9.24 into producers, herbivores, carnivores or omnivores.



Eastern pygmy possum | Red-necked wallaby | Little penguin

Short-beaked echidna | Waratah | Pink cockatoo

Figure 9.24 Organisms native to New South Wales

Identifying types of consumer

One way that biologists can identify if a consumer is a carnivore, herbivore or omnivore is by looking at their teeth. Members of each type of consumer display similar features to others in that group.

Humans are natural omnivores, which means that we have evolved to eat both plants and animals. This is why we have a range of different teeth. At the front of our mouth are the incisors. These are sharp, flat, cutting teeth. They are used to bite or shear off pieces of food. Herbivores use these teeth to nibble away at plants and, as they are used constantly, they tend to wear down. Due to this, the incisors of animals like rabbits and wombats continue growing throughout their lives. Other herbivores such as cattle and sheep lack upper incisors. Instead, they cut grass with their lower-jaw incisors against a dental pad.

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The long, sharp, pointed teeth next to incisors are called canines. They are near the front of the mouth and are used to hold and tear at food. Carnivores have large, well-developed canines that they use to catch and kill their prey. Many herbivores lack canines as they do not hold and tear at the food they eat. Carnivores also have carnassial teeth, which are modified paired teeth that are used for shearing meat.

The flat teeth at the back of your mouth are known as pre-molars and molars. These teeth are for chewing and grinding and are found in herbivores, carnivores and omnivores. Herbivores have large, almost flat molars that allow them to grind plant material into very small pieces before swallowing.

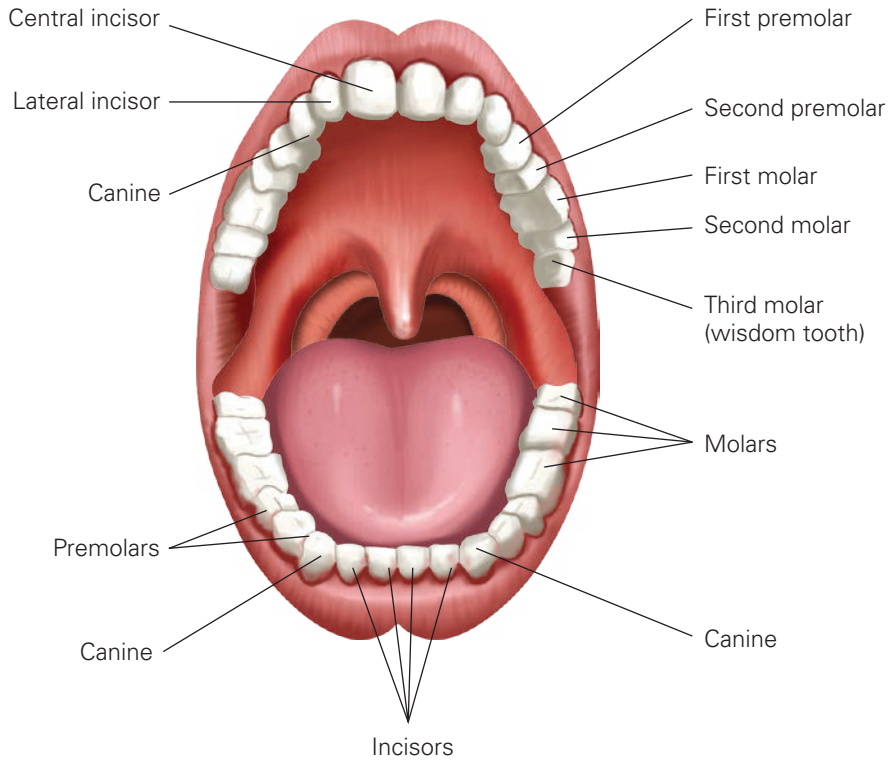


Figure 9.25 Human teeth identify us as omnivores.



Figure 9.26 The dental pad of a grazing animal

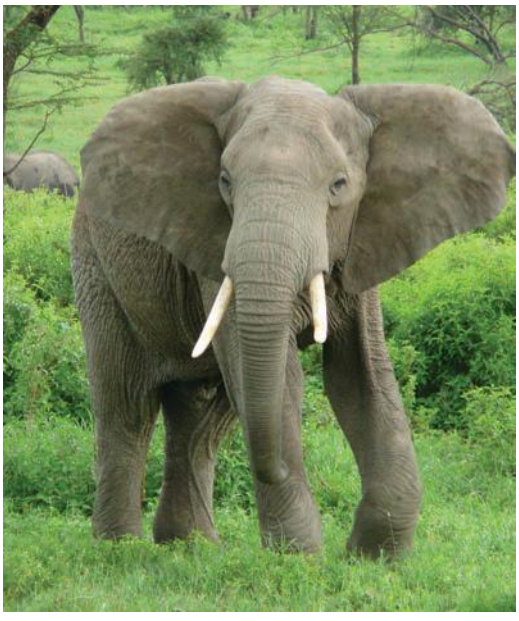


Figure 9.27 Elephant tusks are elongated incisors!

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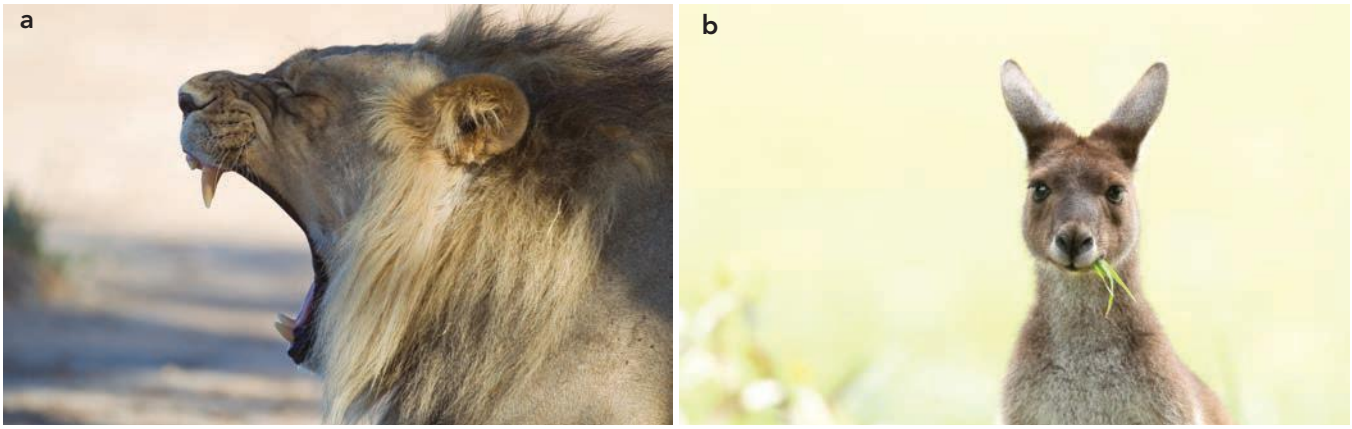


Figure 9.28 (a) Lion canines can grow up to 10 cm long. **(b)** The molars of kangaroos replace themselves when they wear down. They fall out and their rear molars move forward.

Try this 9.8

Animal teeth

Look at the animal skulls below. You may be able to identify some of the animals you see, but take on the role of a scientist and check their teeth. Do they have incisors? Canines? Molars? Can you confirm what the animal might eat and therefore have more evidence as to what the animal is? You may like to tabulate your observations and then compare with your classmates.



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Quick check 9.7

1. **Define** the term 'consumer' in your own words.
2. There are three main types of consumer.
   a. **Name** the three types.
   b. **State** what each group eats.
3. **Examine** the images in Figure 9.29 and for each determine:
   i. the type of teeth
   ii. the structure and function of the teeth
   iii. the animal types in which those kinds of teeth are found.



Figure 9.29 Images of animals with different types of teeth

Food chains: Who eats whom?

food chain
a sequence of living things that shows their feeding relationship and the flow of energy between them

Food chains show the feeding relationships in an ecosystem. Each organism is food for another organism – they are interdependent. The energy stored in an organism will be passed to the organism that feeds on it. The arrows show the flow of energy through the food chain.

An example of a simple food chain would be:

grass → mouse → hawk

Note that the arrows show the flow of energy from the grass into the mouse, and from the mouse into the hawk.

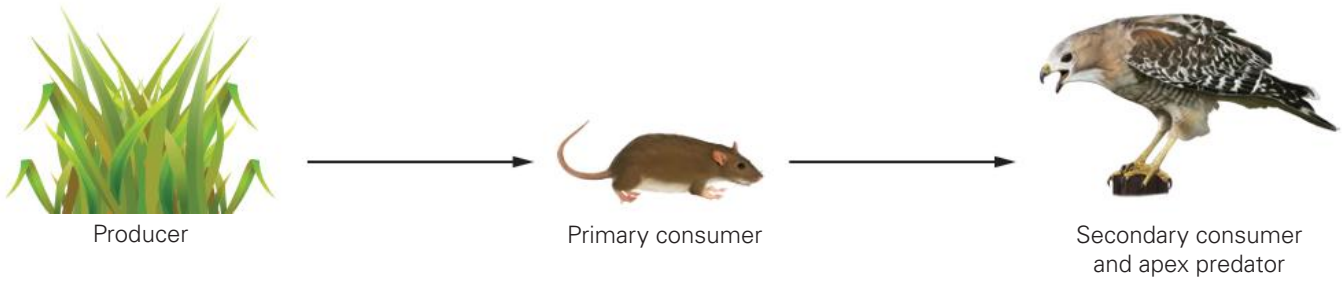


Figure 9.30 A hawk is an example of an apex predator as it has no natural predators.

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The food chain in Figure 9.30 introduces some new terms, which are explained in Table 9.5.

Term	Definition	Example
Primary consumer	The first consumer in the food chain that eats the producer and is therefore always a herbivore	Termites eat a wattle tree (producer)
Secondary consumer	A consumer that eats the primary consumer or herbivore. It is usually a carnivore, but it can sometimes be an omnivore.	Numbat eats the termites (primary consumer)
Tertiary consumer	A consumer that eats the secondary consumer	Dingo eats the numbat (secondary consumer)
Apex predator	A consumer at the top or end of the food chain that usually only has humans as a possible predator	Dingo

primary consumer an organism that eats plants

secondary consumer an organism that eats primary consumers

tertiary consumer an organism that eats secondary consumers

apex predator a predator at the top of a food chain

Table 9.5 Consumers can be classified into these groups, based on their position in a food chain.



VIDEO Australian apex predators

Figure 9.31 Numbats are an example of a secondary consumer.

Try this 9.9

What food chains can tell us

Consider the food chain below and answer the following questions.

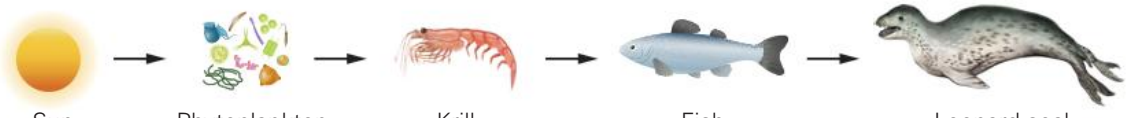


Figure 9.32 What does this food chain tell us?

1. State what the arrows show the flow of.
2. Identify where all the energy originally comes from.
3. Identify the producer, first consumer, second consumer, tertiary consumer and apex predator.
4. Identify the herbivore.
5. Predict what would happen if:
   - **a.** fairy penguins moved into the area and ate all the krill before the fish could get to it
   - **b.** a local commercial fishing company over-fished the area
   - **c.** chemicals running off farmland killed all the phytoplankton.

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Quick check 9.8

1. **Define** the term 'food chain'.
2. **Recall** where the Sun should go in a food chain and why.
3. Draw an Australian food chain of your choice and **identify** the producer, primary consumer, secondary consumer, tertiary consumer and apex predator.
4. **Recall** what sort of information you can find out from looking at a food chain.

WIDGET
Food web

Food webs

There are many different types of organisms in any habitat, and most communities are not made of single food chains. A **food web** is made up of interconnected food chains and represents multiple pathways through which energy can flow in an ecosystem. Although there are many food chains displayed in the food web in Figure 9.33, there is a maximum of four organisms in each food chain.

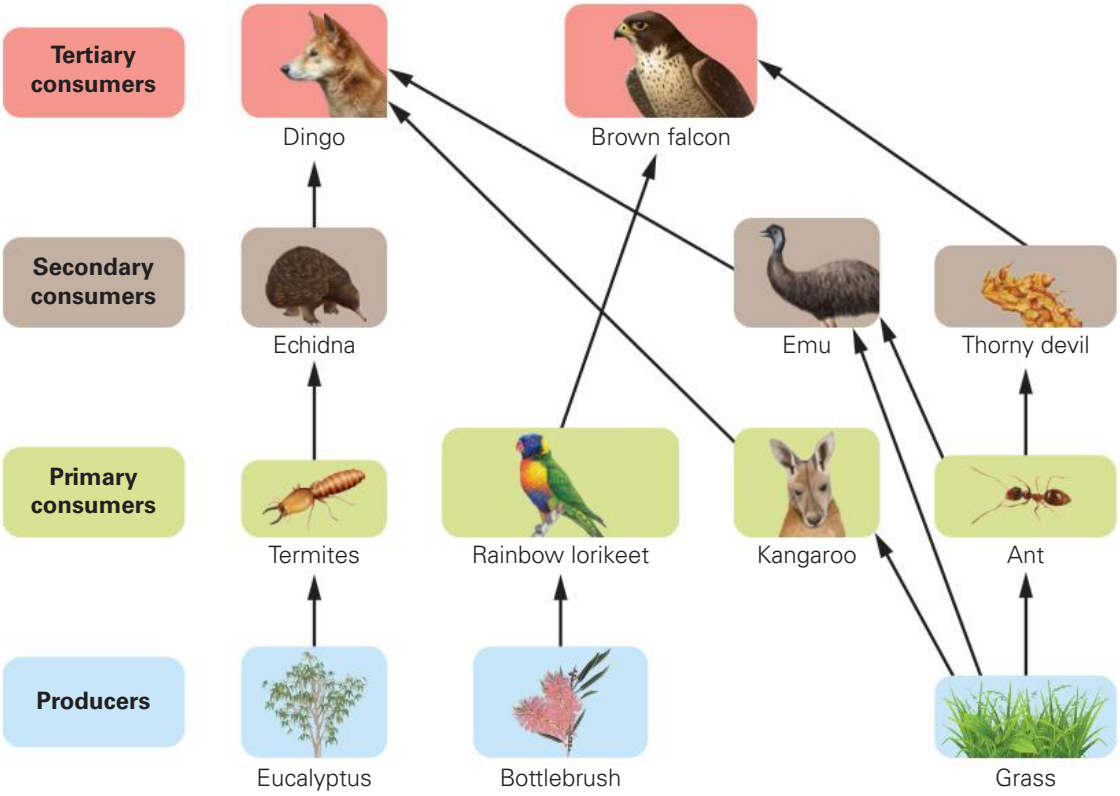


Figure 9.33 An example of an Australian food web

food web
a group of interconnected food chains

pyramid of numbers
a graphical representation that shows the number of organisms at each trophic level in an ecosystem

biomass
the total mass of all organisms under consideration in an area or trophic level, which may refer to certain species or all organisms

trophic level
an organism's level or position in a food web; it is based on an organism's feeding habits, where producers occupy the first trophic level

Pyramids

Pyramids of numbers and **biomass** can be used to show the relationship between different **trophic levels** in an ecosystem.

A pyramid of numbers depicts the number of organisms at each trophic level. The number of organisms decreases as you move up the pyramid, reflecting the smaller number of consumers at higher trophic levels.

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A **pyramid of biomass** represents the total mass of organisms at each trophic level. In most ecosystems, the biomass pyramid is upright, with the greatest biomass at the base (producers) and progressively smaller biomass at higher trophic levels. However, in some aquatic ecosystems the pyramid of biomass can be inverted, with the biomass of consumers exceeding that of producers. This occurs when the rate of reproduction of producers is very high compared to their biomass, such as in the case of phytoplankton in the ocean.

The number of organisms typically decreases as you move up the trophic levels. This is because energy flows in one direction up the food chain but is lost from each trophic level as it passes from the producers to each consumer. Typically, only 10% of the energy is passed on to the next trophic level and is therefore available to the next consumer population. This is known as the **10% rule**. It is a generalisation averaged across a population and should not be applied to individuals.

The rest of the energy is lost to the environment in the following ways:

- Energy undergoes cellular respiration and is lost as heat when the organism respires.
- Not every part of the organism is eaten. Roots and tough woody parts of plants, and the bones of animals, are not directly consumed.
- Consumers cannot digest all the food they eat (for example, cellulose in plants or the hair and fur of animals), so the chemical energy in this food is lost in **egestion**.
- **Excretion** causes energy to be lost in waste products. This means that there can only be a limited number of animals at the top of the food chain as there is less energy available for them.

pyramid of biomass
a graphical representation that illustrates the total mass of organisms at each trophic level in an ecosystem

10% rule
when energy is passed from one trophic level to another, only 10% of the energy will be passed on

egestion
the process of removing undigested waste material from the body in faeces

excretion
the process of removing metabolic waste from the blood via the liver, kidneys lungs and skin

energy pyramid
a graphical representation that shows the amount of energy available at each trophic level in an ecosystem

Did you know? 9.1

Hindgut fermentation

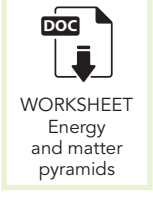
Members of the Lagomorpha family such as rabbits and hares are herbivores, eating mostly grass. However, this cellulose-rich diet is difficult to digest, and so a lot of energy is lost in their faeces. The animals can access this energy though, with a special type of digestion called hindgut fermentation. In short, they eat their own faeces and digest it a second time to maximise the energy they can get! If you ever spot any rabbit droppings, you may notice that there are two different types: small round black ones, and bigger softer ones. The bigger ones are called cecotropes and are the ones that are eaten.



Figure 9.34 Rabbits eat their own cecotropes.

This flow of energy can be shown in an **energy pyramid**, which is a graphical representation showing the energy available at each trophic level in an ecosystem. The pyramid is widest at the base, representing the large amount of energy in the producers, and narrows toward the top, indicating the decreasing energy levels as it moves up through consumers.

Figure 9.35 shows an energy pyramid. Note that the kilojoule (kJ) is used as it is the SI unit of energy. Some sources in ecology use kilocalories (kcal), where 1 kcal = 4.18 kJ to two decimal places. It is common to use energy per unit area, kJ/m^2, and quoted figures are usually given for one year, so you will see kJ/m^2/year in some sources.



WORKSHEET
Energy and matter pyramids

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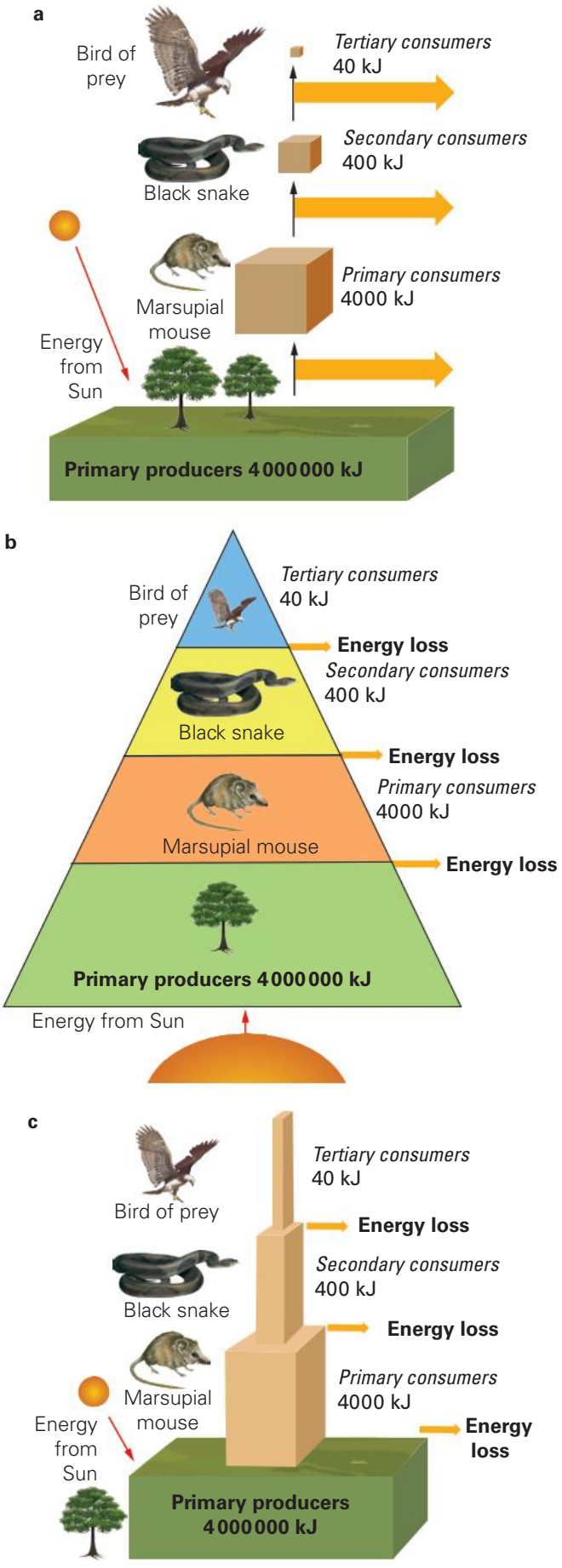


Figure 9.35 Three different types of energy pyramid showing the energy flow and loss through a food chain. **(a)** Blocks representing energy are added to a food web. **(b)** A simple energy pyramid. **(c)** An energy pyramid of blocks. The sizes of the blocks in panels **(a)** and **(c)** are proportional to the energy in each level. The levels in the simple pyramid in panel **(b)** aren't sized in proportion to the energy, but sometimes the height of the levels do relate to the amount of energy. All three types of pyramid could be used to show numbers or biomass instead of energy.

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Try this 9.10

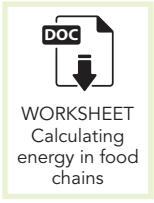
Ecosystem pyramids

Create a written text explaining how pyramids can be used to demonstrate the amount of energy or matter present at each trophic level in an ecosystem.

Quick check 9.9

1. **Explain** what a food web is.
2. **Recall** what organisms need energy for.
3. **Describe** how energy is lost from an organism or a food chain.
4. **Summarise** what you notice about the amount of energy that is passed on from the producers to the primary consumers and from the primary consumers to the secondary consumers.
5. *Challenge question*: Using Figure 9.35, **calculate** how much energy is passed on at each trophic level as a percentage of the original amount of energy.

Worked example 9.1



WORKSHEET Calculating energy in food chains

Calculating energy in a food chain

Use Figure 9.35 to answer the following questions.

a. If the black snake population consumes energy at the rate of 350 kJ/m²/year, calculate how much energy would be available to the bird of prey population per year.

b. Calculate how much energy was originally available to the marsupial mouse population from the producers.

Working	Explanation
a. energy for bird of prey population = 10% × 350 kJ/m²/year $= \frac{10}{100} \times 350$ kJ/m²/year OR 0.1 × 350 kJ/m²/year = 35 kJ/m²/year	By the 10% rule, only 10% of 350 kJ/m²/year will be available to the bird of prey population.10% is equivalent to $\frac{10}{100}$ or 0.1.
b. 350 kJ/m²/year = $\frac{10}{100}$ × energy for marsupial mouse population energy for marsupial mouse population = $\frac{100}{10} \times 350$ kJ/m²/year = 10 × 350 kJ/m²/year = 3500 kJ/m²/year	If the black snake population had 350 kJ/m²/year available, and that was 10% of what had been available to the marsupial mouse population, then the marsupial mouse population would have had 3500 kJ/m²/year available to it.

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Try this 9.11

Food web model

Model the flow of energy in food webs from producer to consumers using the following materials:

- photos of producers, primary consumers, secondary consumers, tertiary consumers and apex predators, in the normal ratio of these types of organisms in the wild
- different coloured balls of yarn
- scissors

Procedure

1. Each student will be allocated a photo.
2. Stand in a circle as a class. A student with a photo of a producer will take the end of the piece of yarn. The piece of yarn will represent the flow of energy along the food chain.
3. The producer should choose what primary consumer it wishes to be eaten by and pass that person the ball of yarn. (The producer should keep hold of the end of the yarn.)
4. The primary consumer will then choose the secondary consumer they wish to be eaten by and pass them the ball of yarn.
5. Repeat this process with the secondary consumer.
6. When the yarn reaches the apex predator, cut it, but each person in the chain should keep hold of it.
7. Take a photo each time a food chain is made, so that the development of the web can be seen.
8. Start a new chain by using a new piece of yarn in a different colour. Try to pick different organisms at first, but you can also re-use organisms. Repeat this process many times, starting with different producers.
9. A complex web will form between you and your classmates.
10. Discuss the complex nature of the food web you have produced as a class.
11. Ask one organism in the food web to 'die' by dropping the string. Discuss as a class the effect that the loss of that organism from the ecosystem would have on the remaining organisms.

Discussion

1. Follow one of the threads of yarn and write down a food chain.
2. Describe the effect that removing a producer from this food web would have.
3. Explain why an ecosystem with many types of organisms would be able to cope with the loss of one species.
4. Critique whether your model of a food web accurately depicts a real ecosystem.
5. Propose one way in which this model could be improved.


INVESTIGATION

Explore! 9.3

How Tasmanian devils can change ecosystems

The dingo is Australia's largest carnivorous mammal, first appearing on the mainland between 5000 and 3500 years ago. During this time, the Tasmanian tiger and Tasmanian devil, two marsupial predators, went extinct from the mainland but remained on Tasmania, somewhere the dingoes never colonised. This suggests that dingoes probably contributed to the extinction of these marsupial predators.



Figure 9.36 In Queensland, the dingo is a restricted invasive animal.

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Dingoes are widely regarded as pests in Australia because they prey on livestock, so their populations are often managed using poisoned bait, trapping, and shooting. There is some evidence that reducing dingo populations can affect other species.



Figure 9.37 Tasmanian devils are ecosystem engineers that restore and rebalance ecosystems, benefiting other native wildlife.



Figure 9.38 European colonisers tried to introduce foxes to Tasmania and failed every time, possibly because Tasmanian devils were already established there.

A reduction in dingo numbers has been connected to increases in the abundance of invasive predators such as the red fox and feral cat (known as **mesopredators**). It has also led to increases of herbivores like kangaroos and wallabies that consume large amounts of vegetation. This then causes a decline in small and medium-sized native mammals due to increased mesopredator predation and reduced food supply. Research suggests that cats kill more than 2 billion wild animals in Australia each year. One study estimated that in just a single day, Australian cats kill 1.3 million birds, 1.8 million reptiles and over 3.1 million mammals.

mesopredator a predator in a mid-ranking trophic level, which usually hunts smaller animals

rewilding the process of protecting an environment and returning it to its natural state, for example by bringing back wild animals that used to live there

In 2020, 26 Tasmanian devils were reintroduced to the mainland at Barrington Tops, New South Wales, and it is suggested that they can be used as an alternative apex predator and will deter or disrupt the hunting of mesopredators. They are not as great a threat to livestock as dingoes, but by competing directly with feral cats and foxes, they have positive effects on smaller mammals. Native mammals enrich soil, increase plant diversity and disperse seeds, helping forest regeneration. As scavengers, Tasmanian devils can also help keep ecosystems free from disease, and by burying leaf litter, they help reduce fuel loads, and make bushfires less intense.

The reintroduction of Tasmanian devils to the mainland may also save the endangered species. Their population has been devastated over the past few years due to devil facial tumour disease (DFTD), an infectious cancer. It is hoped that by **rewilding** disease-free individuals, the species may again thrive on the mainland.

Research the ecosystem changes that may be brought about by the reintroduction of Tasmanian devils.

1. Name four organisms that are affected by the presence of dingoes.
2. Explain why foxes were never successfully introduced to Tasmania by European colonisers.
3. Explain why Tasmanian devils are described as 'ecosystem engineers'.
4. 'The impact of producers on an ecosystem is greater than that of apex predators.' Evaluate this statement and give your opinion.



DEPTH STUDY IDEA
Investigate rewilding in Australia

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VIDEO
Recycling in the deep ocean

Detritus food chains

You already know consumers get their energy from producers or other consumers, and that producers get their energy from the Sun. This is the basis of the green food web, which is based on energy initially gained from green plants.

Any energy that is within an organism is not trapped in it forever. The energy is passed to the next trophic level when the organism is eaten, but some parts of the organism and the organism's waste may not be eaten. This material, as well as dead organisms, becomes detritus and starts the brown or detritus food chain.

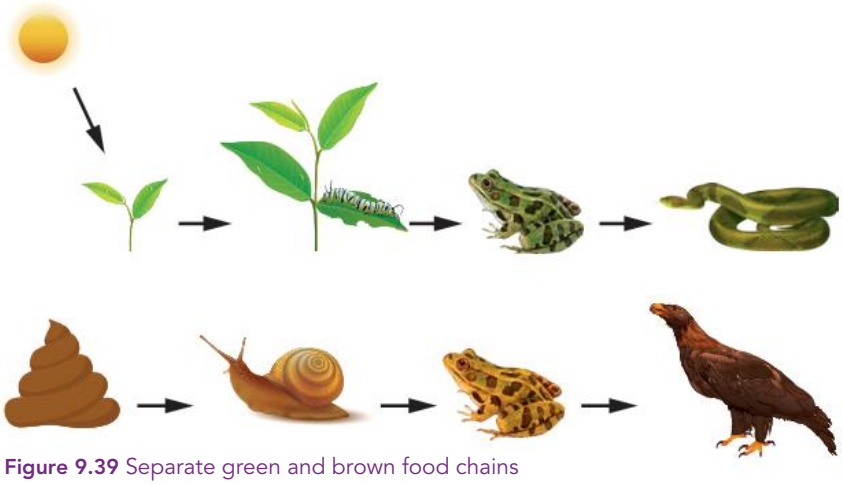


Figure 9.39 Separate green and brown food chains

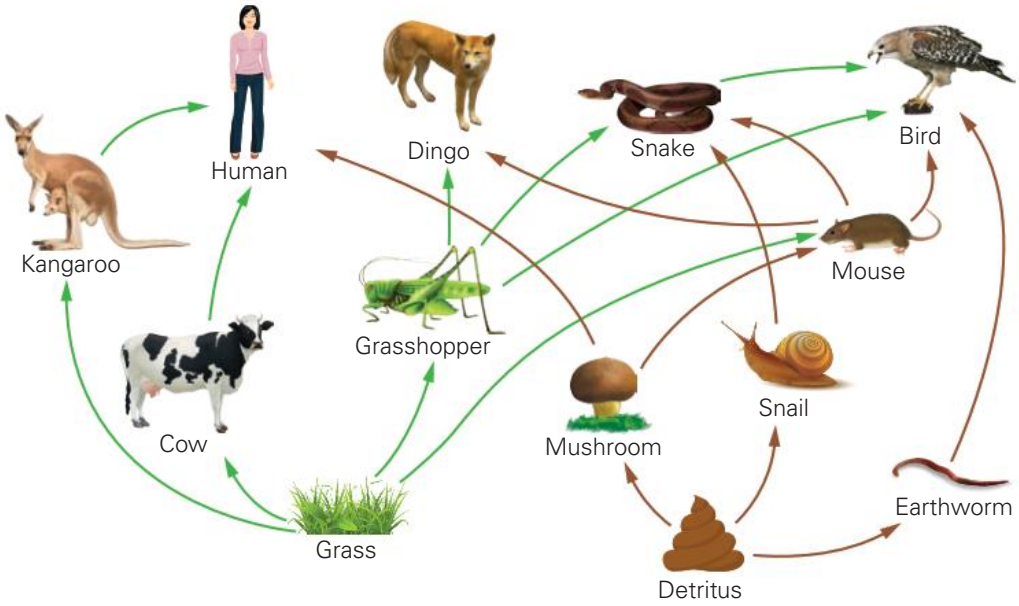


Figure 9.40 Combined green and brown food webs

scavenger an organism that feeds on dead animals that it has not killed itself

detritivore an organism that feeds on dead or decaying organic matter

decomposer an organism such as a bacterium or fungus that breaks down organic material

All living things within an ecosystem can therefore fall into three categories:

- organisms that make their own food (producers)
- organisms that eat other living organisms (consumers)
- organisms that contribute to recycling dead and waste material (**scavengers**, **detritivores** and **decomposers**).

The brown food chain is directly linked to the green food webs found in every ecosystem. When detritus is included in a food web diagram, it shows the complex and important interactions that decomposers have in an ecosystem (see Figure 9.40).

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Scavengers

Scavengers start the recycling process of dead animals. They don't directly kill their prey; instead they eat carrion, or animals that have been killed by other predators. Normally, they don't eat things that have been dead for a long time but do use their heightened sense of smell to locate carrion. They may also follow predators and feed on their leftovers.

Scavengers can be found anywhere in the world – on land and in marine environments. In Australia, they include monitors (carnivorous lizards), spotted-tail quoll, dingoes and Torresian crows. The role of scavengers is vital for any ecosystem as they contribute to the decomposition process by breaking down carrion into smaller pieces.

Detritivores

Detritivores are also involved in recycling nutrients. They have mouthpieces that help speed up decay by ingesting detritus, which they then digest and egest. These smaller-sized pieces increase the surface area available for decomposers to break down. Detritivores include beetles, flies, slugs, snails and earthworms. Marine detritivores include crabs, lobsters, sea stars and sea cucumbers.



Figure 9.41 Examples of detritivores: **(a)** woodlice, **(b)** fiddler crabs and **(c)** dung beetles

Decomposers

Decomposers gain their energy by breaking down already-dead organisms. Bacteria and fungi are examples of decomposers. Often **microorganisms**, they secrete chemicals called enzymes that break down the dead organisms and can then absorb the products. When decomposers break down organic matter, nutrients are released back into the soil, which plants then use to grow. This then supports a new green food chain.



Figure 9.42 Decomposition provides the nutrients to support new life.

microorganism an organism that can only be seen through a microscope

Quick check 9.10

1. **Define** the terms 'scavenger' and 'decomposer'.
2. **Define** the term 'detritivore'.
3. **Explain** why plants rely on decomposers.
4. **Distinguish** between detritivores and decomposers.

WORKSHEET Decomposers and scavengers

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Section 9.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 9.3 questions

Remembering

1. **State** how the flow of energy is represented in a food chain.
2. **State** the process by which plants produce their own food.
3. **Name** the components that plants need to make food.

Understanding

4. **Define** these terms.
   - **a.** Carnivore
   - **b.** Herbivore
   - **c.** Omnivore
5. **Outline** why all food chains must contain a producer.
6. **Describe** why decomposers are an important part of an ecosystem.

Applying

7. Look at the food web in Figure 9.43.
   - **a.** **Identify** and **draw** three food chains in the food web.
   - **b.** **List** the producers and apex predators based on the diagram.
   - **c.** **State** the organisms that dingoes eat.
   - **d.** **Name** any organisms that are secondary and tertiary consumers.
   - **e.** **Describe** the impact on this ecosystem if a fungus killed all the grasses.

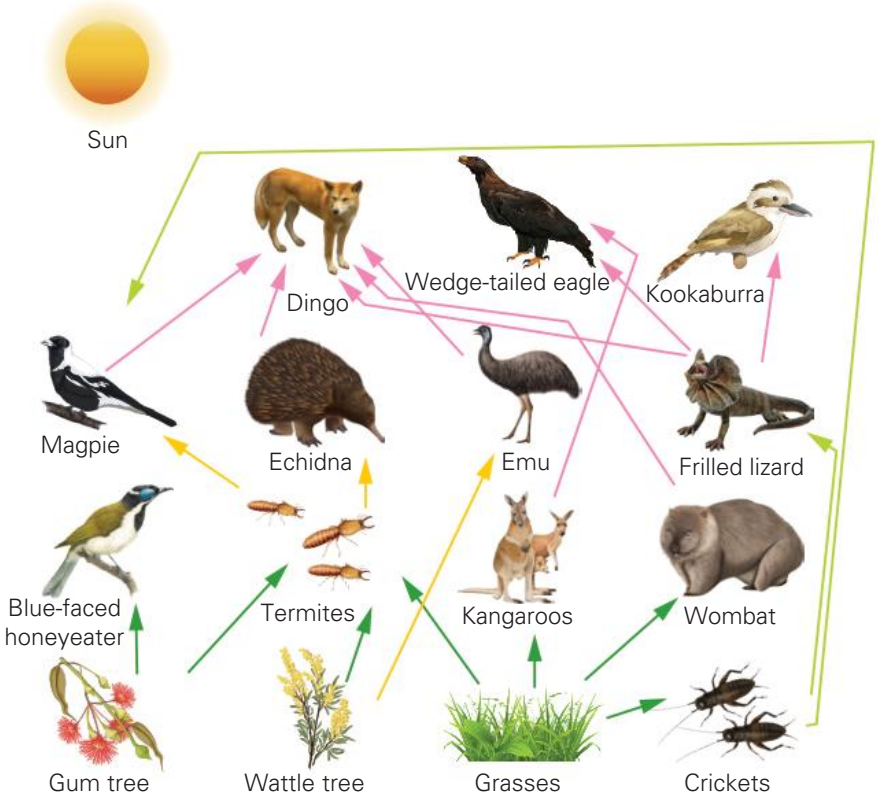


Figure 9.43 A food web

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8. A brown food chain that could be found on a coral reef is:
   detritus → snail → small fish → sea turtles.
   Classify each of the organisms in the food chain as decomposer, primary consumer or secondary consumer.

Analysing

9. **Compare** a herbivore to an omnivore.
10. **Distinguish** between food chains and food webs and then determine why food webs are more useful to scientists.
11. Look at the ecosystems in Figure 9.44 and decide which one is more likely to survive an environmental disaster. **Explain** your choice.

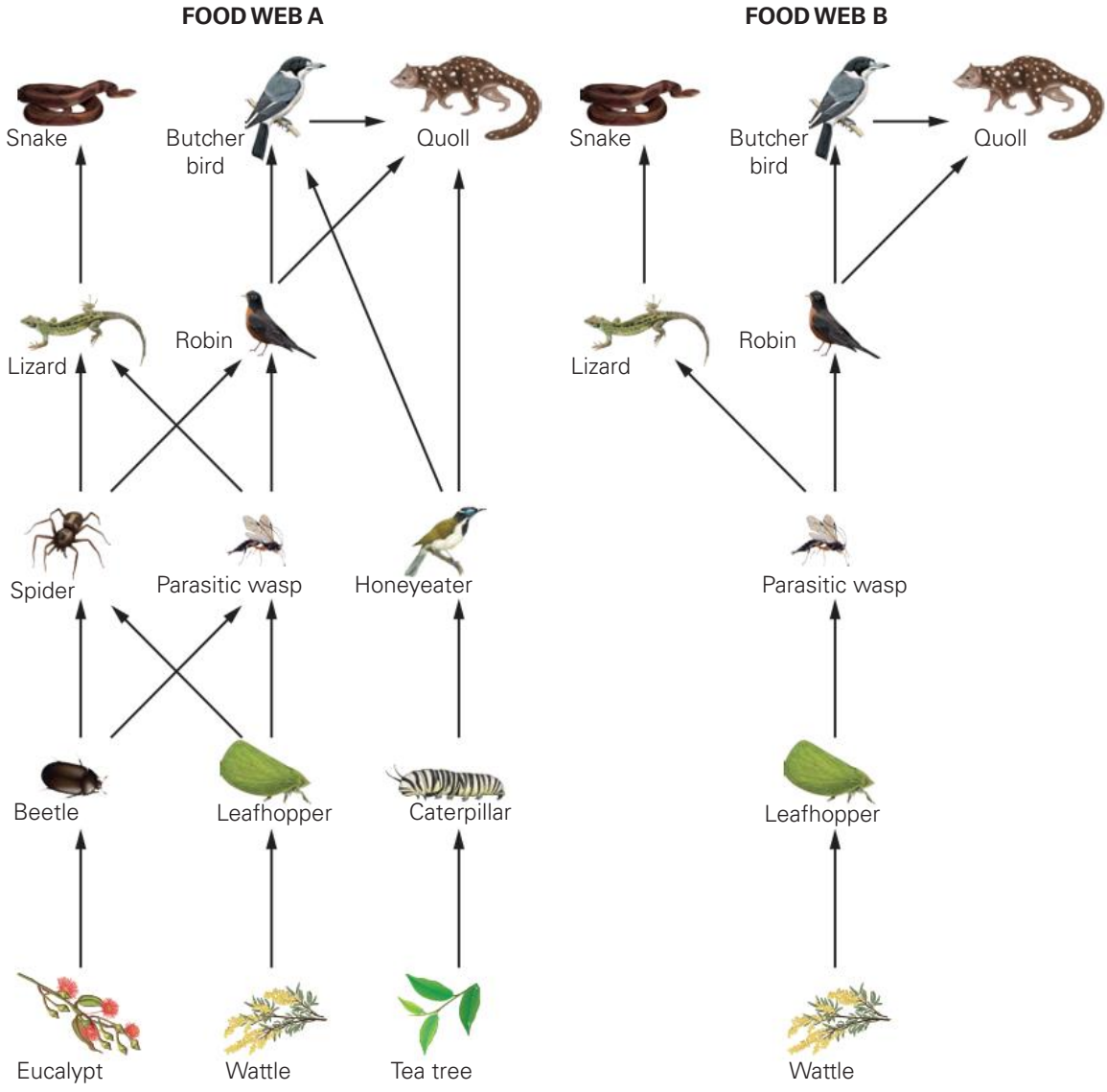


Figure 9.44 Two different ecosystems support these two food webs.

12. **Distinguish** between a decomposer and a detritivore.

Evaluating

13. **Propose** a reason that a herbivore would not be able to eat meat easily.
14. **Predict** two effects of removing a predator from a food web.
15. **Predict** how a food web would change if all the decomposers in an ecosystem died. Give reasons for your decisions.

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9.4 Population decline and extinction

WORKSHEET
Human impact on ecosystems

Learning outcomes

At the end of this section, I will be able to:

1. investigate and describe factors that threaten biodiversity and lead to a species becoming endangered or extinct.
2. examine examples of the impact of the introduction of a new (invasive) species to an ecosystem.
3. explain why Australia has some of the world's highest rates of species population decline and extinction.

Population decline and extinctions is an area that should be considered within the overall context of biodiversity (introduced at the beginning of this chapter).

Threats to biodiversity

Thirty-eight key threatening processes are identified that can negatively impact New South Wales's biodiversity (2018 NSW Government report *Saving our Species: Key Threatening Processes Strategy*). Alongside climate change, the most significant are:

- invasive species
- habitat change
- disease
- altered fire regimes
- pollution.

VIDEO
Causes of bushfires

These threats not only endanger individual species but also increase the risk of **extinctions**, particularly on a small-scale level.

extinction
the complete disappearance of a species or group of organisms from Earth

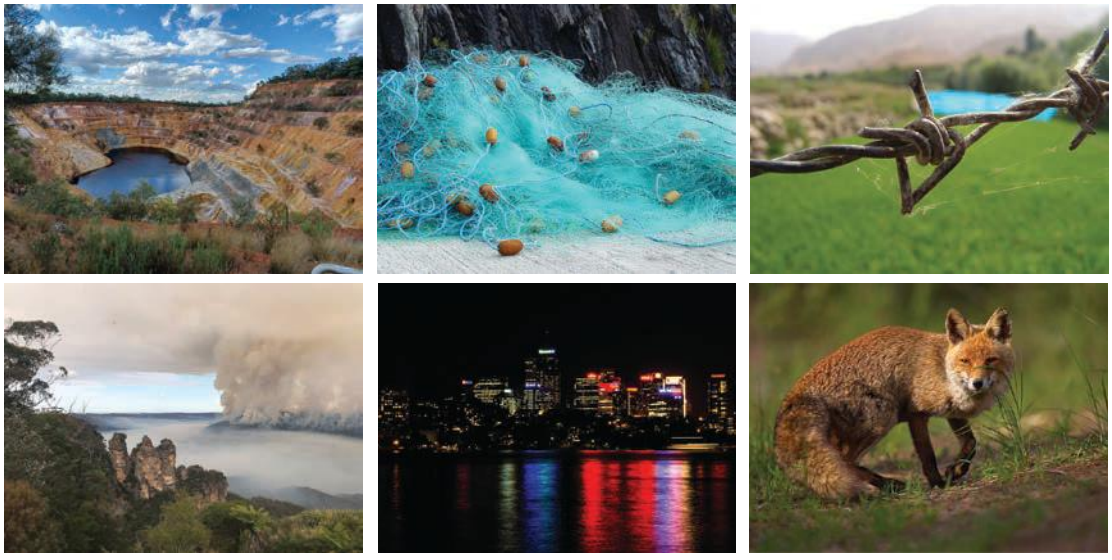


Figure 9.45 Can you identify some of the threats to New South Wales's biodiversity?

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Explore! 9.4

INVESTIGATION

Sustainable harvesting practices

Populations of dugong (*Dugong dugon*) and green turtle (*Chelonia mydas*) have suffered global population declines due to threats including boat strikes, marine pollution and habitat loss. The species are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.



Figure 9.46 The dugong is an important food source for certain groups of Aboriginal and Torres Strait Islander Peoples.

For many Aboriginal and Torres Strait Islander Peoples, turtle and dugong are culturally significant and are an important source of protein. Traditional Owners hold a cultural responsibility to manage the impacts of human activity on the environment and have sustainably hunted the species for thousands of years. Dugong and turtle are hunted at specific times in their lifecycle, using knowledge about population density and dynamics to ensure populations remain sustainable and are protected for future generations.

Investigate how the dugong bone mounds of the Western Torres Strait islands may have supported sustainable harvesting practices.

Investigation 9.3

Analysing biodiversity at your school

Be careful
Try to avoid biting and stinging insects.

Aim

To compare the biodiversity of two different areas in the school grounds.

Background information

INVESTIGATION

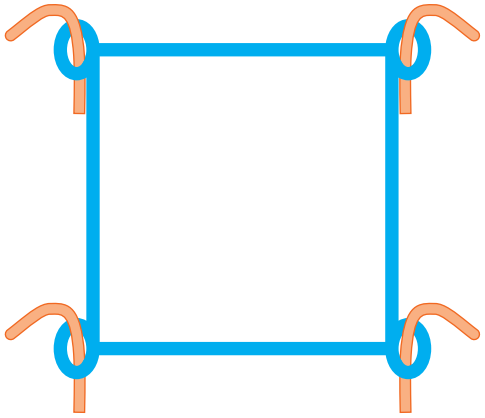
Biodiversity is a measure of how many different species live in an area and whether these species are equally abundant in numbers, or if one species dominates with a comparatively larger number of individuals. Healthy habitats have a higher biodiversity index. One biodiversity index that can be used is called the Menhinick index. It can be calculated using the following equation. Higher numbers indicate higher levels of biodiversity.

$$\text{Menhinick biodiversity index} = \frac{\text{number of species in survey area}}{\sqrt{\text{total number of individuals}}}$$

For example, in a survey recording 26 individual invertebrates belonging to five different species, the biodiversity would be biodiversity index $= \frac{5}{\sqrt{26}} = 0.98$

Materials

- Invertebrate identification key
- magnifying glass
- quadrats, if available, or if they are unavailable:
- four tent pegs and 4.5 m of fine stringline with loops tied every metre (the tent pegs must be able to fit through the loops). A one-metre quadrat can be created by pegging out the stringline into the shape of a square. Push the tent pegs through each loop to pin the corners to the ground.



continued ...

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Procedure

1. Choose two different survey areas to assess within the school grounds, such as a grassy area and a garden.
2. Take all equipment to the first survey area.
3. Randomly choose a spot to place your quadrat.
4. Take photos of any invertebrates you record. This will help you to later identify any species you cannot name.
5. Repeat steps **3** and **4** in another four random spots.
6. Move to the second survey area and repeat steps **3**–**5**.

Data Analysis

1. Develop a table to record the data from each survey area. Include a place to record the survey area, type of invertebrate and number of individuals.
2. Identify any unknown invertebrates using an invertebrate identification key. Record this data in the table.
3. Count the number of each invertebrate. Record this data in the table.
4. Calculate the total number of individual invertebrates found in each survey area.
5. Calculate the Menhinick biodiversity index (how biodiverse an area is) for each survey area by using the equation on the previous page. Show your working for each area.
6. Record the level of biodiversity for each survey area in the table.
7. Contrast the Menhinick biodiversity index results for the two areas.
8. Identify the survey area that would be considered more biodiverse.
9. Discuss the reasons for any differences found when comparing the two survey areas.

Peer review

1. Swap your data with another group to give each other feedback on how easily the table can be used to compare the two survey areas. Your feedback should discuss the following:
   - how well the table is organised to compare the two survey areas
   - how clearly the biodiversity calculations have been written
   - any other suggestions to improve the quality of the data presented in the table.
2. After receiving feedback, make alterations to the table to address the identified issues and write up a final copy to present to the class.

Discussion

1. Compare the level of biodiversity calculated by each of the other groups. Determine how much variation was found between different group results.
2. Compare the different types of species found in each survey area with other groups. Identify species that were not found consistently in each survey area.
3. Discuss if the biodiversity of the two survey areas can be reliably compared, based on your response to the previous question.
4. Decide upon some changes that could be made to the method to improve the quality of the data in future experiments.
5. The equation only takes into account the number of different species, instead of the number of different species and their abundance. Complete some research to find a better equation that can be used to determine the level of biodiversity.

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Try this 9.12

Building reserves for biodiversity

There are approximately 900 national parks and reserves in New South Wales. When building reserves for biodiversity conservation purposes, it has been suggested that larger reserves in more isolated locations may be better than multiple smaller ones.



Figure 9.47 Iluka Nature Reserve is a 136-hectare site. It preserves the largest stand of littoral rainforest in New South Wales.



Figure 9.48 Yathong Nature Reserve is a 115 604-hectare reserve established in 1971. A number of rare plant species can be found here, and it is one of the few places in the world where the mukarrthippi grasswren lives.

Examples of threats to biodiversity in New South Wales

Table 9.6 gives some examples identified in New South Wales.

Threat type	How it causes population decline	Example and origin
Invasive species	Competition	Noisy miner: a native bird that is better adapted to human-modified habitats and drives out other native birds in urban areas, parks and gardens
	Predation	Fox: introduced by colonial settlers, preys on native animals
		Lantana: introduced by colonial settlers
		Competes for nutrients and sunlight with native plants
Habitat change	Reduces the availability of food, shelter from weather or predators and space for breeding or living. It can also alter temperature, pH, water or sunlight, or impact symbiotic relationships.	Land clearing and deforestation lead to the loss of native vegetation, which serves as food and habitat for native species. This is driven by human activities such as agriculture, forestry, mining and construction, which increase competition for resources.
Disease	Introduced pathogen kills native species that have little resistance due to lack of exposure	Amphibian chytrid disease is a fungal infection affecting native frogs. The pathogen spreads through human activities, such as exotic animal export and travel.

Table 9.6 Examples of threats to biodiversity in NSW that contribute to population decline

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Altered fire regimes	Larger and more devastating bushfires	Native vegetation and wildlife are adapted to regular, low-intensity bushfires. However, poor land management and climate change have led to a dangerous build-up of fuel, resulting in more intense fires that severely threaten biodiversity.
Pollution	Contaminating habitats, reducing water quality and impacting the health of organisms	Pollution from chemicals, plastic waste and runoff into waterways harms native species and disrupts ecosystems.

Table 9.6 *(continued)*



Explore! 9.5

Threats causing population declines in NSW

Research an example of a biodiversity threat causing a decline in a population in New South Wales. To find an example, search online for an update to the NSW Government report *Saving our Species: Key Threatening Processes Strategy* and consult the list of key threats. Include in your report the species being harmed, the cause and scale of the problem, along with proposed remedies.

invasive species an organism that is not native to an environment and causes harm to native organisms

biological control the practice of introducing an organism into an ecosystem with the intention of limiting the spread of another organism

calicivirus a disease that damages a rabbit's internal organs and can cause bleeding

Invasive species

An **invasive species** is an introduced non-native organism that overpopulates and harms its new environment. The introduction of the species is usually done accidentally, but sometimes it is done on purpose. Australia has many invasive species such as foxes, camels, rabbits, goats, and feral cats and pigs. All these species were introduced by European colonists for hunting, farming or to make Australia feel more like Europe. Invasive species are one of the largest threats to Australian ecosystems, and sometimes another species can be introduced to help control the invasive species population. This is known as **biological control**. Biological control uses the natural enemies of the invasive species. They can be bacteria, fungi, viruses or even parasites or predators.



Explore! 9.6

Controlling rabbit populations

Rabbits were introduced to Australia in 1859 by a grazier in Victoria. They are considered a major pest, so much so that landowners in New South Wales are obliged to control rabbit populations on their land. In 1996, the **calicivirus** was introduced as a biological control, to reduce the massive rabbit population. However, some rabbits were immune to the virus, and foxes (another pest) had now lost a food source and so were eating native wildlife instead. Go online to investigate the following.

1. Find out about the rabbit-proof fences built in Western Australia in the 1900s, as shown in Figure 9.49. Report on how they were used to try to limit the spread of plagues of rabbits.
2. Find out about the myxoma virus and its release in Australia in 1950 in an attempt to control the rabbit population. Summarise your findings.

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Figure 9.49 Rabbit-proof fences were built to try to limit the devastation caused by rabbits. When completed, the rabbit-proof fences stretched 3256 km.

Disastrous control

The cane toad originally comes from Puerto Rico but was brought to Australia in an attempt to manage beetles that were eating sugar cane crops in Queensland. The cane toad had been introduced to Hawaii for the same purpose with no issues. However, after they were released in the sugar cane plantations of north Queensland in 1935, their population exploded, and they quickly became a huge pest. Cane toads have many ecological impacts such as competing with native species for food and space. They are also poisonous and so kill any predatory native species that eat them, such as quolls, snakes and crocodiles.



Figure 9.50 The cane toad was originally introduced as a biological control but is now considered a pest.

Effective control

Not all examples of biological control in Australia have gone wrong. In 1840, European settlers brought a cactus known as the 'prickly pear' to Australia to use as a food source for a beetle that produced a red dye to produce soldiers' uniforms. The cactus thrived in Australia and soon infested 30 million hectares around Brisbane. Research was undertaken to find an insect that could feed on the prickly pear, and after a global search, the cactus moth (*Cactoblastis cactorum*) was introduced as a biological control.

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In less than ten years, it was estimated that the larvae of the moth had consumed 1.5 trillion kg of cactus! Another benefit of the moth is that when there is no cactus left, it dies off because the cactus is its only food source. Several years after the introduction of the moth, the cactus population was under control, even though it is still around today in smaller numbers. Aboriginal and Torres Strait Islander Peoples may use cool fires to control the growth of invasive species such as African lovegrass (*Eragrostis spp.*) and lantana (*Lantana camara*).



Figure 9.51 Prickly pear plant

Did you know? 9.2

Stress, wash and eat

citizen scientist a member of the public that assists a professional scientist by voluntarily collecting data relating to the natural world

The Australian white ibis are well known for feeding on food thrown away by humans, but they may well be developing a taste for something else. **Citizen scientists** have reported that ibis will use a 'stress and wash' technique so they can eat toxic cane toads.

The ibis will pick the cane toad up by the neck and throw them about. This stresses out the toad, causing it to release a toxin called bufotoxin from the parotoid glands located around the neck. This is a normal defence response to any predator, and the thick, milky toxin easily sticks to the inside of an animal's mouth. That toxin is then absorbed into the body where it can lead to serious complications or even death.

Ibis have learned how to avoid the toxin though: after stressing the toads out so they create the bufotoxin, the ibis will then wash them in a creek, before swallowing them whole.



Figure 9.52 The Australian white ibis may be the answer to the cane toad crisis.

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Aboriginal and Torres Strait Islander Peoples' land management

With our dry climate, bushfires are one of the most dangerous and threatening events that can happen to an ecosystem. However, they also play an important role in maintaining biodiversity. Aboriginal and Torres Strait Islander Peoples have managed land with fire for millennia for cultural purposes such as hunting, ceremony and Caring for Country.

Firestick farming, cultural burning or cool burning involves low-intensity burns carried out regularly to clear undergrowth. For thousands of years, Aboriginal and Torres Strait Islander Peoples have used cool burning to promote plant growth. The effective use of cool burns changes vegetation structure by reducing the density of plants like casuarina. Some plant species also require burning to activate their seeds.

Firestick farming clears undergrowth, creating vast grasslands on high-quality soil, resulting in animals directly grazing in the area and being hunted for food. Before European invasion, the careful selection of where and when burning occurred also resulted in a mosaic of trees and grasslands, preventing dangerous wildfires in eucalyptus forests.

The slow-burning nature of these fires allowed any animals hiding in burrows to come out into the open. With animals no longer in their burrows and less vegetation for them hide behind, people were able to hunt easily.

With the arrival of Europeans, much traditional burning practice was restricted due to frontier wars and land dispossession. Research has shown that in areas that were not impacted by Europeans farming, shrub-rich dense woodlands developed. This has caused an increase in the frequency and intensity of hot fires, worsened by climate change and population growth.

Hot fires burn areas of thick vegetation including trees and shrubs, which are important habitats for animals. These fires are very dangerous and destructive, moving quickly and killing everything in their path.



Figure 9.53 Regrowth of eucalyptus trees after a bushfire. These shoots allow the tree to continue photosynthesising while the canopy recovers.



Figure 9.54 Before European colonisation, Aboriginal and Torres Strait Islander Peoples maintained a complex system of land management, involving creating a mosaic of burned and regenerating areas. By using fire as a tool, Aboriginal and Torres Strait Islander Peoples planned plant growth through careful burn patterns, creating grasslands that they utilised to attract animals to hunt.

firestick farming the cool burning of areas of bush in stages, by the application of firesticks, to encourage new growth



Figure 9.55 Devastating hot fire

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DEPTH STUDY IDEA
How do Aboriginal and Torres Strait Islander Peoples manage fire risk?

Try this 9.13

Addressing environmental issues

You will work in teams to collaborate with local groups to address environmental issues in your community.

Research the environmental issues – such as pests, weeds or habitat destruction – affecting your local area. Identify relevant local groups or organisations that are already working to address these issues. Try groups or organisations such as the local council, Bushcare, Aboriginal Land Councils or national parks.

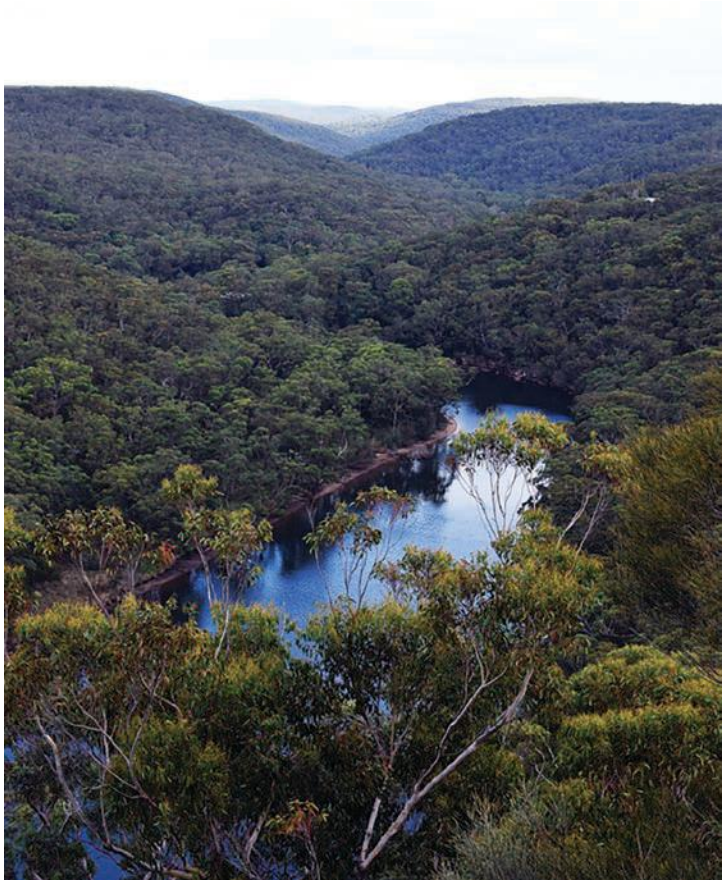


Figure 9.56 In 2023, coal mine waste contaminated Hacking River in Royal National Park, threatening the population of platypus that had been relocated there earlier in the year.

Contact one of these groups to learn more about the specific environmental issues and the work being done to address them. You may have an opportunity to be involved in conducting surveys, collecting samples or monitoring wildlife. Analyse the data collected or provided by the local groups and, within your team, propose some solutions to the issues identified. Consider factors such as feasibility, cost-effectiveness and potential impact.

Reflect on the experience of working with local groups and the impact of your proposed solutions. Consider how you can continue to contribute to environmental conservation efforts in your community.

Quick check 9.11

1. **Propose** some causes of fire in Australia before Aboriginal and Torres Strait Islander Peoples arrived.
2. **Recall** three main uses of firestick farming.
3. **Describe** how firestick farming helps to promote new plant growth.
4. **Contrast** the two types of fire used in firestick farming.
5. Currently, we use controlled burns in winter to reduce natural bushfires in summer. **Predict** a problem with disrupting this natural event.

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Extinctions

Extinction, the permanent loss of a species, is a natural process that has occurred throughout Earth's history.

Extinctions can be categorised into several types. They are shown in Table 9.7.

Type of extinction	Description	Example
Mass	This occurs when a significant proportion of Earth's species is wiped out in a relatively short period, often due to catastrophic events like asteroid impacts, volcanic eruptions or extreme climate change.	The Cretaceous–Paleogene extinction, 66 million years ago, was caused by a massive asteroid impact in Yucatán, Mexico that wiped out 75% of all species. 
Functional	This occurs when a species becomes so rare that it cannot play its ecological role effectively or the population becomes too small to sustain itself over multiple generations. While some individuals may still exist, the species is effectively extinct.	The Eastern Quoll (*Dasyurus viverrinus*) was once widespread across southeastern Australia, but they have experienced a significant decline in population numbers. Their numbers in NSW are so low that they no longer play a significant ecological role. 

Table 9.7 The categories of extinctions

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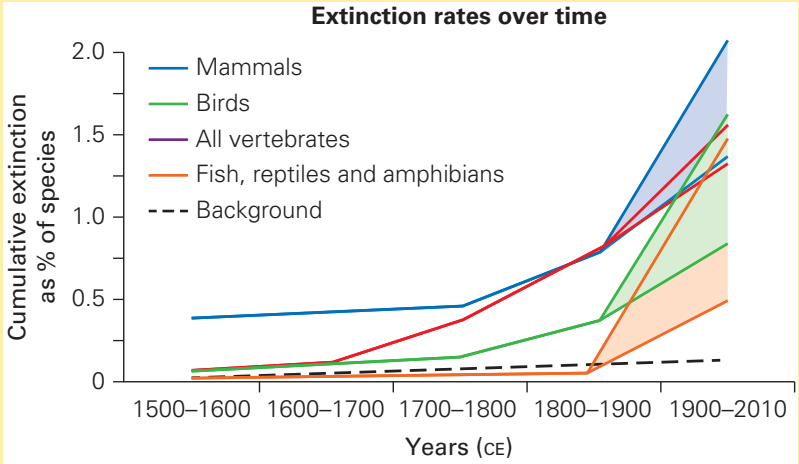
Type of extinction	Description	Example
Small-scale	These are localised events that often affect specific species or populations due to targeted threats such as habitat loss, pollution, climate change or invasive species. Though smaller in scale, these extinctions can still disrupt local ecosystems and food webs.	The Bramble Cay melomys (*Melomys rubicola*) was endemic to Bramble Cay, a tiny coral island in the Torres Strait. The melomys was the only mammal species native to the island and was well adapted to its sandy habitat. Unfortunately, the Bramble Cay melomys became the first mammal species to be declared extinct due to climate change. Rising sea levels and an increased frequency of extreme weather events led to the loss of much of the melomys' habitat. It was declared extinct in 2016. 
Background	This is the standard rate of extinction that occurs naturally over time due to environmental changes, genetic factors and interactions with other species. It represents a baseline level of species loss against which other extinction events are measured.	On average, 10% of species are lost every million years, 30% every 10 million years, and 65% every 100 million years.  *Source: "The Anthropocene is functionally and stratigraphically distinct from the Holocene"*
Anthropogenic (human-led)	These extinctions are caused directly by human activities, including habitat destruction, overexploitation, pollution, introduction of invasive species, and climate change. This type of extinction is concerning due to its accelerated rate and widespread impact.	The thylacine (*Thylacinus cynocephalus*) was once widespread across mainland Australia and Tasmania but was hunted by European settlers. As a result, the thylacine's population rapidly declined, and the last known wild specimen was shot in Tasmania in 1930. Despite efforts to preserve the species in captivity, the last thylacine died in Hobart Zoo in 1936. 

Table 9.7 *(continued)*

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Try this 9.14

VIDEO
Extinctions

WORKSHEET
Extinctions

Extinctions

Complete some research to investigate factors that lead to a species becoming endangered or extinct. You should develop a presentation such as a poster, video or report describing the factors that led to the endangerment or extinction of your chosen animal.





Figure 9.57 The critically endangered *Callistemon purpurascens* (left) and the red-tailed black cockatoo, *Calyptorhynchus banksii* (right)

In your class, go on a mock 'field trip', moving between your classmates' presentations to learn the reasons for each of their animal's endangerment or extinction. Once all data has been collected, you should work together as a class to explain why Australia has some of the world's highest rates of species population decline and extinction.





Figure 9.58 Some critically endangered species found in New South Wales. **(a)** Kaputar rock skink (*Egernia roomi*). **(b)** Grassland earless dragon (*Tympanocryptis pinguicolla*)

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Quick check 9.12

1. **Describe** background extinction.
2. **Name** some causes of anthropogenic-driven extinctions.
3. At the end of the Permian era (250 million years ago), 96% of species became extinct due to intense volcanic activity in Siberia that caused global warming and ocean acidification. **Identify** the type of extinction that occurred.

Australia's rate of species population decline and extinction

Australia has experienced significant species population decline and local extinction, with some species facing total extinction. The country has some of the highest rates of species loss globally. Several factors contribute to this situation, including:

- Colonisation: European settlement caused habitat destruction, introduced invasive species and disrupted Indigenous land management.
- Habitat loss: Land clearing for agriculture, urban development, mining and infrastructure destroyed habitats for many species.
- Land management: Changes in fire regimes and farming practices have degraded habitats.
- Invasive species: International trade and travel have spread non-native species, which outcompete or harm native wildlife.
- Pollution: Chemical runoff, plastic waste and air pollution harm ecosystems and species, health.
- Climate change: Rising temperatures, altered rainfall and extreme weather events are threatening habitats and species.

These factors can be explored in more detail in *Explore! 9.7*.

INVESTIGATION

Explore! 9.7

Species population decline and extinction in Australia, and remedies

1. Research the rates of species population decline and extinction in Australia and report on how they compare to the rest of the world.
2. Research general biodiversity threats in Australia and examples of actual harm to species.
3. List reasons for species population decline and extinction.
4. Propose action to prevent the reasons listed in **3** from bringing about further species population decline and extinction.



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Section 9.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 9.4 questions

Remembering

1. **Name** the three types of biodiversity.
2. **List** four examples of invasive species.

Understanding

3. **Define** the following terms.
   a. Species diversity
   b. Genetic diversity
   c. Ecosystem diversity
4. **Describe** the use of 'firestick farming' by Aboriginal and Torres Strait Islander Peoples.

Applying

5. **Explain** why some introduced species are classified as pests.
6. **Explain** why the cactus moth is referred to as an effective biological control.
7. **Describe** some of the impact that humans are having on oceanic ecosystems.

Analysing

8. **Compare** the use of 'hot fire' and 'cold fire' burning techniques by Aboriginal and Torres Strait Islander Peoples.
9. Go online to research the work a group is doing to counteract the impact humans are having on biodiversity loss. Try to choose a group that you may find interesting. Write a journal **reflection** of your findings.

Evaluating

10. Bushfires naturally occur in Australia, and many organisms have adapted to cope with this. Natural bushfires may occur around once every five to 10 years; however, many areas undergo controlled burns yearly to prevent wildfires. **Propose** how this might damage the ecosystem.
11. **Create** a list of pros and cons for the role of invasive species.
12. **Evaluate** the statement: *Human actions threaten more species with global extinction now than ever before.*



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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
9.1	identify the components that make up an ecosystem.	1
9.2	describe factors that change populations.	5
9.2	describe interactions in an ecosystem between biotic and abiotic components, as well as between different biotic components.	3, 8, 12
9.2	examine examples of factors that change populations.	14
9.3	describe how matter and energy are cycled through an ecosystem.	6
9.3	create and analyse food webs to show feeding relationships.	7, 13
9.3	create an ecological energy pyramid.	4, 11
9.3	describe how energy pyramids show energy or matter at each level.	4
9.4	investigate and describe factors threatening biodiversity and leading a species becoming endangered or extinct.	2, 10, 15
9.4	examine examples of the impact of the introduction of a new (invasive) species to an ecosystem.	9, 10
9.4	explain why Australia has some of the world's highest rates of species decline and extinction.	9, 15

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Identify** the top level of components that make up an ecosystem.
2. **Identify** two natural and two human threats to an ecosystem.
3. **Name** the type(s) of consumers (in terms of what they mainly eat) that have prominent canine teeth.

Understanding

4. **Describe** an energy pyramid, how it shows the energy or matter in each trophic level and how it shows energy or matter being lost along a food chain.
5. **Explain** how high biodiversity can be a sign of a healthy ecosystem.
6. A producer is always part of a food chain. **Explain** how a producer fits into the brown food chain.

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Applying

7. Use the following list of organisms to answer the questions below: koala, grass, dingo, beetle, eucalyptus, possum, kangaroo, earthworm.
   a. **Illustrate** the interactions between the organisms by connecting them with arrows.
   b. **Classify** each organism as producer, consumer or decomposer. Each organism may have more than one label.
   c. **Classify** the organisms as (if any) herbivores, carnivores, omnivores or detritivores.

Analysing

8. **Compare** the roles of decomposers and consumers.
9. **Explain** the impact of the introduction of cane toads in Australia and the efforts to control them.
10. **Analyse** what would happen to a population of long-nosed bandicoots if a population of foxes moved into their area.
11. Using the pictures of organisms in Figure 9.59:
    a. identify the food chain and **create** a food energy pyramid
    b. **calculate** the food energy in each trophic level using the 10% rule, starting from 1 000 000 kJ in the producers' level, and label the energy pyramid with these figures.



Figure 9.59 Various parts of a food chain

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Evaluating

12. A grassland ecosystem changes dramatically throughout the year. **Propose** several abiotic and biotic changes that may occur in a grassland ecosystem during summer and winter.

13. Look at the food web in Figure 9.60. **Predict** what would happen if the mouse was removed from the food web.

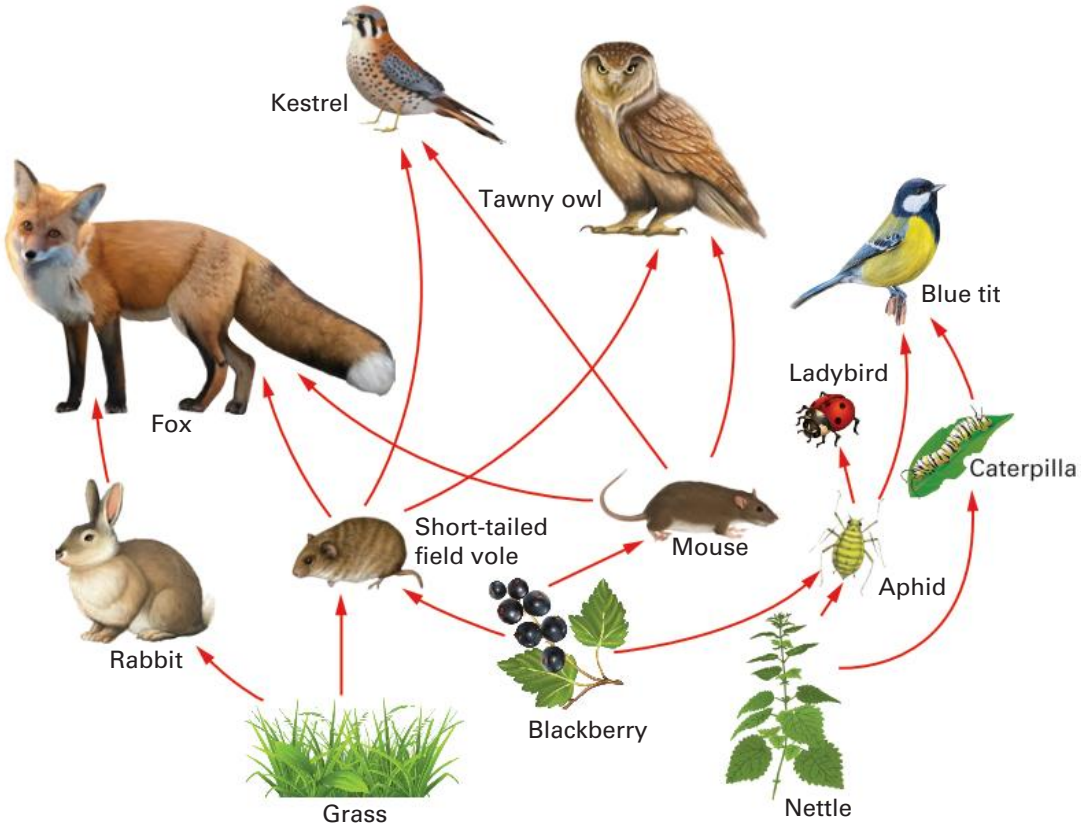


Figure 9.60 Various parts of a food web

14. A population of platypus located in Barrington Tops is genetically more diverse than a population located in Sundown National Park. **Predict** and **justify** which population is more likely to survive if the environment changes.

15. **Explain** why the thylacine became extinct, firstly in mainland Australia and then in Tasmania, and discuss what measures could have been taken to prevent this from happening.

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Data questions

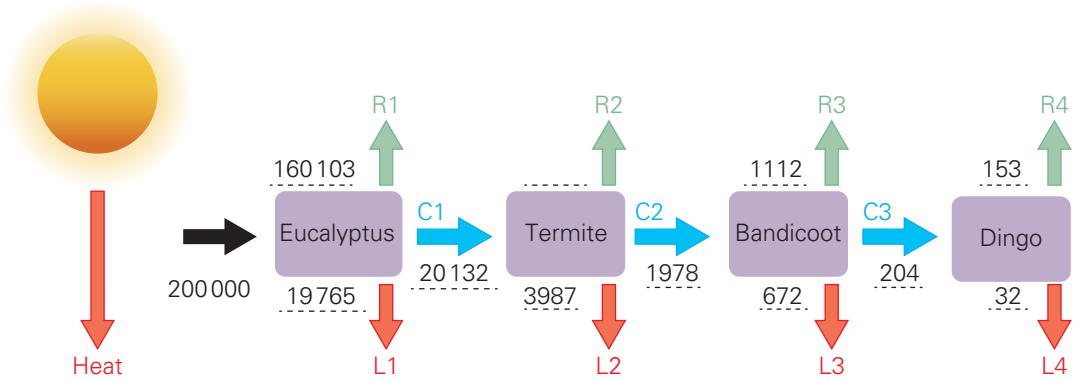


Figure 9.61 Energy transfer in an Australian food chain. Blue arrows (C1–3) represent energy transferred through the food chain; green arrows (R1–4) represent energy lost as heat and through respiration; and the red arrows (L1–4) represent the energy lost as detritus (dead organic matter and waste).

1. **Identify** the secondary consumer in Figure 9.61.
2. **Calculate** the R2 value.
3. **Calculate** the efficiency of the energy transfer through the termite in Figure 9.61.
4. **Organise** the efficiency of energy transfers (C1, C2 and C3) from highest to lowest, using Figure 9.61.
5. **Deduce** why the food chain does not extend further than the dingo. Provide appropriate data to **justify** your response.
6. Geckos will also eat termites. They are far smaller than a bandicoot. **Predict** whether the gecko's L3 value would be higher or lower than the bandicoot's L3 value in Figure 9.61.
7. **Justify** your answer to Question **6**.



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STEM activity: Controlling feral animal populations

Background information

Introduced feral animals such as cats, foxes, cane toads and rabbits are a significant problem in Australia, causing extensive damage to the native wildlife. For example, feral cats are efficient predators, hunting birds, reptiles and small mammals, leading to a decline in native species. Controlling the population of these animals is crucial to protecting Australia's biodiversity. Humane methods of control and deterrence are preferred to ensure the wellbeing of all animals involved.

DESIGN BRIEF

Create a prototype of a device or system that can be used to humanely deter or control a feral animal population.

Activity instructions

In this task, you will investigate different methods to control a feral animal population. Then, you will design and construct a prototype device or system that could be used by individuals and government organisations to deter or manage these animals. You will need to consider the following information and design constraints:

1. The design and construction must be cost-effective.
2. The prototype must be constructed so that no animal is harmed.
3. The prototype must be able to be left in a way so that curious people cannot injure themselves by touching the device or possibly encountering a deterred animal.
4. The prototype device must be able to be transported for safe relocation if necessary.



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Suggested materials

- recyclable materials such as plastic bottles, containers, boxes
- duct tape
- scissors
- ruler
- balls the size of cats

Research and feasibility

1. Research and explain what 'humane' means and discuss in your group why your prototype design must be humane.
2. Research why feral animals have become such pests in Australia.
3. Research and identify the ways that feral animal populations can be controlled.

Design

4. Decide in your group the method you are going to use to reduce a feral animal population. You may want to use a table like this one to list the positives and negatives of each method.

Method of control	Positive	Negative
Motion-activated sprinklers		
Animal-proof fencing		
Scented deterrents		

5. Design your prototype device and label the key components of the design. How do the components of the design help your invention to be humane, safe, effective and affordable?

Create

6. Construct your prototype device using the available materials.
7. Test your prototype device for durability and get other groups to test how well it works.

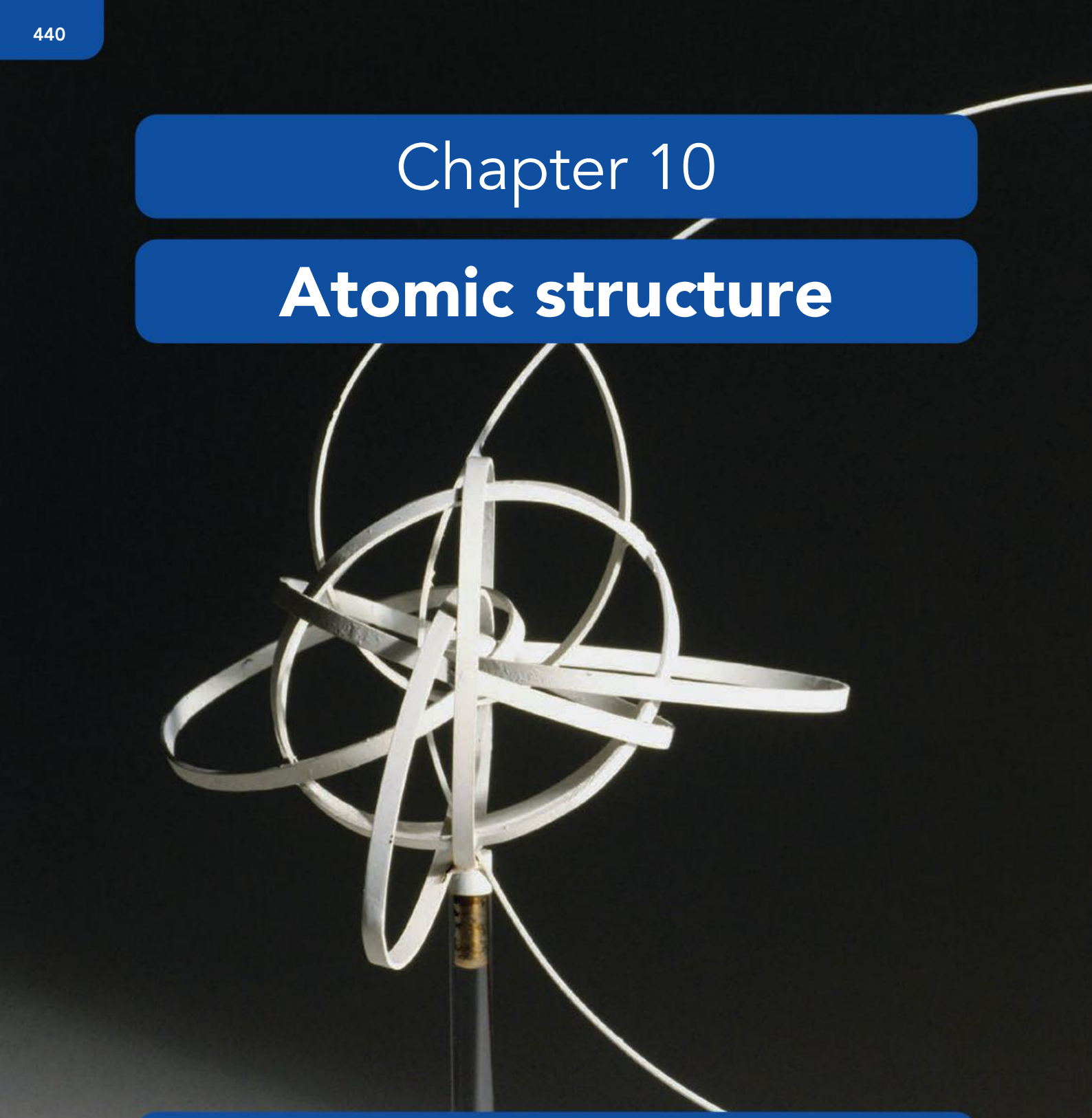
Evaluate and modify

8. Discuss in your group how well your prototype device worked and reflect on how effective you think it will be.
9. Evaluate if you now think that other methods of controlling the population would be more effective. Would you like to make any changes to your prototype?
10. Present your prototype to the class and ask your peers how effective the prototype would be where they live, and what suggestions they can offer to improve it.

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Chapter 10

Atomic structure



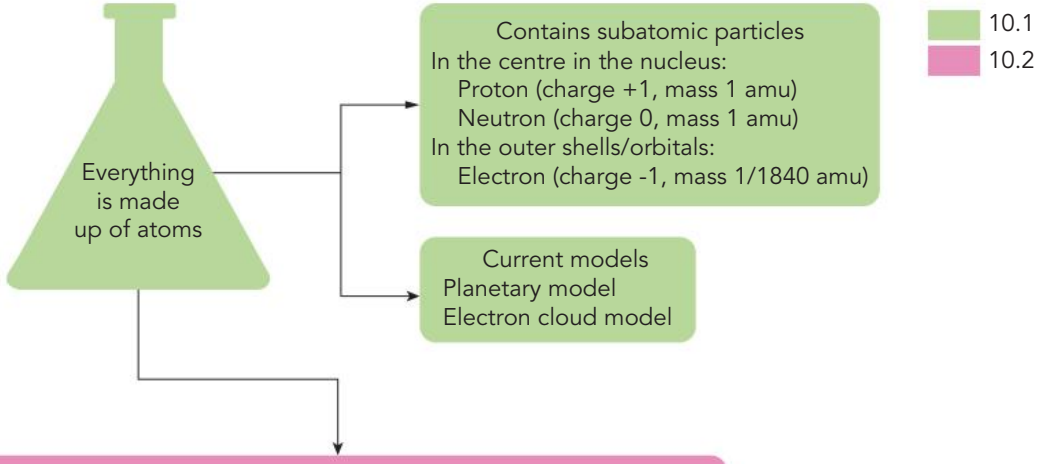
Chapter introduction

You have learned that elements are an example of a pure substance that is made up of just one type of atom or one type of molecule. Elements make up everything we know of. But what makes the elements differ from each other? What gives the elements their different properties? They are made of different atoms and these, in different combinations, make up things with very different properties.

This chapter is all about atoms. You will learn that atoms are made of very small subatomic particles called protons, neutrons and electrons. You will compare the masses and charges of these subatomic particles, and you will learn about the many different scientists who contributed to the current knowledge and understanding of atomic structure.

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Chapter map



Development of the atomic model crosses centuries	New technologies
Democritus 442 BCE – Greek philosopher who developed one of the first atomic theories	No technology – used observations of nature and reasoning
John Dalton 1803 – Proposed that elements contain atoms	Sensitive weighing scales, equipment to measure gas volume and pressure
JJ Thomson 1906 – Discovered the electron and proposed the 'plum pudding' model	Cathode ray tube (electrical and magnetic technologies plus the vacuum pump)
Ernest Rutherford 1911 – Discovered the nucleus and proposed the nuclear model	Use of natural radioactive elements, emitting particles to penetrate and smash atoms
Niels Bohr 1913 – Proposed the electron shell/ planetary model	Mathematical analysis; spectroscopy confirmed predictions
Erwin Schrödinger 1926 – Proposed electron cloud model	Mathematical analysis; confirmed by electron diffraction
James Chadwick 1932 – Discovered the neutron	Stronger radioactive elements and improved detectors

Glossary terms

alpha particle
atom
electron
neutron
nucleus
proton
subatomic particle

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10.1 The planetary atomic model

WORKSHEET
Structure of the atom

Learning outcomes

At the end of this section, I will be able to:

1. identify the atom as the smallest part of an element that retains the element's properties.
2. describe the structure of an atom in terms of its subatomic particles (protons, neutrons and electrons).
3. use the planetary atomic model to describe the location, relative charge and mass of protons, neutrons and electrons.

Atoms

atom
the smallest possible piece of any substance; it makes up all matter

Atoms are the building blocks of matter around us. The word 'atom' comes from the Greek word *atomos*, which means 'indivisible' or 'un-cuttable'. If you had a silver ring and cut that ring in half and then in half again and continued to do this, you would eventually be left with an atom of silver. At one time it was thought that this silver atom could not be divided into smaller pieces, and so atoms were the smallest particles that could exist. However, scientists have discovered that there are actually smaller particles than atoms. We will learn about these in this section.



Figure 10.1 A ring made of silver atoms

Did you know? 10.1

You are a star!

More than 98% of all the atoms in the universe come from the two lightest elements: hydrogen and helium. The heavier elements are created at the end of a large star's life cycle in a massive explosion called a supernova. The elements that make up all humans have, at one point, come from a star.



Figure 10.2 A digital impression of an exploding supernova

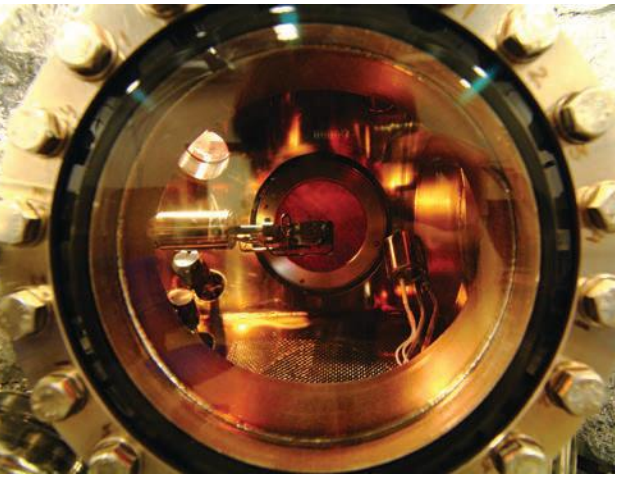


Figure 10.3 The interior of a scanning tunnelling microscope used to view the first image of an atom

An atom is the smallest possible form of an element. There is a unique atom for every element. An atom of silver is different from an atom of oxygen. If you made any changes to one of these atoms, for example, cutting it in half, it would no longer be the same element.

Atoms are so small that you will probably never see one. Take a human hair for example: it is about as thick as 500 000 carbon atoms stacked on top of each other. Imagine you have been shrunk to the size of an atom. You are standing next to a grain of salt. That grain of salt next to you would be the height of Mount Everest. Even with examples like this, it is really difficult to completely understand how small atoms are. Scientists can see atoms with highly specialised microscopes called scanning tunnelling microscopes, as shown in Figure 10.3.

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The first scanning tunnelling microscope was developed in 1981, by physicists Gerd Binnig and Heinrich Rohrer. They were awarded a Nobel Prize for Physics in 1986 for their efforts. This exciting discovery allowed scientists to view images of many different atoms that had previously been unseen.

Advances in science 10.1

The world's smallest movie

In 2013, researchers at IBM created the world's smallest movie. They used carbon monoxide molecules and moved them using the small tip of the scanning tunnelling microscope. The record-breaking movie is called *A Boy and His Atom* – a boy meets an atom and they become friends. It was created using individual frames that were put together using stop-motion software. You can search for this film using your preferred search engine. Although it was created for fun, it shows just how far physics has come in the study of atoms.

Quick check 10.1

1. **Define** the term 'atom' in your own words.
2. **Recall** the name of the microscope which allowed scientists to view atoms.



VIDEO
Scanning tunnelling microscope

Practical skills 10.1

Splitting molecules into atoms and forming new molecules

Be careful



Care should be taken with electricity and water. Do not touch the water when the battery is connected.

Aim

To split molecules into elements, forming new molecules.

Materials

- baking soda
- distilled water
- 250 millilitres (mL) beaker
- 250 mL measuring cylinder
- stirring rod
- safety glasses
- spatula
- 2 pencils sharpened at both ends
- 2 power leads
- 2 alligator clips
- 9 V battery

Procedure

1. Using the 250 mL measuring cylinder, measure 150 mL of distilled water and pour it into the beaker.
2. Add a heaped spatula of the baking soda to the beaker and stir it using the stirring rod until the baking soda has dissolved in the water. Note: the baking soda will enhance the reaction, but it is not directly involved.
3. Attach each lead to the 9 V battery.
4. To the other end of each lead, attach an alligator clip, making sure the wires do not touch each other.

continued ...

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5. Place one end of each pencil in the water in the beaker, ensuring they do not touch each other.
6. Use the alligator clips to attach the leads to the tips of the pencils.
7. Leave this set-up for 10 minutes. During this time you should see bubbles forming at the bottom of each pencil.

Results

Make a list of the observations that you made from this experiment. Remember, observations are things that you can see happening, not an explanation of what is happening.

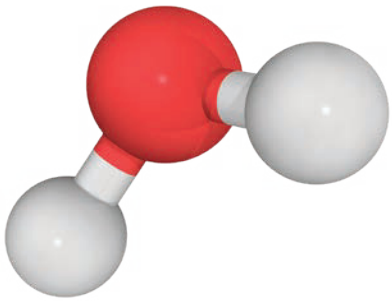


Figure 10.4 This molecular model of a water molecule shows two hydrogen atoms (white) and one oxygen atom (red).

Discussion

1. In this experiment, you split up water molecules into their atoms. Identify which atoms make up water molecules and how many of each single atom there are. Refer to Figure 10.4 if you need help with this.
2. Could you tell which pencil was attracting hydrogen atoms and which was attracting oxygen atoms? Did you see more bubbles on one pencil than the other?
3. Distilled water is water that has undergone a process to remove impurities. Propose a reason why the use of distilled water was specified and suggest what, if any, effect this may have had on the outcome.

Subatomic particles

subatomic particle one of the particles that make up an atom

proton a subatomic particle with a positive charge found in the nucleus of an atom

neutron a subatomic particle with a neutral charge found in the nucleus of an atom

electron a subatomic particle with a negative charge found outside the nucleus in all atoms

You have already learned that the word 'atom' comes from the Greek word *atomos* meaning 'indivisible'. The idea that atoms are the smallest particles to exist has been around for a long time.

As new technologies have been developed, scientists have discovered that the atom is made up of three **subatomic particles**: **protons**, **neutrons** and **electrons**. There are different numbers of these subatomic particles in each element. The number of particles are unique to each element and give the elements their different properties.

VIDEO Subatomic particles

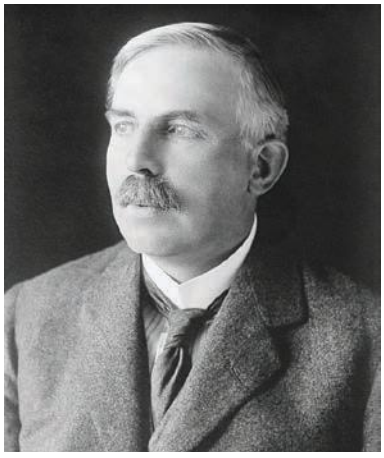


Figure 10.5 Ernest Rutherford was one of the first scientists to suggest that atoms were not the most basic form of matter.



Figure 10.6 These Russian dolls fit inside each other, getting progressively smaller, just like an atom and the subatomic particles within it.

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Did you know? 10.2

Ordinary hydrogen – an unusual element

Hydrogen is the only element that does not contain all three subatomic particles. A hydrogen atom only contains one proton and one electron. It is missing a neutron!

The modern planetary atomic model

Even with the most powerful microscopes, scientists cannot see inside the atom, so they create models of the atom to show ideas that cannot be seen. There have been many models of the atom over time. One of the most useful and current versions models the atom as a mini solar system. In the middle of our solar system is the Sun and orbiting the Sun are the planets, with most of the rest of the solar system being empty space.

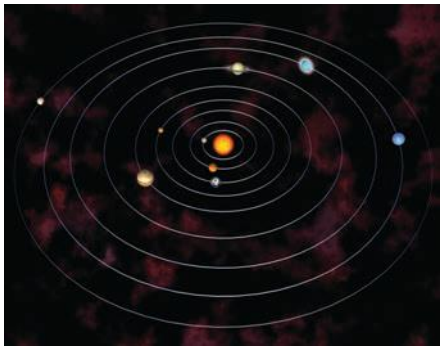


Figure 10.7 The solar system. The planetary model of the atom is based on the structure of our solar system.

The atom has a similar kind of structure. In the middle of the atom is an area called the **nucleus**, which is where the protons and neutrons are found. Orbiting (circling around) the nucleus are the electrons. We say they can be found in shells or orbits. These shells are drawn as circles and are different distances away from the nucleus. It takes energy for the electrons to stay outside of the nucleus. The further away they are, the more energy, so the different shells are also different energy levels. You will learn more about these later in this chapter. This planetary model was proposed by Niels Bohr in 1913 and is often referred to as a Bohr diagram.

nucleus
(plural: nuclei) the central part of the atom containing its protons and neutrons

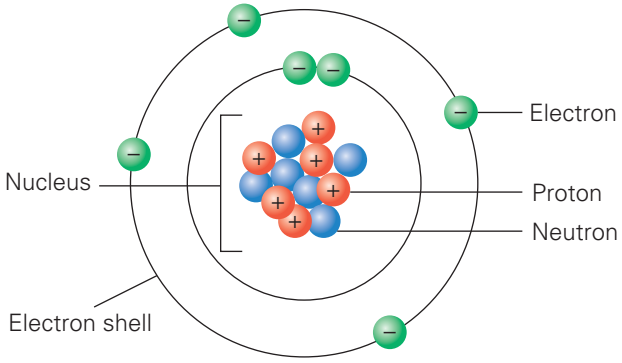


Figure 10.8 A Bohr diagram shows the nucleus containing protons, which have a positive charge, and neutrons, which have a neutral charge. The nucleus is surrounded by electrons, which have a negative charge, orbiting in shells of different energy levels.

Just like the solar system, most of the atom is made up of empty space. To give you an idea of how empty, if the atom was an Olympic athletics track, then the nucleus would only be the size of a pea in the middle of it!

Try this 10.1

Building atomic models

Build your own model of the atom using everyday household objects. Make sure you include labels. Take a photograph and explain your model to your classmates.

Quick check 10.2

1. **Name** the structure at the centre of the atom and **state** what it contains.
2. **Identify** where in an atom the electrons are located.

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Properties of subatomic particles

Atoms give elements their physical and chemical properties. To understand more about atoms and how they behave, you need to know more about the three types of subatomic particles inside them: protons, neutrons and electrons.

Charge

You may be wondering what keeps the electrons inside the atom. If they are moving around at an enormous speed inside the atom, why don't they fly off into space? They stay in the nucleus due to the electrical charges of the subatomic particles. The protons in the nucleus in the middle of the atom have a positive charge (+1). Electrons orbiting the nucleus have a negative charge (–1). Positive and negative charges follow the basic rules: opposite charges attract and like (the same) charges repel. This means that the protons and electrons in an atom are attracted to each other, stopping the electrons from flying off into space. Neutrons are electrically neutral, which means they have no charge at all (0). Table 10.1 summarises what you need to know about the charges of the subatomic particles.

Subatomic particle	Charge
Proton	+1 (positive)
Neutron	0 (neutral)
Electron	–1 (negative)

Table 10.1 The charges of the three subatomic particles

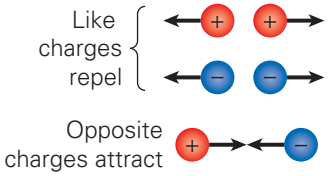


Figure 10.9 Charge is an electrical property. Like charges repel and opposite charges attract.

Try this 10.2

Demonstrating the attractions between charged objects

Investigate attractions between charged objects with the following two activities.

Activity 1

Follow the instructions using two balloons, two pieces of string about 1 metre (m) long, and a plastic tube.

1. Blow up both balloons and tie one piece of string to each balloon.
2. Hang both balloons from a common point on the ceiling.
3. Charge a plastic tube by rubbing it on some fabric.
4. Note the position of the two balloons.
5. Put the plastic tube between the two balloons and observe the effect.

Activity 2

Follow the instructions using an inflated balloon.

1. Rub the balloon on the hair of a friend.
2. Bring the balloon away from their head and observe what happens.

Discussion

1. Determine which experiment showed repulsion. Suggest a reason for your answer.
2. Determine which experiment showed attraction. Suggest a reason for your answer.
3. Discuss what is happening in both experiments at an atomic level.
   Hint: think about charged particles.

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Mass

As well as knowing the charge of the subatomic particles, you also need to be able to recall their masses. Protons and neutrons have very similar masses: a proton has a mass of 1.673×10^{-24} grams (g) and a neutron has a mass of 1.675×10^{-24} g. These numbers are *very* small and almost the same, so to make things simpler, both protons and neutrons are given a mass of 1 atomic mass unit (amu). This value is much easier to remember and work with.

Electrons have an even smaller mass, about $\frac{1}{1840}$ of a proton or a neutron. It is so tiny that we usually discount the mass of an electron when we are talking about the mass of different atoms. This means that the mass of an atom is found in the nucleus at the centre.

Table 10.2 summarises what you need to know about the masses of the three subatomic particles.

Subatomic particle	Relative mass (amu)
Proton	1
Neutron	1
Electron	$\frac{1}{1840}$

Table 10.2 The relative mass of the three subatomic particles

Explore! 10.1





Inventing a new unit of measurement

Subatomic particles have such small masses that scientists saw the need to make a new unit to measure their mass. The invention of the atomic mass unit (amu) made it much easier to talk about the mass of atoms.

Research how the atomic mass unit came about. Who proposed it? How does amu relate to the element carbon?

Quick check 10.3

1. Copy and **complete** this table summarising the differences in charge and relative mass of the three subatomic particles.

Subatomic particle	Symbol	Location	Charge	Relative mass (amu)
Proton	p^+			
Neutron	n^0			
Electron	e^-			



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Section 10.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 10.1 questions

Remembering

1. **Name** the two most common elements in the universe.
2. **Recall** the definition of an atom.
3. **Name** the three subatomic particles that make up the atom.
4. **Recall** the name of the structure at the centre of the atom where the protons and neutrons are located.
5. In the table below, **match** the subatomic particle to the correct charge.

Subatomic particle	Charge (e)
Proton	0
Neutron	–1
Electron	+1

Understanding

6. **Compare** and **contrast** the masses of protons, neutrons and electrons.

Applying

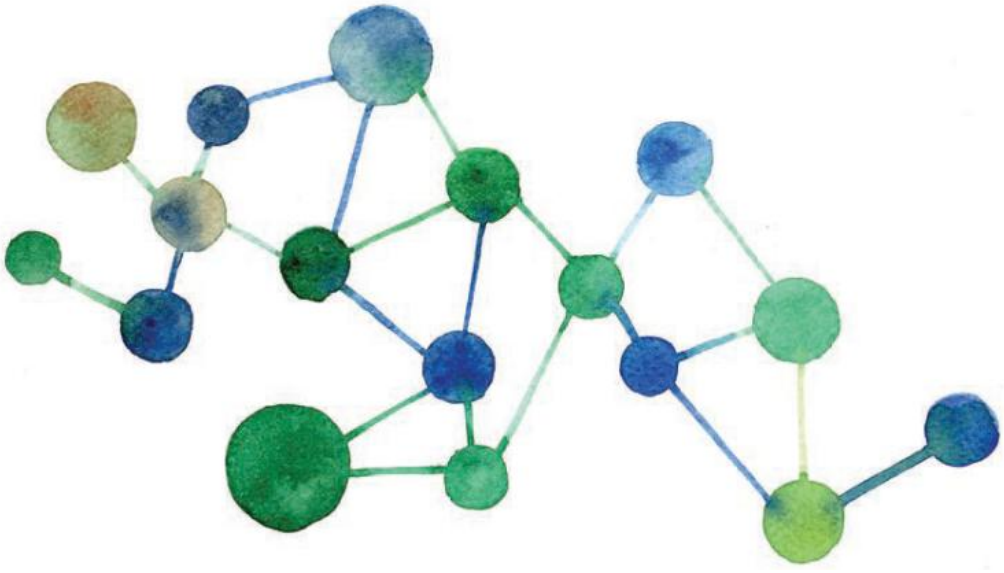
7. Water (H_2O) is made up of two different elements: hydrogen (H) and oxygen (O). **Determine** how many different elements make up vinegar (CH_3COOH).
8. **Construct** a labelled diagram that shows the planetary model of the atom.

Analysing

9. **State** which subatomic particles are used to calculate the mass of an atom and **justify** why this is so.

Evaluating

10. **Propose** several reasons why models are so useful in science. **Explain** any limitations you can think of when using models.



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10.2 Development of the atomic model

Learning outcomes

At the end of this section, I will be able to:

1. describe how the atomic model has changed over time.
2. explain how new technologies have improved our understanding of the atomic structure.
3. recall the contributions of various scientists to our current understanding of the atomic model.

WORKSHEET Development of the atomic model

Scientists have been talking about the atom and its structure and improving the atomic model for hundreds of years. Understanding how models have been created and updated can help us to understand and remember the models themselves, so in this section you will learn about the major discoveries that have helped our understanding of the atom. You will also gain an understanding of how new technologies and experimental evidence can lead to a scientific model being updated or replaced. In understanding the changes to the model over time, it is helpful to learn about the people who made those changes.

Democritus 460–370 BCE

Democritus was one of the first people to talk about the atom. He was actually a philosopher (someone who thinks about big questions like the meaning of life, justice and knowledge), and in the year 442 BCE, he said that if you take an object and cut it into smaller and smaller pieces, eventually you would reach a point where you could no longer cut it anymore. You would end up with a piece that was indivisible. Democritus called this piece *atomos*, which means 'indivisible' in Greek. Although he used observations of nature, he did not carry out experiments and did not use technology.

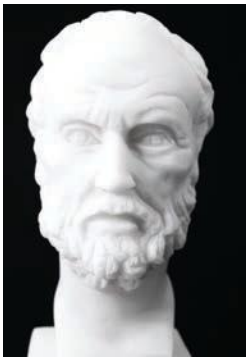


Figure 10.10 Sculpture of the Greek philosopher Democritus

Aristotle 384–322 BCE

Another philosopher, Aristotle, disagreed with Democritus and presented his theory that matter on Earth was made up of four elements – earth, air, fire and water – and the amounts of these elements determined how materials behaved. There was more evidence for the model of the atom that Democritus had given, but Aristotle had more followers at the time, so his idea was believed for some time. Technology for scientific inquiry into matter did not exist at that time.

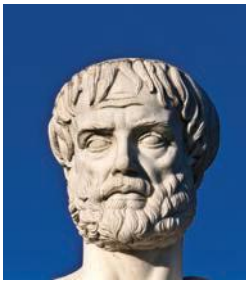


Figure 10.11 Sculpture of the Greek philosopher Aristotle

John Dalton 1766–1844

Dalton is credited for starting the push for research into modern atomic theory in 1803, more than 2000 years after Democritus first suggested his ideas on the atom. Dalton suggested that all elements contained atoms, and that atoms of the same element would be identical in size, shape and mass. Importantly, Dalton also stated that compounds were a combination of elements and that they would always combine in a fixed ratio. We now know that this is true. For example, every water atom (H_2O) is a combination of two hydrogen atoms (H) and one oxygen atom (O).



Figure 10.12 John Dalton was an English chemist, physicist and meteorologist. He is best known for sparking research into modern atomic theory.

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In Dalton's time, basic chemical laboratories existed with balances to weigh reactants and products, and apparatus to collect and measure gas volumes and pressures. Matter could be measured, and quantitative analysis drove his discoveries.

Joseph John Thomson 1856–1940

Thomson was the first scientist to discover particles smaller than the atom, disproving Dalton's and Democritus's theories. Surprisingly, the first subatomic particle to be discovered was the lightest – the electron – and Thomson won a Nobel Prize for his work in 1906. By studying 'rays' within a cathode ray tube, Thomson was able to determine that these 'rays' had a mass 1000 times smaller than a hydrogen atom, the lightest piece of matter known to science at the time. These particles also had a negative charge. These 'rays' turned out to be what we now know to be electrons.

By Thomson's time, physics laboratories had a variety of electrical and magnetic technologies available to them, as well as vacuum pumps – the cathode rays could only be observed in a vacuum inside the tube.

From this discovery, Thomson came up with the first real model of the structure of the atom. He named it the plum pudding model, as he imagined the atom as the negatively charged electrons that he had discovered (plums) embedded in a large 'sea' of positively charged 'pudding'. If you can't imagine what a plum pudding looks like (it is a traditional English dessert), perhaps imagine a modern version of this model as a blueberry muffin.



Figure 10.13 Joseph John Thomson proposed the 'plum pudding' model and is credited with discovering the electron.

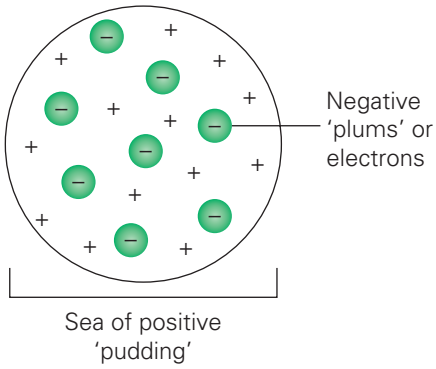


Figure 10.14 The plum pudding model, comprising negative electrons (the plums) scattered through a sea of positive charge (the pudding)

Ernest Rutherford 1871–1937

In 1911, Ernest Rutherford and his fellow scientists Hans Geiger and Ernest Marsden fired **alpha particles** (helium nuclei) at a thin piece of gold foil, in the famous gold foil experiment.

alpha particle a positively charged particle released from the nuclei of some radioactive elements

Rutherford predicted that if the atom was like Thomson's plum pudding model (evenly spread negative 'plums' in a positive sea of 'pudding'), then all the alpha particles should pass straight through the gold atoms, but this is not what happened! It was true that almost all (99.99%) of the alpha particles passed straight through the foil and were detected at the other side by the detector, but some of the alpha particles surprisingly bounced back or were deflected as if they had hit something (see Figure 10.16). To explain this observation, Rutherford said there must be an area of charge, concentrated in the middle of the atom, with enough mass to cause the alpha particles to deflect or bounce back. This observation disproved the plum pudding model altogether.

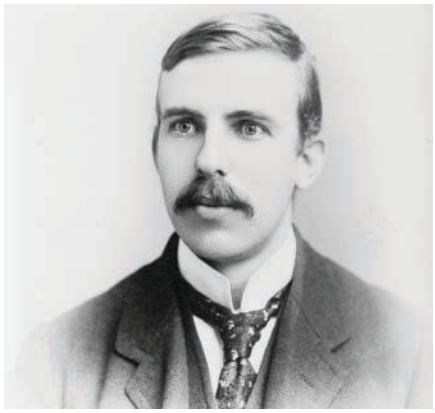
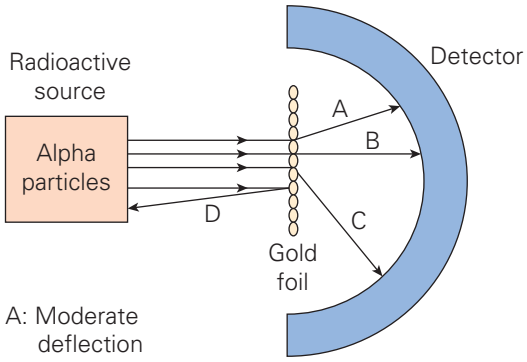


Figure 10.15 Ernest Rutherford said that there was a large amount of charge and mass in the centre of the atom and that most of the atom was empty space.

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In analysing the results of this experiment, Rutherford created a new model of the atom. This model had a charged area with substantial mass concentrated in the middle of the atom, called the nucleus. Rutherford assumed that the nucleus was positively charged as it repelled the positively charged alpha particles (remember that like charges repel each other). Rutherford concluded the negative electrons Thomson had discovered must orbit around this central region. Rutherford's model is also called the 'nuclear' or 'planetary' model of the atom. Most scientific discoveries are due to the work of many scientists, which was the case with this model, but it was Rutherford who discovered and named the positively charged particles in the nucleus 'protons'.

The discovery of natural radioactive elements emitting particles was essential to Rutherford's model, and in time this led to the first 'atom smashing' experiment.



A: Moderate deflection

B: Passed straight through

C: Large deflection

D: Bounced back

Figure 10.16 The gold foil experiment conducted by Ernest Rutherford and colleagues proved that most of the atom was empty space and that there was an area of charge and mass concentrated in the middle of the atom.

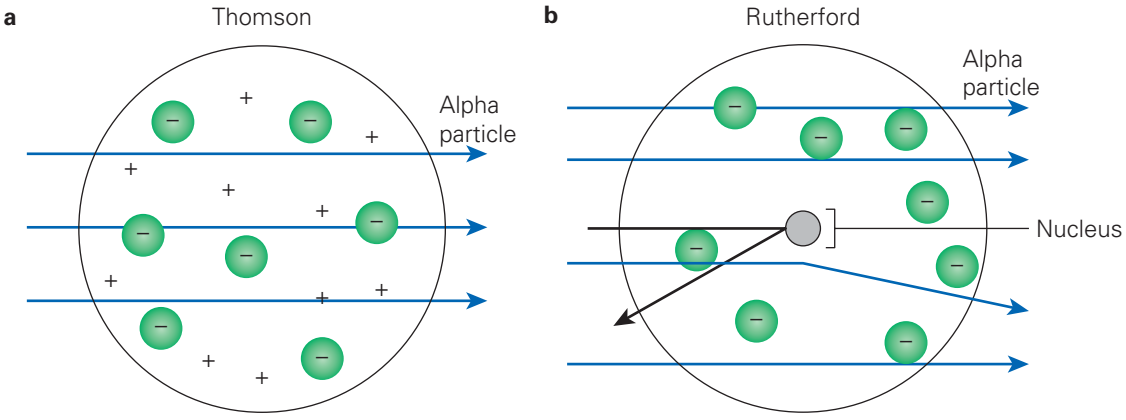


Figure 10.17 Comparison between atomic models: **(a)** Thomson's plum pudding and **(b)** Rutherford's nuclear model.

Quick check 10.4

1. **Recall** what Aristotle believed all matter on Earth was composed of.
2. **State** the name of the subatomic particle that Thomson discovered and the name of his atomic model.
3. **Complete** the sentences below using the word list: alpha, empty space, plum pudding model, nucleus, passed through.
   Rutherford conducted the gold foil experiment, firing _____ particles at a thin piece of gold foil. Most of the alpha particles _____; however, a small number were deflected back.
   Rutherford hypothesised that the reason for this was that the alpha particles either passed through a region of _____ or hit a central region of concentrated mass and positive charge, which he called the _____, disproving the _____.

WORKSHEET
The gold foil experiment

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Practical skills 10.2

Invisible spaces in water

Aim

To investigate the three-dimensional structure of molecules.

Materials

- 200 mL propan-2-ol (alcohol)
- 3 × 250 mL beakers
- 100 mL measuring cylinder

Procedure

1. Copy the results table shown in the Results section.
2. Predict what will happen to the total volume when 100 mL of water is added to 100 mL of water.
3. Measure 100 mL of water using the 100 mL measuring cylinder and pour it into the beaker.
4. Using the same measuring cylinder, measure another 100 mL of water and pour it into the beaker already containing water.
5. Note the actual total volume when the two solutions are mixed together.
6. Repeat steps **2**–**5** for 2 × 100 mL propan-2-ol.
7. Repeat steps **2**–**5** for 100 mL water and 100 mL propan-2-ol.

Results

Prediction of volume with 100 mL of water and 100 mL of water	
Actual volume with 100 mL of water and 100 mL of water	
Prediction of volume with 100 mL of alcohol and 100 mL of alcohol	
Actual volume with 100 mL of alcohol and 100 mL of alcohol	
Prediction of volume with 100 mL of water and 100 mL of alcohol	
Actual volume with 100 mL of water and 100 mL of alcohol	

Discussion

Discuss whether the actual final volumes differed from your prediction, and why this was the case.



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Try this 10.3

Most of an atom is empty space

In this activity, you are going to make a scale model of a hydrogen atom. A hydrogen atom contains one proton and one electron; it is the simplest atom on Earth. You may need a larger space than the classroom to do this – a corridor or playing field may be more suitable. To complete the experiment correctly, you need to know these following important facts:

- The distance between an electron and a proton is 50 000 times the diameter of a proton.
- The mass of a proton is 1840 times greater than the mass of an electron.

Materials

- calculator
- metre ruler
- measuring wheel
- various spherical objects such as marbles, table tennis balls, dried peas
- pencil
- 30 cm ruler
- scissors
- ball of string
- compass (for drawing a circle)
- A4 plain paper

Procedure

1. Draw the results table shown in the Results section.
2. Using the compass, draw a small circle on a piece of paper and record the exact diameter in the results table. This represents a proton.
3. Using the important facts at the start of the activity, calculate the relative distance of the electron from the proton.
4. Measure a piece of string to the distance calculated in step **3** and record the length in the results table. If you are outside on a field, you could stick the metre ruler into the grass, tie the string around it and draw out how big the atom would be for the proton drawn on your paper.
5. Repeat the calculation with one of the spherical objects to represent a different proton. Measure the diameter of your chosen spherical object with the 30 cm ruler and record it in the results table.
6. This is the diameter of your new hydrogen proton. Now calculate the relative distance of the hydrogen electron from the proton.
7. Measure a piece of string to the distance calculated in step **6** and record the length in the results table. Again, if you are on a field, you could stick the metre ruler into the grass, tie the string around it and draw out how big the atom would be.
8. If you have time, repeat the above steps for the other spherical objects.

Results

Diameter of spherical object (cm)	Length of string/radius of the atom (cm)
Your circle	

Discussion

1. Design another way in which you can show the relative size of an atom.
2. State a conclusion about the size of the proton and the distance between it and the electron.

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Niels Bohr 1885–1962



Figure 10.18 Niels Bohr suggested that electrons were not just spread across the atom randomly but were arranged in different energy levels or shells.

Niels Bohr suggested his model of the atom (an updated version of Rutherford's theory) in 1913 after studying how electrons behave. He said electrons moved in fixed circular orbits around the nucleus in structures called shells, and that these shells were specific distances away from the nucleus and the same for all atoms. Electrons located in shells that were further away from the nucleus had higher energies than those closer to it. These electrons were able to move from one energy level to another by gaining or losing energy.

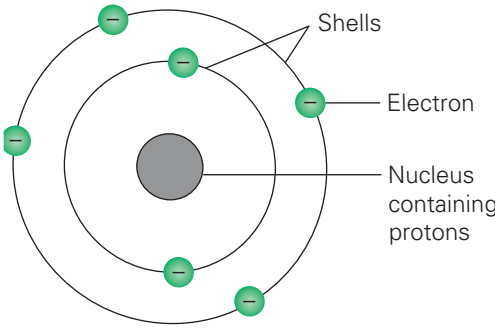


Figure 10.19 Bohr's model of the atom is sometimes called the planetary model. It shows electrons in fixed shells around a central nucleus.

Scientists now know that Bohr's model has some errors, but it was a very important step in understanding the behaviour of electrons. Importantly, it is the model that you will learn and use the most in your science studies.

Bohr did not carry out major experiments himself but used mathematics to make predictions from published experimental results that others could test. The key technology that confirmed his predictions was spectroscopy – the analysis of the light emitted when atoms are heated. The equipment used, a spectrometer, is now a standard piece of equipment in science laboratories.



Figure 10.20 Erwin Schrödinger proposed the electron cloud model, different to Bohr's model of fixed electron shells.

DEPTH STUDY IDEA
The modern model of the atom

Erwin Schrödinger 1887–1961

Erwin Schrödinger said that it is impossible to predict where a specific electron will be situated in an atom at any given time. The only thing you can predict is where in the atom you are most likely to find an electron. This was very different to Bohr's idea of electrons being in fixed shells/orbits at a specific distance around the nucleus. Schrödinger proposed the electron cloud model, which shows the locations in the atom with the greatest probability of finding an electron – in other words, the locations where electrons are most likely to be found.

Schrödinger's work was mostly mathematical but he made predictions that were confirmed by experimenters.

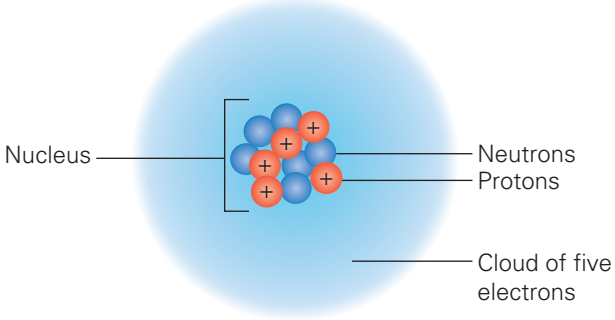


Figure 10.21 The electron cloud model of a boron atom shown in three dimensions – it is a shell around the nucleus; electrons are not found close to the nucleus.

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James Chadwick 1891–1974



Figure 10.22 James Chadwick discovered the neutron, the last part of the atomic model we use today.

So far in this chapter we have learned about protons and electrons and how they were discovered, but we have said very little about neutrons. You may not be surprised that the neutron was the last of the three subatomic particles to be discovered. As it has no charge and does not repel the protons in the nucleus, it was hard to detect. This was the case until James Chadwick started working with beryllium atoms and alpha particles in 1932. When he smashed these two particles together, unknown neutrally charged particles were released. He named these particles neutrons. This discovery completed the general model of the atom that scientists currently use.

Chadwick used a natural 'atom smasher' base on a radioactive element, like Rutherford, but his radioactive source was more powerful and his detectors more sensitive. Since his time, many discoveries have been made by firing particles and energy to try to smash subatomic particles. This has has been done in increasingly large and powerful particle accelerators, which use electromagnetic fields to accelerate charged particles. The technology of detectors has also improved greatly.

Explore! 10.2

INVESTIGATION

Other significant developments in the atomic model throughout history



Figure 10.23 Nobel Laureate Maria Goeppert Mayer

A number of other scientists have been involved in developing our understanding of atomic structure. Research the following scientists, noting their significant discoveries and how each discovery changed our understanding of the atom around at that time:

- Robert Millikan: measured the charge on the electron
- Werner Heisenberg: developed the uncertainly principle, concerning the speed and location of electrons
- Louis de Broglie: justified why electrons orbit in fixed shells in Bohr's model
- Lise Meitner: discovered and explained nuclear fission
- Maria Goeppert Mayer: discovered and explained the nuclear shell model.

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How science advances

The development and change of the atomic model over time is an excellent example of how different scientists individually contributed to and continue to update our understanding of atomic structure. However, it is important to note that they still may not be completely right! After all, there was a time when it was thought that the plum pudding model was correct. It is important that scientists continue to ask questions, conduct experiments using new technologies and review other people's work to increase humanity's understanding of atomic structure. Figure 10.24 summarises the development of the modern atomic model.

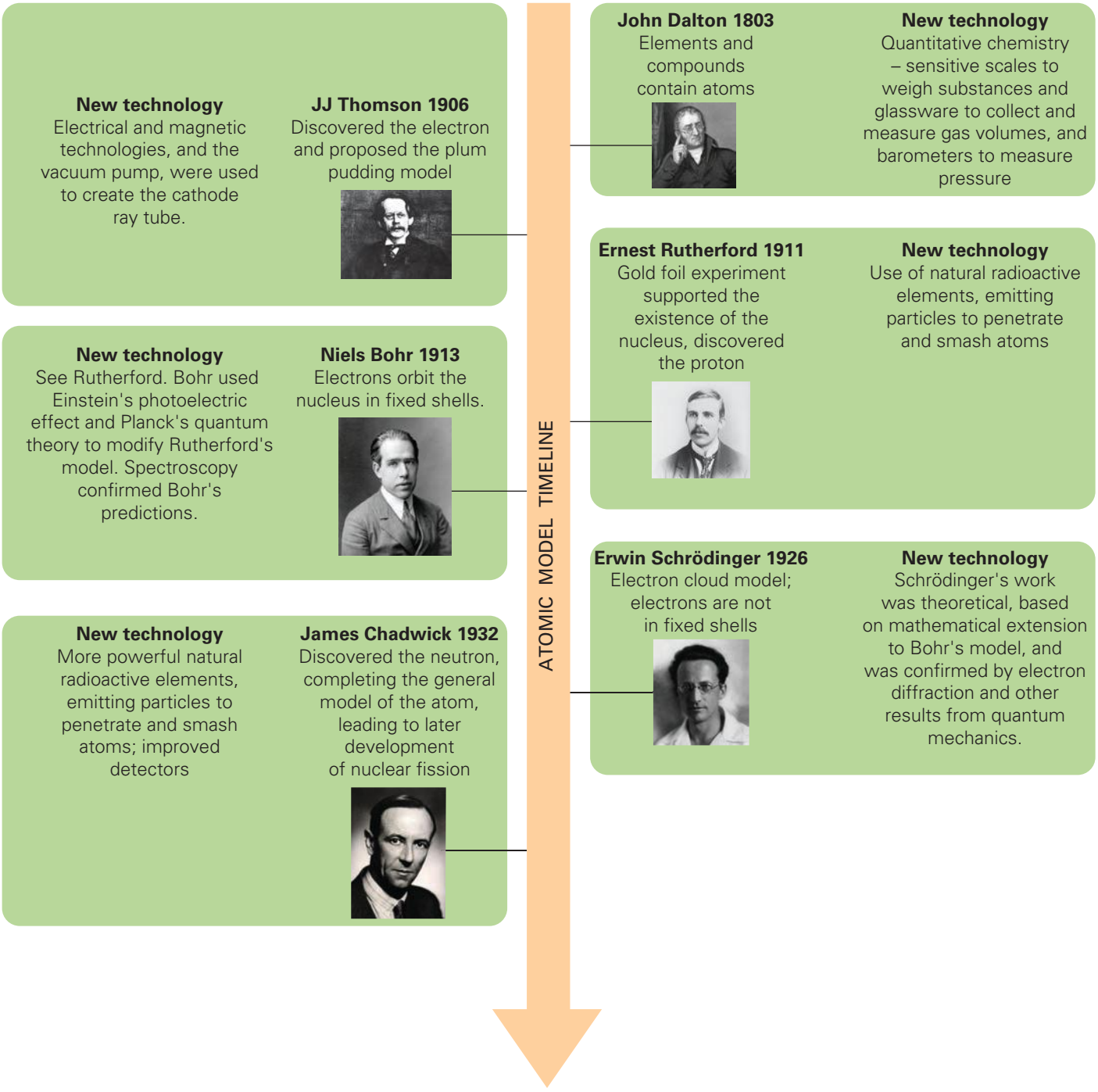


Figure 10.24 A timeline of the development of the modern atomic model with key scientists and new technologies that enabled the advances

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Quick check 10.5

1. **Recall** the name Bohr gave to the structures that contained electrons.
2. **Describe** how this explanation of these structures differed from Rutherford's model.
3. **Identify** the subatomic particle that James Chadwick discovered.

Advances in science 10.2

DEPTH STUDY IDEA
Why is the Higgs boson important?

The Higgs boson

Scientists are always trying to improve our understanding of how things work, so they did not stop investigating the atomic model after the neutron was discovered. In 1960, a British-born physicist named Peter Higgs proposed the existence of a new particle that later was named after him: the Higgs boson. This particle was believed to be essential for all atoms and for mass, so detection of this particle was his goal and the goal of many others for some time.

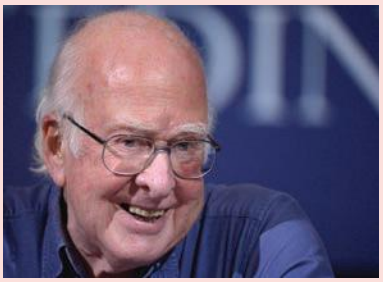


Figure 10.25 Peter Higgs (1929–2024) discovered the presence of a new particle, which was named the Higgs boson.

In 2012, the European Organization for Nuclear Research (CERN) announced that they had conducted experiments on the Large Hadron Collider, a 27-kilometre underground structure, which showed promising results of a particle that could be a Higgs-like boson. In 2013, after almost 55 years of research, CERN finally had enough evidence to confirm that they had recorded the presence of a Higgs boson, and Higgs was awarded a Nobel Prize for Physics in the same year. Of course, even this discovery is not the end. Further experiments are already underway, looking to build upon this work and expand our knowledge.



Figure 10.26 Engineers working on a part of the Large Hadron Collider at CERN where the Higgs boson was discovered

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Explore! 10.3

Other updated scientific theories

Scientists are continually trying to improve our knowledge of the world around us. They do this by discovering new things and building on previous discoveries. Most scientific theories or models are based on current knowledge, so they are essentially a 'best educated guess'. Many theories, in addition to atomic theory, have been updated or even discarded over time. Conduct your own research and see how many past scientific theories you can find that seem obviously incorrect with what we know now!

Imagine you are a scientist who has discovered something that contradicts a popular scientific theory. How would you go about explaining and proving your discovery to other scientists?

Go online to access the interactive section review and more!

Section 10.2 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 10.2 questions

Remembering

1. **Recall** what the Greek word *atomos* means in English. How does this relate to the word 'atom'?
2. **State** who discovered the neutron.

Understanding

3. Before carrying out the gold foil experiment, **summarise** what Rutherford thought would happen when alpha particles were fired at Thomson's plum pudding model of the atom.
4. **Compare** and **contrast** Rutherford's model of the atom with Thomson's plum pudding model.

Applying

5. **Identify** the reason why some alpha particles bounced back towards the detector in Rutherford's gold foil experiment.
6. **Explain** why the neutron was difficult to discover.

Analysing

7. **Analyse** the differences between Schrödinger's and Bohr's models of the atom.
8. Democritus and Aristotle were philosophers, not modern scientists. **Examine** in what ways their thoughts were 'scientific' and in what ways they were 'not scientific'.

Evaluating

9. **Describe** and explain the evidence that led to Rutherford concluding that most of the mass and all the positive charge of the atom was concentrated in the centre.
10. **Suggest** why the atomic model has changed and why it may continue to do so.
11. 'The current atomic model is perfect and accurate.' **Appraise** the accuracy of this statement.
12. Do you expect the atomic model to change significantly in the future? **Justify** your answer.
13. **Deduce** why there is usually such a long period between a scientist proposing a theory and the theory being supported or refuted by valid scientific evidence.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
10.1	identify the atom as the smallest part of an element that retains the element's properties.	4, 9, 10
10.1	describe the structure of an atom in terms of its subatomic particles (protons, neutrons and electrons).	2, 3, 7
10.1	use the planetary atomic model to describe the location, relative charge and mass of protons, neutrons and electrons.	1, 6
10.2	describe how the atomic model has changed over time.	5, 8, 13, 15
10.2	explain how new technologies have improved our understanding of the atomic structure.	8, 11, 14
10.2	recall the contributions of various scientists to our current understanding of the atomic model.	8, 12

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **Draw** and label the modern planetary atomic model.
2. **Recall** which subatomic particle has a charge of:
   - **a.** –1
   - **b.** 0
   - **c.** +1.
3. **State** where electrons are located within the atom.

Understanding

4. **Identify** the smallest particle of gold that has the properties of gold.
5. **Describe** the differences between Rutherford's and Bohr's models of the atom.
6. **Explain** why atoms of elements have a neutral overall charge.

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Applying

7. In each of the following scenarios, based on their charge, **explain** which subatomic particles are involved or could be involved. There could be more than one possibility. Two subatomic particles:
   a. attract each other
   b. repel each other
   c. neither attract nor repel each other.

8. **Explain** how Rutherford's gold foil experiment led to the discovery of the nucleus.

9. Using water as an example, **explain** how the fact that it always contains the same proportion of hydrogen and oxygen is evidence for the existence of atoms.

Analysing

10. **Contrast** an element and a compound.

11. **Propose** a reason why microscopes did not lead to the discovery of atoms or their structure, but they have eventually confirmed their existence.

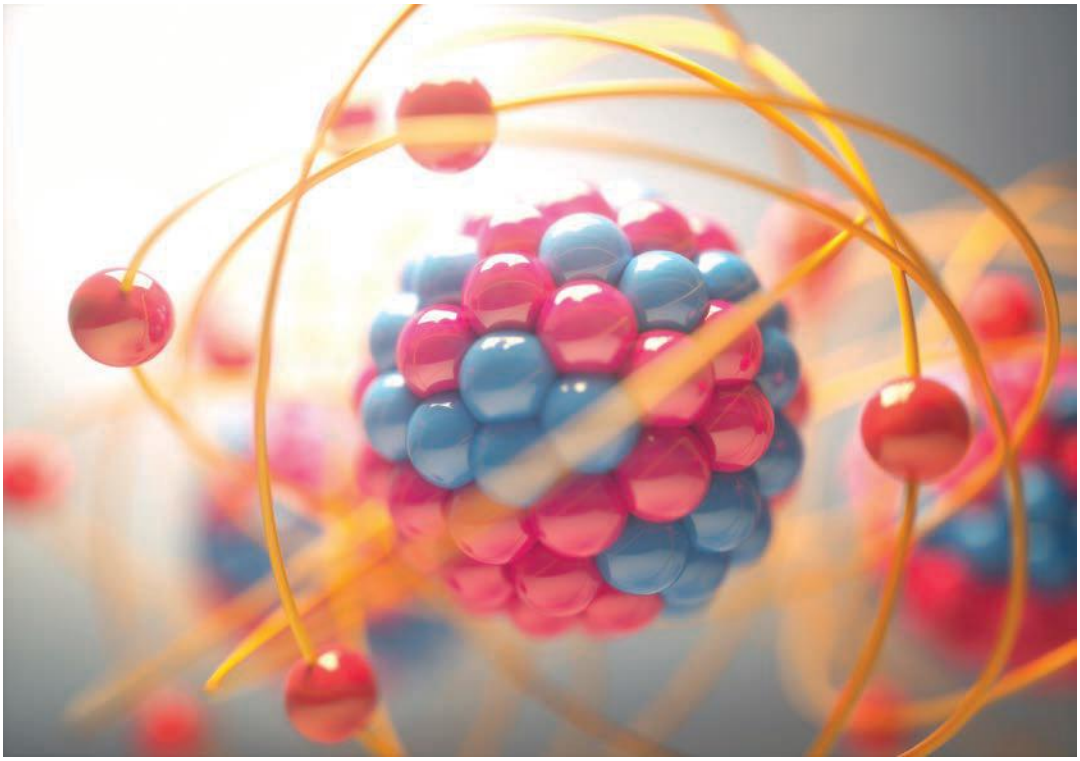
Evaluating

12. Democritus and Aristotle were philosophers, not modern scientists. **Discuss**:
   a. the ways in which their ideas were 'scientific'
   b. how significant their contributions were to atomic theory.

13. 'The current atomic model is perfect and accurate.' **Evaluate** the accuracy of this statement.

14. **Discuss** whether you expect the atomic model to change significantly in the future. **Justify** your answer.

15. **Deduce** why there is usually such a long period between a scientist proposing a theory and the theory being supported or refuted by valid scientific evidence.



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Data questions

A simple experiment was carried out where baking soda (sodium hydrogen carbonate) was added to vinegar (acetic acid). A chemical change occurred and one of the products was a gas (carbon dioxide), which was collected and measured.

1. Using graph paper, plot a suitable graph of the results shown in the table below:

Time (seconds)	0	30	60	90	120	150	180	210	240
Volume of gas collected (cm^3)	0	80	135	160	210	230	240	240	240

2. From your graph, between what times was the rate of reaction greatest?

3. Mark a point on your graph when the reaction started to slow down.

4. Describe what might have taken place for the reaction to slow down.

5. Do any of the data points look like outliers?

6. What could be done to make these results more accurate and to reduce the chance of outliers?



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STEM activity: Designing and creating using bioplastics

Background information

Molecules are atoms that are bonded together. Chemically, plastic is what is known as a polymer. It is a substance consisting of long chains of molecules made up of repeating units. This is why the names of many plastics start with 'poly'. The polymers are made up of carbon and hydrogen, and sometimes oxygen, nitrogen, sulfur, phosphorus, fluorine or silicon.

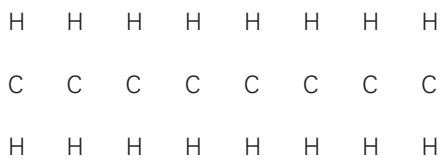


Figure 10.27 Polyethylene is the simplest plastic, consisting of a long chain of carbon atoms and hydrogen atoms.

Bioplastics are a type of plastic made from renewable resources like plants. They can easily be made at home with readily available ingredients. While they cannot solve the plastic problem alone, they can reduce carbon dioxide emissions, and some have the potential to biodegrade more easily than traditional plastics.

DESIGN BRIEF

Design and create a product using bioplastics.

Activity instructions

In groups of two or three, your task is to think of a product that is made of plastic and find a way of making it out of bioplastic.

Be careful – Safety glasses

Extreme care must be taken when working around the hotplate and handling the hot mixture. Ensure the hotplate is cool before moving it.

Suggested materials

- corn starch
- vinegar
- glycerine
- water
- food dye (optional)
- saucepan
- wooden spoon
- hotplate
- non-stick/baking paper/aluminium foil and tray
- cookie cutters or moulds to shape the plastic
- safety glasses

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Research and feasibility

1. Discuss different plastic products you use in your everyday life, and list all the benefits of manufacturing them from bioplastic.
2. List all the restrictions you have to consider in your design based on the materials and space you have available.
3. Research how you would use the suggested materials, or other materials safe for use in a school science laboratory, to manufacture the bioplastic.

Design and sustainability

4. Decide on a plastic product that you could make using a bioplastic. Justify your choice in your group by considering your constraints.
5. Design the method for manufacturing the bioplastic.
6. Design the mould you will use.

Create

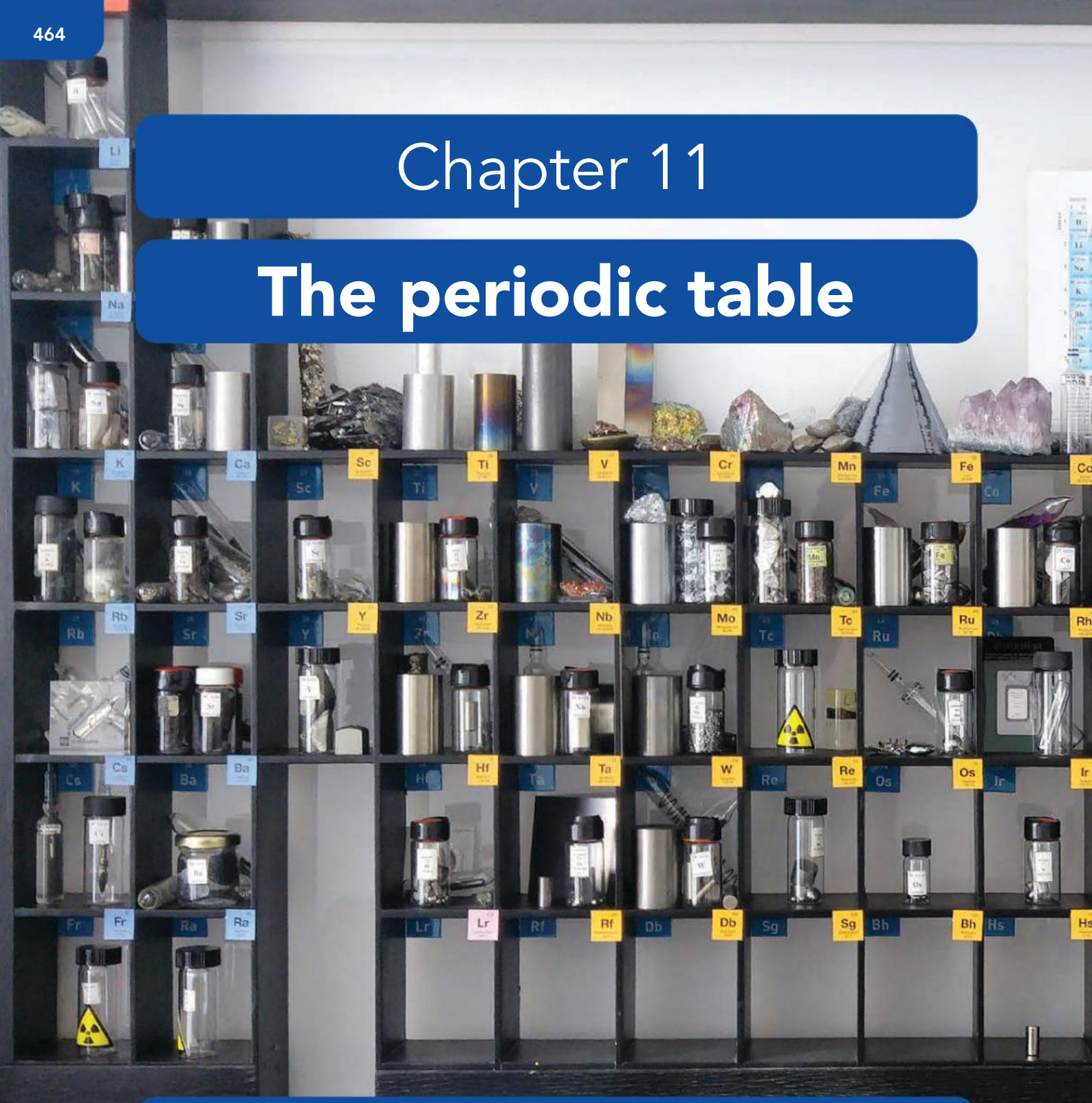
7. Create the mould you will use for your bioplastic product.
8. Follow your design method and construct your bioplastic product solution.

Evaluate and modify

9. Describe any difficulties you encountered.
10. Suggest ways that the design of your product could be improved.
11. List the physical properties of your bioplastic and comment on how appropriate these properties were.
12. Test your product by using it for its intended purpose under different conditions.
13. Evaluate the effectiveness of your product.



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Chapter 11

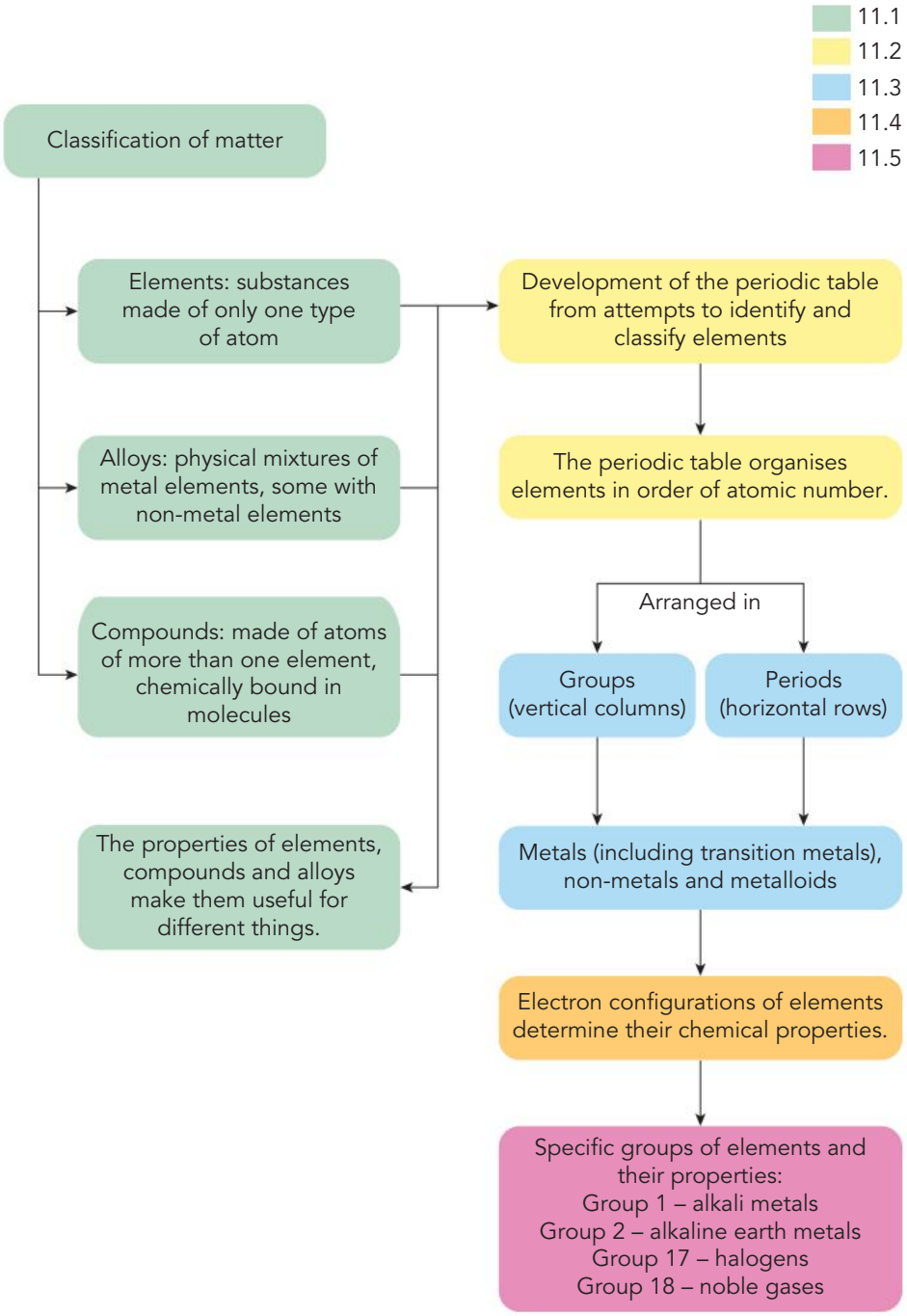
The periodic table

Chapter introduction

We have already seen that all matter is made up of particles. Subatomic particles make up atoms, and different atoms are unique to different elements. In fact, every single thing in our world is made up of some arrangement of just 118 elements. For hundreds of years, since the discovery of elements, scientists have been trying to sort elements into groups based on how they behave. The outcome of this is the periodic table of elements. In this chapter you will explore the periodic table, learn how the elements are arranged and what this arrangement tells us about their properties. You will investigate the properties of the elements and discover how these characteristics determine what the elements are used for. Finally, you will also learn about Dmitri Mendeleev, the scientist who came up with the foundation for the modern-day periodic table.

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Chapter map



Glossary terms

alloy
atomic number
conductivity
ductility
electron configuration
group
inert
lustre
malleability
metal
metalloid
non-metal
period
transition metals
valence electrons

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11.1 Classification of matter

WORKSHEET
Atoms, elements and compounds

Learning outcomes

At the end of this section, I will be able to:

1. identify elements in everyday objects.
2. compare the physical properties of metals, non-metals and metalloids.
3. explain how the properties of some elements, compounds and alloys relate to their uses.

Elements' properties relate to their uses in everyday objects

Everything we see is made from just 118 elements. Sometimes the materials around us are in the form of a pure element; sometimes an element is chemically combined with other elements in compounds; and sometimes elements are in mixtures such as **alloys**.

Many elements are found uncombined in everyday objects. For example:

- party balloons are filled with helium
- neon is used in fluorescent signs
- aluminium is used for cans of soft drink
- silver, gold and platinum are used to make jewellery.

alloy
a metallic substance made of two or more elements

inert
a substance that does not easily react

But why is each element used in that particular way? Both neon and helium are gases, so why is neon used in signs, but not in balloons? Well, it is like how we choose the best stationary item from our pencil case for a particular job, such as choosing a pencil for drawing diagrams, and a highlighter for highlighting as we read. Why do we make those choices? Usually, it is based on the properties or characteristics of the stationary item. A pencil can be rubbed out, making it good for diagrams where we might want to make changes easily. A highlighter is bright, so it helps show the parts of text we think are important. In the same way, elements are chosen for particular jobs based on their properties. Helium is useful for filling balloons as it is lighter than air, and this means the balloon will float. Helium is also **inert**, meaning it is stable, making it a safe choice But neon also shares these properties. Why use helium and not neon? Neon is not as light as helium and, because it is rare, is more expensive.





Figure 11.1 Helium and neon are both gases, but each has different uses. Helium is used in balloons as it is lighter than air. Neon is rarer than helium but has special properties that make it useful for fluorescent signs.

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Element	Properties	Use
Helium	Lighter than air, inert	To fill balloons so that they float
Neon	Emits a bright glow when electrified, inert	Glowing signs
Magnesium	Burns with a bright white light	Used on sparklers for the bright light produced
Aluminium	Lightweight and non-corroding	Aeroplane parts and soft drink cans
Copper	An excellent conductor of electricity and heat	Used in electrical wires and electronics as it conducts electricity. Used in pots, radiators and heating systems due to its thermal conductivity.
Silver, platinum and gold	Non-reactive, shiny, soft and malleable	Easy to shape into jewellery that will not react with the air or skin. It is shiny in appearance.
Tungsten	Highest melting point of all the metals	Used in the filaments of light globes

Table 11.1 Some common elements, their uses and the properties that make them suitable for that use

Try this 11.1

Element detective

Be an element detective. Choose an everyday object and see if you can find out what elements it is made up of.

Then, investigate what properties make the element suitable for that use and make a list of these.

Properties of metals and non-metals

As in other areas of science, in chemistry we like to classify (organise) things into groups: pure substances/mixtures, solids/liquids/gases and so on. One of the first steps in classifying elements is to determine whether the substance is a **metal** or a **non-metal**. To do this, scientists look at the general properties that the elements have in common (see Table 11.2).

Property	Metals	Non-metals
State at room temperature	Solid (exception is mercury)	Solid, gas or liquid
Colour	Silver/grey	A range of colours, including colourless
Lustre	Shiny when polished	Usually dull
Conductivity	Conducts electricity and heat	Cannot usually conduct electricity or heat
Malleability	Can be bent or flattened	Cannot be bent or flattened; often brittle
Ductility	Can be made into a wire	Cannot be made into a wire
Melting point	Usually a high temperature (the exception is mercury)	Usually a low temperature

Table 11.2 The general properties of the metal and non-metal elements

metal
a substance that is shiny, can conduct electricity, can be bent, is usually silver/grey and is ductile

non-metal
a substance that is dull, cannot usually conduct electricity, is brittle and is not ductile

lustre
the ability of a substance to become shiny when polished

conductivity
the ability of a substance to conduct or carry electricity or heat

malleability
the ability of a substance to be bent or flattened into a range of shapes

ductility
the ability of a substance to be drawn into a wire

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Lattices

All metals in their solid state (and some non-metals, such as carbon and silicon) are organised in what we call a lattice formation. A lattice is a three-dimensional shape that allows the atoms to pack together very tightly and form the strongest bonds. With metals, the lattice layers can slide past each other, provided they stay in contact with each other, contributing to the physical properties of malleability and ductility.

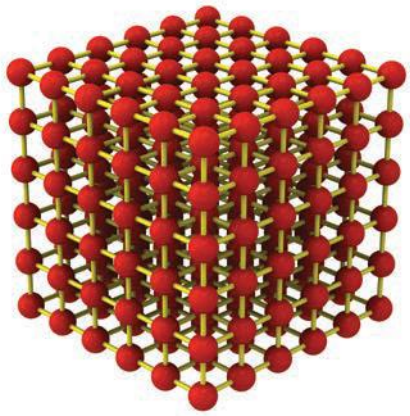


Figure 11.2 A lattice structure. Every atom is attached tightly to other atoms in all directions.

Try this 11.2

Visualising a metal lattice

To imagine how metal atoms pack together and form a lattice, imagine marbles that need to be packed in a box. The marbles would be placed on the bottom of the box in neat, orderly rows, and then a second layer of marbles would move into the spaces between marbles in the first layer. Give this a try, and you will model the lattice formed by metal atoms.



Figure 11.3 Stacking glass marbles of the same size in a box can be used to model how metal atoms pack together and form a lattice.

Metalloids

metalloid
a substance that has some of the properties of both metals and non-metals

Some of the elements in the non-metal group have some similar properties to the metals. One example is silicon (see Figure 11.4). Silicon can conduct heat and electricity a little, but it cannot be bent or made into wire. It is shiny when polished but is brittle and shatters like glass. When an element has properties of both metals and non-metals, it is called a **metalloid**. There are just eight metalloids: antimony, arsenic, astatine, boron, germanium, polonium, silicon and tellurium.



Figure 11.4 Three examples of metalloids. **(a)** Silicon is shiny and brittle, and can conduct electricity, but not as well as a metal. **(b)** Antimony is shiny like a metal, but brittle like a non-metal. **(c)** Boron conducts electricity but is brittle.

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Did you know? 11.1

Conductors and semiconductors

Some non-metals are good conductors. Carbon in the form of graphite is both a good heat and electrical conductor, and surprisingly, carbon in the form of diamond is the best-known thermal conductor, with a conductivity five times higher than copper!

Metalloids have a heat conductivity between metals and non-metals, and if they can conduct electricity, this usually can only occur at higher temperatures. Metalloids that are good electrical conductors at high temperatures are called semiconductors. Silicon is an example of a semiconductor.

After oxygen, silicon is the second most abundant element in Earth's crust, but is rarely found naturally in its pure form. Instead, it can be extracted from silica sand, a combination of silicon and oxygen.

You may have heard of Silicon Valley in California and may think it's because of a number of technology company headquarters being located there (silicon is used widely in computer chips). However, originally it was named after the silica sand found in the area.

Practical skills 11.1: Teacher demonstration

Metals versus non-metals

Be careful



Electrical shocks may occur.
Elements may become hot.
Ensure the voltage output is not exceeded. Turn the power supply off when changing the circuit.

Aim

To investigate the properties of metals, non-metals and metalloids.

Materials

- 12 V light globe (LEDs can also be used)
- connecting wires and alligator clips
- 12 V battery or power pack
- fine sandpaper
- samples of six metals, non-metals and metalloids – for example, sulfur, magnesium, silicon, copper, iron/steel, tin, zinc, aluminium, carbon

Procedure

1. Draw up a table like the one in the Results section. Include the six elements you are investigating. Also select a property you would like to investigate in addition to those already listed.
2. Use the fine sandpaper to rub each substance and determine its lustre – is it shiny or dull? Record your observations in your table. Try to bend each of the substances – is it malleable or not? Record your observations in your table.
3. Make a prediction about the electrical conductivity of each of the substances.

continued …

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4. Connect each substance to an electrical circuit as shown in Figure 11.5. Does the substance allow electricity to pass through, making the globe glow? Record your observations in your table.

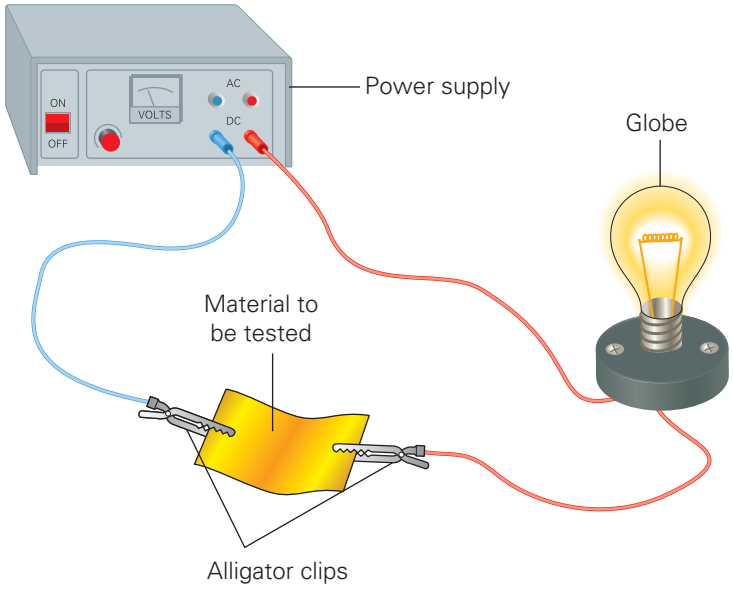


Figure 11.5 Experimental set-up for testing the electrical conductivity of different substances

5. Investigate your choice of property.

Results

Element	Lustre	Malleability	Electrical conductivity	Your choice of property

Discussion

1. Which of the substances you tested were metals and which were non-metals or metalloids?
2. Explain how you tested for your choice of property.
3. Recall the difference between a physical property and a chemical property. Then, summarise the physical properties that metals have in common and the physical properties that non-metals have in common. Name some exceptions and state how they are different.
4. Are the substances you tested pure substances or mixtures? Explain your answer by including definitions of these terms.
5. Imagine you have discovered a new element. What tests would you carry out in order to determine whether the substance was a metal or a non-metal?

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Quick check 11.1

1. **Define** the following key terms: element, metal, non-metal, metalloid, malleability, lustre, conductivity, ductility. Provide examples where possible.
2. **Demonstrate** your knowledge of metals and non-metals by rewriting the following properties in the correct columns.

Metals	Non-metals
Solid, liquid or gas	Usually dull
Solid	Shiny surface
Usually unable to conduct electricity or heat	Can conduct electricity and heat
Ductile	Unable to be made into a wire
Low melting temperature	Malleable
High melting temperature	Unable to be bent

Compounds

So far, we have looked at how the 118 elements can be used in their pure, uncombined form in everyday objects. However, as you learnt in Chapter 7, elements are not the only pure substances. Elements are often found chemically combined with other elements in compounds. The properties of a compound can be very different to those of the elements that make it up. One example is sodium chloride. We sprinkle white crystals of salt on our hot chips to add flavour, and the result is both safe to eat and delicious. The elements that make up this salt, sodium and chlorine, are very different though! Sodium is a shiny, soft metal that is highly reactive and can explode when exposed to water. In fact, because it is highly reactive, sodium is rarely found in its element form. Chlorine is a toxic greenish-yellow gas that is used to sterilise water. When sodium and chlorine form chemical bonds, their atoms undergo changes that cause the resultant compound, sodium chloride, to have different properties than the individual elements that comprise it.

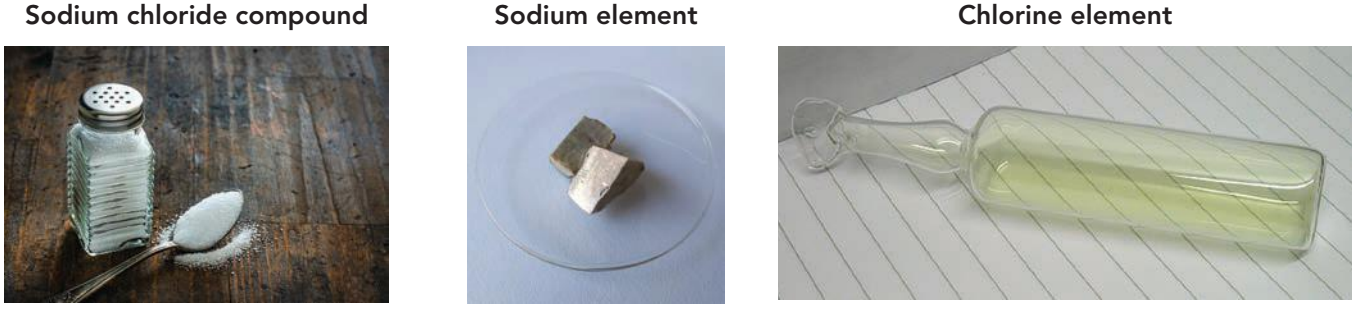


Figure 11.6 Sodium chloride (salt) is a white compound with a crystalline structure. It is very different from the elements it is formed from: the metal sodium and the toxic gas chlorine.

Water is another commonly found compound, and it is one that is essential for life. Each water molecule consists of two hydrogen atoms bonded with one oxygen atom. Both hydrogen and oxygen are gases at room temperature. However, when they join together chemically as a compound, their properties change to become a liquid.

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Alloys

Alloys are made by heating and mixing together a metal with another metal so that they fuse together, forming a new substance. For example, bronze is an alloy of copper and tin. In rarer cases the alloy is formed when the metal is mixed with a non-metal. For example, steel is an alloy of iron and carbon. In an alloy, the elements do not combine chemically but remain a mixture. Alloys are made to have a combination of properties that are more useful than the original elements. They can be stronger, more resistant to corrosion or cheaper to produce.

For example, we have already seen that aluminium has useful properties, such as being lightweight and corrosion-resistant. However, on its own, it is a fairly soft metal. Combined with titanium and iron, an alloy is formed that is an incredibly strong, lightweight metal and is heat-resistant. This makes it perfect for using in the aerospace industry and in engines as it maintains its strength even under extremes of temperature.

Alloys can be made with different compositions to obtain the required properties. Steel alloys are a common example. Traditionally, steel was made from just iron and carbon to increase its strength. Now, steel alloys are made by adding other elements such as nickel, chromium, manganese, molybdenum, vanadium, silicon and boron. By alloying with these elements, the hardness, strength and wear-resistance properties of the steel alloy can be changed as required. Different steel alloys can then be used for different jobs, from building and construction to furniture or home appliances and packaging.

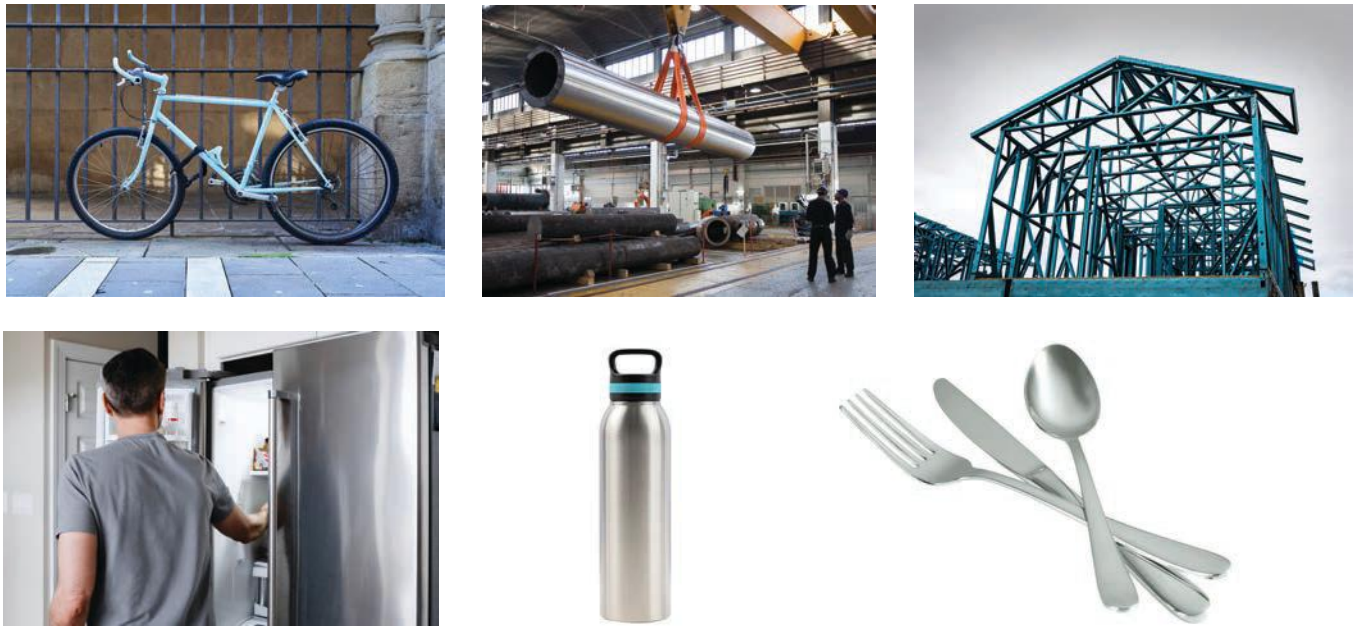


Figure 11.7 Different steel alloys are found in many everyday objects, including bike frames, steel pipes, building frames and, household appliances like fridges, water bottles and cutlery.

Increasing strength is not the only reason you may create an alloy. Bismuth mixed with cadmium forms an alloy which melts at a very low temperature for a metal (70°C). This property is used in automatic fire sprinkler systems. When hot gases from a fire enter the sprinkler head, they melt the metal, which releases a valve so that water sprays out.

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Section 11.1 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Go online to access the interactive section review and more!

Section 11.1 questions

Remembering

1. **List** three properties of metals and three properties of non-metals.
2. **Summarise** three of the tests you can do to find out whether a substance is a metal or a non-metal. Provide a diagram if necessary.
3. **State** a definition of an alloy and give one example.

Understanding

4. **Explain** what a metalloid is.
5. **Suggest** which two properties of metals make them good materials for electric wiring.

Applying

6. The first bicycles were made of wood, then iron, followed quickly by steel. **State** what type of substance steel is and **explain** why it was used to replace iron in bike frames.

Analysing

7. Consider the table below containing descriptions of the physical properties and uses of a number of materials. For each material, **determine** if it is most likely to be a metal, non-metal or metalloid.

Description	Use	Metal/non-metal/metalloid
Soft, shiny, malleable and ductile. Solid at room temperature.	Electrical wiring	
Dull, black and solid at room temperature. Poor conductor of heat and electricity.	Component of many fuels	
Shiny silvery liquid at room temperature. Good conductor of electricity.	Found in electrical switches	
Hard, brittle and solid at room temperature with a grey lustre. Conducts electricity.	Used to make computer chips	
Yellow/green gas at room temperature	Disinfectant	

Evaluating

8. **Justify** why metalloids are considered a separate group from the metals and non-metals. Use an example to illustrate your point.
9. Here are the answers to some questions. For each answer, **propose** two options for what the question could be.
   - **a.** Atom
   - **b.** Conducts electricity
   - **c.** Compound

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11.2 Development of the periodic table

WORKSHEET
Periodic table timeline

VIDEO
Properties of elements

Learning outcomes

At the end of this section, I will be able to:

1. describe how the historical development of the periodic table came from understanding patterns in the chemical and physical properties of the elements.
2. recall an example of using the periodic table to predict a future element and its properties.

Throughout history, scientists have been challenged by the question of how best to organise chemical elements. In this section, we will summarise the attempts of six scientists and see the progress made over time in understanding patterns (similarities and differences) in the nature of elements. This nature (their properties) has led to their organisation in the table we all recognise as the periodic table. Its basis is repeating patterns.

Timeline of the periodic table

1789



Antoine Lavoisier

- Lavoisier laid the foundations of chemistry as a science by emphasising observation, measurement (quantitative chemistry), and systematic classification. In 1789, there were thought to be 33 elements (including light!). Lavoisier sorted these elements into gases, metals, non-metals and earths, constructing the first list of the known elements.
- His table of elements quickly became outdated as new elements were discovered.

1808



John Dalton

- As you discovered in Chapter 10, Dalton was responsible for developing early atomic theory. He was also the first scientist to try to determine the weights of atoms of different elements.
- He allocated symbols to the 36 known elements.



Figure 11.8 Dalton's element symbols. Do you recognise any of these elements?

1817



Johann Wolfgang Döbereiner

- Döbereiner noticed that known elements could be arranged into groups of three by their similarities in appearance and reactions. He called these groups triads (for example, lithium, sodium, potassium).

continued ...

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1863



Alexandre-Émile Béguyer de Chancourtois

- De Chancourtois arranged known elements by increasing atomic mass.
- He wrapped his list around a cylinder, which allowed sets of similar elements to line up.
- De Chancourtois's system showed repetition in the properties of elements at certain, regular intervals.

1864



John Newlands

- Newlands organised the known elements into horizontal rows, seven elements long. The elements were arranged in order of their atomic masses.
- He stated that the eighth element would have similar properties to the first element in the series.

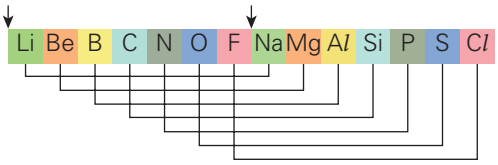
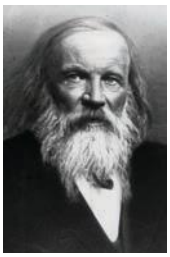


Figure 11.9 Newland's law of octaves. Every eighth element in the row has similar properties. Track the lines and investigate what is similar about each element, e.g. fluorine (F) and chlorine (C).

1869



Dmitri Mendeleev

- By 1869, there were 56 known elements, with a new element being discovered approximately once every year.
- Mendeleev organised the elements into a table with rows and columns, grouping elements by properties and in order of their atomic mass.
- Mendeleev left space in his table for elements he thought would be discovered.

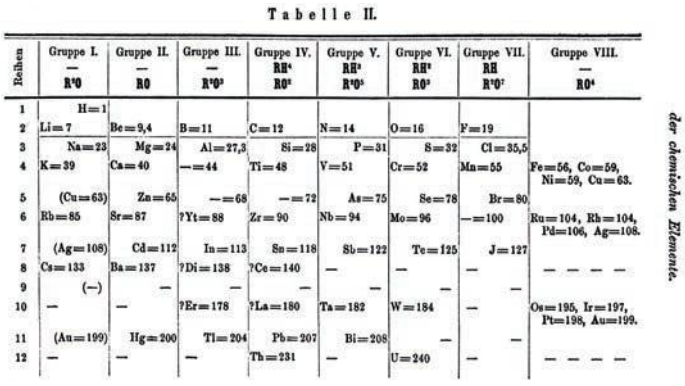


Tabelle II.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

der chemischen Elemente.

Figure 11.10 Mendeleev's early attempt at arranging the known elements into a table

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Quick check 11.2

1. **Describe** how Mendeleev's attempt at organising the elements was similar to those made by other scientists before him.
2. **Describe** how Mendeleev's attempt differed from attempts made by other scientists.

Predicting future elements

Although Mendeleev's approach was similar to that of other scientists, his arrangement did include one thing that the others had missed. Mendeleev realised that new elements were still being discovered and decided that he must consider this when grouping the elements together. For this reason, he left gaps in his table for elements that had not yet been discovered. You can see in Figure 11.10 that he drew lines to show where he thought a discovery would be made. His prediction of new discoveries was amazing, and even more impressively, he also predicted the properties of these unknown elements years before they were discovered!

To explain how Mendeleev made his predictions, we can look at an example: he left a gap between silicon (Si) and tin (Sn) going down the column. He named this element eka-silicon and made the predictions shown in Table 11.3 based on what was known about the properties of the elements above and below it in his table.

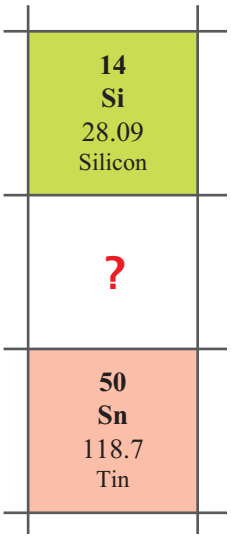


Figure 11.11 Mendeleev predicted that there would be an element between silicon and tin.

Element	Mass	Density (g/cm^3)	Density of its chloride (g/cm^3)	Boiling point of its chloride (°C)
Eka-silicon	72	5.5	1.9	100

Table 11.3 Mendeleev's predictions for some physical properties of eka-silicon

So how close was Mendeleev in his predictions? In 1886, the element germanium (Ge) was discovered, which had the properties shown in Table 11.4.

Element	Mass	Density (g/cm^3)	Density of its chloride (g/cm^3)	Boiling point of its chloride (°C)
Germanium	73	5.3	1.88	86

Table 11.4 The physical properties of germanium compared to eka-silicon

WORKSHEET
Predicting properties

Compare these properties of germanium with Mendeleev's predictions for eka-silicon. He was incredibly close! Luckily, the discovery of germanium occurred within Mendeleev's lifetime and confirmed his decision to arrange elements in the way he did. Unbelievably, Mendeleev did not receive a Nobel Prize for his efforts, but he does have a chemical element named after him: element 101, mendelevium (Md).



Figure 11.12 Mendelevium has the atomic number 101.

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Explore! 11.1



Properties of an element

We have already discussed that Mendeleev arranged the elements in order of their relative atomic mass and that elements with similar properties were placed in the same groups.

Investigate any element you choose. You will need to consult secondary sources to gather information to help you answer these questions.

1. How was the element you have chosen discovered? Is it natural or synthetic?
2. What physical and chemical properties does the element you have chosen have?
3. What other elements have similar properties, and how closely are they located in the periodic table?

Investigation 11.1

Predicting properties of elements



Aim

To investigate the relationship between the position of an element in the periodic table and its density.

Useful formulas

$$\text{Density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

$$\text{Percentage difference} = \frac{\text{(actual value} - \text{predicted value)}}{\text{actual value}} \times 100$$

Materials

- sample elements: carbon rod, zinc, tin
- 25 mL measuring cylinder
- graph paper
- electronic balance
- ruler
- weigh boats (small container to hold sample elements)
- plastic pipette

Procedure

Part 1: Prepare the results table

1. Draw the table shown in the results section into your science journal.
2. Identify and label the position of each element on the periodic table. You will need to refer to a periodic table.

Part 2: Measure the mass of each sample element

1. Place a weigh boat onto the balance and zero the balance by pressing 'tare'.
2. Place the first sample element on the empty weigh boat and record the mass in the table.
3. Remove the sample element.
4. Repeat steps **1**–**3** with the other sample elements.

Part 3: Measure the volume of each sample element

1. Add approximately 15 mL of water to the 25 mL measuring cylinder with water and record the initial volume in cm^3 (1 mL = 1 cm^3).
2. Gently place the first sample element into the measuring cylinder and record the new volume in the table.
3. Remove the sample element by tipping the water out of the measuring cylinder.
4. Repeat steps **1**–**3** with the other sample elements.

continued …

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Results

1. Calculate the volume of each sample element in cm^3 and record it in the results table.
2. Calculate the density of each sample element using the density formula above and record it in the results table.
3. Draw a scatter plot to analyse the relationship between the period number of each metal and its density.
4. Add a line of best fit to the graph, if possible. Note the type of line that fits best to reflect the relationship between the two variables.

Independent variable		Dependent variable						
Element sample	**Position in periodic table (group, period)**	**Mass (g)**	**Initial volume in measuring cylinder (cm^3)**	**Final volume in measuring cylinder (cm^3)**	**Volume of element (cm^3)**	**Calculated density (g/cm^3)**	**Actual density (g/cm^3) (secondary data source)**	**Percentage difference (%)**
Carbon								
Zinc								
Tin								

Discussion

1. Describe the trend or pattern that is found when the line of best fit was applied to the graph. What type of relationship was found?
2. Predict the density of germanium (row 4 of the periodic table) and lead (row 6) using your graph. Record them in your science journal.
3. Compare the actual density for each element with its calculated density.
4. Compare the actual densities for carbon, zinc and tin to the densities predicted mathematically by calculating the percentage difference using the formula above.
5. Was the calculated density data reliable enough to base predictions on? Justify your response with data.
6. Research online to find the actual densities of germanium and lead (the 'properties' tab at ptable.com is a good resource to use). Record the actual densities for each in your science journal.
7. Compare the actual densities for germanium and lead to the densities predicted mathematically by calculating the percentage difference using the formula on the previous page.
8. Can reliable conclusions and predictions be drawn from the results? Justify your response with data.
9. Can you identify possible limitations of this method? Justify your answer using data if possible.
10. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

1. Make a claim about the relationship between the density of an element and its position in the periodic table.
2. Support your statement by explaining how the data you gathered support your claim.
3. State whether your hypothesis was supported or not supported by the data.

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Section 11.2 review

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Section 11.2 questions

Remembering

1. **Name** three scientists who attempted to organise elements.
2. **Name** the scientist who created the first version of the modern periodic table.
3. **Recall** the method most scientists used to arrange chemical elements.

Understanding

4. **Compare** and **contrast** Newlands's and Mendeleev's arrangements.
5. **Summarise** how Mendeleev made his predictions surrounding the properties of elements which had yet to be discovered.

Applying

6. Gold, silver and platinum are all used to make jewellery due to their appearance and the fact that they are very unreactive and so keep their lustrous appearance. **Predict** whether they are close together on the periodic table. **Justify** your response.

Analysing

7. **Analyse** the reasons why Mendeleev's periodic table was accepted by other scientists.

Evaluating

8. **Assess** the reasons why there were multiple ways proposed throughout history to arrange chemical elements.
9. For each of the tables below, **deduce** the approximate properties of the middle element.

a.

	Lithium	Sodium	Potassium
Mass	7		39
Melting point (°C)	180		63

b.

	Silicon	Germanium	Tin
Mass	28		119
Melting point (°C)	1414		232

c.

	Chlorine	Bromine	Iodine
Mass	35.5		127
Melting point (°C)	–101		114

10. **Determine** why the modern periodic table has remained relatively unchanged since it was reordered by atomic number instead of relative atomic mass.

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11.3 Structure of the periodic table

WIDGET
Periodic table

Learning outcomes

At the end of this section, I will be able to:

1. describe the structure of the modern-day periodic table and examples of the patterns and relationships found within it.
2. understand why symbols are used to represent the elements, and identify symbols of common elements.
3. explain the organisation of the elements in the table using their atomic number and properties.
4. identify the elements in some common compounds using the periodic table.

The periodic table is arranged by atomic number

The modern-day periodic table is a list of all the known elements in order of their atomic number. The atomic number is the number of protons in an element. This makes hydrogen (H) the first element in the periodic table as it has one proton and therefore an atomic number of 1. As of 2025, oganesson (Og), a synthetic element discovered by Russian scientists in 2002 and officially named in 2016, is the last element, with an atomic number of 118.

Symbols for elements

Chemistry has its own language, with all the elements represented by symbols. It is a shorthand way of writing the name of the element so that every scientist in every country can understand it.

In Table 11.5, notice that sometimes an element's symbol consists of the first and second letters of the name. For example, the symbol for hydrogen is H, and the symbol for helium is He. This is because if helium were to also have the symbol H, it would be confused with hydrogen. Note that the first letter of the symbol is always capitalised, and the second letter is never capitalised. But what about chlorine? You would think that chlorine would have the symbol Ch, but it is actually Cl. In this case it is distinguished by its third letter.

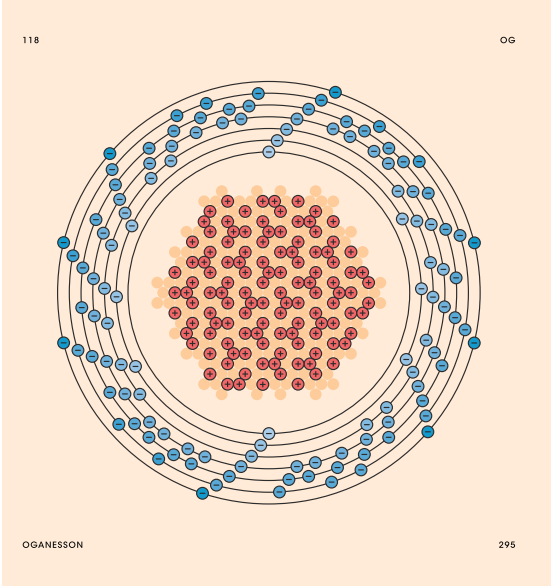


Figure 11.13 Oganesson (Og) was the last element on the periodic table in 2025, with an atomic number of 118. This diagram shows its electron configuration and nuclear particles.

Sometimes the letters from the element's Latin or Greek name are used. For example, the symbol for copper is Cu. The Latin word for copper is *cuprium*, and this is where its symbol comes from. Another example is mercury, which has the symbol Hg, taken from its Latin name *hydragyrum*, which means 'shining water'. Some elements are also named after famous people or places, like einsteinium and francium.

The symbols used in the periodic table can be used to identify the elements that make up compounds. For example, H_2O (water) contains hydrogen (H) and oxygen (O), and CH_4 (methane) contains carbon (C) and hydrogen (H).

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Element	Symbol	Metal/non-metal	Melting point (°C)	Year of discovery
Hydrogen	H	Non-metal	−259	1766
Helium	He	Non-metal	−272	1895
Lithium	Li	Metal	180	1817
Beryllium	Be	Metal	1278	1798
Boron	B	Metalloid	2300	1808
Carbon	C	Non-metal	3500	Ancient
Nitrogen	N	Non-metal	−210	1772
Oxygen	O	Non-metal	−219	1774
Fluorine	F	Non-metal	−220	1886
Neon	Ne	Non-metal	−249	1898
Sodium	Na	Metal	98	1807
Magnesium	Mg	Metal	650	1755
Aluminium	A*l*	Metal	660	1825
Silicon	Si	Metalloid	1410	1824
Phosphorus	P	Non-metal	44	1669
Sulfur	S	Non-metal	119	Ancient
Chlorine	C*l*	Non-metal	−101	1774
Argon	Ar	Non-metal	−189	1894
Potassium	K	Metal	64	1807
Calcium	Ca	Metal	850	1808

Table 11.5 Twenty elements, their symbols and some of their properties

Explore! 11.2

INVESTIGATION

Naming the elements

Many elements on the periodic table have 'weird' symbols that do not match their name. There are also elements named after scientists.

For the following elements, research why they have that name or symbol:

- sodium (Na)
- iron (Fe)
- curium (Cm)
- mendelevium (Md)
- rutherfordium (Rf)

Quick check 11.3

1. **Explain** why not all the elements are named after the first letter of their name.
2. **Recall** the reason for using symbols instead of the elements' full names.
3. Refer to Table 11.5 above with the 20 elements listed.
   a. **Name** the elements with the following symbols: K, S, Mg, Be, B.
   b. **Identify** the element with the lowest melting point.
   c. **Identify** the most recently discovered element.
4. **Demonstrate** your understanding of symbols by matching the following elements with their correct symbol.
   Names: hydrogen, carbon, oxygen, nitrogen, helium, sulfur, magnesium, aluminium
   Symbols: Mg, O, A*l*, S, N, H, C, He
5. **State** the elements that are found in CO_2 (carbon dioxide).

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Groups of the periodic table

group
the vertical columns in the periodic table

The periodic table is arranged into vertical columns called **groups**. There are 18 groups in total.

Elements in the same group all have similar properties; for example, they react with the same chemicals in similar ways. This allows us to predict the properties of elements by looking at others in the same group.

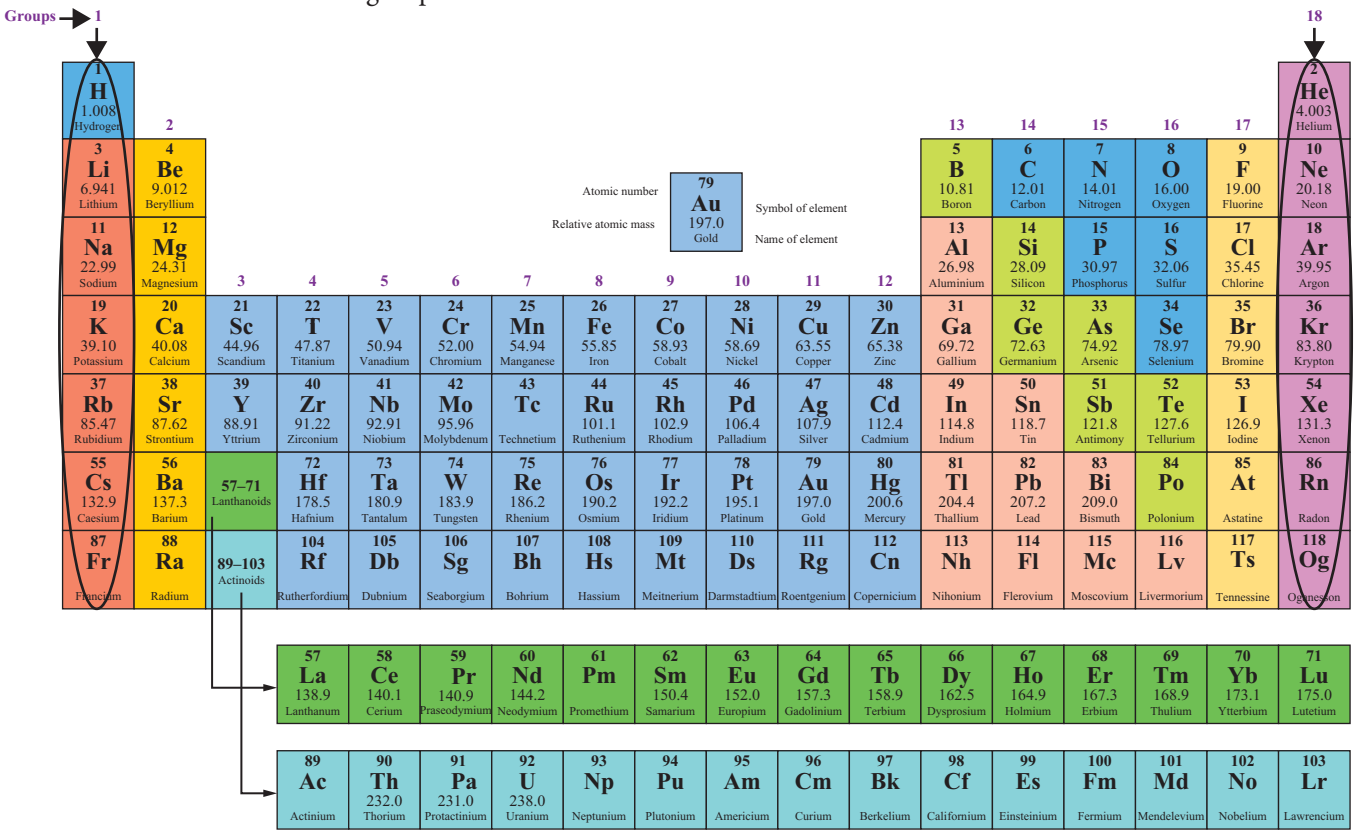


Figure 11.14 Groups are the vertical columns of the periodic table.

Quick check 11.4

1. Barium (Ba) in group 2 reacts with oxygen (O) to form barium oxide, a metal oxide with the formula BaO. Potassium (K) in group 1 reacts with oxygen (O) to form potassium oxide with the formula K_2O. An unknown element was reacted with oxygen. The product was a metal oxide with the formula XO (X being the unknown element). In which group would you place the unknown element? **Explain** why.

Periods of the periodic table

period
the horizontal rows in the periodic table

As groups are the vertical columns, we call the horizontal rows **periods**. There are seven periods in total.

Hydrogen (H) and helium (He) are the only elements that make up period 1. As you move from left to right across a period, the atomic number increases (that is, the number of protons increases), as does the number of electrons.

This arrangement into groups and periods causes elements to have a specific position on the periodic table. For example, carbon (C) is placed in group 14, period 2, and helium (He) is in group 18, period 1.

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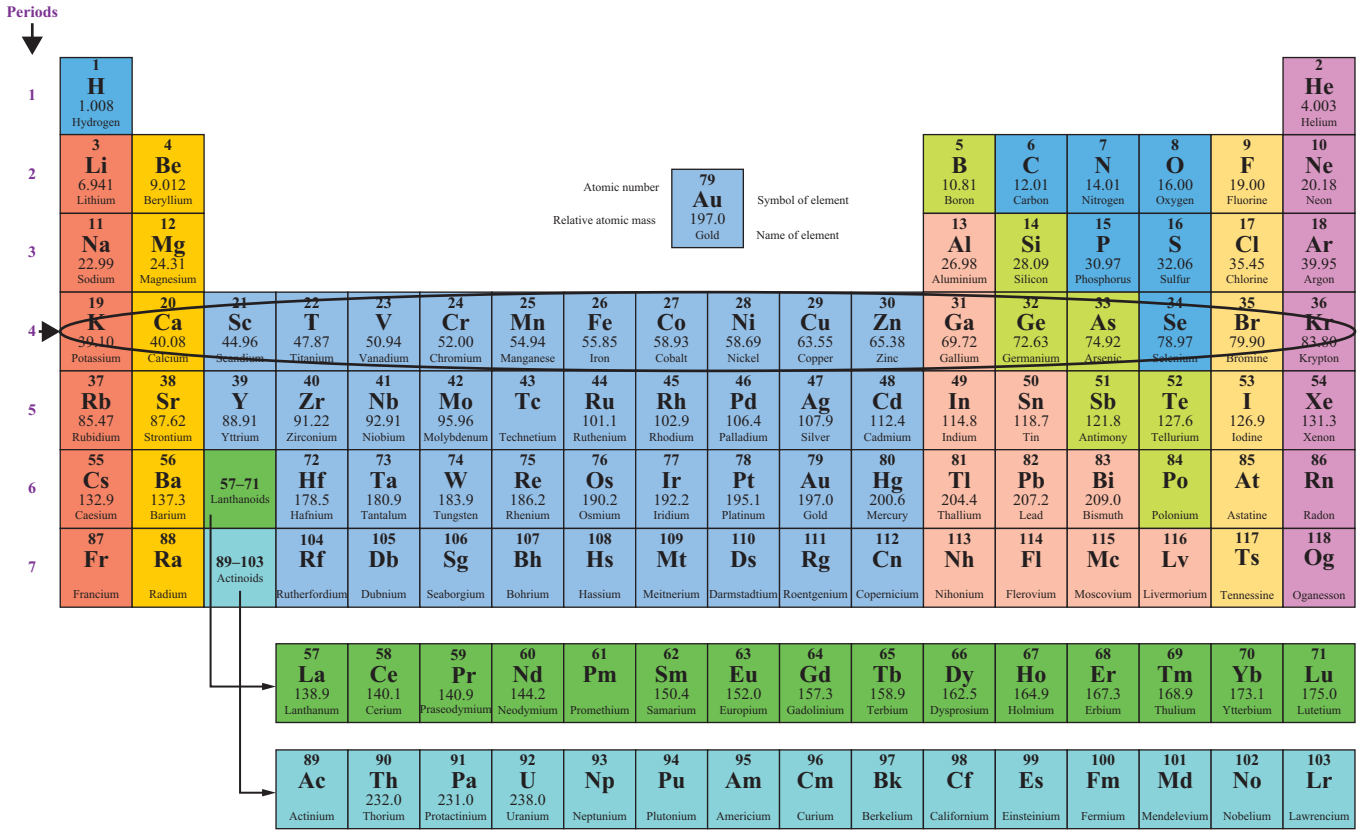


Figure 11.15 Periods are the horizontal rows in the periodic table.

Quick check 11.5

1. **Decide** whether the following statements are true or false.
   - **a.** Periods are the horizontal rows in the periodic table.
   - **b.** Lithium (Li) is in period 1.
2. **State** the position (group and period) of the following elements in the periodic table.
   - **a.** Copper (Cu)
   - **b.** Calcium (Ca)
   - **c.** Neon (Ne)
   - **d.** Aluminium (Al)

Metals, non-metals and metalloids

Earlier in this chapter, we learnt about the properties of metals, non-metals and metalloids. As the periodic table groups elements by their properties, it isn't be surprising that the elements are organised into these three main groups: metals, non-metals or metalloids.

Metals

Metals make up the majority of the elements in the periodic table. In fact, 91 of the 118 known elements are metals, and they sit on the left-hand side of the periodic table. Almost all the metals in the periodic table are solids; the exception is mercury (Hg), which is a liquid at room temperature.

Transition metals

The **transition metals** are a large block of metals in the middle of the table, containing the elements from groups 3 to 12 in periods 4 to 7. They are generally hard and dense. Iron, silver, copper and gold are important transition metals.

transition metals the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

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Advances in science 11.1

Killer asteroid killing cancer?

How can a metal found in the asteroid that may have killed the dinosaurs help in our fight against cancer? Transition metals have been used in medical treatments for decades now. The transition metal platinum has been used for many years in the chemotherapy drug cisplatin.

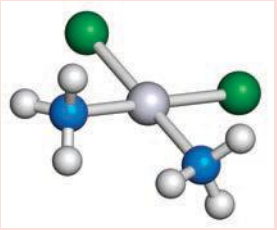


Figure 11.16 Platinum is used in the anti-cancer drug cisplatin, $Pt(NH_3)_2Cl_2$.

This has led to scientists researching the potential applications of other transition metals such as iridium for use in the medical industry.

Iridium is the world's second densest metal. It is rarely found on Earth but has been brought to us from space via asteroids, including the giant asteroid whose impact is thought to have led to the extinction of the dinosaurs.

Destroying cancer cells using iridium

Iridium can be used to kill cancer cells by filling them with a deadly form of oxygen. Oxygen in the form of O_2 is harmless and, of course, beneficial to cells. But when O_2 is converted into a single oxygen atom (O), it is poisonous and can actually kill cells. This can be used to treat cancer without harming healthy cells. The process works by giving patients a drug which contains the iridium. The drug containing iridium infuses every layer of the tumour. Then, a visible laser shone on to the skin where the cancer is located activates the drug, causing it to produce the harmful form of oxygen which can kill cancer cells. This is a very promising breakthrough for cancer patients.

Quick check 11.6

1. **Name** the block of elements in the middle of the periodic table, containing groups 3 to 12.
2. **Identify** which of the following is a transition metal: sodium (Na), tungsten (W), europium (Eu), aluminium (A*l*).

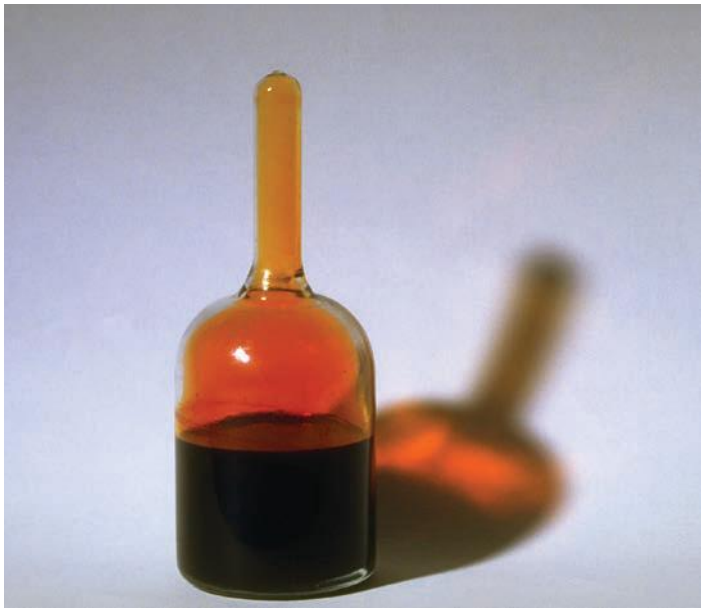


Figure 11.17 A bottle of liquid bromine, the only non-metal that is a liquid at room temperature.

Non-metals

Non-metals are located on the right-hand side of the periodic table (except hydrogen). There are fewer non-metals than metals, but their properties are much more varied. They consist of one liquid, bromine (Br), five solids and 11 gases.

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Practical skills 11.2: Teacher demonstration

Tests to identify some gases

Many of the 11 gases found in the periodic table are colourless, but there are some simple tests that can be used to identify them in the lab. Your teacher will use chemical reactions to make oxygen and hydrogen to test and then demonstrate the identifying tests.

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To discriminate between oxygen (O_2) and hydrogen (H_2) gas in the laboratory using simple tests.

Materials

- hydrogen peroxide
- manganese(IV) oxide
- 1 mol L^{-1} hydrochloric acid (HC*l*)
- zinc pieces (granulated are ideal)
- conical flask with bung and sidearm
- thistle funnel or similar delivery system
- glass water trough
- splint and matches

Procedure

1. Set up the equipment as shown in Figure 11.18.

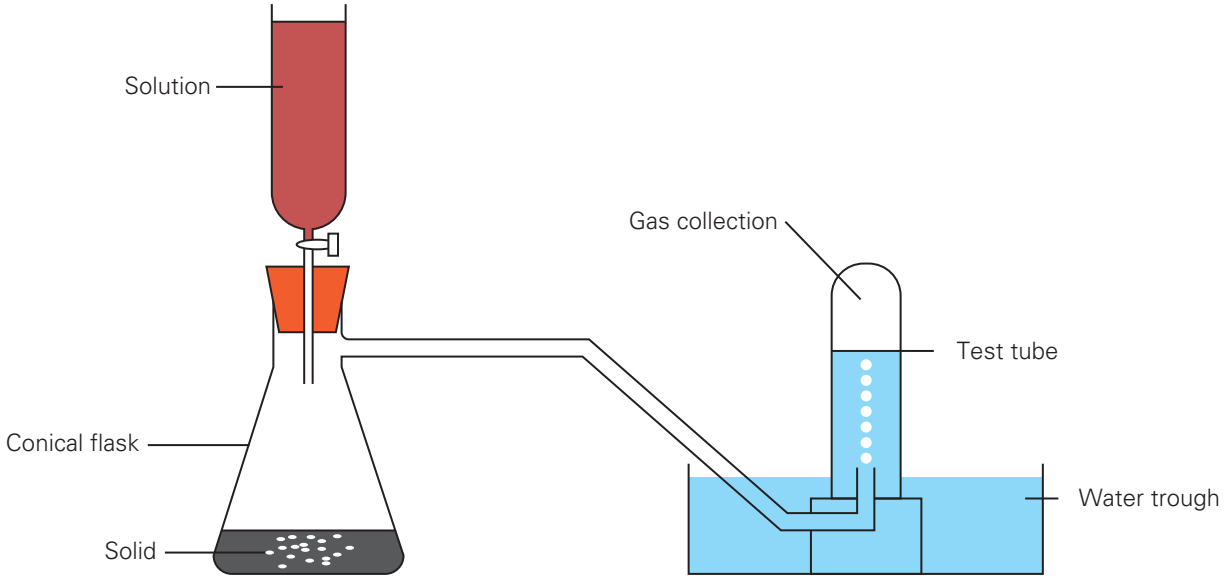


Figure 11.18 Experimental set-up to collect gases to test

2. Prepare the hydrogen by placing a small amount of granulated zinc in the bottom of the conical flask, adding a small amount of 1mol L^{-1} HC*l* and collecting the gas.
3. Light a splint and put it into the mouth of the hydrogen-filled test tube. Observe what happens.
4. Repeat step **2** using a small piece of manganese(IV) oxide and hydrogen peroxide to produce and collect oxygen.
5. Place a glowing splint (recently extinguished) into the mouth of the oxygen-filled test tube. Observe what happens.

Results

Note down the results in your science journal.

You should have observed a pop when the flame was placed in hydrogen and that the glowing splint relit when it was placed in oxygen.

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Metalloids

The elements located between the metals and non-metals are called metalloids. As we know, these elements tend to look like metals but behave more like non-metals. For example, tellurium (Te) is shiny and a fair conductor of electricity like a metal, but it is brittle like a non-metal.

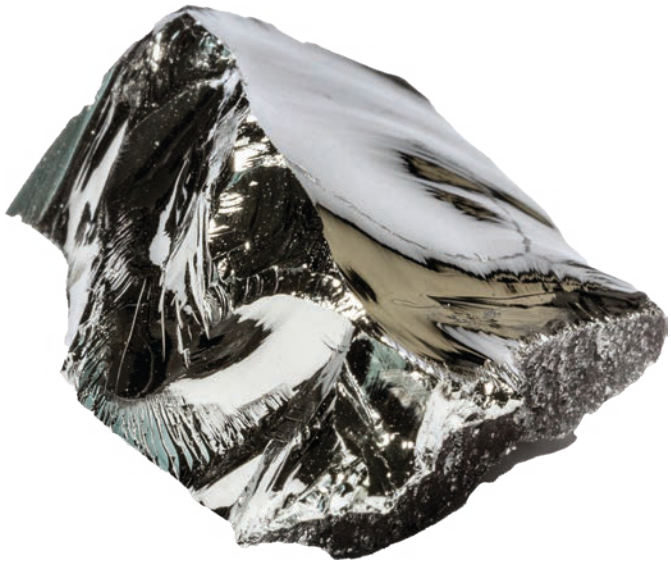


Figure 11.19 Arsenic, found in rock, is a metalloid.



Figure 11.20 Arsenic, found in rock, is a metalloid.It can form alloys with other metals, but is brittle like a non-metal.

Quick check 11.7

1. **Recall** the side of the periodic table where metals are located.
2. **Select** the correct word to complete this sentence:
   The name given to elements found between the metals and non-metals in the periodic table is _____.

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Section 11.3 review

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Section 11.3 questions

Remembering

1. **State** the chemical symbol for the following elements.
   - **a.** Carbon
   - **b.** Oxygen
   - **c.** Hydrogen
   - **d.** Silicon
   - **e.** Sodium
   - **f.** Copper
   - **g.** Chlorine
   - **h.** Potassium
2. **Name** these elements.
   - **a.** Ag
   - **b.** Au
   - **c.** Sn
   - **d.** Si
   - **e.** Hg
   - **f.** Na
   - **g.** Zn
   - **h.** Pb
3. **Recall** how many groups there are on the periodic table.
4. **Name** an element in:
   - **a.** period 3
   - **b.** group 15
   - **c.** the transition metals.
5. **Identify** which period hydrogen and helium are in.

Understanding

6. **Classify** the following elements as either metals or non-metals.

Element	Metal or non-metal
Oxygen (O)	
Boron (B)	
Aluminium (A*l*)	
Iodine (*I*)	
Nickel (Ni)	

Applying

7. **Identify** the element that is in:
   - **a.** period 4, group 6
   - **b.** period 2, group 13
   - **c.** period 5, group 18
   - **d.** period 7, group 1
   - **e.** period 6, group 15.

Analysing

8. **Categorise** the following elements as transition metals, metals or metalloids.

Element	Category
Rubidium (Rb)	
Arsenic (As)	
Vanadium (V)	

Evaluating

9. **Decide** what happens to the number of protons as you move to the right across a period.
10. **Determine** the relationship between an element's atomic number, its number of electrons and its position in the periodic table.

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11.4 Electron configurations of the elements

WORKSHEET Electron configuration

Learning outcomes

At the end of this section, I will be able to:

1. recall the electron configuration of the first 18 elements and identify that it changes with increasing atomic number.
2. investigate flame tests to identify metals.
3. explain how the electron configuration of elements relates to their properties.
4. predict the properties of elements using the periodic table.

Where are the electrons?

atomic number the number of protons in the nucleus of an element, which determines the element's place in the periodic table

The atomic model was introduced in Chapter 10, stating that electrons are located in shells, and that they 'orbit' the centre of the atom, known as the nucleus. You should also know that the protons and the neutrons of an element are found in the nucleus.

The number of protons in the nucleus of an element gives the element its unique **atomic number**. You can work out how many electrons an element has as it will be the same as the number of protons, and therefore the same as the atomic number.

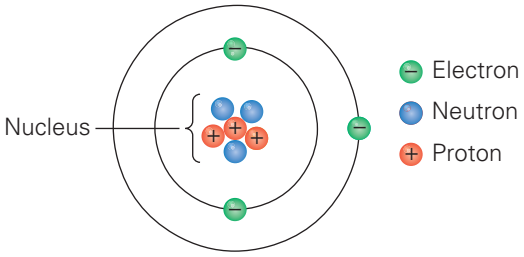


Figure 11.21 An atomic model for lithium (Li). Lithium has three protons and therefore an atomic number of 3.

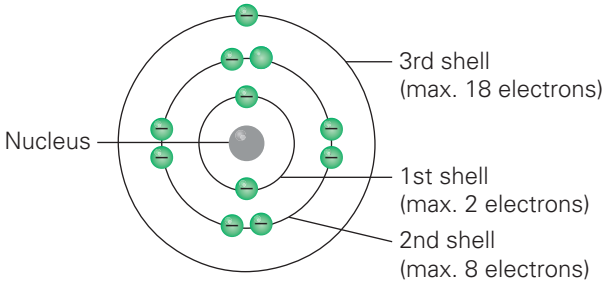


Figure 11.22 A diagram of electron arrangement in shells around the nucleus of a sodium (Na) atom

In the Bohr model (also known as the planetary model) of the atom, which is most commonly used, electrons generally fill the electron shell closest to the nucleus first. This is because it takes the least energy to fill. It is the lowest energy state for an atom, also known as the ground state. Electrons, being negatively charged, are attracted to the positively charged nucleus. This is why the closest shell is filled first; it takes energy for the electrons to move against the attraction of the charge, so filling the closest shell first requires the least amount of energy.

Each shell can only hold up to a specific number of electrons. Table 11.6 summarises how many electrons can be housed in each electron shell. In this chapter, we will concentrate on elements 1–18. An element with an atomic number of 18 has 18 protons and 18 electrons. The electrons will arrange themselves so that there are two in the first shell, eight in the second shell and eight in the third shell.

Shell	Maximum number of electrons it can house
1st (lowest energy level)	2
2nd	8
3rd	18
4th (higher energy level)	32

Table 11.6 The number of electrons housed in each shell

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Quick check 11.8

1. **Describe** how electrons arrange themselves in an atom.
2. **Complete** the sentence by picking the correct words:
   The electron shell *closest to/furthest from* the nucleus is the *first/last* to be filled.
3. **State** the maximum number of electrons that can be housed in the:
   a. first shell
   b. second shell.

Practical skills 11.3

Flame tests

When metals are heated, the energy from the heat means that electrons temporarily move to higher orbitals. As they fall back to their original orbitals, the extra energy is emitted as light of a colour that is specific to the metal. This can help us to identify metals in the lab.

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To investigate the colour of a flame when an element is heated within it and use this information to determine the metal element in four unknown samples.

Materials

- 5 mol L^{-1} hydrochloric acid in labelled test tubes
- known test solutions in a test-tube rack:
  - barium (barium chloride)
  - calcium (calcium chloride)
  - copper (copper(II) chloride)
  - strontium (strontium chloride)
  - sodium (sodium chloride)
  - four unknown samples
- heatproof mat
- Bunsen burner
- 10 flame test wires



Figure 11.23 A substance burning in the flame of a Bunsen burner, producing an orange flame

Procedure

1. Clean your flame wires by holding the metal loop in the hottest part of the blue Bunsen burner flame. If it is not clean, a coloured flame will appear, so clean it by dipping it into the hydrochloric acid provided and then holding the loop in the Bunsen burner flame again.
2. Dip the clean flame test loop into one of the known test solutions, then hold the metal loop in the hottest part of the Bunsen burner flame. Record the colour of the flame in your results table.
3. Clean the flame test wire, then test another known test solution. Keep going until you have recorded the colour for all the known solutions.
4. Flame test the four unknown solutions and record their flame colours in a second results table.
5. Work out which metals are in each of the unknown samples and record them in your table.

continued …

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Results

Flame colours of known substances

	Barium	Calcium	Copper	Strontium	Sodium
Flame colour					

Flame colour of each unknown substance, and the metal indicated by the colour

	Sample 1	Sample 2	Sample 3	Sample 4
Flame colour				
Metal				

Discussion

1. Suggest why a blue flame, not a yellow flame, on the Bunsen burner is necessary.
2. List the elements that produced the most easily identified colours. Were there any colours that were tricky to identify?
3. Based on your observations, would this method be useful to determine the identity of metals that are in a *mixture*? Why or why not?
4. Give at least two reasons why the flame test may not always provide the right answer.
5. Describe some sources of error for this experiment and the improvements you would make if you were to repeat this task.

Electron configurations of the elements

electron configuration the arrangement of an atom's electrons in the shells around the nucleus

The **electron configuration** shows how the electrons for a particular element are arranged. Magnesium (Mg) has an atomic number of 12, so it has 12 electrons. It has an electron configuration of 2,8,2. This shows that there are two electrons in the first shell, eight in the second and two in the third. Figure 11.24 shows the electron arrangement of a magnesium atom. As you can see from the diagram, shell 4 is empty, as magnesium does not have enough electrons for this shell to be occupied.

The sum of all the numbers in the electron configuration should add up to the total number of electrons in that atom.

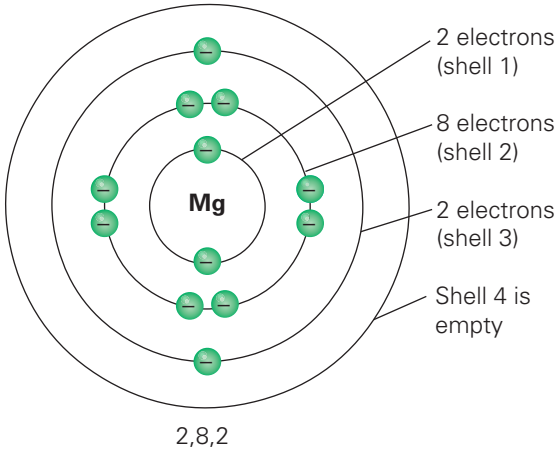


Figure 11.24 The electron configuration of magnesium

Quick check 11.9

1. **State** the number of electrons an element with an electron configuration of 2,8,3 has.
2. **State** the atomic number of an element which has 18 electrons.
3. **State** the electron configuration of oxygen (eight electrons).

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Electron configuration and element properties

The chemical properties of different elements are due to the way their atoms react, and the way atoms react is mostly due to the arrangement of their electrons. Protons and neutrons are found in the centre of the atom (in the nucleus) and so are not affected when atoms bump into one another during chemical reactions. It is the electrons which are the most affected.

The outermost electrons in an atom are called **valence electrons**. It is these electrons in the outer shell that are most affected when atoms bump into one another during chemical reactions.

valence electrons the electrons in the outer shell of an element

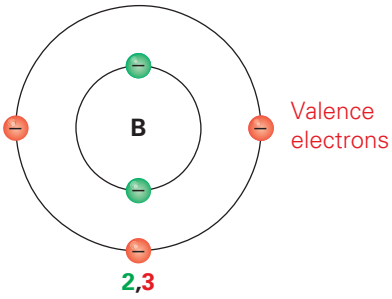


Figure 11.25 Boron (B) has an electron configuration of 2,3. It therefore has three valence electrons (red).

Elements with the same number of valence electrons are grouped together in the periodic table because it is the number of outer-shell electrons that have the biggest effect on their properties. For example, all elements in group 1 have one valence electron. Their electron configurations all end in the number one. The last digit of group 17 tells us that elements in this group have seven valence electrons. This handy trick works for all the elements up to calcium (Ca), which has an atomic number of 20.

We can also work out the period an element is in using its electron configuration. For example, if an electron configuration contains two numbers (as for lithium), then it is in period 2.

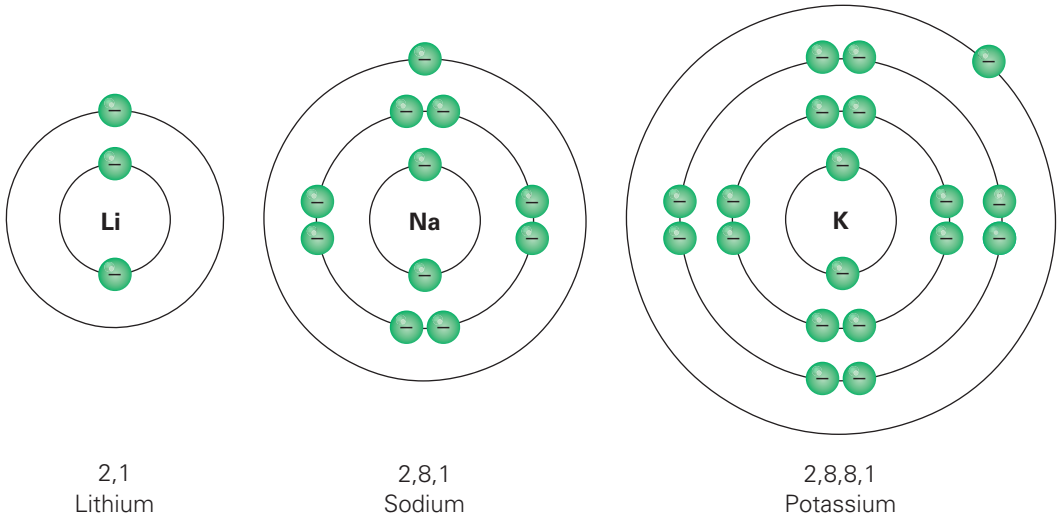


Figure 11.26 These elements in group 1 have one valence electron.

Quick check 11.10

1. **Recall** what the reactivity of a chemical element is determined by.
2. **State** the group that the element with the electron configuration 2,8 belongs to.
3. **State** the period that the element with the electron configuration 2,8,4 belongs to.

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Section 11.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 11.4 questions

Remembering

1. **Identify** the missing information in the following table:

Electron shell	Maximum number of electrons housed
1st	
	8
3rd	

2. **Recall** why the shell closest to the nucleus is filled with electrons first.
3. For the following electron configurations:
   - **name** the element
   - **identify** the number of valence electrons
   - **identify** the period and group they are in.

   a. 2,8,1
   b. 1
   c. 2,7
   d. 2,8,8
4. **Determine** the electron configurations for the following elements.
   a. Helium (He)
   b. Beryllium (Be)
   c. Phosphorus (P)
   d. Lithium (Li)

Understanding

5. The electron configuration of carbon is 2,4. **List** all the information you can determine from this.
6. **Describe** and explain the order in which electrons fill shells around the nucleus.

Applying

7. **Apply** your knowledge of electron arrangement to explain what is significant about the electron configurations of group 18 elements.
8. Chlorine has the electron configuration 2,8,7. **Construct** a diagram showing the arrangement of the electrons within a chlorine atom.

Analysing

9. **Distinguish** between valence electrons and other electrons of an atom.

Evaluating

10. Helium, a group 18 element, has the electron configuration 2, meaning that it has two valence electrons. **Explain** why helium is not located next to hydrogen with the other group 2 elements, which also have two valence electrons.
11. **Explain** why atoms in the same group have similar properties.

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11.5 Specific groups of elements and their properties

Learning outcomes

At the end of this section, I will be able to:

1. recall the properties of elements in specific groups.
2. describe patterns and relationships found in the periodic table, including reactivity.

WORKSHEET Group 1 and group 17

You now know that elements in the periodic table are organised in order of their atomic number and into columns known as groups, containing elements that share similar properties. You should also recall that their properties come largely from the number of valence (outer shell) electrons they have. This is because elements with the same number of valence electrons will usually react and bond with other elements in the same way.

In addition to groups having similar chemical properties, they often have similar physical properties. You can see in Figure 11.27 that the elements in group 14 look similar.



Carbon (C) Silicon (Si) Germanium (Ge) Tin (Sn) Lead (Pb)

Figure 11.27 Group 14 elements

The alkali metals (group 1)

VIDEO Reactive metals

Let's consider some of the groups of the periodic table and their properties, starting with group 1, also known as the alkali metals. These make up the first group of the periodic table.

As the name and their position on the left-hand side of the periodic table suggests, the elements of this group are metals. However, unlike most metals you will have come across, lithium (Li), sodium (Na) and potassium (K) are soft and can be cut with a knife. When they are cut open, they have a shiny appearance on the inside compared to their dull outer surface. This is because their outer surfaces react easily with oxygen in the air and become dull.

In fact, all group 1 metals are highly reactive due to their one valence electron. Elements are stable when they have a full outer shell of electrons, so group 1 metals are more than happy to react with other substances and give up their one valence electron. Once elements have gained a full outer shell, either by losing or gaining electrons, they are much more stable and unlikely to react any further.



Figure 11.28 A piece of sodium metal which has been cut by a knife. It is shiny on the inside and dull on the outside.

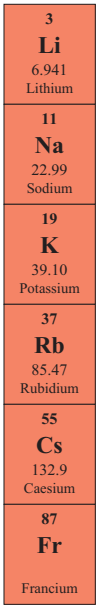


Figure 11.29 The elements in group 1 are known as the alkali metals.

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The reactivity of group 1 metals increases down the group. This is because it becomes easier to remove the valence electron as the atom gets bigger and the outer shell gets further away from the nucleus. Can you think why this is the case?

Consider the force of attraction between the negatively charged electrons and the positively charged protons in the nucleus. The further away from the nucleus the electrons are, the weaker the attraction becomes and so they are easier to remove.

Alkali metals are most famous for their reaction with water, and this is where they get their name. All group 1 metals react violently with water, producing hydrogen gas and an alkaline solution.

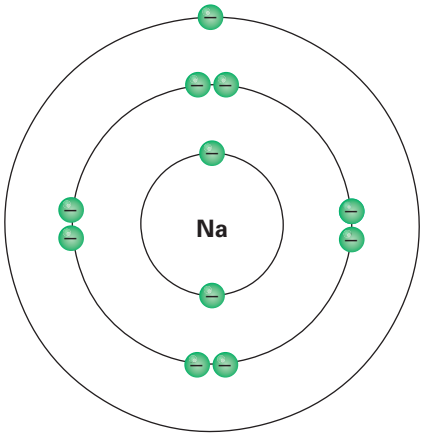


Figure 11.30 The one valence electron in group 1 elements makes them highly reactive.

This word equation shows what happens when sodium reacts with water.

sodium + water → sodium hydroxide + hydrogen

You can use this equation to predict what will happen when other alkali metals react with water.

Did you know? 11.2

Do not touch group 1!

At school, all the group 1 metals will be stored in bottles of oil, and teachers will never touch them with their hands. They are so reactive that even if they come into contact with water vapour in the air or sweat on your hands, they will react violently. In fact, caesium and francium at the bottom of group 1 are the most reactive elements of the periodic table!

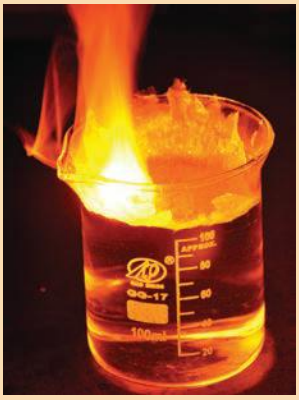


Figure 11.31 What happens when sodium reacts with water? Here, the hydrogen gas produced has ignited.

Investigation 11.2: Teacher demonstration

Investigating the reactivity of group 1 metals

Aim

To determine the order of reactivity of two group 1 metals.

Hypothesis

Write a prediction stating which metal you think will be the most reactive out of sodium and potassium.

Be careful

This demonstration should only be performed by your teacher. Stay behind the safety screen at all times. Wear appropriate PPE.

Materials

- sodium and potassium metals
- large, thick-walled glass bowl
- scalpel blade
- white tile
- absorbent paper
- tweezers
- safety screen
- disposable gloves

INVESTIGATION

continued ...

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Procedure

1. Copy the results table below.

VIDEO Reactivity of group 1 metals

Steps 2–6 will be performed by your teacher

2. Half fill the large glass bowl with water and add about 10 mL of universal indicator, until the colour can be seen throughout the liquid.
3. Using the tweezers, take a piece of sodium from its bottle and place it on the white tile.
4. Use the scalpel to cut off a small piece of the metal and observe the appearance of the metal on the inner and outer surfaces.
5. Making sure that all students are behind the safety screen, add the small piece of metal to the water and record your observations.
6. Repeat steps 2–5 with potassium.

Results

	Hard or soft	Appearance when cut	Observations during reaction
Sodium			
Potassium			

Risk assessment

1. Explain the decision to use tweezers rather than hands to pick up the metals.
2. Why was a safety screen necessary when conducting this experiment?

Discussion

1. Describe any patterns, trends or relationships in your results.
2. Describe how you determined the reactivity of each of the metals investigated.
3. Explain how the reactivity of the metals changes as you go down group 1.

Conclusion

1. Make a claim regarding the varying levels of reactivity of group 1 metals based on this experiment.
2. Justify your claim by explaining how the observations you gathered support it.
2. State whether your hypothesis was supported or not supported based on your findings.

The alkaline earth metals (group 2)

Group 2 contains the alkaline earth metals. They tend to be shiny and silvery-white. Magnesium and calcium are abundant in Earth's crust and are considered essential to all living organisms. For example, you probably know that calcium in your diet is important for strong bones.

All group 2 elements are reactive, but not as reactive as group 1 elements. This is because they have two valence electrons compared to one in group 1 elements. Group 2 elements need to lose two electrons when they react, and as with group 1, they become more reactive as you move down the group.

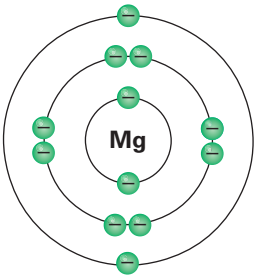
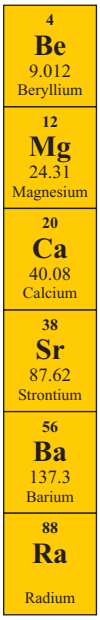


Figure 11.32 Group 2 elements have two valence electrons.



Quick check 11.11

1. **Recall** how many valence electrons group 1 metals, also known as alkali metals, have.
2. **Detail** why alkali metals are shiny on the inside and dull on the outside.
3. **State** whether the following statements are true or false.
   a. Alkali metals get more reactive as you move down the group.
   b. Alkali metals are safe to handle in the lab.
4. **Name** two of the alkaline earth metals.

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Investigation 11.3: Teacher demonstration

Investigating the reactivity of group 2 metals

Be careful



To reduce risk of skin burn from acid:

- wear appropriate personal protective equipment
- wear safety glasses at all times
- wash your hands after the investigation.



Aim

To investigate the relationship between the position of a group 2 element in the periodic table and its reactivity with acid.

Background information

Prior understanding

Metals in group 2 of the periodic table are less reactive than those in group 1. This investigation will determine the order of reactivity within group 2.

Useful formula

Change in volume (mL) = final volume (mL) − initial volume (mL)

$$\text{Rate of gas produced (mL/min)} = \frac{\text{mean change in volume (mL)}}{\text{mean reaction time (min)}}$$

Materials

- 3 similarly sized samples of calcium (approximately 5 mm in diameter)
- 3 similarly sized samples of magnesium (approximately 5 mm in diameter)
- 30 mL hydrochloric acid (1 mol L^{-1})
- 6 test tubes
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- test-tube holder
- rubber stopper with glass tubing inserted through to fit the test tube
- rubber stopper to fit the 100 mL measuring cylinder
- 4 mm plastic tubing (minimum 30 cm)
- 1 large bowl
- retort stand, bosshead and clamp
- stopwatch
- tweezers

Planning

1. Develop a hypothesis by predicting how the reactivity of group 2 metals will change with their position in the periodic table.
2. Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
3. Complete a risk assessment for this investigation, describing how any risks will be controlled.

Procedure

Part 1: Prepare the results table

Draw the table shown in the results section into your science journal.

continued …

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Part 2: Measure the reactivity of the first metal sample

1. The teacher will fill the large bowl with tap water.
2. Fill the 100 mL measuring cylinder with tap water.
3. Stopper the measuring cylinder using the rubber stopper (a complete seal will not be possible).
4. Invert the measuring cylinder into the large bowl and clamp it in place with the stopper below the water line, as shown in Figure 11.33.
5. Remove the stopper from the measuring cylinder.
6. Attach the plastic tubing to the glass tubing on the rubber stopper. Place it beside the measuring cylinder for easy access later.
7. Measure 5 mL of 1 mol L^{-1} hydrochloric acid and pour it into a test tube.
8. Using tweezers, add a piece of the first metal sample into the acid in the test tube. Be careful not to splash the acid.
9. Attach the rubber stopper with the plastic tubing to the test tube and position the end of the plastic tubing underneath the measuring cylinder so the gas can be collected.
10. Measure the initial volume of the gas in the inverted measuring cylinder and record it in your table. Start the stopwatch.
11. After five minutes, record the final volume of the gas in the inverted measuring cylinder in your table.
12. Remove the rubber stopper and tubing from the test tube. Store the test tube and contents in the test-tube holder.
13. Repeat steps **7–12** with the other two samples of the first metal.
14. Remove the measuring cylinder and refill it with tap water.

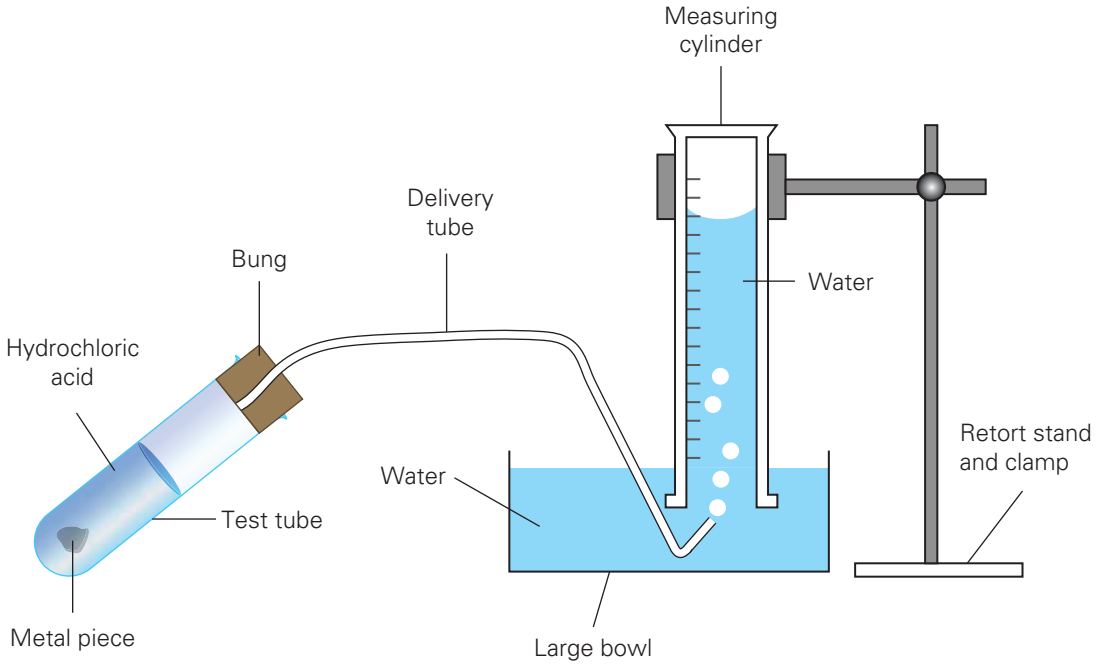


Figure 11.33 Diagram of experimental set-up

15. Stopper the measuring cylinder using the rubber stopper.
16. Invert the measuring cylinder into the large bowl and clamp it in place with the stopper below the water line.
17. Remove the stopper from the measuring cylinder.

Part 3: Measure the reactivity of second metal sample

Repeat steps **7–12** with the second metal samples.

continued …

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Results

1. Calculate the change in gas volume for each trial and record it in the results table.
2. Calculate the rate of gas production in mL/min for each metal and record it in the results table.

	Measurements	Trial 1	Trial 2	Trial 3	Mean rate of gas production (mL/min)
Period 2 magnesium	Initial volume (mL)				
	Final volume (mL)				
	Change in volume (mL)				
	Rate of gas production (mL/min)				
Period 3 calcium	Initial volume (mL)				
	Final volume (mL)				
	Change in volume (mL)				
	Rate of gas production (mL/min)				

Discussion

1. Compare the mean rate of gas production for the different elements.
2. Predict the trend in reactivity for all group 2 elements.
3. Draw a conclusion about the rate of gas production in reaction with acids for group 2 elements further down the group.
4. Consider the management of the controlled variables. Were they managed properly to ensure they did not change and affect the measurements?
5. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

1. Make a claim about the relationship between the position of a group 2 element in the periodic table and its reactivity with acid.
2. Justify your claim by explaining how the data you gathered support it.
3. State whether your hypothesis was supported or not supported.

9 **F** 19.00 Fluorine
17 **Cl** 35.45 Chlorine
35 **Br** 79.90 Bromine
53 **I** 126.9 Iodine
85 **At** Astatine
117 **Ts** Tennessine

The halogens (group 17)

Group 17 elements are also known as the halogens. At room temperature, fluorine (F) and chlorine (Cl) are gases, bromine (Br) is a liquid and iodine (I) is a solid. The halogens are non-metals. They are used as bleaching agents and can kill bacteria. This is why chlorine is added to the water in swimming pools and iodine is used as an antiseptic.

All group 17 elements have seven valence electrons. To get a full outer shell of electrons, rather than lose seven electrons when they react with other substances, they gain one electron. This gives them a full outer shell of eight electrons. Because halogens only need to gain one electron to fill their outer shells, they are quite reactive.

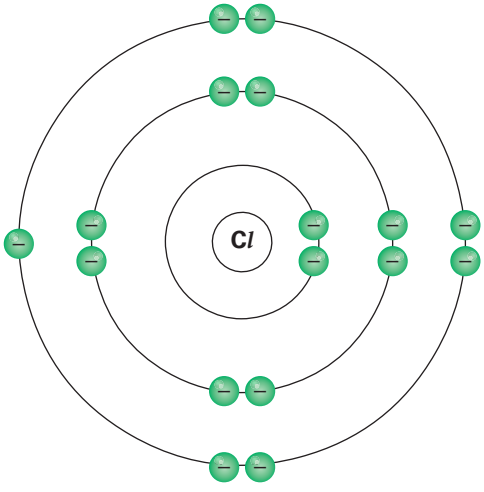


Figure 11.34 Group 17 elements have seven valence electrons.

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As shown in Table 11.7, the reactivity of group 17 elements decreases as you move down the group. This is because as the size of the atom increases down the group, the attraction from the positively charged nucleus becomes weaker, and it is harder for it to gain an electron. This is the opposite of groups 1 and 2.

They all also form molecules that are made up of two atoms – so we call them diatomic, for example, Br_2.

Halogen	Formula	State at 25°C	Colour	Melting point (°C)	Boiling point (°C)	Reactivity
Fluorine	F_2	Gas	Pale yellow	−220	−188	↑ Reactivity increases up the group
Chlorine	Cl_2	Gas	Pale green	−101	−35	
Bromine	Br_2	Liquid	Brown	−7.2	58.8	
Iodine	I_2	Solid	Purple	114	184	

Table 11.7 Some properties of the halogens

The noble gases (group 18)

Group 18 elements are also known as the noble gases. These gases tend to be colourless, odourless and non-flammable. They are found in neon signs and used in medical imaging and radiotherapy to treat cancer.

Unlike the other groups we have discussed, noble gases are extremely unreactive. They have a full outer shell of electrons already and so are incredibly stable. In fact they were once called inert gases because it was thought that they did not react with anything.

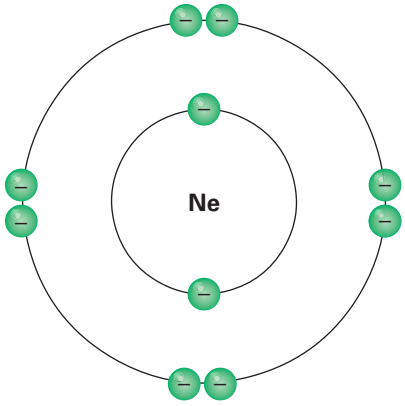


Figure 11.35 Group 18 elements all have eight valence electrons and therefore a full outer shell.



Figure 11.36 Neon is used in fluorescent signs.

2
He
4.003
Helium
10
Ne
20.18
Neon
18
Ar
39.95
Argon
36
Kr
83.80
Krypton
54
Xe
131.3
Xenon
86
Rn
Radon

Quick check 11.12

1. **Name** three elements in group 17.
2. **State** one physical or chemical trend that can be observed going down group 17.
3. **Name** three elements in group 18.
4. **Recall** why noble gases are so unreactive.

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INVESTIGATION

Explore! 11.3

The Hindenburg disaster

The Hindenburg airship could travel from Europe to North and South America in half the time of the fastest ocean liner. The airship was filled with hydrogen rather than helium due to export restrictions that the United States imposed on Nazi Germany.

In 1937, while trying to land in New Jersey, US, the Hindenburg caught fire and burst into flames. It was completely destroyed. Out of 97 people on board, 35 were killed.

1. What was the problem with using hydrogen gas in the Hindenburg airship?
2. Why would helium have been a safer alternative?
3. Why is helium able to be used to fill airships?
4. Helium is heavier than hydrogen and therefore provides less lift. Why is this a problem for airship designers?

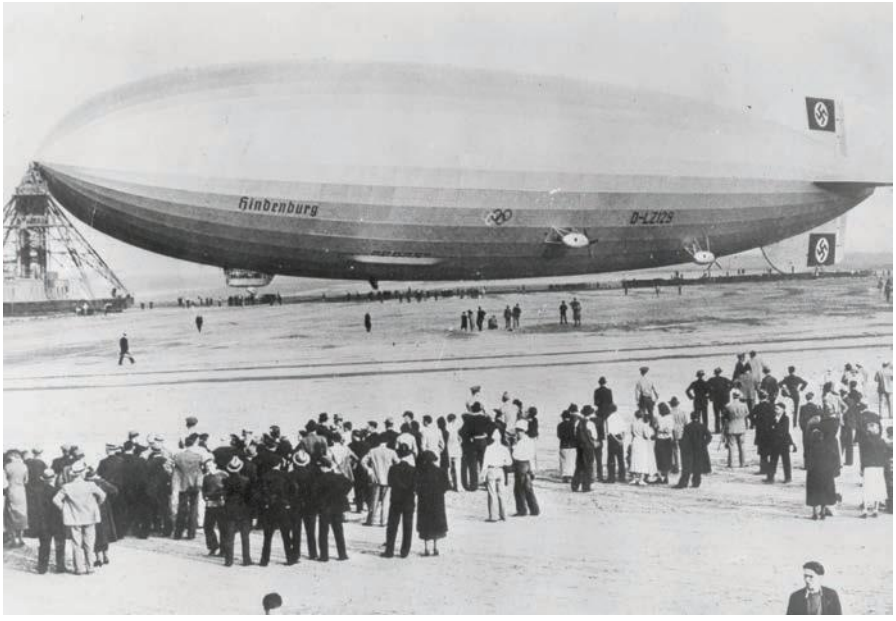


Figure 11.37 The Hindenburg airship was a revolution in travel.



Figure 11.38 The Hindenburg bursting into flames on arrival in New Jersey, USA

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Section 11.5 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

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Section 11.5 questions

Remembering

1. **Identify** the group number of the:
   - **a.** alkaline earth metals
   - **b.** halogens
   - **c.** noble gases
   - **d.** alkali metals.
2. **Recall** what happens to the reactivity as you move down group 1.
3. **State** whether these statements are true or false.
   - **a.** All halogens are gases.
   - **b.** Noble gases have full outer shells.
4. **State** how many valence electrons each of the following groups has:
   - **a.** alkali metals
   - **b.** alkaline earth metals
   - **c.** halogens
   - **d.** noble gases.
5. A new element is discovered. It is extremely reactive and has one valence electron. **Identify** the group it should belong to.

Understanding

6. **Explain** why group 2 elements are less reactive than group 1.
7. Helium does not have eight valence electrons. **Explain** why it is still classified as a noble gas.
8. **Explain** why alkali metals are stored in oil.

Applying

9. **Classify** the following elements as alkali metals, alkaline earth metals, halogens or noble gases:
   - **a.** magnesium
   - **b.** argon
   - **c.** sodium
   - **d.** potassium
   - **e.** iodine.

Analysing

10. **Compare** and **contrast** the properties and reactions of group 1 and 2 elements.

Evaluating

11. **Deduce** why Mendeleev did not include group 18 in his periodic table.
12. Chemically, would you expect strontium to be more similar to calcium or rubidium? **Justify** your choice.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
11.1	identify elements in everyday objects.	1
11.1	compare the physical properties of metals, non-metals and metalloids.	1
11.1	explain how the properties of some elements, compounds and alloys relate to their uses.	14
11.2	describe how the historical development of the periodic table came from understanding patterns in the chemical and physical properties of the elements.	6
11.2	recall an example of using the periodic table to predict a future element and its properties.	11
11.3	describe the structure of the modern-day periodic table and examples of the patterns and relationships found within it.	5, 7
11.3	understand why symbols are used to represent the elements and identify symbols of common elements.	2, 12
11.3	explain the organisation of the elements in the table using their atomic number and properties.	5, 8, 19
11.3	identify the elements in some common compounds using the periodic table.	15
11.4	recall the electron configuration of the first 18 elements and identify that it changes with increasing atomic number.	3, 9, 13, 19
11.4	investigate flame tests to identify metals.	10
11.4	explain how the electron configuration of elements relates to their properties.	8
11.4	predict the properties of elements using the periodic table.	16
11.5	recall the properties of elements in specific groups.	3, 4, 17, 18
11.5	describe patterns and relationships found in the periodic table, including reactivity.	17, 18, 19, 20

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Scorcher competition 

Review questions 

Data questions 

Go online to access the interactive chapter review!

Review questions

Remembering

1. Copy and **complete** the following table.

	Metals	Metalloids	Non-metals
Appearance	Lustrous		
State at room temperature	Solid (except mercury)	Often lustrous	
Boiling point			Low
Malleability and ductility			Brittle
Conduction of electricity	Good		Poor
Conduction of heat		Moderate	
Examples	Copper, gold		
Example of use		Silicon is used in computer chips.	

2. **State** the atomic number, group and period of the following elements.
   - **a.** Boron (B)
   - **b.** Titanium (Ti)
   - **c.** Platinum (Pt)
   - **d.** Strontium (Sr)
3. **State** the group number of the following elements.
   - **a.** An element with the electron configuration 2,8,1
   - **b.** An element with 18 electrons
   - **c.** A halogen
   - **d.** A noble gas
4. Magnesium and beryllium are in group 2. **Recall** the other name given to elements in group 2.

Understanding

5. **Determine** the relationship of an element's atomic number, number of electrons and its position in the periodic table.
6. **Describe** three advances made in the development of the modern periodic table.
7. **Describe** the position of metals, metalloids and non-metals on the periodic table.
8. **Explain** the reasons for placing elements together in the same group.
9. **Write** the electron configuration for a sulfur atom and its number of valence electrons.
10. **Describe** how to carry out a flame test using an example for a named metal.
11. **Explain** why Mendeleev left gaps in his periodic table.
12. **Explain** why symbols are used to represent elements.
13. **Represent** the electron arrangement of an atom of carbon in a diagram.

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Applying

14. A range of alloys including titanium and stainless steel are used in construction. **Explain** what alloys are and why their use might be advantageous in the construction industry.



15. Identify the elements in the compounds with these chemical formulas:

- **a.** KCl
- **b.** CH_4
- **c.** $Ca_3(PO_4)_2$.

16. Describe the change in properties of the halogens as you move down group 17.

Analysing

17. Distinguish between elements in group 1 and elements in group 2.

18. Explain why group 18 elements are referred to as inert.

Evaluating

19. An unknown element is found to:

- react violently with water
- feel soft
- have an electron configuration of 2,8,8,1.

Given those properties, determine the group in which it belongs. **Justify** your choice.

20. Compare the elements of periods 2 and 3 in terms of their valence electrons and the pattern of reactivity across each period.

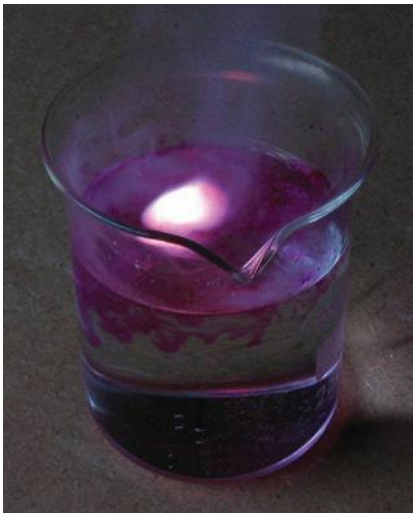


Figure 11.39 A substance reacting violently with water

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Data questions

Refer to Table 11.8 and Figure 11.40.

Classification	Element	Melting point (°C)	Boiling point (°C)
Non-metal	Carbon	3550	4827
Non-metal	Nitrogen	−210	−196
Non-metal	Oxygen	−219	−183
Noble gas	Helium	−272	−269
Noble gas	Neon	−249	−246
Halogen	Fluorine	−220	−188
Halogen	Chlorine	−102	−34
Halogen	Bromine	−7	59
Halogen	Iodine	114	184
Metal	Magnesium	650	1091
Metal	Iron	1538	2861
Metal	Nickel	1455	2913
Metal	Copper	1085	2560
Metal	Silver	962	2162
Metal	Platinum	1768	3825
Metal	Gold	1064	2836
Metal	Mercury	−39	357

Table 11.8 Classification, and melting and boiling point of various elements

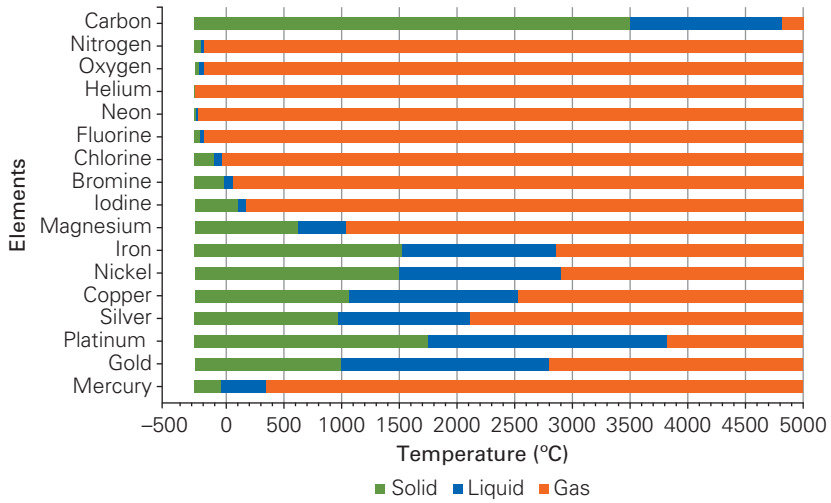


Figure 11.40 States of the elements in Table 11.8 at different temperatures

1. Calculate the difference between the melting and boiling point of mercury in °C.
2. Identify the element with the lowest melting point.
3. Identify which elements in Table 11.8 are classified as halogens.
4. Contrast the general melting point of the noble gases and the metals in Table 11.8.
5. Identify the element where the data does not match that of similarly classified elements.
6. Categorise the halogen elements as either 'a gas at 25°C' or 'not a gas at 25°C'.
7. Given the data in Table 11.8, deduce whether the noble gases can exist in the liquid state.
8. Argon is another noble gas element. Predict whether the boiling point of elemental argon is closer to 3000°C, 100°C or −150°C.

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STEM activity: Creating composite materials

Background information

Materials engineers develop and test new materials. 'Composite materials' are made by combining two or more materials, usually those with different properties. The materials do not blend with one another.

DESIGN BRIEF

Create a composite material for the purpose of building a specific product.



Figure 11.41 Mud bricks are a composite of mud and straw. Mud is strong if you compress it but breaks when you bend it. Straw is strong if you pull on it but is easily crumpled. Mud bricks combine the two materials to create better building blocks that hold shape when squeezed or bent.

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Activity instructions

Suggested materials

- web browser
- scissors
- ruler
- coins
- paper towels
- tape
- PVA glue
- ice block sticks
- paper
- cardboard
- elastic bands
- string or yarn
- other materials, where possible

Research and feasibility

1. Research the two composite materials: glass fibre-reinforced concrete (GFRC) and steel-reinforced concrete. Copy and complete the table below and add other properties you believe are important.
   a. What are the differences and what are the benefits of one material over the other?
   b. How would the discovery of each material change the way we use concrete?

	Glass fibre-reinforced concrete (GFRC)	Steel-reinforced concrete
Strength		
Benefits compared to concrete		
Temperature variance		

2. As a group, decide on a purpose for creating a new material for manufacture. Research the important properties and features the new composite material will require.

Design and sustainability

3. List the ratios of each component material used in the composite, and the method of manufacturing and testing your composite material.
4. Design the best possible method to create your new composite material.
5. Discuss the sustainability of your material and its environmental impact. Your new material must have a positive environmental impact and be sustainable to manufacture.

Create

6. Manufacture the composite material in the various ratios as set out in the design phase and allow it to set if required.
7. Test your material by applying forces to your material. Record the type of force.

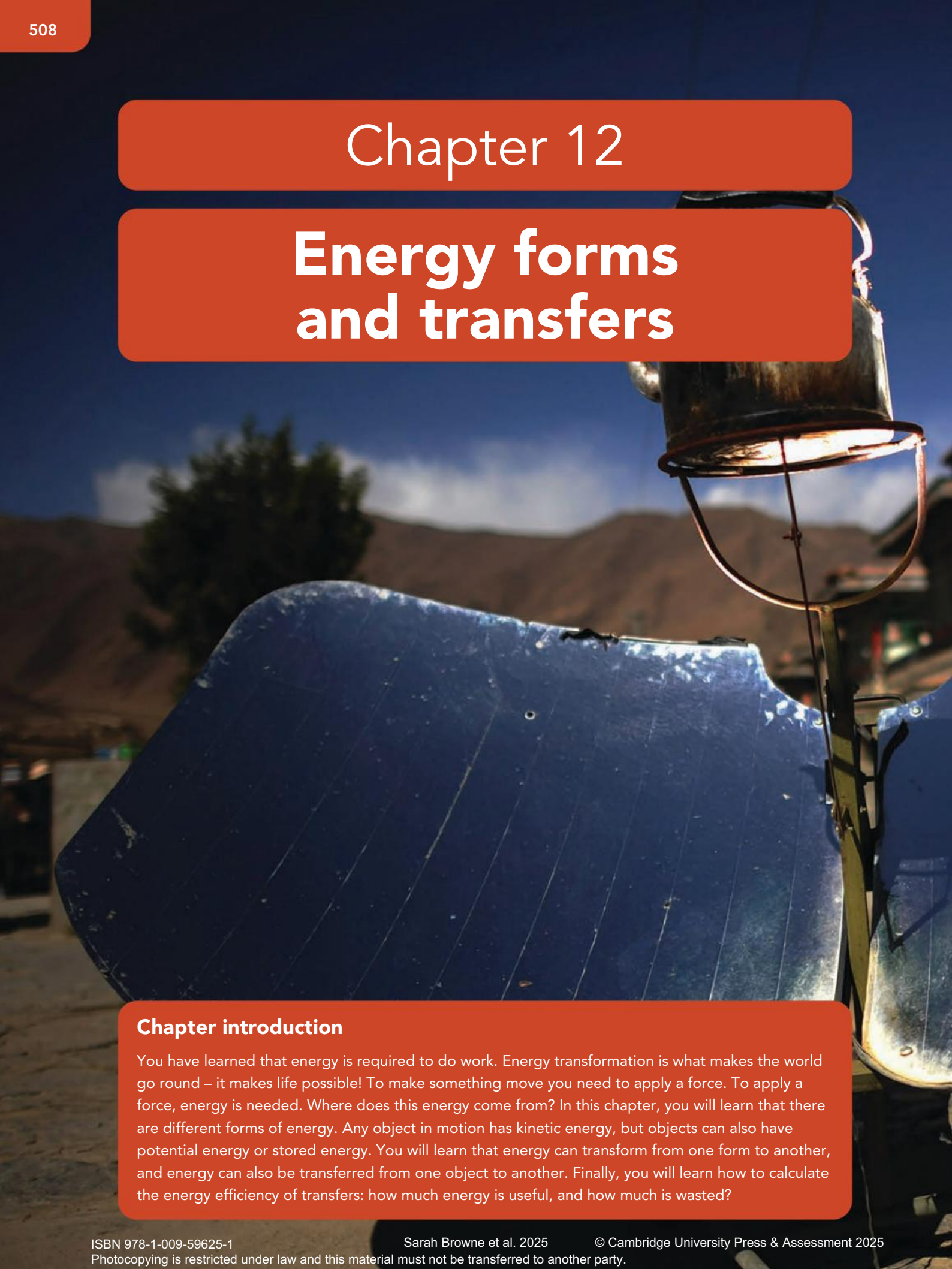
Evaluate and modify

8. Evaluate the original material capabilities compared to the new material. Discuss and explain the difference.
9. What are the maximum forces that could be applied to each ratio? Explain the effect of the ratios of the single materials when used as a composite material.
10. Suggest ways to improve the composite material. Should another material be added?
11. Should the ratios of the component materials be altered?
12. Predict how the composite material might behave if it was constructed differently but with the same materials.

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Chapter 12

Energy forms and transfers

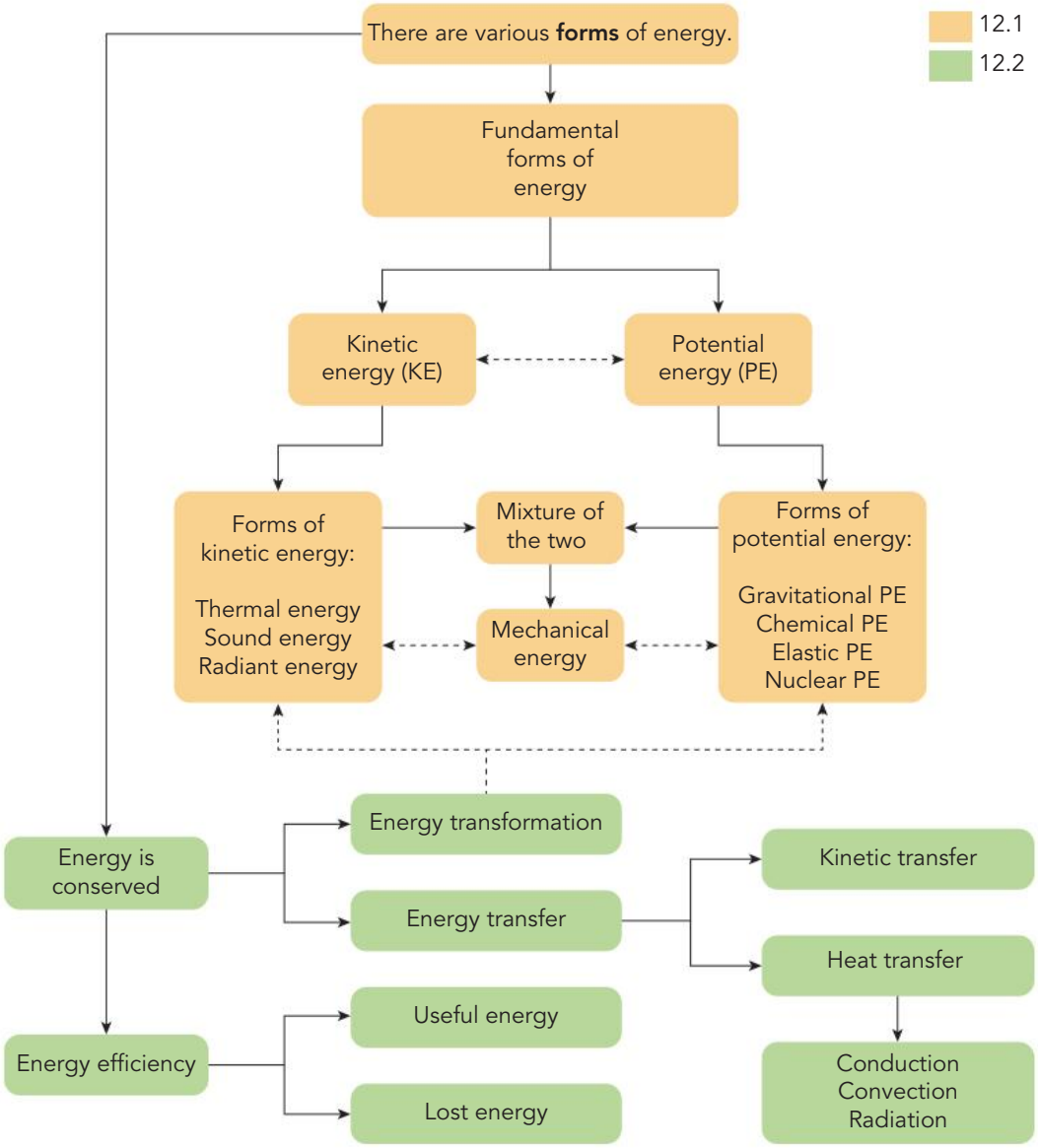


Chapter introduction

You have learned that energy is required to do work. Energy transformation is what makes the world go round – it makes life possible! To make something move you need to apply a force. To apply a force, energy is needed. Where does this energy come from? In this chapter, you will learn that there are different forms of energy. Any object in motion has kinetic energy, but objects can also have potential energy or stored energy. You will learn that energy can transform from one form to another, and energy can also be transferred from one object to another. Finally, you will learn how to calculate the energy efficiency of transfers: how much energy is useful, and how much is wasted?

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Chapter map



Glossary terms

chemical potential energy
closed system
current
efficiency
elastic (material)
elastic potential energy
electrical energy
energy
energy transfer
energy transformation
gravitational potential energy
heat
heat transfer (thermal transfer)
joule
kinetic energy
kinetic transfer
law of conservation of energy
light energy
mechanical energy
nuclear energy
open system
photons
potential energy
radiant energy
radioactive
sound energy
temperature
thermal energy
useful energy
waste energy (or energy lost)

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12.1 Forms of energy

WORKSHEET Forms of energy

VIDEO Energy transformations in a hot air balloon

energy the ability or capacity to do work

joule the unit of energy or work done

kinetic energy the energy of moving matter

potential energy stored energy

mechanical energy the sum of potential energy and kinetic energy

Learning outcomes

At the end of this section, I will be able to:

1. define and use the terms 'potential energy' (PE) and 'kinetic energy' (KE).
2. recall different forms of energy, including thermal, elastic, chemical and gravitational potential energy.
3. describe how systems can store different forms of energy.

What is energy?

Energy is the ability or capacity to do work. It can't be created or destroyed; that is, the amount of energy in our universe is always the same. However, energy can change form, be transferred from one object to another, or be stored for later use. For all the different forms of energy, the unit of measurement is the **joule** (J).

There are just two fundamental forms of energy: **kinetic energy** and **potential energy**. All the other forms are one or other of these, or a mixture of the two. The sum of kinetic and potential energy is called **mechanical energy**.

Kinetic energy

The energy an object has when it is moving is called kinetic energy (KE). The amount of energy depends on the mass of the object and its speed. The faster the object is moving, the more kinetic energy it has. A small increase in speed results in a large increase in kinetic energy. The energy an object has because of its speed is given by the following formula:

$$\text{KE} = \frac{1}{2}mv^2$$

Here, KE is the kinetic energy in joules (J), m is the mass of the object in kilograms (kg) and v is the speed or velocity of the object in metres per second (m/s).

Worked example 12.1

Calculating kinetic energy

A car is travelling down a straight flat road at 20 m/s. The mass of the car (including the driver) is 2000 kg. How much kinetic energy does the car have?

Working	Explanation
v = 20 m/s m = 2000 kg	Identify the values given in the question.
$\text{KE} = \frac{1}{2}mv^2$	Identify the formula needed to answer the question.
$\text{KE} = \frac{1}{2} \times 2000 \times 20^2$	Substitute the relevant values into the formula.
KE = 400 000 J or 400 kJ	Give the answer with correct units.

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Figure 12.1 Fast-moving cars have a lot of kinetic energy.

Radiant energy including light energy

Radiant energy is a type of kinetic energy because it is the movement of packets of energy called **photons**. Photons can have a whole range of energies and as well as forming visible light, they also form infrared, ultraviolet, X-rays, gamma rays and radio waves: these are all types of radiant energy. The term **light energy** is also used for radiant energy, not just the energy of visible light. When photons strike and are absorbed by matter, they transfer heat, especially photons in the infrared range. Next time you are near a warm campfire, notice that you can see the light emitted by the fire and you can also feel the warmth transferred by radiant energy.



Figure 12.2 A fire emits radiant energy, both light energy and infrared energy felt as heat.

Thermal energy

Thermal energy is a type of kinetic energy because it is caused by vibration and movement of particles of matter. **Heat** is the effect of an increase in the thermal energy of a solid, liquid or gas causing its **temperature** to rise. Temperature is a measure of average kinetic energy of the particles in a substance. Radiant energy also transfers thermal energy, as shown in Figure 12.2.

Sound energy

Sound energy is also a type of kinetic energy as it is carried by vibrations. The vibrations travel through solids, liquids or gases in waves. Sound energy needs matter to travel through.

Electrical energy

When electricity flows there is a movement of electrons in matter, and it does work, so we know it is **electrical energy**. Since there is movement, it is also kinetic energy. The flow of electrons in a wire is called a **current**.

radiant energy
the kinetic energy of moving photons

photons
packets of energy that move at the speed of light and behave as particles and waves

light energy
the energy of visible light, also used generally as an alternative term for radiant energy

thermal energy
the energy caused by vibration or movement of particles

heat
the effect of thermal energy in a material causing temperature to increase

temperature
a measure of the average kinetic energy of the particles in a substance

sound energy
the kinetic energy of waves of vibration of particles moving through solids, liquids and gases

electrical energy
the kinetic energy of moving electrons

current
the flow of electrons in a wire, which provides us with electricity

Quick check 12.1

1. **Define** energy.
2. **Calculate** the kinetic energy of a person with mass 60 kg running at 5 m/s.
3. **Explain** why radio waves, electricity and sound are types of kinetic energy.

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VIDEO
Types of stored energy

Potential energy

Some objects can store energy until it is ready to be used. This stored energy is called potential energy because it has the potential to do work or make an object move. For example, an object held in your hand has stored gravitational potential energy. You do not need to add energy to make it move, you only need to release it from your hand and it will fall. Here, gravitational potential energy is transformed into kinetic energy. Some forms of stored energy are summarised in Table 12.1.

Form of potential energy	Description
Gravitational potential energy (GPE)	Energy stored when an object is lifted off the ground; energy released when the object falls
Chemical potential energy	Energy stored in chemicals such as fuel and in batteries (when connected to an electric circuit, the chemical potential energy is converted to electrical energy)
Elastic potential energy	Energy stored when an object is stretched or compressed; energy released when an object returns to its original size and shape
Nuclear energy	Energy stored in nuclei of atoms; energy released in fission when heavy, unstable radioactive atoms decay (split); energy released in fusion when two light atoms fuse to make a heavier one

Table 12.1 Potential energy is a form of energy that can be stored.

Gravitational potential energy

gravitational potential energy a type of potential energy an object has due to its mass and height above the ground

When an object is lifted, it gains and stores **gravitational potential energy** (GPE). The energy an object has because of its height is given by the following formula:

$$\text{GPE} = mgh$$

Here, GPE is the gravitation potential energy in joules (J), m is the mass of the object in kilograms (kg), g is acceleration due to gravity in m/s^2 and h is the height of the object above the surface of Earth in metres (m).



Figure 12.3 Running upstairs converts chemical potential energy into KE. Once the women reach the top of the stairs, energy has been converted to GPE.

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Worked example 12.2

Calculating gravitational potential energy

A package has been delivered to your front door! You are very excited as you had ordered a new pair of shoes. As you pick it up, you realise you will need to put in a bit of energy to lift it off the ground. How much energy do you need to lift your package 1 m off the ground if it has a mass of 1.5 kg? (Use a value of 10 m/s^2 for *g*.)

Working	Explanation
h = 1 m m = 1.5 kg g = 10 m/s^2	Identify the values given in the question.
GPE = mgh	Identify the formula needed to answer the question.
GPE = 1.5 × 10 × 1	Substitute the relevant values into the formula.
GPE = 15 J	Give the answer with correct units.

Quick check 12.2

1. **State** three types of potential energy.
2. Look at the image of a playground in Figure 12.4. **Explain** where you would stand to have the greatest gravitational potential energy.



Figure 12.4 Where is GPE greatest?

3. Figure 12.5 shows a rollercoaster. Rollercoasters are a great example of GPE.
   a. **Identify** the position (A, B, C, D or E) where the cart would have the greatest GPE.
   b. **Identify** the position where the cart would have the greatest KE (moving the fastest).

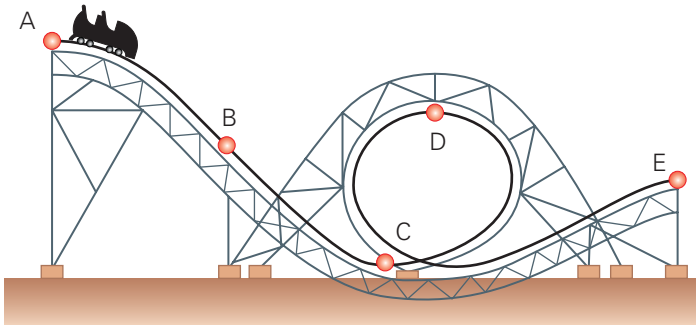


Figure 12.5 A rollercoaster

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chemical potential energy the energy stored in the bonds between atoms

elastic (material) able to return to its original shape when compressed, stretched or deformed

elastic potential energy the energy stored when an elastic material is compressed or stretched

nuclear energy potential energy stored in and released by the nucleus of an atom

radioactive having or producing the energy that comes from the breaking up of atoms

Chemical potential energy

Many substances contain stored **chemical potential energy**, which can be released in a chemical reaction. For example:

- Batteries store energy.
- When fireworks are lit, chemical potential energy is released as heat, sound and light.
- The food we eat contains chemical potential energy, giving us the energy to keep warm and to move as needed.
- We can also store chemical potential energy from our food in our livers, muscles and other locations.



Figure 12.6 Batteries contain chemical potential energy.

Elastic potential energy

An **elastic** object or material is any that compresses, stretches or deforms due to a force, and returns to its original shape when the force is removed. Examples are rubber bands and springs. When elastic material is acted on by a force, it stores **elastic potential energy**.



Figure 12.7 Trampolines use springs to store and release elastic potential energy.

Nuclear energy

DEPTH STUDY IDEA Nuclear reactors in Australia

Nuclear energy is a form of potential energy stored inside an atom. This is the source of energy of the Sun. Life on Earth depends on energy from the Sun. The Sun's energy comes from fusion. Fusion is the joining together of lighter elements to make heavier ones.

Nuclear power stations harness energy from **radioactive** elements. These elements release energy from fission. Fission is the splitting of heavier elements into lighter ones.



Figure 12.8 The Sun uses nuclear fusion as its source of energy, while nuclear power stations use nuclear fission.

Quick check 12.3

1. **State** two examples of chemical potential energy.
2. **Explain** what is happening to a material if elastic potential energy is being stored.
3. **Explain** where nuclear energy comes from.

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Section 12.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 12.1 questions

Remembering

1. **Identify** the missing words in the table below.

Form of energy	Definition	Is this an example of potential energy?
Kinetic energy		
	Energy an object possesses when it is lifted above the ground	
Chemical potential energy		Yes

2. **Describe** a situation that involves elastic potential energy.
3. **Describe** how sound energy travels.
4. **Recall** why thermal energy is a type of kinetic energy.

Understanding

5. **Identify** the forms of energy contained in a piece of wood.
6. **Identify** the forms of energy a piece of wood gives out when it burns.
7. **Explain** what is meant by the term 'potential energy'.
8. **Explain** why it is harder to stop a bicycle when it is going downhill than when it is going uphill.
9. **Identify** the form of energy other than heat that is gained when a person climbs stairs.
10. **Identify** the main form of energy that peanuts contain.

Applying

11. Look at the diagram in Figure 12.9 and use it to answer the following questions.
    a. **Determine** the letter that represents the position where the ball has the most GPE.
    b. If the ball moved from C to A, **determine** whether there would be an overall gain or loss of GPE.

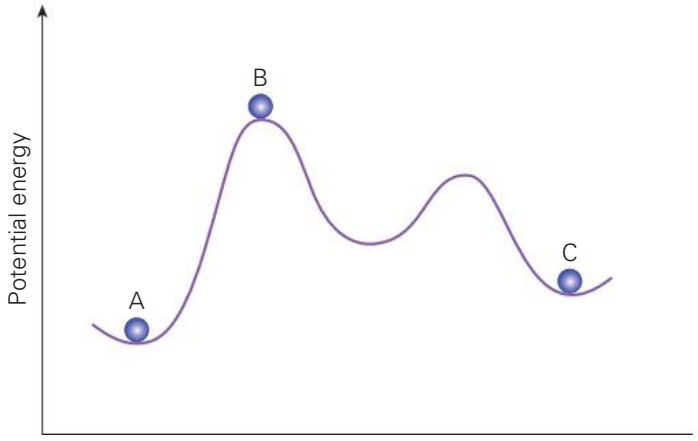


Figure 12.9 Positions of a ball above the ground

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12. Explain which balloon in Figure 12.10 has the most elastic potential energy.

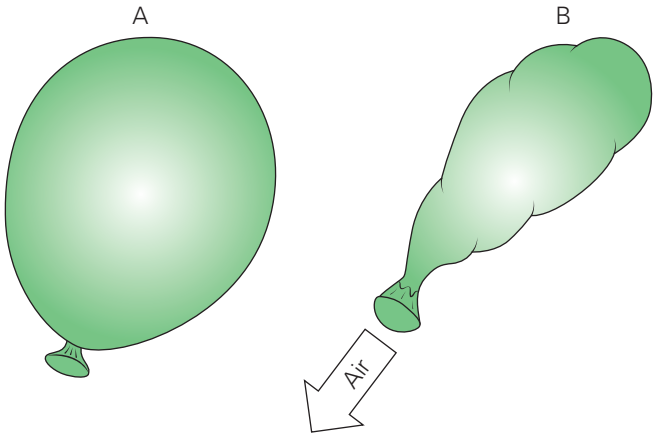


Figure 12.10 Elastic potential energy in balloons

Analysing

13. Analyse the following list of energy sources and rank them from most used to least used in your household.

- Electrical energy
- Chemical potential energy
- Sound energy
- Light energy
- Thermal energy

14. List all the different forms of energy that you can see evidence of in Figure 12.11.



Figure 12.11 Which forms of energy are used in this kitchen?

Evaluating

15. List the devices in your home that use energy, two devices that don't use electricity, and at least one manual (unpowered) device. For each device, state the form of energy used as the input and the forms of energy that they output as well as the wasted energy outputs.

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12.2 Energy transformation, transfer and efficiency

Learning outcomes

At the end of this section, I will be able to:

1. describe examples of energy transformations (change in energy from one form into another).
2. use diagrams to outline energy transformations in everyday situations.
3. identify examples of energy transfer from one object to another, including through conduction, convection and radiation.
4. apply the law of conservation of energy to account for the total energy involved in energy transfers/transformations.
5. perform calculations to determine the efficiency of a system, taking into account useful and wasted energy.
6. define open and closed systems.
7. describe how energy is transferred into and out of systems, and how it cycles within a system.
8. observe or design a chain reaction machine to represent energy stores and transfers.

DOC WORKSHEET Energy transfers and transformations

Energy transformation

Energy cannot be created or destroyed; it can only undergo **transformation** – that is, change from one form to another. This is the **law of conservation of energy**. For example, a falling object loses gravitational potential energy because it's height above the ground decreases. At the same time, it gains kinetic energy as its speed increases while it falls. The gravitational potential energy is transformed into kinetic energy.



Figure 12.12 This lamp demonstrates energy transformation from chemical potential energy stored in the battery into to electrical energy, then into light and thermal energy.

energy transformation change or conversion from one form of energy to another, in line with the law of conservation of energy

law of conservation of energy the law that states that energy cannot be created or destroyed

Energy transformations are never 100% efficient; a little energy is always transformed into heat. In the above example of a falling object, friction with air particles cause some heating, so some of the energy is 'lost' as thermal energy. Energy is referred to as lost when it is not useful energy. Another example is a light globe: it is designed to transform electrical energy into light energy, but some of the energy is transformed to heat, and hence it is considered lost.



Figure 12.13 City lights during the Vivid Sydney festival in 2024. The law of conservation of energy means the amount of electrical energy used by each light is exactly the same as the amount of light energy and thermal energy given out.

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Try this 12.1

Investigating energy with a bouncy ball

Take a bouncy ball and hold it higher than your head. Allow the ball to fall onto the floor and continue bouncing until it comes to rest.

Describe the transformations involved as GPE changes to KE until the ball stops. Explain where elastic potential energy fits in. Why is it different for different balls?

DEPTH STUDY IDEA
The physics of rollercoasters

The law of conservation of energy in practice

Mechanical energy is the sum of kinetic and potential energy in a system. For example, at the highest point of a rollercoaster ride, the gravitational potential energy of the rollercoaster is at a maximum. This gravitational potential energy is transformed into kinetic energy as the rollercoaster moves down the track. The maximum amount of kinetic energy the rollercoaster can gain cannot exceed the maximum gravitational potential energy it had at the top of the ride, because energy cannot be created or destroyed. At any point on the ride, if you add the gravitational potential energy to the kinetic energy, the total sum must be the same apart from a small amount lost due to friction.



Figure 12.14 The sum of kinetic and gravitational potential energy is constant.

Quick check 12.4

1. **Explain** how the law of conservation applies to energy transformations.
2. **Describe** the energy transformations that take place when you use a solar oven, from the energy in the nuclei of atoms in the Sun to the energy in the warm food.

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Try this 12.2

Make a solar oven

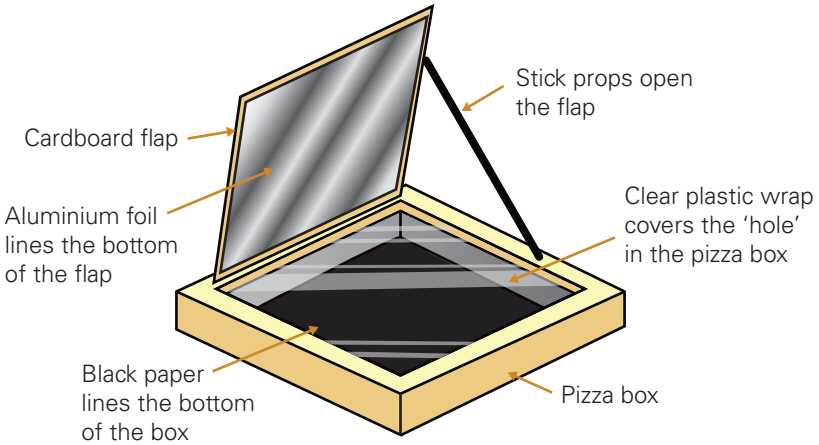
Materials

- cardboard box (a pizza box works well)
- aluminum foil
- plastic wrap (clear)
- black construction paper or black paint
- scissors
- tape (clear or duct tape)
- stick or straw (to prop the lid open)
- marshmallows or other food items to cook
- thermometer (optional)

Procedure

Step 1: Prepare the box

If using a pizza box, clean it out and lay it flat. Cut a flap in the lid of the box. Leave about 3 cm around the edges and cut from the centre to the corners, creating a flap that can be lifted.



Step 2: Add the foil

Carefully cover the underside of the flap you just cut with aluminium foil. Make sure it's shiny side up to reflect sunlight. Smooth it out and tape it in place.

Step 3: Line the bottom

Place black construction paper or paint the bottom of the box with black paint. This helps absorb heat.

Step 4: Seal the box

Cover the opening where the flap is cut with plastic wrap. Stretch it tightly and tape it down to create an airtight seal. This will trap heat inside the oven.

Step 5: Position the flap

Adjust the foil flap so it reflects sunlight into the box. You can use a stick or straw to hold the flap in place at the right angle.

Step 6: Place your food

Put your food items (like marshmallows, nachos or even a small pizza) on the black paper inside the box.

Step 7: Find a sunny spot

Set your solar oven in a sunny area, preferably where it can receive direct sunlight for several hours. Make sure the foil flap is angled to reflect the sunlight into the box.

Step 8: Monitor cooking

If you have a thermometer, place it inside to monitor the temperature. Depending on the sunlight, it can reach temperatures of 93°C or more. Cooking times will vary, but check your food periodically to see if it's ready.

Step 9: Enjoy Your meal

Once your food is cooked, carefully remove it from the solar oven. Enjoy your solar-cooked treat!

Tips

For best results, use your solar oven on a clear, sunny day.

Experiment with different foods and cooking times to see what works best!

Experiment with different solar oven designs. Differently shaped reflective panels have a big impact on the efficiency of the solar oven.

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Energy transfer

In the solar oven, radiant energy in sunlight is transformed to heat in the food. Energy can also be transferred from one object to another without transformation. For example, when one ball strikes another in a game of billiards, kinetic energy is transferred from one ball to another. The second ball will gain speed while the first one will slow down or stop. This is **energy transfer**. When it is kinetic energy that is transferred through a collision, as in this example, it is also called **kinetic transfer**. There are a variety of types of transfer, including electrical and chemical transfer, but the main one we will consider in detail is **heat transfer**.

energy transfer the movement of energy from one place or object to another without changing form

kinetic transfer direct energy transfer through the motion of objects in collisions

heat transfer (thermal transfer) the flow of heat energy from matter at a higher temperature to matter at a lower temperature

Heat transfer

If an object of high temperature is placed next to an object of lower temperature, heat will flow from the object of higher to that of lower temperature. This will continue until the objects are the same temperature. This flow of energy is always from high to low temperature, never the other way around.

There are three different processes that transfer heat from one place to another. These are conduction, convection and radiation.

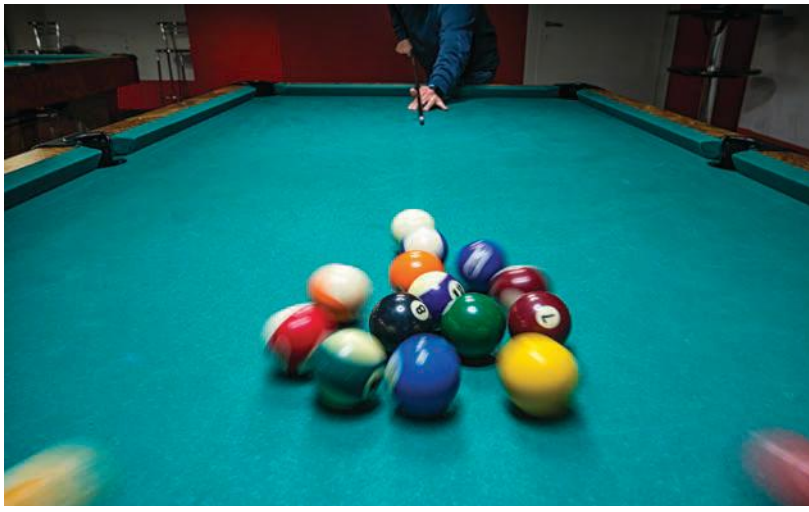


Figure 12.15 Kinetic energy is transferred from the white ball to the other billiard balls.

DOC WORKSHEET Thermal energy transfer

1. Conduction

VIDEO Conduction

Conduction is a mode of heat transfer in solids. In a solid, the particles cannot move away from their position, but they do vibrate. Remember, thermal energy is a form of kinetic energy, as the particles move back and forth as they vibrate. The hotter the material, the faster the particles vibrate. As these particles bump into neighbouring particles, they transfer their kinetic energy to the next particle. This continues until the thermal energy is spread throughout the solid object, causing the cooler section to warm.

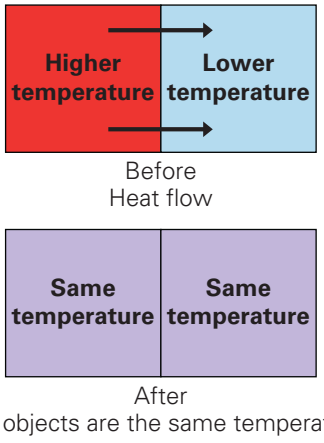


Figure 12.16 Heat (thermal energy in transit) flows from an object of higher temperature to one of lower temperature, until the objects are at the same temperature.

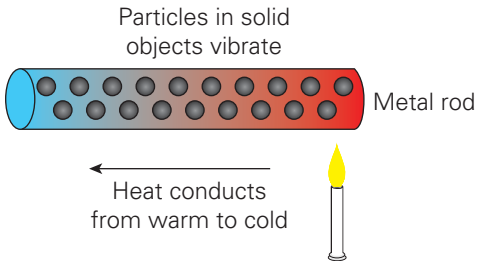


Figure 12.17 As the metal rod is heated, the particles begin to vibrate more rapidly, bumping into the nearby particles, making them move faster too. This allows heat to flow along the metal rod.

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Investigation 12.1

Heat transfer by conduction

Be careful
Do not touch the metal rods when they are hot. Allow time for cooling. Ensure appropriate personal protective equipment is worn.

INVESTIGATION

Aim
To determine which type of metal transfers heat the quickest due to conduction.

Materials
- 4 metals rods made from different metals, e.g. iron, copper, aluminium, brass, zinc
- Vaseline or melted wax
- timer or stopwatch
- paperclip
- tripod
- Bunsen burner

Procedure
1. Attach a paperclip to one end of each metal rod using Vaseline or melted wax.
2. Carefully balance one rod on the tripod so that the end without the paperclip is over the Bunsen burner.
3. Light the Bunsen burner.
4. Time how long it takes for the paperclip to fall from the end of the rod.
5. Record your results.
6. Repeat steps **2–5** for the other rods.

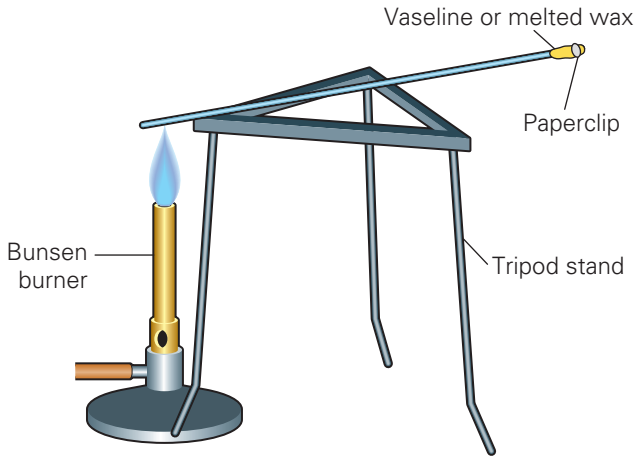


Figure 12.18 Experimental set-up

Results

Name of metal	Time for paperclip to fall (seconds)
1	
2	
3	
4	

Discussion
1. Identify the dependent and independent variables for this investigation.
2. List the controlled variables.
3. Why does the Vaseline or wax melt?
4. If you were to repeat this investigation, what changes would you make?
5. List the metals in order of how fast they conducted heat.

Conclusion
1. Make a claim about which metal transfers heat the quickest based on this investigation.
2. Support your statement by referring to your experimental data.
3. Explaining how the data you gathered support your claim.

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VIDEO
Convection

2. Convection

Liquids and gases are both fluids, as particles are able to move from their original location. Convection occurs when a fluid is heated and the warmer particles rise, while the cooler particles sink. This creates currents in the fluids known as convection currents. This is happening in the atmosphere all the time as the Sun warms the air, and it is how sea breezes are formed.

When particles in a fluid are heated, they gain energy and move faster, causing them to collide with each other with increasing energy. When the particles collide, they bounce further apart from each other. As a result, fewer particles occupy the same space as before they were heated. This means the warm fluid is now less dense and rises. As the fluid gets further away from the heat source, it begins to cool again. Cooler fluid is drawn into the space left behind by the rising warm fluid. This cycling is a convection current.

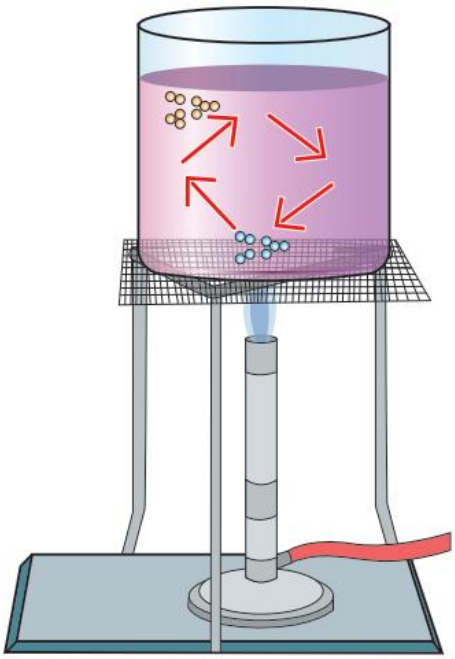


Figure 12.19 Heat transfer by convection

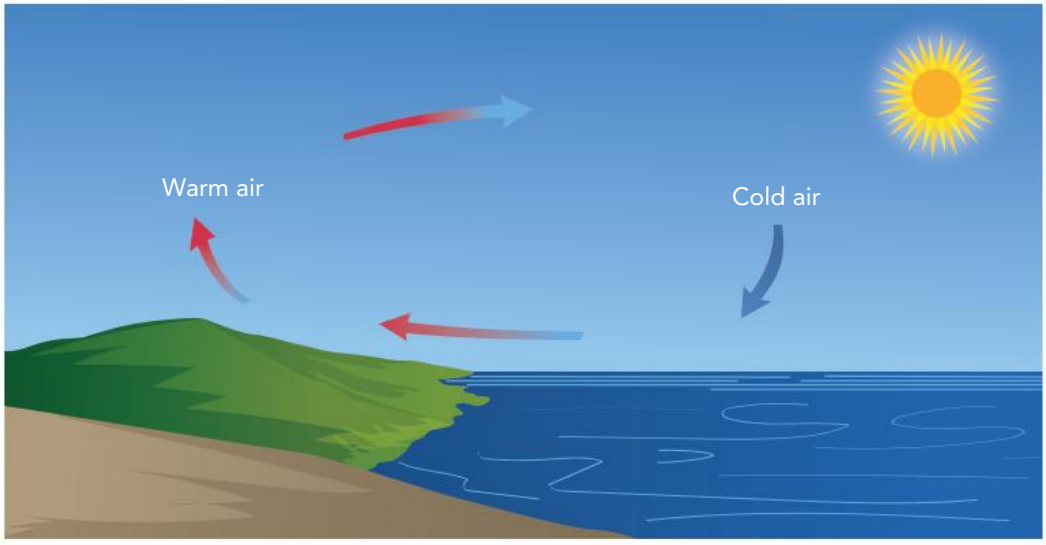


Figure 12.20 How an afternoon sea breeze is caused by convection



Figure 12.21 Lava lamps work by the concept of convection. Have a go at explaining it using what you've learned.

Practical skills 12.1: Teacher demonstration

Heat transfer by convection

Aim

To observe convection currents in water.

Materials

- potassium permanganate crystals (grains of rice work as well)
- beaker or conical flask
- tripod
- Bunsen burner

Be careful

Ensure appropriate personal protective equipment is worn. Ensure potassium permanganate is not disposed of down the drain.

continued ...

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Procedure

1. Set up your materials as shown in the diagram.
2. Light the Bunsen burner and gently heat the water.
3. Observe the motion of the coloured water.

Results

Record your observations in words and draw a series of sketches (or take photos).

Discussion

1. How does this activity demonstrate heat transfer by convection?
2. List some examples of convection currents in nature.

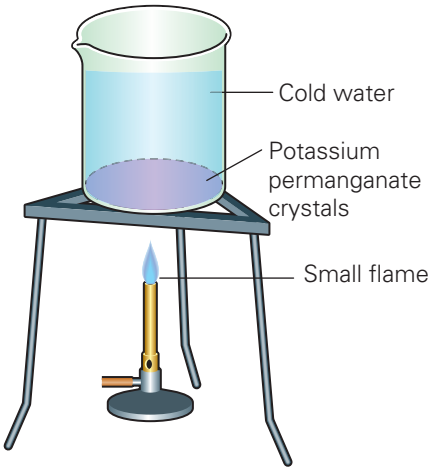


Figure 12.22 Experimental set-up

3. Radiation

Radiant energy introduced earlier in the chapter is energy as photons (waves). Radiation as a form of heat transfer does not rely on the vibration or movement of particles of matter to be transferred. It can travel through space. In fact, the energy produced by the Sun travels to Earth by radiation. Light energy travels by radiation. Infrared radiation is a form of light energy that causes objects to heat up. When an object absorbs the energy from radiation, it causes particles in the object to vibrate quicker, therefore heating the object. All objects transfer some heat by radiation – even your body emits radiant energy. The hotter an object is, the more heat it radiates.



Figure 12.23 Thermal imaging cameras capture infrared radiation and covert it to visible light.

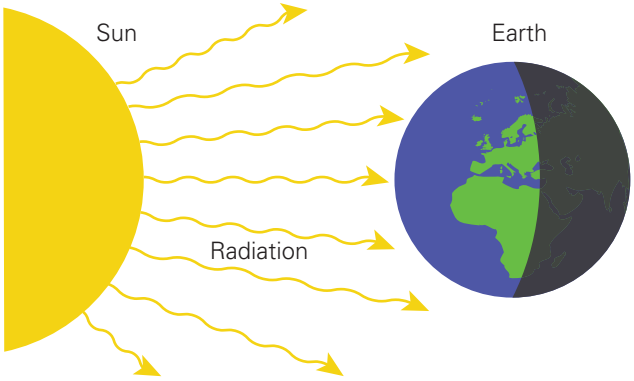


Figure 12.24 Heat transfer from the Sun by infrared radiation

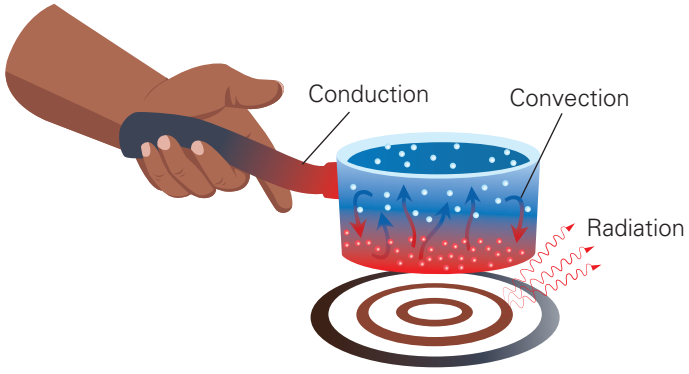


Figure 12.25 An example of the three forms of thermal transfer as you prepare your two-minute noodle snack

Quick check 12.5

1. **Describe** how heat is transferred in a liquid.
2. **Give** one example of heat transfer for each of the following: conduction, convection, radiation.

VIDEO Radiation

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Practical skills 12.2: Teacher demonstration

Heat transfer by radiation

Aim

To demonstrate the transfer of thermal energy by radiation.

Materials

- infrared heat lamp
- digital thermometer (with a large screen)
- vacuum chamber with a vacuum pump

Procedure

1. Set up the vacuum chamber with the digital thermometer inside.
2. Take a reading from the thermometer.
3. Seal the chamber and start the pump.
4. Allow time for air to be removed from chamber.
5. Turn on the infrared lamp and aim it at the thermometer.
6. Record the temperature every five minutes for a whole lesson.

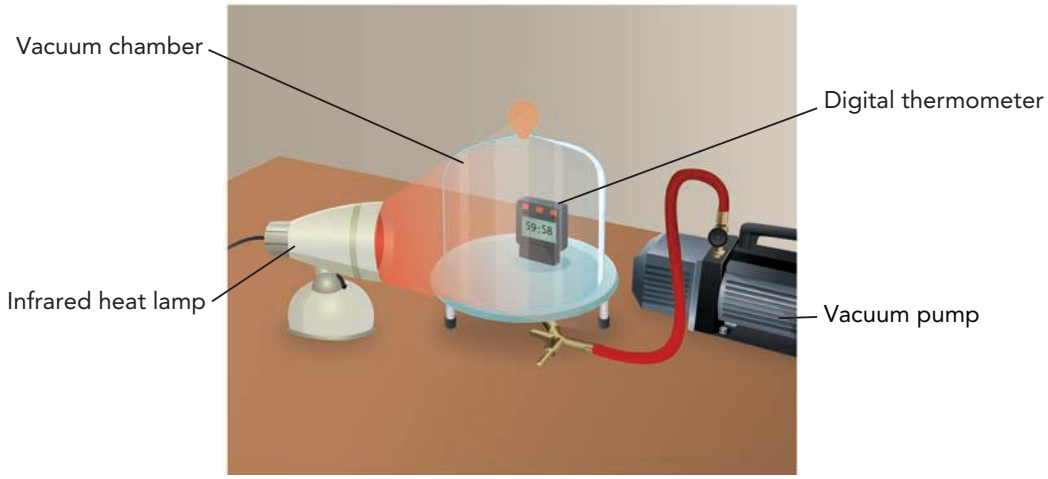


Figure 12.26 Experimental set-up

Results

1. Record your results below.

Time (min)	Temp (°C)	Time (min)	Temp (°C)
0		25	
5		30	
10		35	
15		40	
20		45	

2. Plot a line graph of the results.

Discussion

1. Which measurement is the dependent variable and which is the independent variable?
2. How does this demonstration show heat transfer by radiation?
3. Can you think of another way of showing heat transfer by radiation?

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Try this 12.3

Does colour affect how much heat is absorbed by radiation?

Paint some empty metal cans in different colours. Put them out in the sun with thermometer in each one. Record the temperature every few minutes. Do you notice any difference in temperature in the different containers?

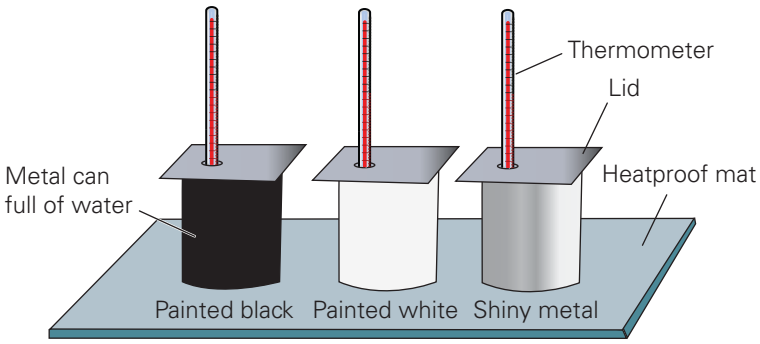


Figure 12.27 Equipment set-up

Energy transformation diagrams

Flow diagrams

Energy transformations can be represented in a flow diagram (see Figure 12.28). On the left-hand side of the flow diagram are the energy inputs. On the right-hand side are the energy outputs. **Waste energy or energy lost** may be included as an energy output but is sometimes omitted.

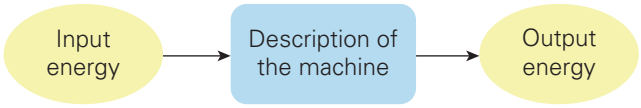


Figure 12.28 A simple energy flow diagram

For example, Figure 12.29 shows the energy flow diagram of plants converting radiant energy from the Sun into chemical potential energy (glucose).

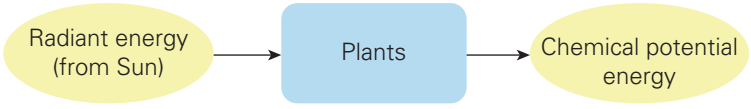


Figure 12.29 Energy flow diagram of photosynthesis in the leaves of plants. The chemical potential energy is stored as glucose.

waste energy (or energy lost) the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy

useful energy the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it creates

An electric light uses electrical energy to create light as useful energy; any thermal energy produced is waste energy. A petrol-driven lawnmower converts chemical potential energy in the petrol into kinetic energy and rotational kinetic energy, with thermal energy and sound as waste forms of energy.
A two-step example is a battery-powered torch (see Figure 12.30). The input energy source is chemical potential energy in the battery. This is converted first to electrical energy and then to light energy in the globe, with some waste thermal energy also.

Useful energy is the output energy the process is designed to produce. Waste energy is any other form of energy, usually thermal energy or sound, that is not wanted.

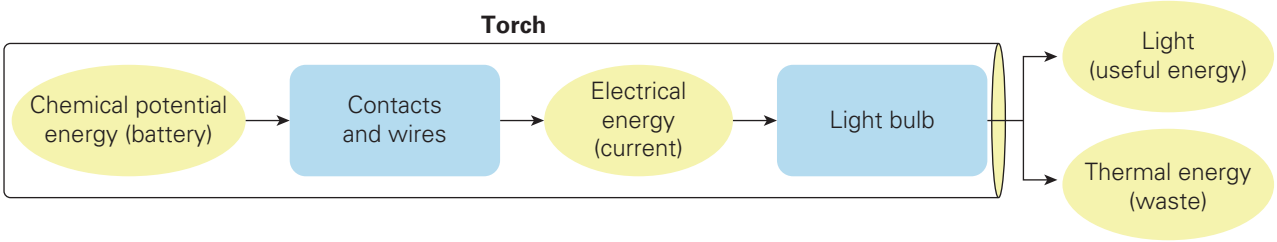


Figure 12.30 An energy flow diagram of a battery-powered torch

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WIDGET
Energy conversion flow diagrams

Quick check 12.6

1. **Draw** flow diagrams for the following energy transformations and **indicate** the waste energy.
   - **a.** A television converting electrical energy to sound, thermal and light energy
   - **b.** A light globe converting electrical energy to light and thermal energy
   - **c.** A human converting chemical potential energy from food into kinetic energy and thermal energy when moving

Sankey diagrams

Sankey diagrams are another way to represent energy transformations while also giving an indication of the amount of energy that has been transformed.
Figure 12.32 shows the general form of a Sankey diagram.

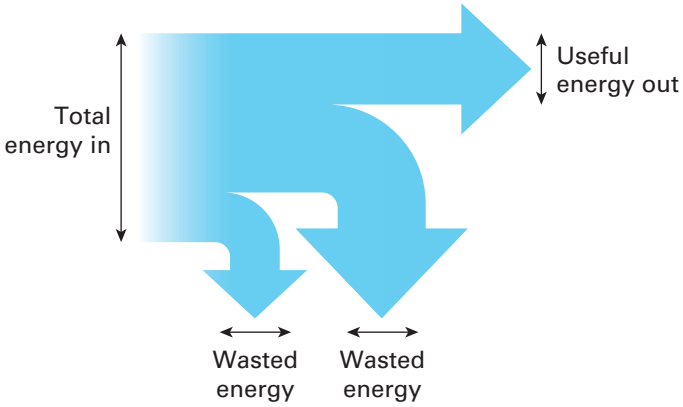


Figure 12.31 How a Sankey diagram is used to show energy conversions and output

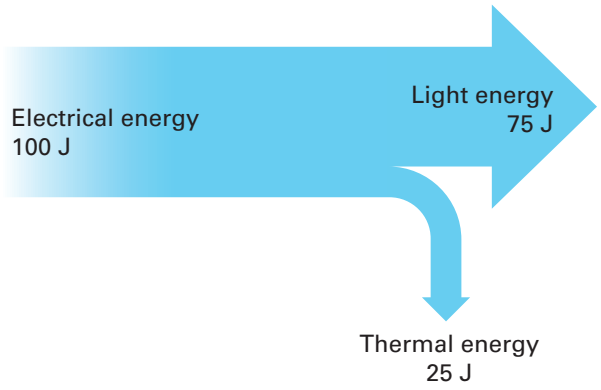


Figure 12.32 This Sankey diagram shows the energy conversions for an energy-efficient LED light globe. The output energy shows that only a small amount of energy is lost as thermal energy.

Try this 12.4

Drawing Sankey diagrams

Draw a Sankey diagram for a hairdryer. Think about all the ways in which energy is transferred, transformed and lost to heat.

Energy efficiency

efficiency
the percentage of input energy that is converted to useful energy by a machine

The **efficiency** of a machine is a measure of how good the machine is at converting the input energy to useful energy. The percentage of input energy that is converted to useful energy is used to give a machine an efficiency rating. The formula used to calculate the efficiency rating is:

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

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Worked example 12.3

A kettle uses 261 500 J of electrical energy to heat 500 mL of water. If the thermal energy of the water is 209 200 J, calculate the efficiency of the kettle.

Working	Explanation
Useful output energy = 209 200 J Input energy = 261 500 J	Identify the values given in the question.
efficiency (%) = $\frac{\text{useful output energy}}{\text{input energy}} \times 100$	Identify the formula needed to answer the question.
efficiency = $\frac{209\,200\text{ J}}{209\,200\text{ J}} \times 100$	Substitute the relevant values into the formula.
efficiency = 80%	Give the answer with correct units.

Worked example 12.4

A girl runs upstairs and uses up 4000 J of energy from food she has eaten. If she gains 1000 J of gravitational potential energy, calculate the efficiency of her muscles.

Working	Explanation
Useful output energy = 10000 J Input energy = 4000 J	Identify the values given in the question.
efficiency (%) = $\frac{\text{useful output energy}}{\text{input energy}} \times 100$	Identify the formula needed to answer the question.
efficiency = $\frac{1000\text{ J}}{4000\text{ J}} \times 100$	Substitute the relevant values into the formula.
efficiency = 25%	Give the answer with correct units.

The other 75% would be waste energy, lost mainly as thermal energy as she climbs.

Try this 12.5

Calculating energy efficiency

Calculate the energy efficiency of each of the light globes shown below. State which light globe is no longer recommended for household use and justify your choice.

DEPTH STUDY IDEA
The history of electric lighting

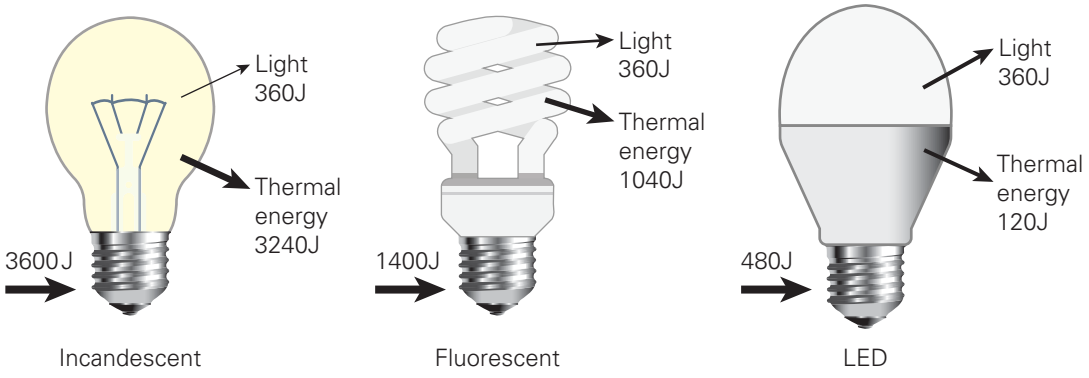


Figure 12.33 How efficient is each type of light globe?

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Did you know? 12.1

Efficient light globes

Old-fashioned incandescent light globes work by passing electricity through a thin metal filament, which glows white-hot. However, their energy efficiency is only about 2–3%, so 97–98% of that electrical energy is transformed into thermal energy. These days, compact fluorescent lights (CFLs) and light-emitting diodes (LEDs) are more efficient, with energy efficiencies of 15% and 25–30% respectively. This still means most of the electrical energy is wasted as thermal energy. Improvements to LEDs continue to be made, but as of 2025, even in research laboratories, they have yet to reach an energy efficiency of 50%.

Quick check 12.7

1. **Define** the term 'energy efficiency'.
2. Copy and complete the table to **state** an example of the useful energy and waste energy produced by each of the following devices.

Device	Useful energy output	Waste energy output
Light globe		
Car		
Lawnmower		

3. A light globe uses 3000 J of electrical energy. Of this, 600 J is transformed into light energy and 2400 J is transformed into thermal energy. **Calculate** the energy efficiency of this globe.

Practical skills 12.3

Energy efficiency of bouncy balls

Aim

To investigate which type of bouncy ball is most energy-efficient.

Materials

- a range of bouncy balls (sizes, brands, etc.)
- metre rulers

Procedure

Design an experiment that will test the rebound height of a range of bouncy balls. In a group, discuss how you will carry out this experiment, and write out a step-by-step procedure.

Results

1. Draw a results table for your experiment.
2. Produce a suitable graph for your experiment.

Discussion

1. Calculate the efficiency of each type of ball using the drop height and the rebound height.
2. Identify sources of uncertainty in your experiment.
3. Suggest how your experiment may be improved.

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Explore! 12.1

INVESTIGATION

Sankey diagrams for solar, wind and wave energy for electricity generation

Research the energy transformation and efficiency of the following systems used to generate electricity (electrical energy is the output):

- solar panels made from silicon
- solar thermal collectors heating water to drive steam turbines
- wind turbines
- wave-powered turbines.

Use a Sankey diagram to outline the energy transformations, outputs of useful energy and energy losses for each one. Compare them to a Sankey diagram for photosynthesis in green plants.

Try this 12.6

Home electricity audit

Use the Australian Government's 'Energy rating calculator' website to audit the energy efficiency of appliances around your house. You may choose to investigate your TV, washing machine, dishwasher or fridge. Compare how much it costs to run each appliance for a year.

In your classroom, is one appliance consistently more efficient than others?

Open and closed systems

Energy cannot be created or destroyed; it can only change form as stated by the law of conservation of energy. However, we have said that energy that is not useful for the intended purpose is wasted or lost. So, where does it go? To answer this question, we need to define open and closed systems.

open system a system that allows exchange of energy and matter in and out of the system

closed system a system that allows exchange of only energy in and out of the system

- An **open system** allows exchange of energy and matter in and out of the system. For example, our human bodies are systems that need inputs of both matter and energy, and also output matter and energy. A terrarium is a box for growing plants indoors: Figure 12.34 shows an open terrarium on the left.
- A **closed system** only allows exchange of energy, but no or very little exchange of matter. For example, a terrarium may be closed, as shown in panel b of Figure 12.34. Another example is our planet Earth, which depends on the incoming energy from the Sun and radiates heat energy, but hardly exchanges any matter with its surroundings.

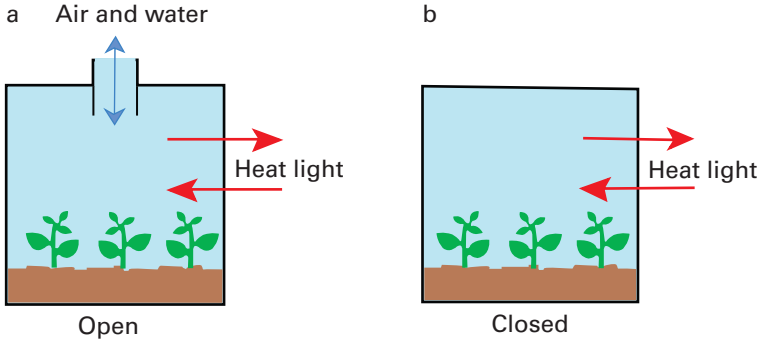


Figure 12.34 Open and closed systems: an open glass terrarium **(a)** and a sealed one **(b)**

In senior science, when considering the energy of a system, it is very important to consider whether the system is open or closed. If it is open, there are no restrictions, and matter coming in or out will have its own energy, which could be, for example, kinetic energy or gravitational or chemical potential energy. This is in addition to any energy that comes in or out without being in matter.

In a closed system, the energy going in or out can't be in matter. This restricts it to, for example:

- radiant energy
- thermal energy
- sound energy (vibrations)
- electrical energy (as a current in wires through the walls of the system).

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Knowing whether a system is open or closed helps in tracking where matter and energy goes both within the system and to and from the outside. It helps identify where energy is being lost, and this can help make systems more efficient.

A system that does not exchange either energy or matter is called an isolated system. Total energy is constant in an isolated system.

Earth is a closed system. Due to the greenhouse effect, it is taking in more energy than it is radiating, leading to an overall increase of energy in the system. This is causing global warming.

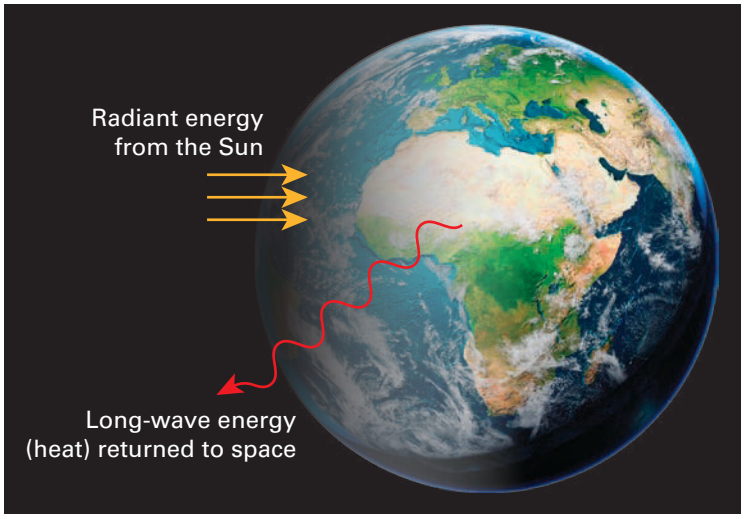


Figure 12.35 The Earth is a closed system.

Did you know? 12.2

Perpetual motion

Perpetual motion machines do not exist, although many have tried to invent them!

The idea is that the energy output of the machine feeds back into the machine to serve as the energy input, so in theory it could go on forever without any external energy input.

In the 15th century, Leonardo da Vinci sketched several ideas for perpetual motion machines, including the 'overbalanced wheel', which was supposed to keep turning forever by using shifting weights. Despite countless attempts and creative designs, none have ever succeeded.

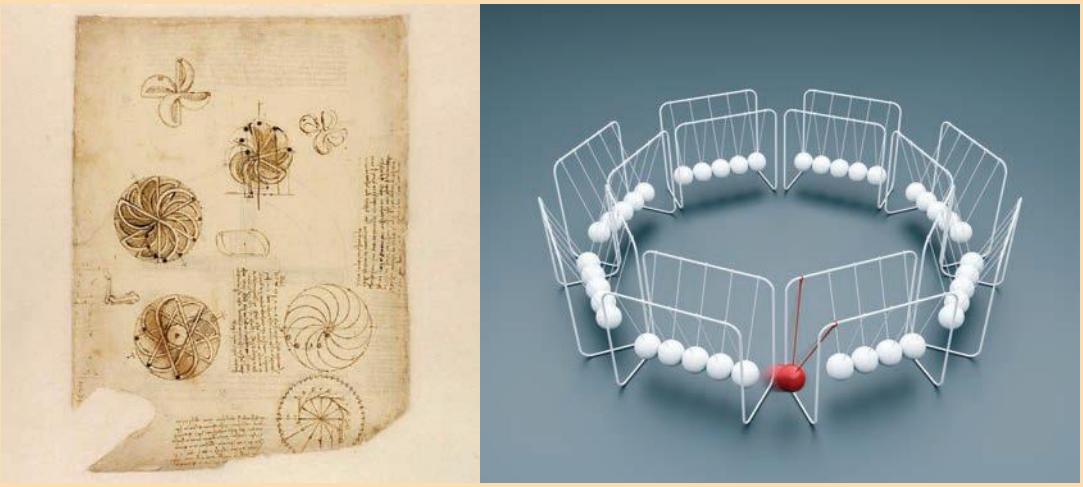


Figure 12.36 Nice try! But some energy is always lost from the system, so it will not keep going forever!

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Chain reaction machines representing energy stores and transfers

A chain reaction machine is usually not a single machine but a sequence of mechanical devices set up in such a way that a force input at the start moves the first device, which transfers its movement to the second, and so on to the end of the chain. They are often called 'Rube Goldberg' machines after an American cartoonist whose whimsical drawings of impractical inventions were widely distributed.

A chain reaction machine can represent a variety of energy stores and transfers. Analysing an existing representation is good practice for learning energy transfers and transformations; designing one is even better.

Try this 12.7

Rube Goldberg machines

Look at the system in the image below. Can you identify the energy transfer and transformations in the image?



Figure 12.37 A Rube Goldberg machine is a chain reaction-type contraption intentionally designed to perform a simple task in an indirect and (impractically) overly complicated way.

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Try this 12.8

Design your own Rube Goldberg machine!

Figure 12.38 shows an example of a Rube Goldberg machine. Many movies and cartoons have shown these clever designs in use – for example, Kevin McCallister making traps for invaders in *Home Alone* or Wallace and Gromit making breakfast and getting dressed in *A Grand Day Out*. The image below shows an example of a plan.

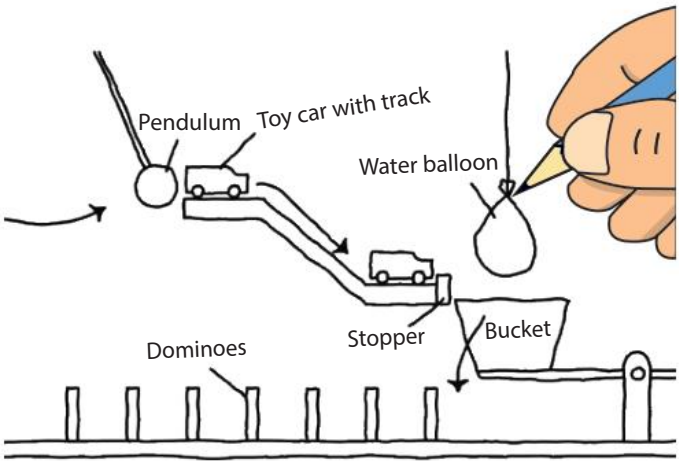


Figure 12.38 A homemade Rube Goldberg machine

1. Decide the task you want your machine to perform. It could be as simple as knocking over an action figure or switching on a light, or a trickier task like blowing up a balloon, feeding the dog or making a sandwich.
2. Find out which materials are available. They could be anything – for example, cardboard rolls, string, sticky tape, dominoes or marbles.
3. Draw a plan of your machine.
4. Describe all the energy transformations and/or transfers in your machine.
5. (Optional) Construct and test your machine!

Go online to access the interactive section review and more!

Section 12.2 review

Online quiz | Section questions | Teachers can assign tasks and track results

Section 12.2 questions

Remembering

1. **Describe** the difference between an energy transfer and an energy transformation.
2. **Recall** the three ways in which heat can be transferred.
3. **Identify** the words that will complete the following sentences.
   Heat naturally moves from a _____ object to a _____ object.
   A liquid or gas is generally heated through the process of _____. Heat moves through _____ in a process called conduction.

Understanding

4. Using the law of conservation of energy, **explain** why thermal energy from a light globe is considered as wasted energy.
5. **Explain** why the process of convection is important in nature.
6. **Describe** the energy transformation that occurs in photosynthesis.

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Applying

7. **Draw** or **describe** the energy flow diagram for each of the following situations.
   - **a.** A stone is dropped from the top of a building.
   - **b.** A car is slowing down as it moves up a hill.
   - **c.** A charcoal fire is burning in a barbeque.
   - **d.** A bungee jumper jumps from the top of the jump to the bottom.
   - **e.** An electric tram starts from rest and builds up to full speed.
   - **f.** A person rides on an escalator from the bottom to the top.
   - **g.** A sheepdog runs up a hill.
8. **Sketch** a diagram to show the three ways in which heat can be transferred.

Analysing

9. Think about all the different types of energy we encounter every day – driving a car is one example. Pick another example and **suggest** how you can make the process more energy-efficient.
10. Look closely at Figure 12.39.
    - **a.** **Identify** the components of the playground that involve gravitational potential energy.
    - **b.** **Suggest** ways in which elastic potential energy could be incorporated into this playground setting.



Figure 12.39 Gravitational potential energy in a playground

Evaluating

11. Energy wastage occurs when energy is transferred from one form to another. For example, an incandescent light globe takes in electrical energy and gives off light, but heat is also produced as a waste energy.
    Propose some ways in which waste energy could be made useful.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
12.1	define and use the terms 'potential energy' (PE) and 'kinetic energy' (KE).	5
12.1	recall different forms of energy, including thermal, elastic, chemical and gravitational potential energy.	4, 9
12.1	describe how systems can store different forms of energy.	1, 2, 3, 7
12.2	describe examples of energy transformations (change in energy from one form into another).	8
12.2	identify examples of energy transfer from one object to another, including through conduction, convection and radiation.	13c, 14
12.2	apply the law of conservation of energy to account for the total energy involved in energy transfers/transformations.	6
12.2	use diagrams to outline energy transformations in everyday situations, including how solar energy can be transformed.	11, 12
12.2	perform calculations to determine the efficiency of a system, taking into account useful and wasted energy.	13a, 13b
12.2	define open and closed systems.	17
12.2	describe how energy is transferred into and out of systems, and how it cycles within a system.	15
12.2	observe or design a chain reaction machine to represent energy stores and explain the transfers in the system.	18

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Define** 'energy transfer' and 'energy transformation'.
2. **State** the kind of energy that increases if you climb a mountain.
3. **Recall** the term for energy that is stored when a spring is compressed.

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4. **Select** the correct description for each term in the table below.

Term	Description
Sound energy	The energy that moving objects have
Kinetic energy	The energy of photons that can travel through space
Electrical energy	The energy carried by waves of vibrations moving through matter
Thermal energy	The energy of electrons moving in matter
Light energy	The energy that moves between two objects of differing temperatures

Understanding

5. **Compare** and contrast potential energy and kinetic energy.
6. **State** which physical law governs energy transformation and describe how it does so.
7. **State** whether each of the following sentences is true or false.
   - **a.** When bouncing a ball, elastic potential energy is involved.
   - **b.** An object can have energy even when it is stationary.
   - **c.** An object must be moving to transform energy from one form to another.
   - **d.** When driving a car, chemical potential, gravitational potential and kinetic energy are involved.
8. **Name** an object that transforms:
   - **a.** electrical energy into thermal energy
   - **b.** elastic energy into kinetic energy
   - **c.** chemical potential energy into kinetic energy
   - **d.** chemical potential energy into thermal energy
9. Look around your environment and **identify** four examples of forms of energy that you can detect.
10. **Identify** four examples of energy transformations that occur in your typical day, including at least one transformation that you identify as storing energy for later use.

Applying

11. **Draw** a flow diagram showing the energy transformation that occurs in a gas stove.
12. Use the diagram in Figure 12.40 to **draw** an energy flow diagram that explains how a waterwheel generates energy.

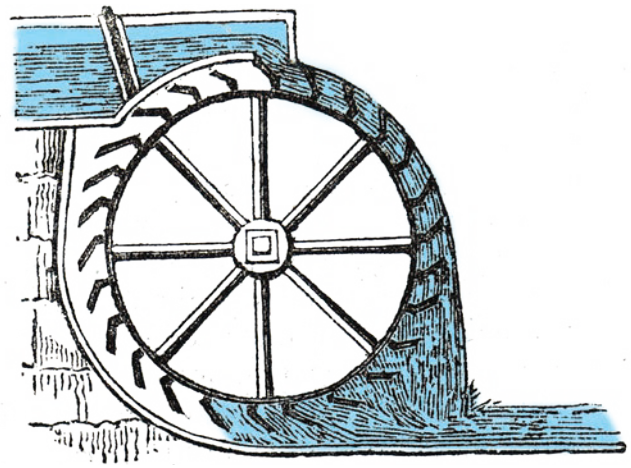


Figure 12.40 An overshot waterwheel

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Analysing

13. A ceiling fan has an input of 2400 J of electrical energy. Of this, 300 J of energy output is lost as thermal energy due to friction between metallic parts, and 40 J is lost as sound energy.

a. **Calculate** the energy efficiency of the fan.

b. **Sketch** a Sankey diagram for the ceiling fan.

c. **Describe** how thermal energy is transferred between the metallic parts.



14. **Compare** and **contrast** convection and radiation in terms of thermal energy transfer.

15. **Identify** three forms of energy that can be transferred out of or into a closed system.

Evaluating

16. Consider the Sun's role in life on Earth. **Explain** why there would be no life on Earth without the Sun.

17. **Discuss** whether a spacecraft travelling through space is an open or closed system, and the extent to which the answer may depend on its features and design.



18. **Explain** what a chain reaction machine can demonstrate about energy.

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Data questions

A tennis ball and golf ball are dropped from the same height, and their first two bounces are recorded. The results are shown in Figure 12.41.

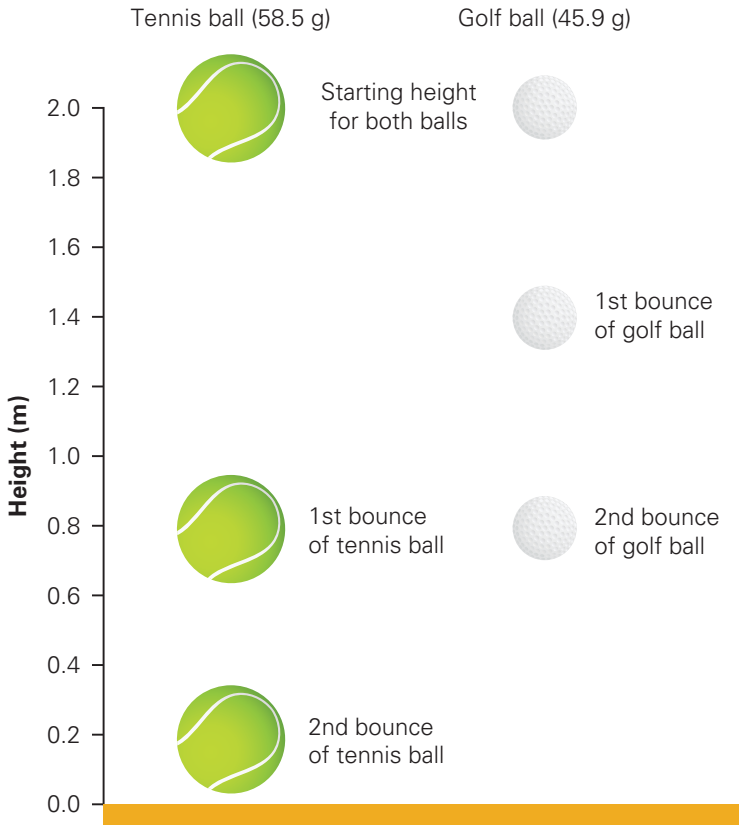


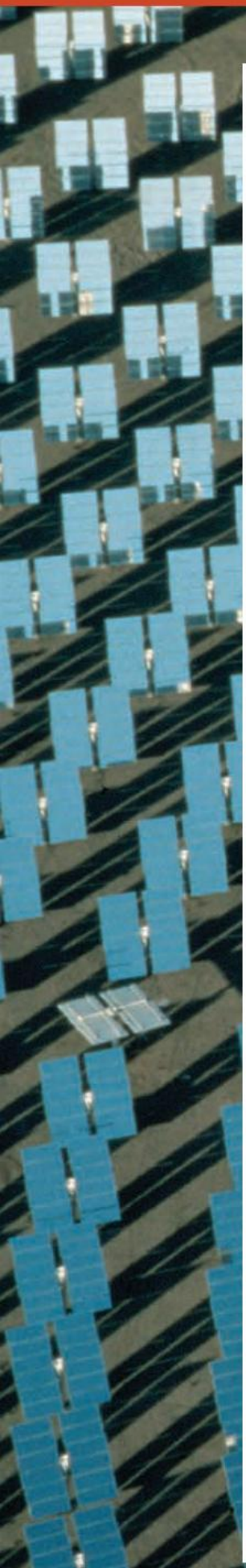
Figure 12.41 Dropping a tennis and golf ball from the same height and recording the heights of their first two bounces

1. Use the data from Figure 12.41 to **calculate** the missing information on the balls' gravitational potential energy in the table.

Ball	Weight (kg)	Starting height (m)	Height of 1st bounce (m)	Height of 2nd bounce (m)	GPE at starting height (J)	GPE at 1st bounce (J)	GPE at 2nd bounce (J)
Tennis	0.0585	2.0	0.8	0.2			
Golf	0.0459	2.0	1.4	0.8			

2. **Contrast** the differences between the two balls to determine which is more efficient in converting gravitational potential energy to kinetic energy and back again.
3. **Extrapolate** from the data to predict how high the golf ball will reach on its third bounce.
4. **Infer** where the 'missing' energy has gone for both balls.
5. **Deduce** why the golf ball is more efficient than the tennis ball.

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STEM activity: Energy transformations in rollercoasters

Background information

Energy can be transformed from one type to another type, depending on the intended use. Rollercoasters take advantage of this and require no additional input energy once the carriage has reached its maximum height. There are a number of energy transformations that take place when the carriage is travelling along the tracks.

DESIGN BRIEF

Create a rollercoaster for a marble so energy transformations can be observed.

Activity instructions

In groups, you will design and construct a simple rollercoaster for a marble. The track must include one vertical loop and two curves or bends. The marble must be able to travel the whole length of the track without stopping.

Suggested materials

- pool noodles
- marble or ball bearing
- masking/packing tape
- toothpicks
- scissors
- box cutter knife
- string
- paper or cardboard

Research and feasibility

1. Research and discuss in your group how a rollercoaster operates using gravity.
2. Discuss the constraints of your building materials and testing area.

Design and sustainability

3. Sketch a number of rollercoaster designs for your group. Discuss the feasibility of your designs. For example, will this design allow the marble to reach the end of the track?
4. Identify and discuss the energy transformations that will affect your rollercoaster.
5. Discuss how sustainable your designs are. Are these realistic for a real-life rollercoaster?
6. Discuss the effectiveness of each design with respect to using gravitational potential energy as your initial energy source.

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Create and modify

7. Construct your preferred rollercoaster model.
8. Test your model and make any necessary modifications.
9. Mark on your model where gravitational potential energy (GPE) is increasing and where it is decreasing.
10. Mark on your model where kinetic energy (KE) is increasing and where it is decreasing.

Evaluate

11. Discuss and suggest three possible solutions to problems you encountered with your design and construction. (What modifications did you need to make and why?)
12. Predict what would happen if your model's starting point was raised higher, and then lower. Try this and describe what happens.
13. Did your group notice a relationship between GPE and KE? What is it?
14. Evaluate your model and present it to your class, describing the energy transformations that occur throughout the journey of the marble.





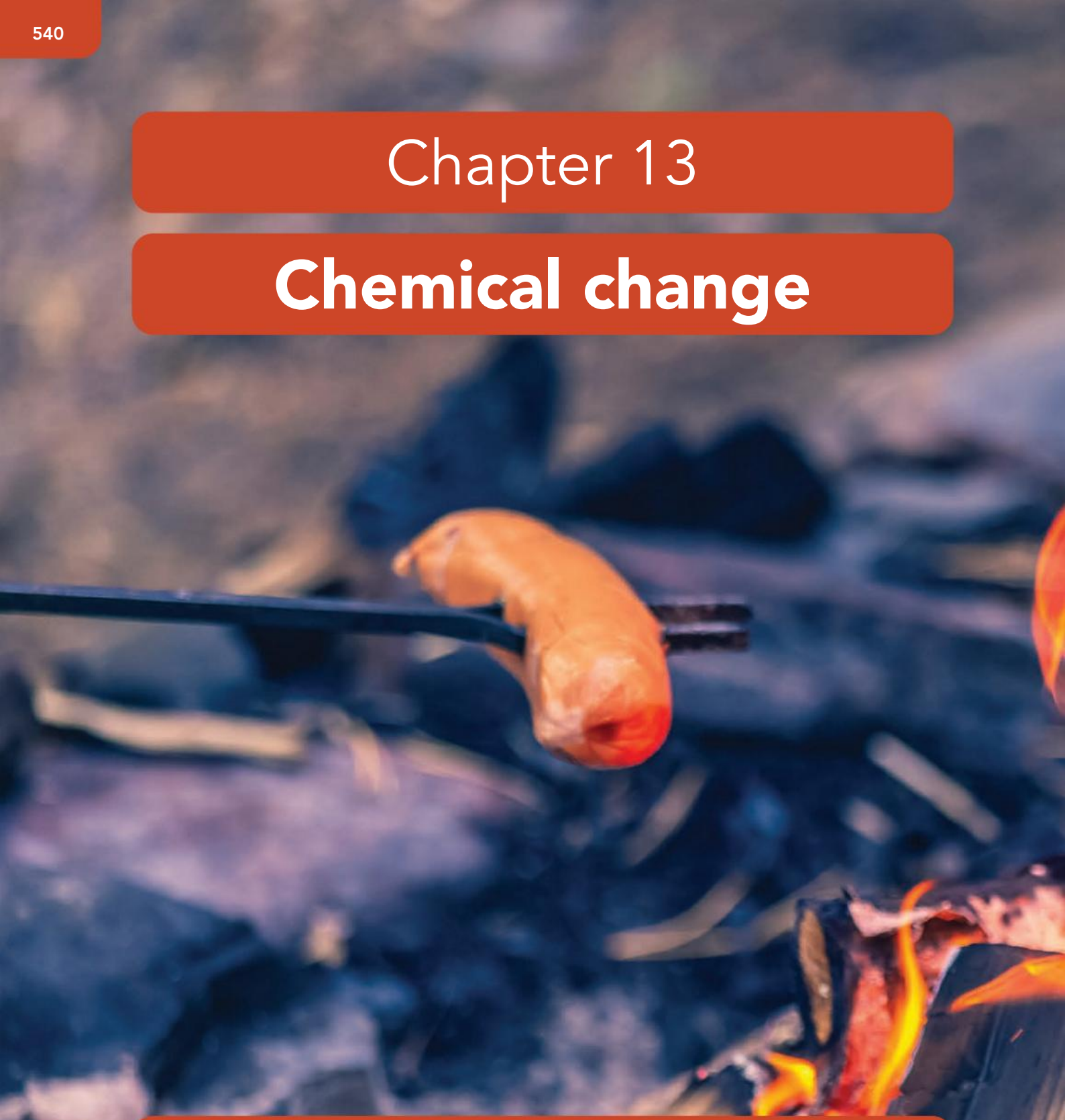


Figure 12.42 Different types of rollercoasters

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Chapter 13

Chemical change

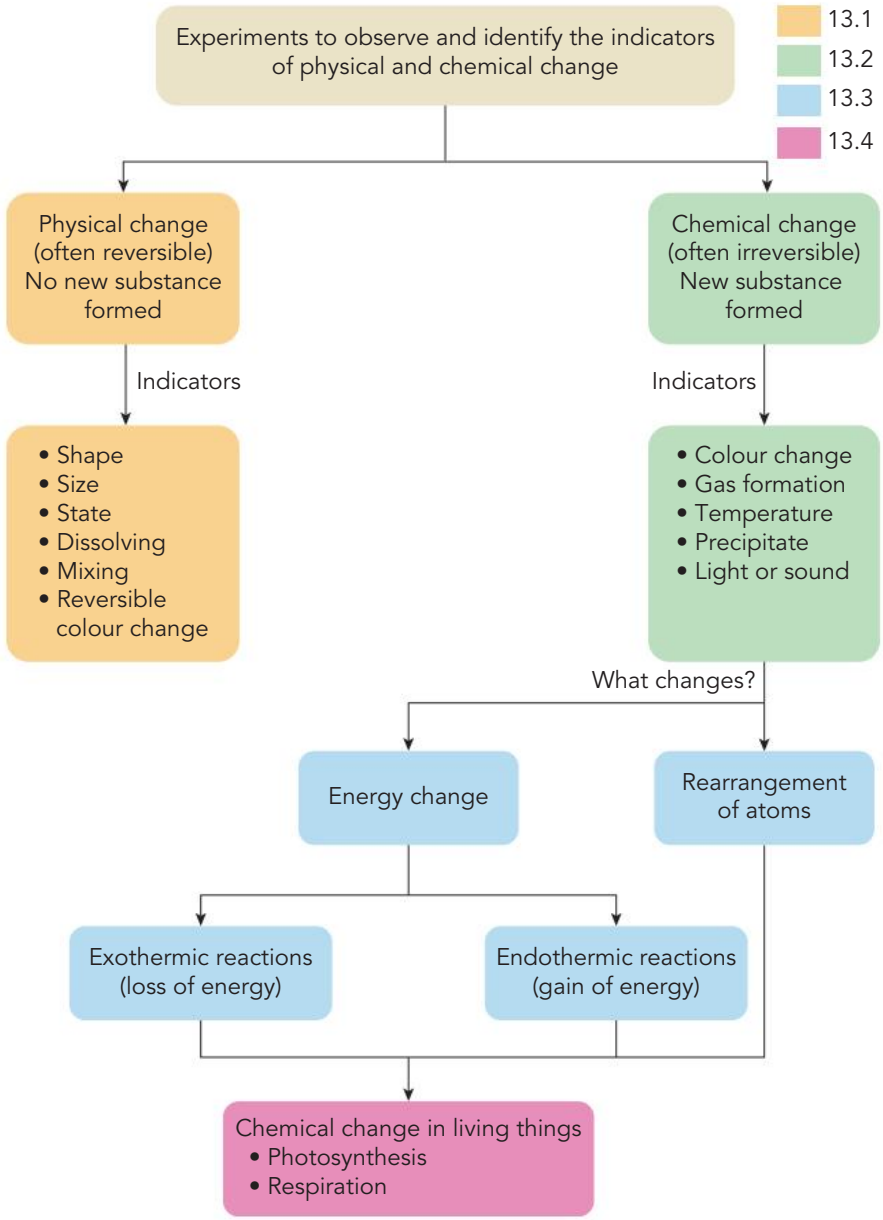


Chapter introduction

The world is filled with physical and chemical changes happening all around us. In this chapter, you will learn about how substances react to form new substances and how to determine whether a reaction has occurred. You will look at how glow sticks work, how marshmallows go gooey and delicious over a fire, how fruit ripens and how fireflies glow in the dark. You will learn the basics of how to write a word equation to represent a chemical reaction. You will also examine the role of energy in everyday chemical reactions. Finally, you will investigate two reactions that are vital for life: respiration and photosynthesis.

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Chapter map



Glossary terms

biochemical reaction
bioluminescence
bonds
chemical change
chemiluminescence
corrosion
decomposition
dissolving
endothermic reaction
exothermic reaction
galvanisation
indicator (of physical or chemical change)
irreversible
photosynthesis
physical change
precipitate
products
reactants
reaction conditions
rearrange
respiration
reversible
word equation

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13.1 Indicators of physical change

VIDEO
Physical change

Learning outcomes

At the end of this section, I will be able to:

1. carry out experiments to observe and identify the indicators of physical change.
2. describe the indicators of a physical change.
3. give examples of physical changes.

What is physical change?

physical change when the physical properties of a substance change in some way, but no new substance is formed

reversible able to go in the opposite direction

irreversible unable to go in the opposite direction

indicator (of physical or chemical change) a property that changes when a particular physical or chemical change happens, providing evidence of change and type of change

During a **physical change**, the characteristics of a substance, or its physical properties, change in some way, but no new substance is formed. Examples of physical properties are texture, shape, size, colour, odour, volume, mass and density. The chemical composition of the substance is unchanged.

Physical change can be **reversible** (e.g. ice melting into water can be refrozen) or **irreversible** (e.g. cutting a piece of paper).

When trying to determine whether a physical change has occurred, there are several **indicators** of physical change to look for, such as:

- a change in shape
- expansion (increase in size) or contraction (decrease in size) – introduced in Chapter 6
- a change in state – covered in Chapter 6
- mixing or dissolving occurring – covered in Chapter 7
- a non-permanent colour change.

Examples of indicators of physical change

Changing shape

When an object changes shape, we say it has undergone a physical change. For example, when an elastic band is stretched, the physical properties of the elastic band change but not its chemical structure; nothing new has formed and the change is reversible. Think about a soft drink can being crushed. Have its physical properties changed? Has its chemical structure changed? Has anything new been made? So: is it a physical change?

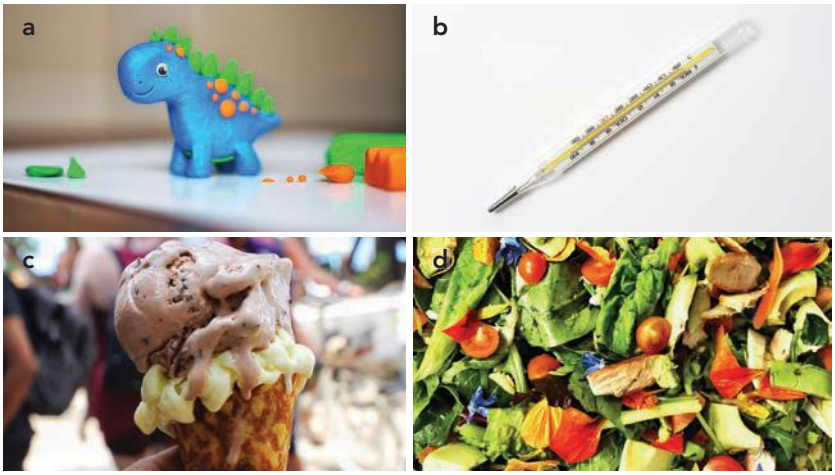


Figure 13.1 Different indicators that a physical change has occurred: change in shape **(a)**, expansion or contraction **(b)**, change in state **(c)**, change in mixture **(d)**

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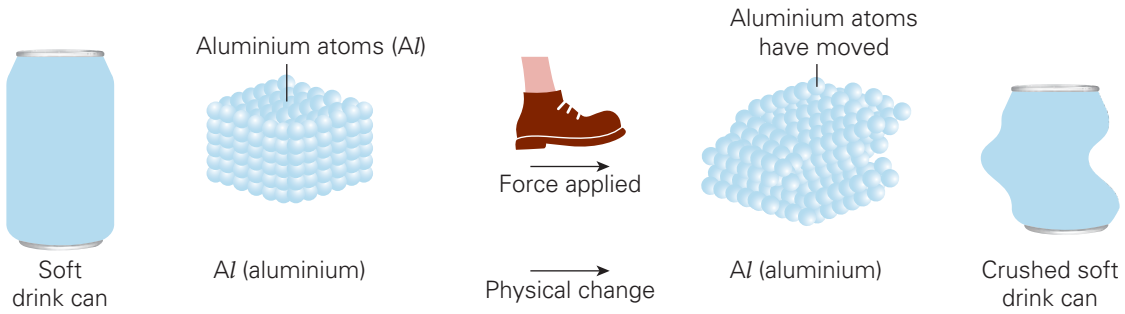


Figure 13.2 When an aluminium can is crushed, the shape of the can has changed, but nothing new is formed. Therefore, it is a physical change.

Breaking glass is another example of physical change. Can you explain why?



Figure 13.3 An example of a physical change is when glass breaks: its physical characteristics change, but it is still glass.

Quick check 13.1

1. **Define** the term 'physical change'.
2. **Name** four pieces of evidence to look for when determining whether a physical change has occurred.
3. **Explain** how changing shape is an example of physical change.

Expansion and contraction

The particle model and different states of matter was introduced in Chapter 6. The particle model – which describes the behaviour of atoms in solids, liquids and gases – suggests that if you heat up a substance, the atoms in the substance will gain energy, move faster, and increase the distance between one another. This process of atoms moving away from one another is called expansion. Expansion is an example of physical change – the properties of the substance have changed (volume increases and density decreases), but no new substance has formed, and it is reversible. Hot air balloons and thermometers are two examples of where we can see evidence of a physical change occurring in this way.

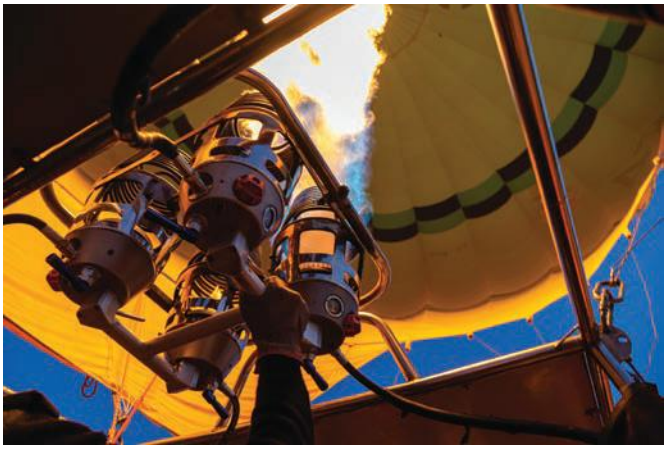


Figure 13.4 When the air inside a hot air balloon is heated, the atoms in the heated air gain energy, move faster, move away from each other and therefore take up more space. This is an example of a physical change occurring, and it results in the air being less dense on the inside of the balloon, so the balloon rises.

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The reverse of expansion is contraction, and this is also evidence of a physical change occurring. The substance cools down, the atoms lose energy, they slow down, and the distance between the atoms gets smaller (volume decreases and density increases).

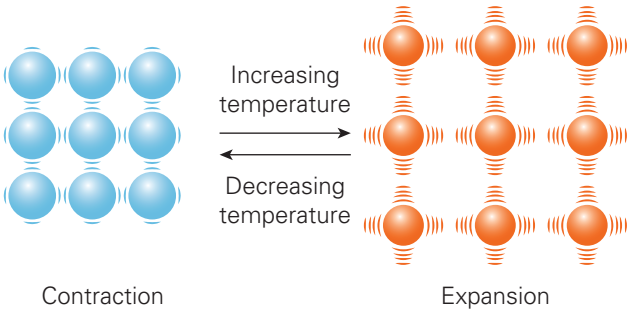


Figure 13.5 The physical changes experienced by atoms during expansion and contraction

VIDEO Making a model thermometer

Practical skills 13.1

Demonstrating expansion and contraction in a model thermometer

Aim

To demonstrate expansion and contraction by making a model thermometer.

Materials

- 250 mL beaker
- 250 mL conical flask
- glass thermometer
- glass tube (or plastic straw)
- ice-cream container
- red food colouring
- kettle or hotplate
- permanent marker
- rubber stopper
- water
- ice or chilled water

Procedure

1. Half-fill the conical flask with water.
2. Add a drop or two of food colouring.
3. Place the glass tube in the flask, but do not let it touch the bottom. Place the rubber stopper in the top of the flask with the tube in the middle. The stopper will hold the tube in place and prevent it from touching the bottom of the flask.
4. On the side of the flask, use a permanent marker to mark the height of the liquid inside the tube (your thermometer) at room temperature. Record the temperature of the room using the glass thermometer.
5. Place the flask into an ice-cream container with chilled or iced water and allow it to cool. Record the temperature inside the ice-cream container using your glass thermometer and mark the side of the flask to document where the liquid level is up to in your tube.
6. Now heat up some water using a kettle or hotplate and pour into the ice-cream container, being careful not to overfill the container. Let the flask sit there for several minutes. If the liquid level has not changed, you may need to pick up the flask, gently swirl and place back into the water. Record the new temperature using the glass thermometer and mark the side of the flask to document where the liquid level is up to in your tube.
7. Make a scale on your model thermometer, using the temperatures you have recorded and the marks you have made on the flask.
8. Now test your model thermometer by using it to predict the temperature of different environments, such as a sunny spot in the school, or by changing the ratio of hot and cold water in the ice-cream container. Check your predictions with the glass thermometer.

Results

Record your observations and tabulate your results: the temperature of each environment and the height of the fluid in the straw.

continued …

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Discussion

1. Compare your model thermometer results with the actual glass thermometer results. How close are they?
2. Explain your results. Why did the fluid move up/down the straw? Use your knowledge of particle theory to aid your explanation.
3. Imagine you repeated your experiment but with a narrower straw. How would you expect the measurements to be different for a narrower straw? Explain whether this new thermometer would be likely to be more or less accurate than your first thermometer.
4. Outline possible errors in this experiment and explain how each could have affected your results.
5. Suggest improvements for this experiment if you were to carry it out again.

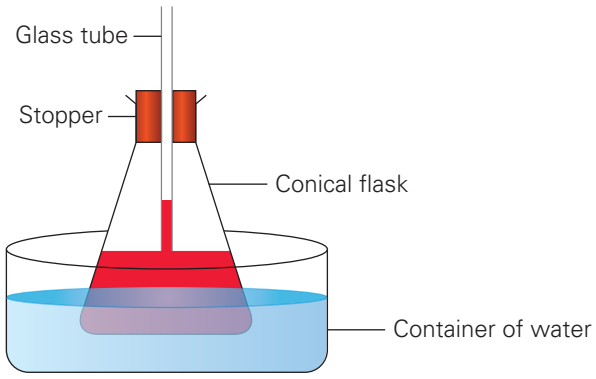


Figure 13.6 Experimental set-up

Explore! 13.1

INVESTIGATION

More indicators of physical changes

Are there other examples of physical change that you have not investigated, or have you covered them all? Find out what you can about the following five situations and provide evidence why each is or is not an example of physical change.

1. The heating of an iron bar until it turns red
2. The magnetising of a piece of iron (see *Try this 3.11 Making a compass*)
3. The glowing filament of a light globe
4. The behaviour of oobleck when it is stirred, poured or compressed (see *Try this 6.4 Making oobleck*)
5. Adding yellow paint to blue paint to make green

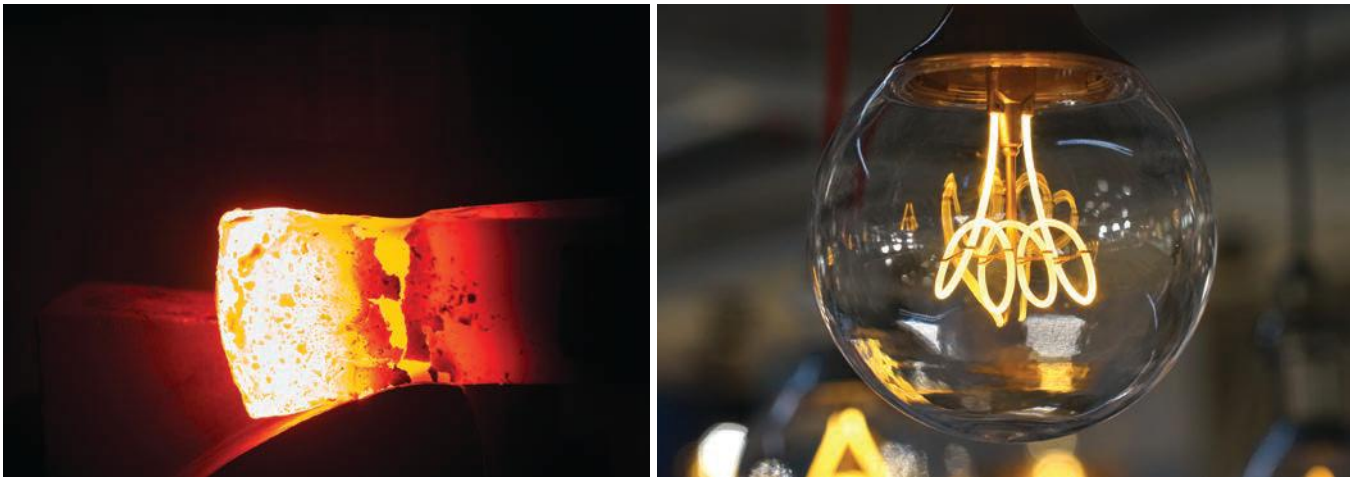


Figure 13.7 An iron bar glows red when heated, and a filament glows in a light globe. Are these examples of physical change?

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Changing state

Recall from Chapter 6 that solids, liquids and gases can change their state. You know that heating up a substance causes an increase in temperature. If enough heat is added, the substance can change its state. When a substance changes state, it is a physical change; it can be reversed, and the actual substance is still chemically the same – only the physical properties have altered. The different changes of state are summarised in Figure 13.8.

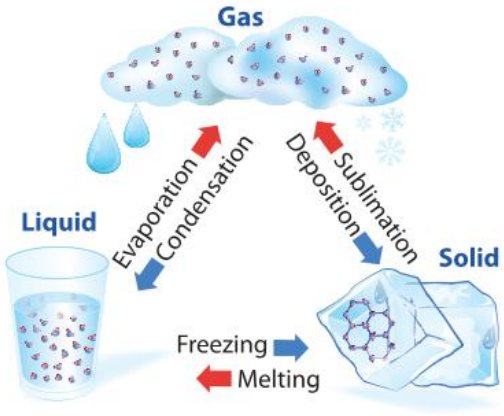


Figure 13.8 When some substances gain or lose heat, they undergo a physical change: no new substance is produced, and the substance changes its physical properties but is still the same substance. This illustration shows the changes in state of water. In each state the same water molecules are found. No new substance is formed.



Figure 13.9 A snowman melting is an example of physical change. Can you explain why?



Figure 13.10 Condensation is an example of a physical change, as no new substance has formed. It is reversible, and it is only the physical properties of the water that have altered, not its chemical make-up.

DEPTH STUDY IDEA
What physical changes occur in space?

Advances in science 13.1

Physical changes have happened on Mars too!

Mars has many surface features such as dried-out river valleys and gigantic outflow channels that could have been caused by glaciers. Scientists believe that in the distant past, Mars had a thick atmosphere and lots of surface water, including a huge ocean that may have covered 40% of its northern hemisphere.

Four billion years ago, the atmosphere of Mars started to thin, causing any liquid on the surface to quickly freeze and evaporate – a physical change.

continued …

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Data collected by the European Space Agency's *Mars Express* spacecraft suggested that there is a pool of liquid water buried under layers of ice and dust in dunes in the south of Mars. In 2021, China's first Mars rover, *Zhurong*, landed and sent back images and information on the chemical composition of the dunes, which provided evidence of liquid water on the surface as recently as 400 000 years ago. Scientists are very interested in possible water on Mars as water is necessary for life to exist. As Mars is the most hospitable planet beyond Earth, the prospect of Martian life continues to inspire both the imagination and scientific inquiry.



Figure 13.11 A photo of the *Tianwen-1* lander and the *Zhurong* rover taken on the Martian surface. The surface of Mars has been shaped by many physical changes that also occur on Earth.

Quick check 13.2

1. **Explain** how expansion and contraction are examples of physical change.
2. **Explain** how changing state is an example of physical change.

Mixing and dissolving

When you mix substances or dissolve one substance in another, a physical change occurs. Think about **dissolving** sugar (solute) in water (solvent) to form a solution. The way the molecules of sugar spread out within the water is called diffusion. Recall from Chapter 6 that diffusion is the movement of particles from an area of high concentration to an area of low concentration. When the sugar is all spread out in the water, you still have sugar, but the molecules have been separated and surrounded by water molecules. The characteristics of the sugar have changed from a crystalline, solid structure to one where all the sugar particles can move around freely in the water. No new substance has been formed, and the process can be reversed if you evaporate the water. Therefore, mixing and dissolving are considered evidence of physical change.

dissolving the process where individual particles of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

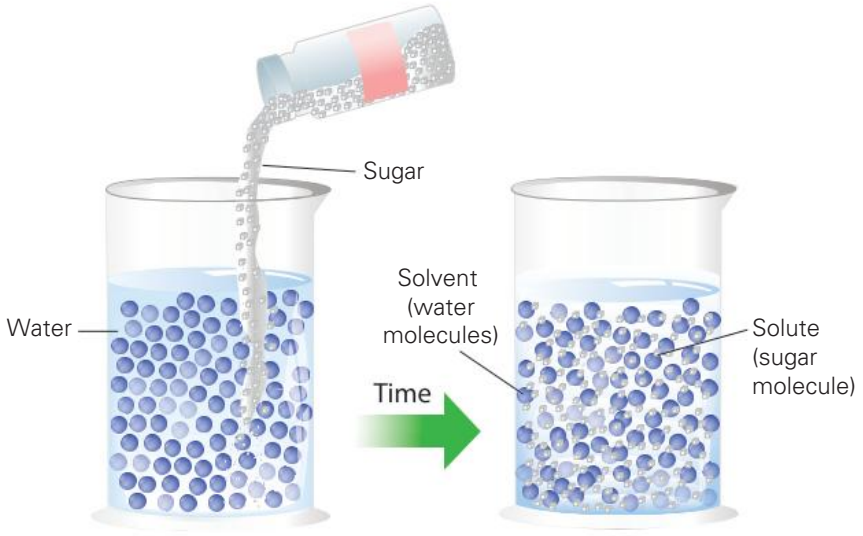


Figure 13.12 Molecules of water (represented by blue spheres) move randomly in a glass. Add sugar (white) and the new, dissolved molecules will eventually become distributed uniformly throughout the water. This is diffusion.

WORKSHEET Dissolving substances

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Try this 13.1

Skittles® and diffusion

Note: This activity uses lollies containing food colouring, which may present a risk if students have food allergies. No food items are to be consumed.

Collect the following materials: Petri dish, stopwatch, filter paper or white paper, five Skittles® of different colours, and a beaker of water.

Now place the Petri dish on the filter or white paper and place the five Skittles® equally spaced in the Petri dish. Slowly pour water into the Petri dish to fill it up and start timing. Record your observations. Explain your observations using the term 'diffusion'.



Figure 13.13 Skittles® can help demonstrate diffusion.

Repeat, but this time use warm water. Explain the differences you observe.

Quick check 13.3

1. **Explain** how mixing and dissolving are examples of physical change.
2. **Identify** which of the following are physical changes.
   - Slicing bread
   - Turning on a light
   - Breaking an egg
   - Mowing grass
   - Setting off fireworks
   - Breaking glass
   - Freezing water
   - Cutting hair
   - Making a fire
   - Drying clothes
   - Burning toast
   - Melting chocolate
   - Colouring hair
   - Yoghurt going 'off'
   - Popping popcorn
   - Squeezing an orange

Go online to access the interactive section review and more!

Section 13.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 13.1 questions

Remembering

1. **Identify** which of the following are examples of physical properties.
   - Blue colour
   - Odour
   - Density
   - Sweet taste
   - Flammable
   - Reacts with air
   - Reacts with water
   - Boiling point
   - Hardness
   - Dissolves in water
   - Lustre

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2 **Identify** which of the following are physical changes.
- Cutting an apple
- Milk going 'off'
- Digesting food
- Ice melting
- Cooking pikelets
- Wood rotting
- Reacting with vinegar
- Inflating a bike tyre
- Grass growing
- Silver tarnishing
- Mopping up water
- Milo® dissolving in milk

3. **Define** the following terms:
   a. reversible
   b. irreversible
   c. expansion
   d. contraction
   e. melting
   f. freezing
   g. evaporation
   h. condensation
   i. dissolving
   j. diffusion

Understanding

4. **State** whether the following statements are true or false. **Rewrite** the false statements so that they are true.
   a. During a physical change, the chemical make-up of a substance changes.
   b. Melting is a physical change.
   c. As particles warm up, expansion can occur, and this is a physical change.
   d. Physical changes are never reversible.
   e. When heat is lost from a substance, the particles can move closer together, and a gas can change to a liquid.
   f. Cutting up a cake changes the shape and size of the cake – this is a physical change.
   g. Burning wood in a fire forms charcoal and ash – this is a physical change.
   h. When a solute dissolves in a solvent, nothing new is formed, so this is a physical change.
5. **Identify** five physical changes that happen in your home.

Applying

6. **Summarise** the physical changes in the following scenarios, using your knowledge of particle theory.
   a Why the tyres on your family car seem more deflated on a cold day
   b How a liquid in glass thermometer works
   c Why on extremely hot days there are concerns about train tracks not working well
7. **Explain** the process whereby a strong-smelling deodorant is sprayed in one corner of the room but eventually everyone in the whole room can smell it.

Analysing

8. **Propose** how you could reverse the following physical changes.
   a. Salt dissolving in water
   b. Inflating a balloon
   c. Ice melting
   d. Glass breaking

Evaluating

9. **Justify** why each of the following is an example of a physical change.
   a. Blow-drying your dog's coat after giving him a bath
   b. Making cordial from a concentrate and water
   c. Inflating your air mattress
   d. Crushing cereal boxes before putting them out for recycling

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13.2 Indicators of chemical change

WORKSHEET Chemical versus physical change

Learning outcomes

At the end of this section, I will be able to:

1. carry out experiments to observe and identify the indicators of chemical change.
2. identify when a chemical change has occurred.
3. give examples of chemical changes.
4. compare physical and chemical changes.

What is chemical change?

chemical change where one or more substances undergo a chemical reaction and a new substance is formed; mostly irreversible

precipitate the solid that forms when two clear solutions are mixed and undergo a chemical change

products the substances that are present at the end of a chemical reaction

reactants the substances that are present at the beginning of a chemical reaction

During a **chemical change**, a new substance is formed. This new substance is chemically different from the starting substance as the particles have been rearranged at the molecular level. This is the key feature of chemical change. To help determine whether a new substance has been formed, and therefore a chemical change has occurred, there are indicators you can watch for. Occasionally there will be exceptions to this list, but most of the time, one or more of the following would be observed:

- a permanent colour change
- a gas being given off (as an odour, or smoke or bubbles)
- a new substance appearing, such as a solid (called a **precipitate**) forming in a solution
- a change in temperature (increase or decrease) over and above any heating or cooling being applied
- energy in the form of light or sound being produced (e.g. flames or an explosion).

Consider the fireworks that light up the night sky each year on New Year's Eve. The bright explosions of colour that we see actually come from metals, like magnesium and copper. They change chemically as they burn, producing fantastic colours. What signs are there that a chemical change has occurred? Referring to the previous list, we see colour, light and smoke, we hear cracking and fizzing, and we know the fireworks are dangerous to get close to, because of the heat they produce.

Chemical changes can be irreversible (e.g. burning paper), or reversible (you will learn more about this in Stage 6 chemistry). When referring to chemical reactions, 'irreversible' means that the **products** cannot be converted back to the substances that formed them (the **reactants**) within the same reaction. Undoing an irreversible chemical change often requires a different chemical reaction (or many different reactions) to take place.

Quick check 13.4

1. **Recall** the key feature of a chemical change.
2. **List** five indicators to look for to **determine** whether a chemical change has occurred.
3. **Identify** the indicator which suggests that a chemical change has occurred in each of these situations.
   a. Leaves turning red in the autumn
   b. Sherbet fizzing in your mouth
   c. Wood burning in a fireplace

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Examples of indicators of chemical change

VIDEO
Evidence of chemical reactions

WORKSHEET
Chemical reactions in bread

Imagine this: it is finally the school holidays and your family is going camping. One cool evening, you are all relaxing around the campfire to keep warm. The adults are cooking sausages on the grill over the flames and damper in the coals beneath. You toast marshmallows using sticks held over the edge of the fire, letting them get all brown, gooey and delicious. On this lovely evening, chemical changes are happening all around you!



Figure 13.14 Damper bread that has been cooked in the coals of a fire shows evidence of a chemical change occurring.

Colour change

Remember: a chemical change is any change that causes a new substance to be formed. For example, when your campfire has burned completely out, ashes are left behind – these are a new substance formed by the burning of wood. This is a chemical change. But what about permanent colour change? This is another indicator that a chemical change has occurred.



Figure 13.15 Tomatoes ripening and changing colour is evidence that a chemical change has occurred.

Your marshmallows, sausages and damper are all browning on the outside from being exposed to the heat of the campfire flames. This is due to a reaction between sugar and amino acids from protein. This is a permanent colour change, indicating that a chemical change has occurred, although there may also be a new substance (charcoal) forming on the outside if your food is burning! Generally speaking, the changes caused by cooking food are all chemical changes.

The ripening of fruit and vegetables is another example of a colour change indicating that a chemical change has occurred. For example, when a tomato reaches the green stage of its development, it starts to produce ethylene gas (also known as ethene). The ethylene then interacts with the tomato fruit to start the ripening process. As it ripens, it turns red. This is evidence of the chemical reactions taking place, which create the chemical change.

corrosion the gradual and natural process of metals breaking down; an example is rusting

word equation a chemical equation written using just the words for reactants and products, with an arrow indicating the direction of the reaction

Rusting, a type of **corrosion**, is a slow and usually unwanted chemical change that causes iron and steel to go flaky and brown. This is not desirable in things like buildings, bridges and train tracks, which are made of iron and steel, because it makes the structures unstable. Rusting occurs when iron reacts with water and with the oxygen in the air to form iron oxide (rust). This is a new substance forming and so, clearly, rusting is a process producing a chemical change.

Given the widespread use of iron and steel, we need ways to prevent rusting. The **word equation** for the process of rusting is:

iron + oxygen + water → iron hydroxide → hydrated iron oxide (rust)

The iron hydroxide molecules formed in an intermediate step rearrange to form hydrated iron oxide (rust). This is made of iron oxide molecules with water molecules attached. You will learn more about writing word equations in the next section.

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This equation means that all three substances on the left of the arrow, the reactants, are required to produce the substance on the right of the arrow, the product. If iron and steel are not exposed to water and oxygen, then iron oxide cannot be made, and rusting is prevented. You may have noticed that, in hardware stores, there are two options for stopping water and oxygen coming into contact with the iron and steel:

- a surface protector can be painted onto the iron or steel surface. This is like the paint we put on cars to prevent the metal panels being exposed to the elements
- **galvanisation**, in which the iron or steel is coated in a layer of zinc. If a corrugated iron roof has been galvanised, the zinc coating will corrode before the iron, and so the iron is protected from rusting.

galvanisation the process of coating iron or steel in zinc to prevent corrosion



Figure 13.16 Screws exposed to water and oxygen will start to corrode or rust, providing evidence of chemical change.



Figure 13.17 A galvanised corrugated iron roof: the zinc coating will corrode before the iron underneath, preventing rusting of the iron.

Investigation 13.1

Investigating chemical change: To rust or not to rust

INVESTIGATION

Aim

To determine the conditions required for, and to observe, the chemical change of rusting.

Materials

- iron nails (not galvanised)
- sandpaper
- large glass test tubes with stoppers
- vegetable oil
- water

Planning

1. Conduct some background research on the process of rusting. Summarise the process and the factors that affect it.
2. Consider what you learned earlier in the chapter and in your background research about the conditions that are required for the chemical change of rusting.
3. Design an experiment that will demonstrate that the conditions you believe to be required for rusting are indeed essential, using iron nails, oil (to prevent air getting access to water or iron nails), stoppers and test tubes. Think about your independent, dependent and controlled variables as you plan. You will need to leave your experiment overnight, or for a few days.
4. Write a specific and relevant research question for your investigation.
5. Identify the independent, dependent and controlled variables.
6. Write a hypothesis for your investigation.
7. Write a risk assessment for your investigation.
8. Draw a diagram of your method, showing what will be added to each test tube.
9. Check your design with your teacher before starting your experiment.

continued …

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Results

1. Draw a results table for your experiment.
2. Produce a suitable graph for your experiment.
3. Describe the changes you see in the nails.

Discussion

1. List any indicators of chemical change (evidence that a chemical change has taken place).
2. Describe any patterns, trends or relationships in your results.
3. Define the terms 'chemical change' and 'rusting'. List any chemical changes you see in this experiment.
4. Write a word equation for the reaction that occurs when rust is produced.
5. Identify any limitations in your investigation.
6. Propose another independent variable that could have been tested, to expand on your results.
7. Suggest some improvements for this experiment.
8. Extension: How can you make the steel nail rust faster? You may like to use salt water, vinegar and soft drinks in your experiment.

Conclusion

1. Draw a conclusion from this experiment regarding the conditions required for rusting, using data to support your statement.
2. Draw a conclusion from this experiment regarding whether a chemical change has taken place, and state the evidence.

Try this 13.2

Steganography

Steganography is the practice of sending hidden messages. For this activity you will need some lemon juice in a small container, white paper, a plastic tray, some cotton buds and access to an iron or a hairdryer. Begin by placing a piece of white paper on your tray. Dip a cotton bud into the lemon juice and write a message on the paper. When your message is dry, your teacher will reveal your message using a heat source (iron or hairdryer). Explain why this is an example of a chemical change.



VIDEO
Airbags

Gas is formed

Continuing with examples of indicators of chemical change, to produce a soft, fluffy loaf of bread or a delicious piece of cake, you need a chemical change to occur. One of the key indicators in this case is a gas being produced. This gas could be in the form of an odour, bubbles or even smoke.

A simple form of bread can be made using a substance known as bicarbonate of soda (or sodium bicarbonate), which is added to the main ingredients – flour, salt, oil and water. The ingredients are mixed into a dough before baking. When heated, the bicarbonate of soda breaks down and produces carbon dioxide gas. As the carbon dioxide is released into the dough, it expands with the heat (remember that this is a physical change covered in Chapter 12). Large bubbles of gas form in the dough, and this is what makes the bread grow and gives its spongy texture.



Figure 13.18 Hot bread is a delicious consequence of chemical change.

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Bread can also be made using microorganisms called yeast. The yeast uses the starch and sugars in the flour to produce alcohol and carbon dioxide. The alcohol escapes during cooking, but the carbon dioxide expands inside the dough, creating bubbles of gas and making the bread rise.

decomposition a reaction in which one substance breaks up into smaller ones

Rotting things often produce gas, and again, this is a sign that a chemical change is occurring. For example, vegetable scraps in the compost bin are broken down by microorganisms in a process called **decomposition**, and this produces carbon dioxide gas, which does not smell, and some other gases and substances that do cause the terrible smell.

Try this 13.3

Ready, set, bake!

Jump online and find a simple bread recipe. Give it a go at home. Write a word equation for the reaction – that is, write the ingredients that go into the bread, and then an arrow to represent the change, and then write the substances that are formed to the right of the arrow. What evidence is there that a chemical change has occurred? Also list any physical changes you notice.

Precipitate is formed

Another indicator that a chemical change has occurred is the formation of a precipitate. A precipitate is the name given to a solid that forms when two clear solutions are mixed. The precipitate is unable to dissolve in water and so, when it forms, it makes the solution look cloudy before it settles on the bottom.



Figure 13.19 A blue precipitate is forming at the surface then settling to the bottom of the test tube as the two clear solutions react.

Quick check 13.5

1. **Name** three examples where a colour change indicates that a chemical change has occurred.
2. **Recall** the process of rusting written as a word equation.
3. **List** two examples where a gas being formed provides evidence of chemical change. In each case, explain the chemical reaction.
4. **Define** the term 'precipitate'.
5. When magnesium ribbon is added to hydrochloric acid, bubbles of hydrogen gas are visible and magnesium chloride is produced. **Write** the word equation that represents this reaction.

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Energy change in chemical reactions: Change in temperature

DEPTH STUDY IDEA
What are the chemical processes involved in cooking an egg?

During a chemical change, new products are formed, but did you know that heat energy may be given off or absorbed during a chemical change? This is another sign that a chemical change has occurred. For example, the burning of natural gas in the kitchen when you are cooking is a chemical change that gives off a great deal of heat. Heat is used in cooking to cause the many chemical changes that result in a delicious meal. Remember how all matter consists of atoms joined together to form different substances? Heat provides energy and can therefore help atoms break free of one another and form different substances. For example, when you cook an egg, the heat makes the atoms in the egg white recombine in a different way, and this appears to us as cooked egg!

Exothermic reactions

exothermic reaction
a chemical reaction that releases heat, causing an increase in the surrounding temperature

endothermic reaction
a chemical reaction that absorbs heat, causing a decrease in the surrounding temperature

Any time you burn something, thermal energy is produced, and the increase in temperature indicates that a chemical change has occurred. Reactions that release energy are described as **exothermic reactions.**

In science, it can be useful to understand where words come from, so let us split up the word *exothermic*. The *exo* part of exothermic means external. The *thermic* part of exothermic means heat. If you put these two parts together, then exothermic just means external heat (heat leaving the reaction). You can tell if a reaction is exothermic because you will measure an increase in temperature. Heat has left the reaction and gone into the immediate surroundings; it is the temperature of the surroundings that you measure in an experiment.

Endothermic reactions

The opposite can also happen: heat energy can be absorbed, and the temperature of the surroundings decreases. Chemical ice packs are probably the most common example of this. If you injure yourself, you may be offered an ice pack. You pop a bubble inside the pack and the pack starts to absorb heat from the surrounding environment (your body), making the pack feel cold. Reactions that take in energy from the surroundings are described as **endothermic reactions**.

In this word, *endo* means internal and *thermic* means heat. You can tell if a reaction is endothermic because you will measure a decrease in temperature: heat has left the immediate surroundings and has gone into the reaction. As for exothermic reactions, in an experiment, you measure the temperature change of the surroundings.



Figure 13.20 When natural gas burns, a lot of heat energy is released, and we use this heat to cook our food.

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VIDEO Endothermic and exothermic reactions

Practical skills 13.2: Teacher demonstration

Endothermic and exothermic reactions

Be careful
Ensure that appropriate gloves are worn during this experiment.

Aim
To determine whether a reaction is endothermic or exothermic.

Materials
Experiment 1
- 1.4 g of potassium iodide
- 35% hydrogen peroxide
- food colouring
- dishwashing detergent
- 100 mL measuring cylinder
- plastic tray
- spatula

Experiment 2
- 10 g of ammonium chloride
- 32 g of barium hydroxide
- thermometer
- heatpoof mat
- glass stirring rod
- 250 mL beaker

Procedure
Copy the results table to record your results.

Experiment 1
1. Place the 100 mL measuring cylinder in the middle of the plastic tray.
2. Add a squirt of dishwashing detergent and three drops of food colouring to the measuring cylinder.
3. Pour about 65 mL of 35% hydrogen peroxide into the measuring cylinder.
4. Add the potassium iodide to the mixture, stand back and watch.
5. Record your observations in the results table.

Experiment 2
1. Place the 250 mL beaker on a heatproof mat.
2. Mix the ammonium chloride and barium hydroxide together in the beaker, stirring with a stirring rod, and observe the change in temperature.
3. Touch the side of the beaker and feel the change in temperature.
4. Record your observations in the results table.

Results

Experiment	Observations	Exothermic or endothermic
1		
2		

Discussion
1. How did you know that a chemical reaction had taken place in both experiments?
2. Determine why the reaction mixture shot out of the measuring cylinder in Experiment 1.

Conclusion
Draw a conclusion from this experiment regarding whether each reaction is endothermic or exothermic.

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Quick check 13.6

1. **List** some examples of where a change in temperature provides evidence of chemical change.
2. **Explain** the difference between an exothermic reaction and an endothermic reaction.

Light or sound produced

Another indicator that a chemical change has occurred is light or sound. Remember the fireworks discussed earlier? During that chemical change, both sound and light are produced. Can you think of other examples where light or sound (or both) are evidence that a chemical change has occurred?

Did you know? 13.1

Fireflies glow because of chemical reactions!

A chemical reaction occurs in fireflies' abdomens, allowing them to produce light. This process is called **bioluminescence** and is shared by many other organisms, mostly sea-dwelling or marine organisms. (Note that bioluminescence is a type of **chemiluminescence**.)

bioluminescence a chemical reaction that produces light in living things

chemiluminescence a chemical reaction that produces light

When oxygen combines with calcium, adenosine triphosphate (ATP) and the chemical luciferin, and a bioluminescent enzyme is also present, light is produced. When oxygen is available, the firefly's light organ glows, and when it is not available, the light goes out. The firefly is able to control the beginning and end of the chemical reaction and so start and stop the production of light. Unlike a light globe, which gets hot when it produces light, a firefly's light is cold, and so very little energy is lost as heat. This is very lucky for the firefly, because it would not survive getting as hot as a light globe!

Fireflies light up for a number of reasons. The larvae produce short glows that act as a warning to predators that they taste bad. As adults, many fireflies have flash patterns unique to their species, and use them to discriminate between members of the opposite sex. In males, a higher rate and intensity of flashing has been shown to be most attractive to females in several firefly species.



Figure 13.21 The abdomen of a firefly produces light through a chemical reaction known as bioluminescence. Bioluminescent jellyfish, fungi and fish show similar reactions.

WIDGET Physical vs. chemical change

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INVESTIGATION

Explore! 13.2

Glow sticks

Have you ever played minigolf in the dark with glow-in-the-dark balls? Have you ever celebrated New Year's Eve with glow sticks? It all comes down to chemical reactions.

1. Define the following key terms: fluorescence, chemiluminescence, bioluminescence.
2. Find out about the structure of glow sticks and explain what is involved in the chemical reaction that produces the light. Summarise your findings and include a picture/diagram.

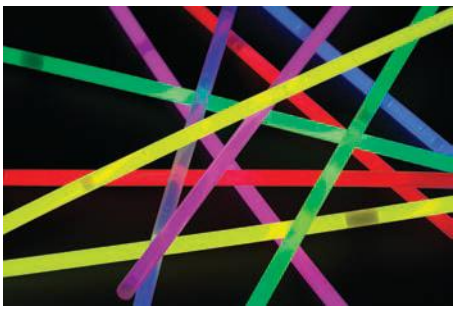


Figure 13.22 Glow sticks work because of chemiluminescence, a chemical reaction that produces light.

VIDEO
Chemical change

Quick check 13.7

1. **List** some examples of where light or sound being formed provides evidence of chemical change.

Practical skills 13.3

Chemical change

Be careful
Personal protective equipment is to be worn. All waste is to be collected and disposed of appropriately.

Aim

To conduct a series of activities/experiments in order to explore chemical change and be able to identify the indicators (evidence) of chemical change.

Materials

- Bunsen burner
- matches
- wooden skewer
- 1 mol L^{-1} strontium chloride solutionn
- 1 mol L^{-1} and 0.1 mol L^{-1} copper(II) sulfate solutions
- 0.1 mol L^{-1} sodium hydroxide solution
- test tubes and test-tube rack
- 2 cm strip of magnesium ribbon
- 2 mol L^{-1} hydrochloric acid
- thermometer
- 200 mL glass beaker
- lemon juice
- baking soda
- Pasteur pipette

Procedure

Copy the results table into your science journal.

Activity 1

1. Light the Bunsen burner.
2. Take a wooden skewer and break it in half.
3. Dip the broken-off end of the skewer into the strontium chloride solution.
4. Place the wet end of the skewer into the flame.
5. Record your observations for Activity 1 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.
6. Repeat the above steps with the 1 mol L^{-1} copper(II) sulfate solution.

continued …

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Activity 2

1. Place 10 mL of sodium hydroxide into a test tube in a rack.
2. Gently stand a thermometer in the same tube.
3. Add the 0.1 mol L^{-1} copper(II) sulfate solution, drop by drop – no more than 10 drops – into the sodium hydroxide.
4. Record your observations for Activity 2 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Activity 3

1. Place approximately 5 mL of dilute hydrochloric acid into a test tube in a rack.
2. Gently stand a thermometer in the same test tube.
3. Add a 2 cm strip of magnesium ribbon to the test tube.
4. Record your observations for Activity 3 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Activity 4

1. Put approximately 40 mL of lemon juice in a 200 mL glass beaker.
2. Gently stand a thermometer in the beaker.
3. Add one heaped teaspoon of baking soda to the lemon juice.
4. Record your observations for Activity 4 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Results

Complete the results table to show the evidence that a chemical change has occurred.

Activity	Observations of reactants	Change in colour	Change in temperature (°C)	Gas produced	Light produced	Precipitate produced	Observations of products
1							
2							
3							
4							

Discussion

1. Define 'chemical change'.
2. For each activity, list all the indicators that a chemical change has occurred.
3. Were there any indicators of chemical change that have been covered so far in this chapter but were not demonstrated during these activities? Write an activity that would allow you to demonstrate this indicator of chemical change. You may need to do some online research first.



Figure 13.23 Can you spot the physical and chemical changes in this photo from a camping trip?

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DOCUMENT Practical skills: Further experiments on chemical change

Further experiments to identify indicators of chemical change

The Interactive Textbook contains further experiments that students can do to observe chemical change and identify indicators. They involve household materials and include safety instructions and teacher guides. The experiments include:

- bicarbonate of soda and vinegar or lemon juice reaction
- milk curdling
- candle burning
- grape juice or cabbage water reaction with acids and bases.

Go online to access the interactive section review and more!

Section 13.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 13.2 questions

Remembering

1. Rewrite the following, **matching** each term from the left column with its correct definition from the right column.

Term	Definition
a. Physical property	a new substance has formed
b. Physical change	the way substances look and act, e.g. colour, melting point, hardness, boiling point, density
c. Chemical property	no new substance has been formed
d. Chemical change	the behaviour of a substance when it reacts with another substance

2. **State** some examples of physical properties.
3. **State** some examples of chemical properties.
4. **List** the five common signs that a chemical change has occurred.

Understanding

5. **Identify** three examples of chemical change occurring in your home.
6. **Explain** the process of rusting and why it is an example of chemical change.
7. A stoppered test tube of yellow liquid is left on the windowsill of a science lab over the weekend. When the students come back to class, they observe that there is condensation on the inside of the tube, the liquid has gone green, and the stopper has popped out. **Explain** whether these observations indicate physical or chemical changes, and how you know.

Applying

8. **Distinguish** between bioluminescence and chemiluminescence.

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9. **Classify** each of the following as physical or chemical change.
   - **a.** Vegetable scraps breaking down in the compost bin
   - **b.** Separating sand from gravel
   - **c.** Cutting fingernails
   - **d.** Drilling a screw into wood
   - **e.** Mulching tree branches
   - **f.** A stock cube dissolving in hot water
   - **g.** Fruit on the ground going mouldy
   - **h.** Crushing a can
   - **i.** Trees growing new leaves in spring
   - **j.** Breakfast cereal going soggy
   - **k.** Rain making the ground muddy
   - **l.** Dropping and breaking a plate
   - **m.** Baking a quiche
10. **Identify** the types of changes occurring in the following situations. (There may be more than one type.)
    - **a.** Pastry is defrosted and then used to make a pie.
    - **b.** To make honeycomb, sugar is mixed with water and honey. The mixture is heated, and then bicarbonate of soda is added.
    - **c.** A candle burns and wax drips down the side.

Analysing

11. For each of the following situations, **summarise** the signs of chemical change you would observe.
    - **a.** Birthday candles are burning.
    - **b.** Glow sticks work when you break them.
    - **c.** Sandwiches go mouldy.
    - **d.** Baking soda and vinegar are mixed together.
12. **Determine** the reasons why galvanised iron does not rust.

Evaluating

13. **Suggest** why rusting occurs faster on door hinges of boat sheds compared to door hinges a kilometre inland from the beach.



14. For each of the following situations, **identify** whether a physical change, a chemical change, or both, has occurred. **Justify** your answers.
    - **a.** Biting, chewing and swallowing noodles
    - **b.** Ice cubes melting in your iced chocolate drink
    - **c.** Petrol burning in a car
    - **d.** Bread dough being kneaded, then rising
    - **e.** A steel spoon being left out after being washed and little red spots forming on it

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13.3 What is happening in a chemical change?

Learning outcomes

At the end of this section, I will be able to:

1. describe the initial situation, what happens and what is produced during a chemical reaction.
2. construct word equations for chemical reactions.
3. investigate and observe energy changes in different chemical reactions.

Rearrangement of atoms

rearrange move things into a different order

bonds the forces that hold atoms together in molecules

The simplest way to describe a chemical reaction is to say that starting substances (reactants) are converted into new substances (products). During chemical reactions, the atoms in the reactants are **rearranged** to make new substances. For this to happen, **bonds** holding the atoms together in the reactants must be broken, and new bonds must form in different arrangements to make the products.



Figure 13.24 Rearranging atoms in a chemical reaction

Figure 13.24 shows a chemical reaction in which compound AB is reacting with element C to make a new compound, BC, and element A. In this reaction, the bond between A and B in the compound AB is broken and a new bond is formed between B and C to form compound BC – the atoms have been rearranged. The products are different from the reactants; therefore, a chemical reaction has taken place. The arrow in a chemical reaction separates the reactants that react together from the products (new substances) created by the reaction.

Let's look at a real-life example. Figure 13.25 shows the chemical reaction between carbon and oxygen. In this chemical reaction, the bonds between the two oxygen atoms are broken, the atoms are rearranged, and new bonds are formed between each oxygen atom and the carbon atom. The product formed has the name carbon dioxide.

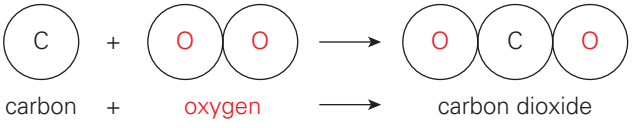


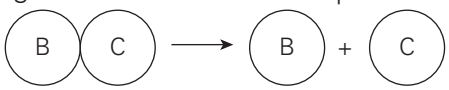
Figure 13.25 Formation of carbon dioxide is a chemical reaction.

The rearrangement of the atoms has a huge effect on the substances in this chemical reaction. Carbon is a solid at room temperature and oxygen is a gas. The compound formed in this reaction, carbon dioxide, is a gas at room temperature. The arrangement of the atoms within a compound determines the properties of a substance, which is why the properties of the compound formed in Figure 13.25 are so different from the properties of the reactants.

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Quick check 13.8

1. **Explain** how new substances are formed during a chemical reaction.
2. **Describe** what is happening to the substances in the equation below.



Advances in science 13.2

Chemical reactions caught on film

Scientists are now able to 'film' intermolecular chemical reactions. They are able to do this using the electron beam from a transmission electron microscope (TEM), like stop-motion or stop-frame filming. This technique can show chemical reactions as they are happening and can help us understand how molecules interact or react with one another at the atomic level, among other things. We may also be able to find out why one product, rather than another, forms.

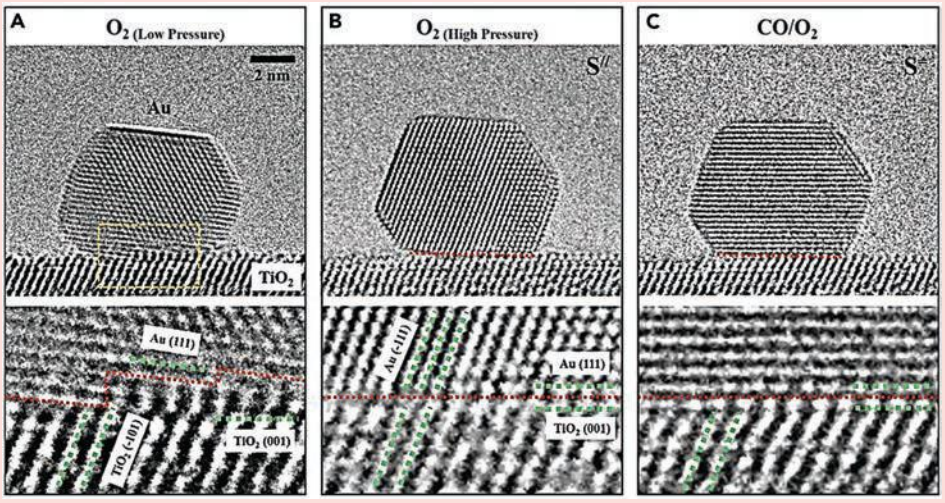


Figure 13.26 Transmission electron microscope images of a gold nanoparticle rotating as the gas surrounding it changes from oxygen **(A)** to high-pressure oxygen **(B)** to a mixture of carbon and oxygen **(C)**.

Advances in science 13.3

Living concrete that can repair itself

Concrete was first used in ancient times and is one of the world's most popular building materials. However, the problem with concrete is that over time it weakens, causing cracks to form. Water can enter these cracks, leading to the collapse of buildings or walls.

Henk Jonkers, of Delft University in the Netherlands, discovered a solution to this problem: concrete that contains bacteria and can repair itself. The bacteria selected for this process must be able to survive dormant for long periods of time without food or oxygen, and to withstand the alkaline conditions within the concrete.

Bacillus pseudofirmus and *sporosarcina pasteurii* bacteria were chosen for the job, but these bacteria do not naturally produce the limestone needed to repair the concrete. Jonkers first used sugar to help the bacteria create limestone, but this made the concrete too weak. The solution was to use calcium lactate.

continued …

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In 2009, Jonkers manufactured capsules made of biodegradable plastic containing calcium lactate and the bacteria. The capsules open when in contact with water; that is, when there is a crack in the concrete. The bacteria feed on the lactate, which causes a chemical reaction that converts the calcium lactate into limestone, and the crack closes. Jonkers had made concrete that repairs itself!



Figure 13.27 The aging and cracked concrete walls of Naples Island, California, are in danger of collapse, which could flood the homes located along the canals.

How is a chemical equation written?

Reactants and products

In a chemical reaction, substances react with each other to form new substances. Recall from earlier in the chapter that the starting substances are called reactants because they are the substances doing the reacting. Reactants are always written on the left-hand side of a chemical equation (written before the arrow). The new substances that are formed are called products as they are the substances produced by the chemical reaction. Products are always written on the right-hand side of an equation (written after the arrow).



WORKSHEET
Writing word equations for chemical reactions

Word equations

One way to represent a chemical reaction is with a word equation. Word equations are written with just the names of the reactants and products in the chemical equation. Below is the word equation for the reaction of two common chemicals. You should already be able to identify the reactants and products yourself.

$$\underbrace{\text{sodium hydroxide + hydrochloric acid}}_{\text{reactants}} \rightarrow \underbrace{\text{sodium chloride + water}}_{\text{products}}$$

Figure 13.28 Chemical reaction between sodium hydroxide and hydrochloric acid

Notice that the reactants are on the left-hand side of the arrow and the products are on the right-hand side. If you are running out of room, it might be tempting to write the same chemical reaction like the example below:

sodium hydroxide + hydrochloric acid →
sodium chloride + water

However, when possible, you should write the reactants on the left and the products on the right of the arrow.

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If you are running out of room, set your word equation out like the one below, with the first word above the second word.

sodium hydroxide + hydrochloric acid → sodium chloride + water

Quick check 13.9

1. **Identify** on which side of a chemical equation the products are written.
2. **Identify** on which side of a chemical equation the reactants are written.

Explore! 13.3

INVESTIGATION

The Haber process

The German scientist Fritz Haber and his assistant Robert Le Rossignol developed the Haber process, which was later industrialised by Carl Bosch. Haber was awarded a Nobel Prize for his efforts in 1918. The Haber process enabled the production of ammonia (NH_3) on a large scale by reacting nitrogen (N_2) gas with hydrogen (H_2) gas under optimum conditions. The largest ammonia plant in Australia is on the Burrup Peninsula in Western Australia: it produces around 330 000 tonnes each year. Ammonia is important in agriculture as it is used to make fertiliser. Use the internet to research and answer the following questions.

1. Write a word equation for the production of ammonia in the Haber process.
2. The Haber process is a reversible reaction. How is this represented in the word equation?
3. Why is the large-scale production of ammonia so beneficial?

Reaction conditions

Not all chemical reactions happen spontaneously – that is, occur without us having to do anything to them. Some reactions require heat or light energy to get started, some require a high pressure, and some need a chemical called a catalyst to speed up the reaction. Some reactions start immediately but require a longer period of time to complete. These factors are called **reaction conditions**. When special reaction conditions are required, they are written above the arrow in a chemical equation. This shows that these conditions are required for the reaction but do not get involved. Think about the reaction conditions required when baking a cake – you certainly cannot do this without time and an oven!



Figure 13.29 Magnesium will not react with oxygen in the air unless heat (such as from a flame) is added to start the reaction.

A reaction you may have performed in the lab is the formation of magnesium oxide by combining magnesium with oxygen in the air. This reaction only occurs incredibly slowly (more slowly than we can watch take place) unless you provide enough heat to get it started (Figure 13.29). We usually do this by placing the magnesium in a Bunsen burner flame.

reaction conditions conditions required for a chemical reaction to proceed

The word equation for this reaction would look like this:

magnesium + oxygen → magnesium oxide

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Energy changes in chemical reactions

Chemical reactions always involve energy changes. As covered in Section 13.2, temperature change is the usual indicator of an energy change, but light and pressure can indicate energy changes too.

Energy is not always included in the word equation for a chemical reaction, but it should be when it is particularly prominent or forms part of the discussion of the reaction. As mentioned above, if an energy input is a reaction condition, it is usually written above the arrow. The same is done if the energy input has to be continued, not just to start the reaction but to keep it going. This will be seen when we come to photosynthesis in Section 13.4.

In the example of burning magnesium, energy was added to start the reaction but then significantly more light and heat energy was produced as the magnesium burned. Overall, it is a strongly exothermic reaction, and the word equation could include energy as a product, but ignore it as a reactant:

magnesium + oxygen → magnesium oxide + energy

Another example of this will be seen when we come to cellular respiration in Section 13.4.

Heat, light and pressure have been mentioned as the two forms of energy involved in chemical reactions. Another is electrical energy, as both a reactant and a product in chemical reactions. An example of a reversible chemical reaction with electrical energy input and output is a rechargeable battery. Charging it drives a chemical reaction which stores electrical energy, and connecting it to a load such as a light globe reverses the reaction to discharge the stored chemical energy.



Figure 13.30 Mobile phones contain a rechargeable battery that runs a reversible chemical reaction inside, with electrical energy input when charging and electrical energy output when discharging.

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Section 13.3 review

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Section 13.3 questions

Remembering

1. **State** what → means in a chemical reaction.
2. **Name** the reactants and products of the following reactions.
   a. sodium hydroxide + iron carbonate → iron hydroxide + sodium carbonate
   b. propane + oxygen → carbon dioxide + water
   c. hydrogen + oxygen → water
   d. calcium carbonate → calcium oxide + carbon dioxide
3. **Recall** the definitions of the following keywords by matching them to the correct definition.

Keyword	Definition
Reactants	The substances formed in a chemical reaction
Products	The type of environment that the reaction needs for it to happen, e.g. temperature or pressure
Reaction conditions	The substances that are reacting in a chemical reaction

4. When sodium reacts with water, sodium hydroxide is produced. Hydrogen gas is also made.
   a. **Name** the reactants in the reaction.
   b. **Name** the products in the reaction.
   c. **Write** a word equation to represent the reaction.

Understanding

5. **Describe** what happens to the atoms in reactants during a chemical reaction.

Applying

6. Nitrogen and oxygen gas exist in our atmosphere, but they do not react together. However, in the high temperatures and pressures of car engines they will react with each other to form water and release energy. **Identify** the reaction conditions needed to cause nitrogen and oxygen to react with each other.
7. **Construct** a paragraph to explain what is happening in this reaction. Include a word equation and use the following keywords: reactants, products, reaction condition.

Analysing

8. **Categorise** the following examples as physical or chemical changes.
   a. Sugar dissolving in a cup of tea
   b. Steel nails rusting
   c. Ice melting to form water
   d. Frying an egg
   e. Toasting bread

Evaluating

9. The following equation shows what happens during respiration in which glucose and oxygen (reactants) react together to make carbon dioxide and water (products). **Assess** whether the following word equation is suitable. If not, rewrite it so that it is.

carbon dioxide and water = glucose + oxygen

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13.4 Chemical reactions in living things

WORKSHEET
Respiration and photosynthesis

Learning outcomes

At the end of this section, I will be able to:

1. construct word equations for respiration and photosynthesis.
2. conduct practical investigations to model respiration and photosynthesis, and report findings.

Reactions of life

photosynthesis the process by which green plants, some protists and bacteria convert light energy into chemical energy in the form of sugars using carbon dioxide and water, and releasing oxygen

cellular respiration a process that occurs inside the mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

Life on Earth is dependent on two chemical reactions above all: **photosynthesis** and **cellular respiration**. These are extremely important chemical reactions for life. There are thousands of vital chemical reactions going on in livings things, such as in digestion (at the end of this section), but photosynthesis and respiration are the primary ones. That is because one is the principal source of energy for life, and the other is the way living things release stored energy.

Photosynthesis is carried out mainly by plants and algae; cellular respiration is carried out by all living organisms.

VIDEO
Cellular respiration

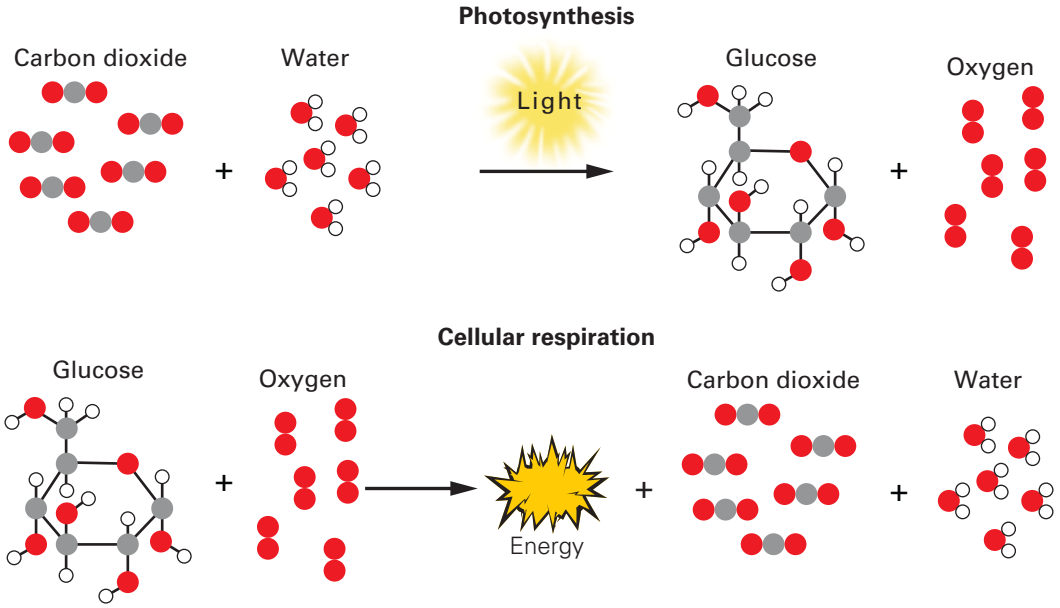


Figure 13.31 The process of photosynthesis and cellular respiration are examples of chemical reactions, illustrated here as rearrangements of the atoms in molcules. Note how the arrangement of the atoms is different in the reactants on the left and the products on the right. Photosynthesis is irreversible but can be undone by a different chemical process: cellular respiration, where the products of photosynthesis become the reactants of cellular respiration, and vice versa.

If we look at photosynthesis, we can identify the reactants as carbon dioxide and water and the products as glucose and oxygen. Can you identify the reactants and products of cellular respiration? We will now investigate photosynthesis and respiration reactions in more depth with a view to modelling them.

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Photosynthesis

Photosynthesis is the process by which plants, algae and some bacteria make their own food in the form of glucose. In plants it takes place in any part that is green and exposed to sunlight. As leaves are exposed to the most sunlight, this is where most photosynthesis takes place. Leaves are green because they contain a green chemical called chlorophyll in tiny structures called chloroplasts. Photosynthesis is a series of **biochemical reactions**, which can be summarised by the word equation below:

biochemical reaction
a chemical reaction that occurs within a living thing

$$\text{carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{glucose + oxygen}$$

For photosynthesis to occur, plants and algae need to take carbon dioxide and water into their chloroplasts. Carbon dioxide comes from the air and is absorbed into the leaf through tiny holes called stomata on the underside of the leaf (see Figure 13.32). Water in the soil is taken up into the plant by its roots.

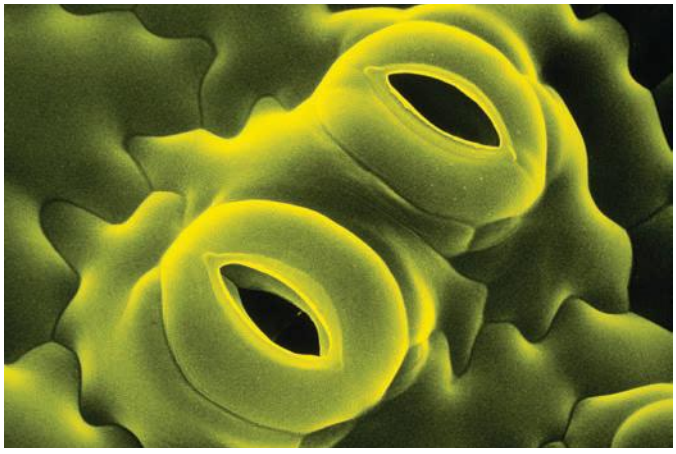


Figure 13.32 A scanning electron microscope image of leaf stomata (tiny holes found in the leaf). Carbon dioxide moves into the leaf through the stomata.

Once carbon dioxide and water are inside the plant, they will not react on their own. For this reaction to take place, energy from sunlight is required. Chlorophyll, the green chemical within the chloroplasts in leaves, is also required to convert the light energy into chemical energy. When carbon dioxide and water react in the presence of sunlight and chlorophyll, glucose and oxygen are formed.

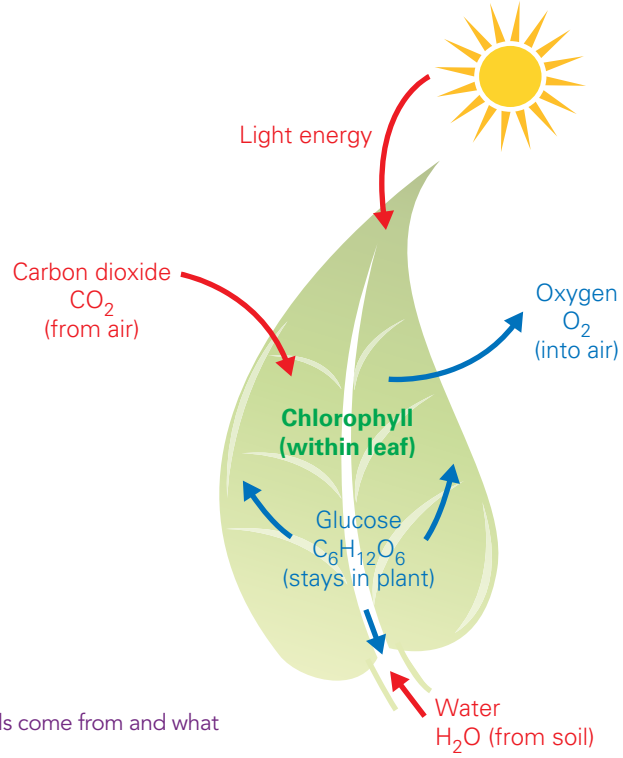


Figure 13.33 Photosynthesis: where the raw materials come from and what happens to the products

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Table 13.1 summarises the chemicals and energy involved in photosynthesis.

Reactants	Reaction conditions	Products
Carbon dioxide	Light energy	Glucose
Water	Chlorophyll	Oxygen

Table 13.1 Chemicals and energy involved in photosynthesis



Investigation 13.2

Investigating factors that affect the rate of photosynthesis

Aim

To investigate how light intensity affects the rate of photosynthesis.

Materials

- water plant (e.g. *Elodea*)
- 250 mL conical flask
- 100 mL measuring cylinder
- electric lamp
- scissors
- metre ruler
- stop clock

Planning

1. Write a summary of the background information about the factors that affect the rate of photosynthesis.
2. Write a specific and relevant research question for your investigation.
3. Identify the independent, dependent and controlled variables.
4. Write a hypothesis for your investigation.

Procedure

1. Copy the results table.
2. Set up the lamp. Using the metre ruler, measure five distances (up to 1 metre [m]) away from the base of the lamp. These are the distances you will investigate. Record these distances in your results table.
3. Measure 100 mL of water using the 100 mL measuring cylinder and add it to the conical flask.
4. Place the conical flask the correct distance from the lamp.
5. Cut a 10 cm length strip of the water plant and add it to the conical flask. At the same time, start the stop clock.
6. Count the number of bubbles that are produced in 1 minute. Record this in your results table.
7. Repeat the investigation using the same procedure, but now choosing a different distance away from the lamp.
8. If you have time, repeat each distance and calculate the mean number of bubbles. Alternatively, you could share your results with the rest of your class so you have more data when calculating the mean.

Results

Distance from the lamp (m)	Number of bubbles produced in 1 minute

continued …

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Data analysis

Plot a scatter plot (with a trend line or a line of best fit) of your results.

Discussion

1. Describe any patterns, trends or relationships in your results.
2. Explain any trends you have identified.
3. Identify any limitations in your investigation.
4. Propose how you could improve the investigation to make the results more:
   a. accurate
   b. reliable.
5. Design an experiment to investigate another factor that may affect the rate of photosynthesis.

Conclusion

1. Make a claim regarding light intensity and the rate of photosynthesis from this experiment.
2. Explaining how the data you gathered support your claim.
3. State whether your hypothesis was supported or not supported based on your findings.

Quick check 13.10

1. **Name** the two reactants required for photosynthesis.
2. **Name** the two products produced during photosynthesis.
3. **Explain** why sunlight is needed for photosynthesis.
4. **Write** a word equation for photosynthesis.

Respiration

Energy is needed by all living things in order to move, grow and perform cellular functions. Respiration is the process by which the cells of living organisms produce energy from glucose. Both plants and animals carry out a process called aerobic respiration, which means respiration requiring oxygen.



Figure 13.34 When you exercise, more energy is required, so you breathe faster.

The glucose plants use in respiration is formed during photosynthesis. In contrast, animals get their glucose from the food they eat. Alongside the useful product of respiration, energy, other less useful products (carbon dioxide and water) are also produced. These waste products then need to be removed from the cells.

Aerobic respiration is a series of biochemical reactions that can be summarised by the word equation below:

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

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Try this 13.4

Aerobic respiration

Limewater becomes cloudy in the presence of carbon dioxide. Get a test tube, a straw and some limewater. Blow into the limewater. What do you think will happen? How does this give us evidence for one product of aerobic respiration?

INVESTIGATION

Explore! 13.4

Aerobic and anaerobic respiration

Australian Lucy Bartholomew and Jamaican Usain Bolt are some of the most famous names in their sports. Usain Bolt ran the 100 m and 200 m, whereas Lucy Bartholomew runs long-distance races, including ultramarathons. The energy requirements for these races differ dramatically and therefore so do the rate and type of respiration.

1. During a race, how would the breathing rates of the two runners differ?
2. During a 100 m race, Usain Bolt only carried out a type of respiration known as anaerobic respiration. Research the differences between aerobic and anaerobic respiration to explain why ultramarathon runners and sprinters use different types of respiration.
3. In an ultramarathon, runners pick up glucose drinks and other food at various points during a race. Propose a reason for this.



Figure 13.35 Lucy Bartholomew races distances of over 100 kilometres on trails.



Figure 13.36 Usain Bolt crossing the finish line.

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Quick check 13.11

1. **Name** the two reactants required for aerobic respiration.
2. **Name** the three products produced during aerobic respiration.

Practical skills 13.4

Modelling photosynthesis and respiration

Aim

To model the reactions of photosynthesis and respiration.

Materials

- molecular model kits
- plasticine, toothpicks or pipe cleaners (or whatever is available to you)
- sheets of coloured paper

Planning

1. Write the word equation for photosynthesis.
2. Research the structures of the reactants and products of photosynthesis.
3. Determine how you will represent the atoms in your model. Develop a key.

Procedure

Model the reaction of photosynthesis.

Results

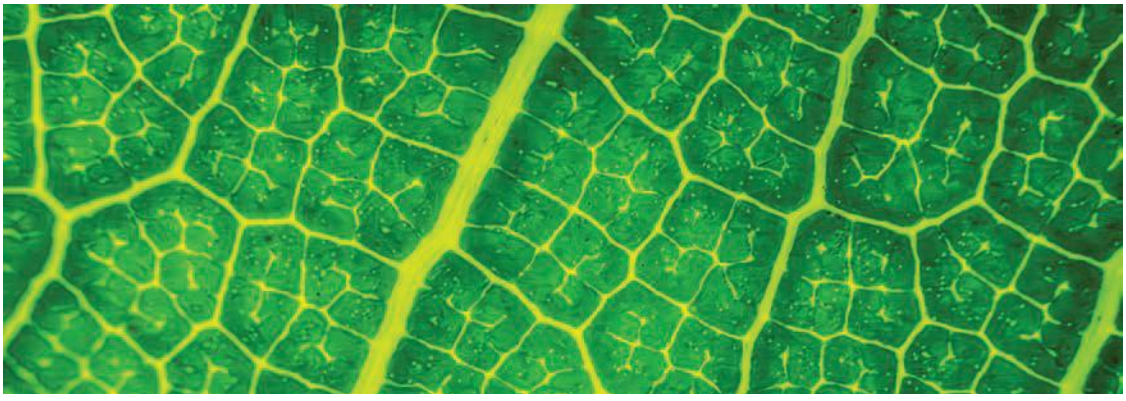
Document your model using photographs or diagrams.
Examine the models produced by other students.

Discussion

1. List the similarities between your model and others you saw.
2. List the differences between your model and others you saw.
3. Propose the features that make a good model.
4. Suggest an improvement to your model.
5. Explain why models such as the one you made are useful for understanding photosynthesis.
6. Suggest a different way of modelling photosynthesis.
7. Repeat steps **1**–**6** for the respiration reaction.

Conclusion

Write a report to include responses to the discussion points, including a conclusion about the overall accuracy and value of the models.



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Did you know? 13.2

Digestion is all about change!

Aside from photosynthesis and respiration, thousands of physical and chemical changes take place during the digestion of your food!

Part of the body	Type of change	Details
Mouth	Physical	Food is chewed by teeth to break it down into smaller pieces so that enzymes have a greater surface area to work on.
	Chemical	An enzyme in saliva (called amylase) starts to break down complex carbohydrates into simpler forms that your body can absorb.
Oesophagus	Physical	As the oesophagus moves food from the mouth to the stomach, the muscles contract, pushing the food along, in a process called peristalsis.
Stomach	Physical	The stomach muscles contract and churn the food to break it into smaller pieces so that enzymes have a greater surface area to work on.
	Chemical	Enzymes start to break down proteins. Hydrochloric acid provides the optimum conditions for this to occur.
Small intestine	Physical	As the small intestine moves food along towards the large intestine via muscle contractions, it mixes the food to help maximise the opportunities for physical and chemical breakdown. Bile emulsifies fats into smaller droplets so that enzymes have a greater surface area to work on.
	Chemical	Enzymes break down proteins and fats even further, so they can be absorbed into your bloodstream through the walls of the intestine.

Table 13.2 Some of the many physical and chemical changes that occur in the digestive system



Figure 13.37 The digestive system uses physical changes and chemical changes to break down your food for absorption.

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Section 13.4 review

Online quiz 

Section questions 

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Section 13.4 questions

Remembering

1. **Name** the molecules that are broken down in respiration.
2. **Name** the green pigment found in chloroplasts of plant cells that converts the Sun's light energy into chemical energy for photosynthesis.
3. **Name** the tiny holes that open to allow carbon dioxide to enter a plant during photosynthesis.
4. **Recall** the word equation for aerobic respiration.
5. **Identify** the missing words to complete the word equation for photosynthesis.
   carbon dioxide + _____ → glucose + _____

Understanding

6. **Explain** why condensation forms when you breathe out onto a cold window.
7. **Describe** ways in which a pot plant can increase its rate of photosynthesis.
8. **Compare** and contrast photosynthesis and respiration.
9. **Explain** why light energy is written above the arrow and chlorophyll is written below in the word equation for photosynthesis.
10. **Outline** the reason why leaves are often flattened and do not overlap.
11. **Explain** why plants compete with each other to be the tallest.

Applying

12. During anaerobic respiration in yeast, glucose is broken down into carbon dioxide and ethanol. **Construct** a word equation for this reaction.

Analysing

13. **Contrast** the ways that plants and animals get the raw materials required for aerobic respiration.
14. **Classify** respiration and photosynthesis as endothermic or exothermic reactions. **Explain** your decisions.
15. **List** some factors that can affect the rate of photosynthesis and **explain** why they affect the rate of the reaction.
16. **Make an inference** for why autumn leaves are orange or brown.

Evaluating

17. **Discuss** the reasons why plants can respire at any time of the day but only photosynthesise during daylight hours.
18. 'Photosynthesis and respiration are the reverse reactions of one another.' **Decide** whether you agree or disagree with the statement and **justify** your response.
19. Biochemistry is the branch of science that involves study of chemical processes within living organisms (plants, animals, microorganisms). For example, a biochemist might research the chemical processes of cell growth, disease and enzymes involved in digestion, as well as how to manage what might go wrong in these processes. **Propose** how research and discoveries in this area might affect people's lives.

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
13.1	carry out experiments to observe and identify the indicators of physical change.	3, 11
13.1	describe the indicators of a physical change.	2, 6, 13
13.1	give examples of physical changes.	3
13.2	carry out experiments to observe and identify the indicators of chemical change.	3, 11, 17
13.2	identify when a chemical change has occurred.	3, 7 ,8, 9, 14
13.2	give examples of chemical changes.	3
13.2	compare physical and chemical changes.	1
13.3	describe the initial situation, what happens and what is produced during a chemical reaction.	5, 15
13.3	construct word equations for chemical reactions.	5
13.3	investigate and observe energy changes in different chemical reactions.	12, 18
13.4	construct word equations for respiration and photosynthesis.	16
13.4	conduct practical investigations to model respiration and photosynthesis, and report findings.	10

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Define** the following key terms: physical property, chemical property, physical change, chemical change, reactant, product.
2. **Recall** the possible evidence that a physical change has occurred.

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3. **State** whether each of the following processes is a physical or chemical change.
   - **a.** Moth balls evaporating in a cupboard
   - **b.** Building a sandcastle
   - **c.** Hydrogen burning in chlorine gas
   - **d.** Fogging up a mirror by breathing on it
   - **e.** Breaking a bone
   - **f.** A broken bone mending
   - **g.** Slicing potatoes for making chips
   - **h.** Hand sanitiser evaporating
   - **i.** Mixing sugar with coffee
   - **j.** Making a paper aeroplane
   - **k.** Pan frying dumplings
   - **l.** Copper turning green when exposed to the air
   - **m.** Paper ripping
4. **Recall** the word equations for respiration and photosynthesis.

Understanding

5. When Tori reacts a lump of calcium carbonate with sulfuric acid, she notes that water, carbon dioxide and calcium sulfate form.
   - **a.** **State** the word equation representing the information given.
   - **b.** **Identify** the reactants and the products and give reasons for your answer.
6. **Explain** why baking biscuits is not an example of physical change.

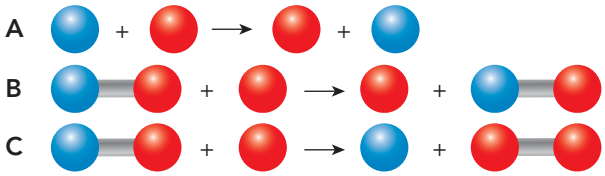


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7. **Explain** why bending metal in half is not an example of chemical change.



8. **Summarise** the observations you could make if a chemical change had occurred.
9. **Identify** which of the following are examples of chemical reactions.



10. **Explain** why the complete process of photosynthesis does not take place at night.

Applying

11. **Describe** an experiment to observe and identify a:
    a. physical change
    b. chemical change.
12. **Describe** the energy change when a:
    a. fuel such as natural gas burns in air
    b. substance is dissolved in water and the temperature of the water decreases.
13. **Compare** and **contrast** three indicators of chemical change with three indicators of physical change.

Analysing

14. **Explain** why a colour change occurring is not always a sign that a chemical change has occurred.
15. **Analyse** the following statement: 'Atoms that are not in the reactants can end up in the products of a chemical reaction.'
16. **Contrast**, using word equations, the processes of photosynthesis and respiration.

Evaluating

17. When you combine bicarbonate of soda and buttermilk, a gas is produced.
    a. **Propose** why the gas is considered evidence that a chemical reaction occurred.
    b. **Propose** whether it is possible to continue adding more and more of only one reactant and expect to get more and more product. **Justify** your response.
18. **Propose** how atomic structure relates to both an electric current and a chemical reaction.

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Data questions

A theoretical chemical reaction occurs such that reactant A reacts to form an intermediate product B, which reacts to form a product C. The chemical reactions occurring are:

$$A \rightarrow B \quad \text{reaction 1}$$

$$B \rightarrow C \quad \text{reaction 2}$$

The mass of each chemical A, B and C is plotted in Figure 13.38, with respect to time passed in the reaction.

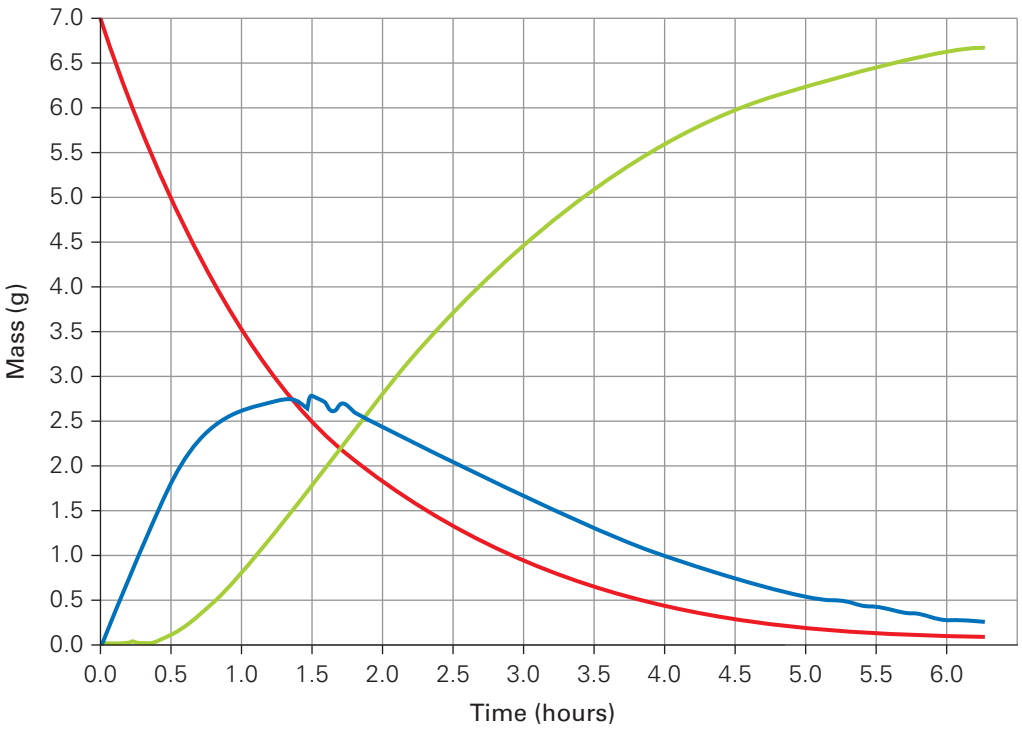


Figure 13.38 Change in mass of each reactant, intermediate and product over time in a chemical reaction

1. **Identify** the colour of the line which represents the reactant, A: the line with a mass greater than zero at the beginning of the reaction.
2. **Identify** which coloured line represents the intermediate product B, that is formed in a reaction of A, and then reacts to form the product, C.
3. **Identify** the time at which the mass of the intermediate product, B is greatest.
4. **Identify** the relationship between the mass of A and the mass of C.
5. **Contrast** the curves for B and C and account for the shape of the blue line.
6. **Infer** why the green line does not increase steadily until after 0.5 h.
7. **Justify** what the total mass of A + B + C will be at 3.0 h if the mass of A was 7 g at time zero.
8. **Predict** whether the mass of C will increase above 7 g.
9. The intermediate, B, has a blue colour when it is produced, and in this reaction this blue colour was only evident when B comprised the majority of the mass of the reaction mixture. **Deduce** which time period after the start of the reaction would the reaction mixture have appeared blue.

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STEM activity: Building a rocket

Background information

Rockets are exciting machines that are designed by engineers and used to explore space. It is amazing to think that someone has worked out how to get these heavy vehicles into space! Rockets depend on a combustion reaction to provide the thrust they need to overcome the force of gravity and shoot up into orbit. Combustion is a fast, exothermic reaction between a fuel and oxygen, in which the fuel burns and heat is produced. As you know, during a chemical reaction, new compounds are made – in this case, these compounds are the rocket's exhaust. The exhaust is pushed out from the bottom of the rocket at high pressure, and this pushes the rocket upward.

In a process known as the engineering design cycle, aerospace engineers design small-scale models to learn from and experiment with. By testing small-scale models, the engineers make sure the rockets will work, without wasting time and money on testing full-size rockets. They can test the thrust and stability and make modifications, in order to design the best rocket they can.

DESIGN BRIEF

Design, build, test and evaluate a rocket that will launch in exactly 10 seconds.

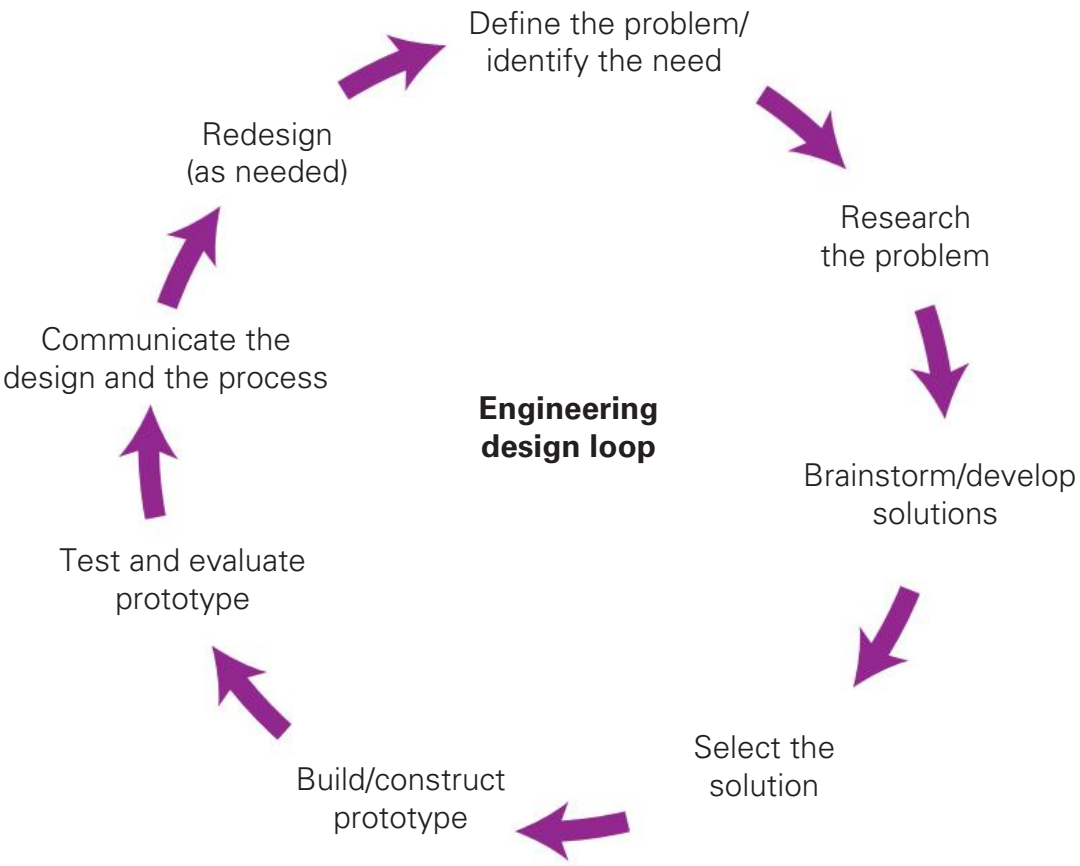


Figure 13.39 Designing and testing of a model comes before construction of the real thing.

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Activity instructions



Figure 13.40 Space launch

In teams, you will take on the role of aerospace engineers. The Super Fast Rocket Company has hired your team to design, build, test and evaluate a rocket that will launch in exactly 10 seconds. You will begin investigating the chemical change that occurs when half an antacid tablet (containing stored chemical energy) and water are put into a film canister. With the lid snapped on, the production of carbon dioxide gas inside the canister causes pressure to build up until the lid pops off, propelling the rocket into the air. To launch your rocket at exactly 10 seconds, your team will need to consider what factors affect the rate or speed of the chemical change that occurs. For example, you will need to investigate whether it is affected by the temperature of the water, the surface area of the tablet, the mass of the tablet, or other factors. Your team will continue to evaluate and refine your prototype until it launches at exactly 10 seconds.

Suggested materials

- 35 mm film canister with an internal snapping lid
- an antacid tablet, such as Alka-Seltzer®
- water
- scissors, sticky tape, textas, paper
- chopping board, mortar and pestle, knife, spoon
- safety glasses

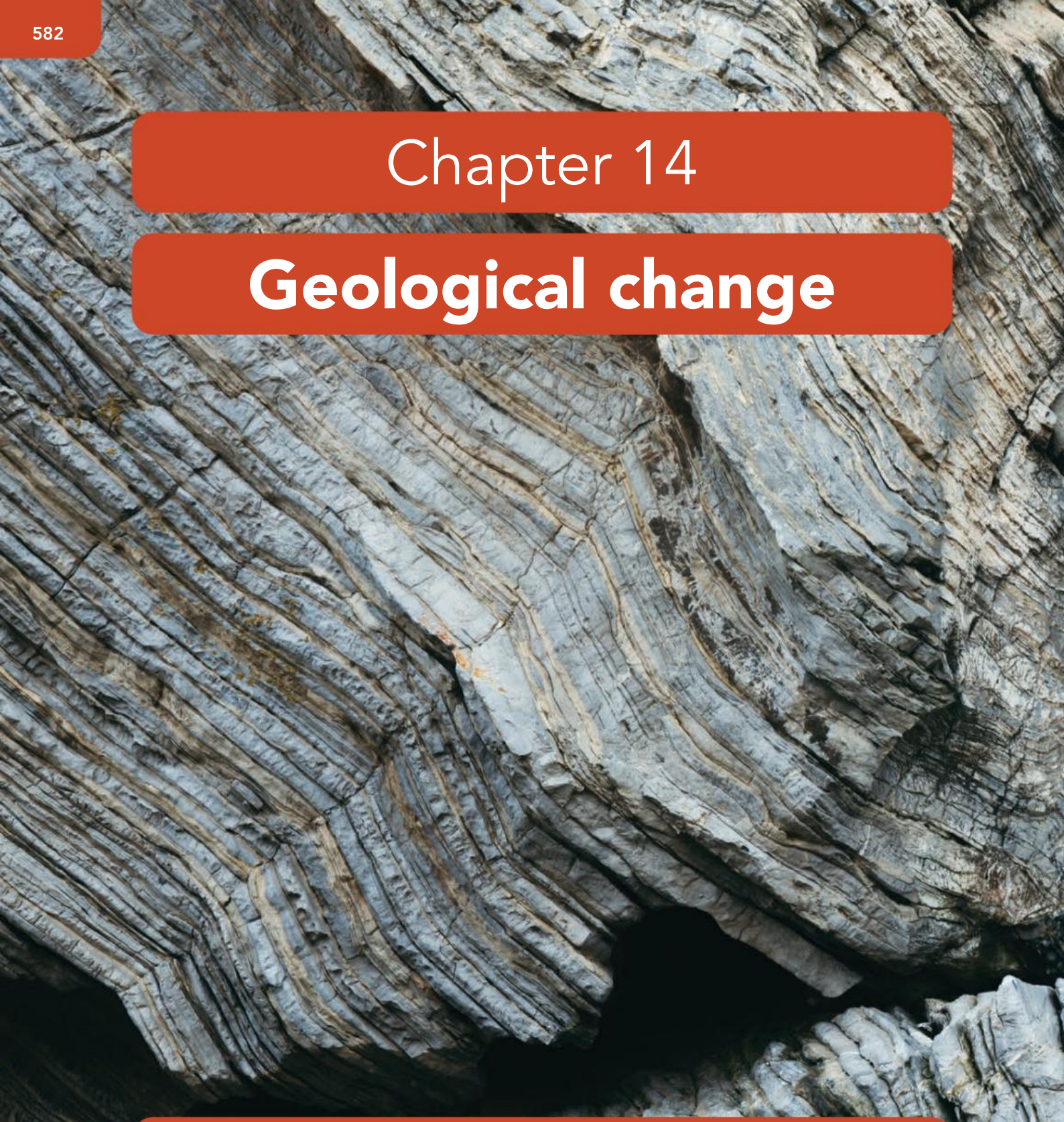
Evaluate and modify

1. Use Microsoft Excel or other graphing tools (such as Desmos) to graph your data. For example, create a scatter plot of mass (horizontal axis) versus time to launch (vertical axis), or temperature versus time to launch. Identify a line of best fit and determine the equation for the line of best fit.
2. Discuss the different conditions you investigated and what you found out about the effect of temperature, surface area and mass on the rocket launch times.
3. Draw a flow chart to show your original design for a 10-second launch and the modifications that followed, ending with your rocket launching at exactly 10 seconds. Highlight the change/improvement you made at each step along the way.
4. Consider both your rocket and the other rockets you observed being launched. Identify and describe the characteristics that make one rocket perform better than another.
5. Discuss what challenges you faced while designing and testing your rocket, and how you overcame these challenges.

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Chapter 14

Geological change

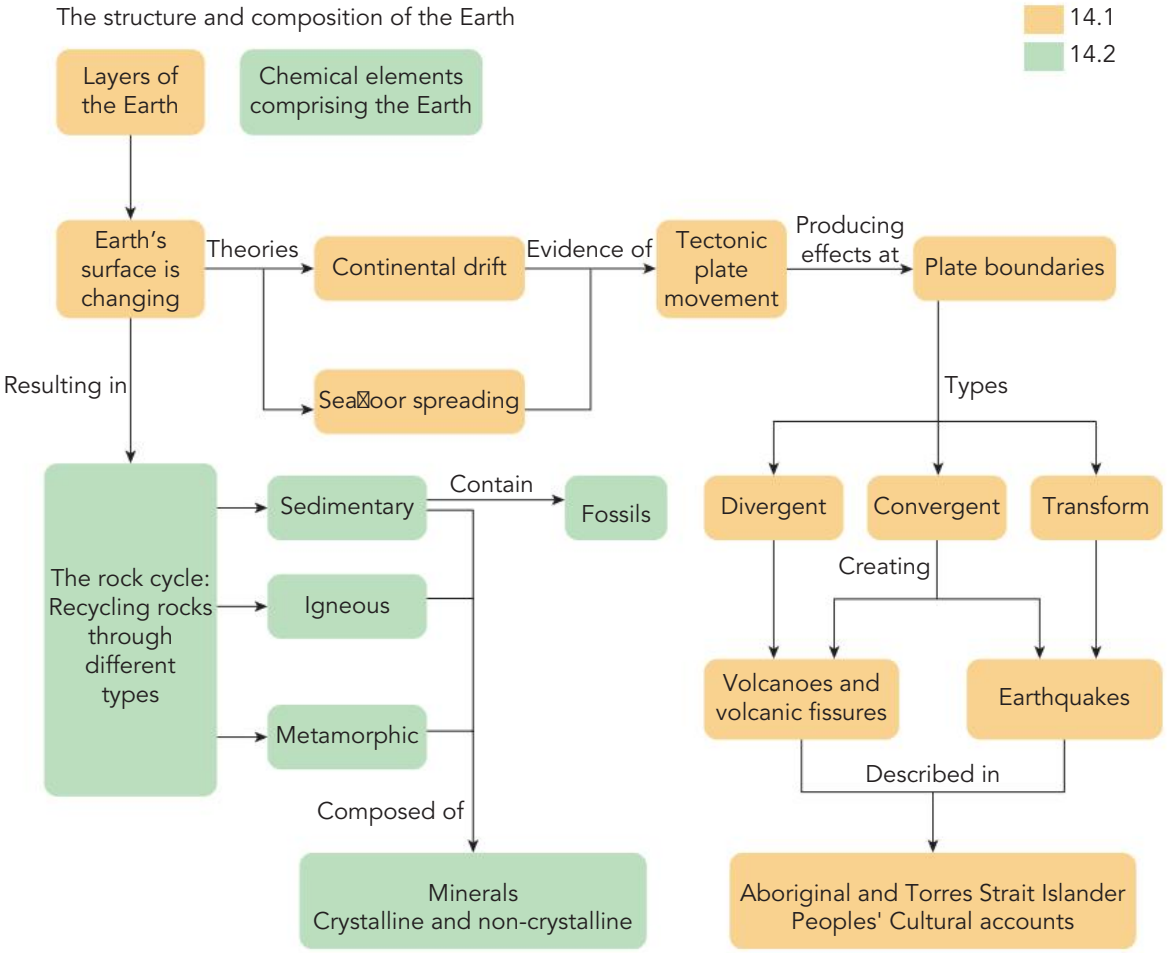


Chapter introduction

Our knowledge of how the world works continuously improves and deepens with the addition of new information from discoveries and experiments. It may seem to us that the continents and oceans haven't changed over the course of our lives, and that they will remain this way in the future. But scientists have collected evidence that Earth has been changing over millions of years. In Eastern Australia there have been both volcanoes and swamps. Rock types that form in these environments contain specific minerals which you will learn to identify. The study of our geological history leads us to know where to look to find resources such as gold, iron, aluminium, uranium or coal.

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Chapter map



Glossary terms

asthenosphere
biological weathering
cementation
chemical weathering
cleavage
compaction
conglomerate
continental drift
convection currents
crust
deposition
erosion
extrusive
foliated
fossil
geology
intrusive
lava
lithosphere
magma
mantle
meteorite
Mohs scale
Pangaea
physical weathering
plate boundaries
plate tectonics
ridge push
rock cycle
seafloor spreading
sediments
slab pull
streak test
subduction
tectonic plates

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14.1 Plate tectonics

VIDEO
Alfred Wegener

Learning outcomes

At the end of this section, I will be able to:

1. explain the evidence used in the development of the theory of continental drift and plate tectonics.
2. describe earthquakes and volcanoes as evidence of geological changes in the Earth's crust.
3. explain the relative significance of different forces involved in tectonic plate movement.
4. describe the forces and movement involved in three types of plate boundaries.
5. model interactions at plate boundaries.
6. describe examples of Aboriginal and Torres Strait Islander Cultural accounts that provide evidence of earthquakes and volcanoes.

WORKSHEET
The theory of continental drift

Evidence for geological change of the Earth's surface

Since the late sixteenth century, a few geographers speculated that continents may have once fitted together in a larger landmass and subsequently split up and drifted. In this section, you will learn about the contribution that various scientists have made to the understanding of the theory of continental drift.

continental drift
the theory of how the continents on Earth have moved over millions of years

Pangaea
the supercontinent which has since broken into pieces and drifted apart

Alfred Wegener – continental drift

In 1912 Alfred Wegener, a German geophysicist and meteorologist, proposed his theory of **continental drift**.

Wegener hypothesised that Earth's continents were once part of a giant landmass, which he called **Pangaea**.



Figure 14.1 Alfred Wegener

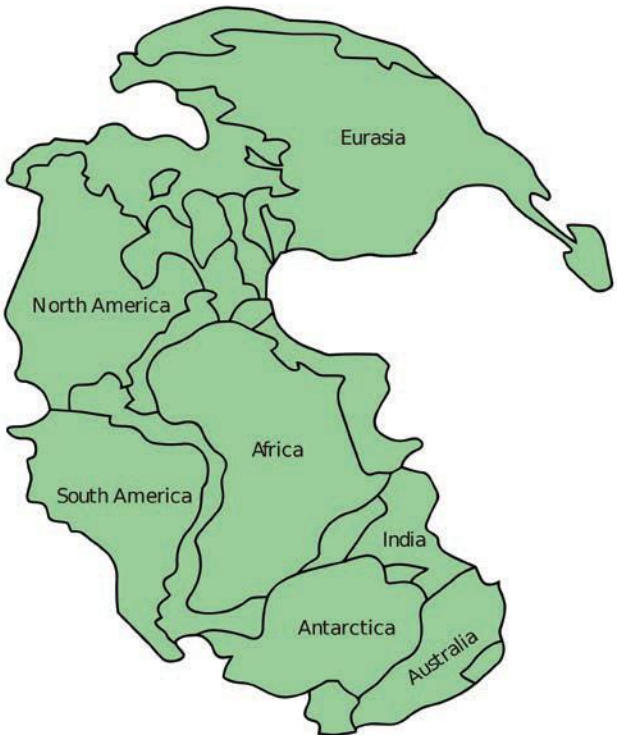


Figure 14.2 Wegener proposed that all the continents were once together in a giant landmass called Pangaea.

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Over time, this giant landmass broke up and drifted apart to form the continents that you know today. Figure 14.3 shows how the continents have moved over millions of years. Follow the movement of Australia to see how far we have moved in that time.

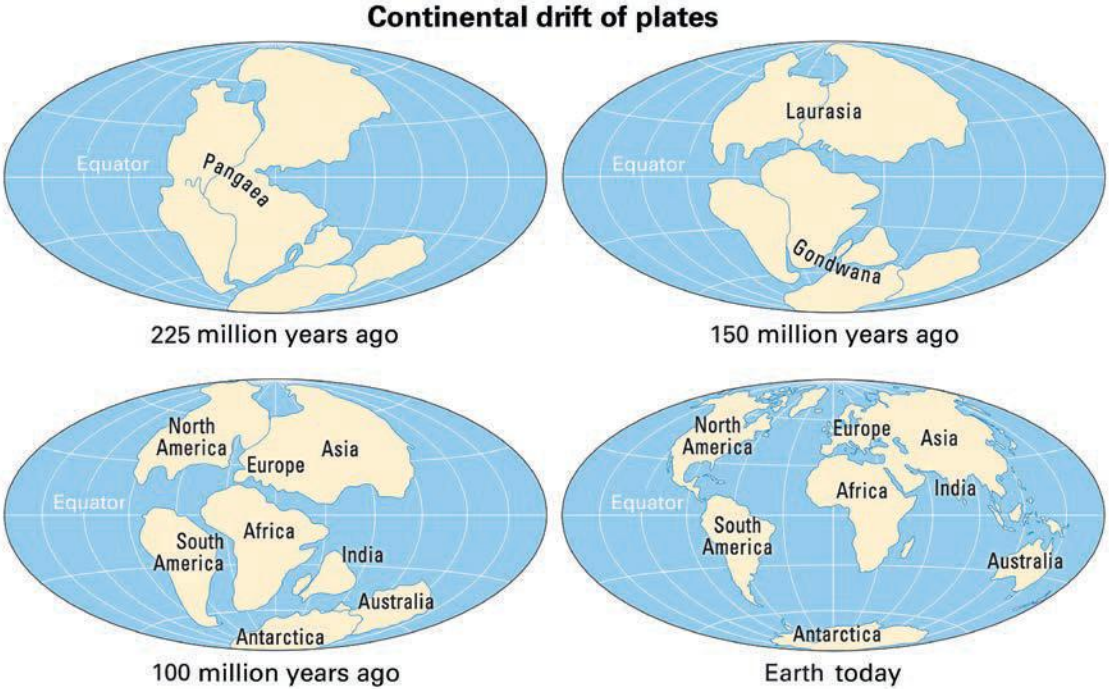


Figure 14.3 The movement of the continents from a single landmass (Pangaea) to their current locations

A scientific theory cannot arise without evidence. So how did Wegener justify his theory to the scientific community? Wegener put forward four different pieces of evidence to support his theory.

1. Continents shapes fit together

You can see from Figure 14.4 that, when put together, some of the existing continents look like they fit into each other – just like pieces of a broken jigsaw puzzle. You could argue that this is just a coincidence, so Wegener needed more evidence to back up his theory.



Figure 14.4 The outlines of Africa and South America fit together like pieces in a jigsaw puzzle.

2. Similar fossils were found on different continents

When observing the types of fossils on different continents, Wegener found examples of the same prehistoric land-based creatures on continents that are now separated by oceans. He stated that the land masses must have been together at some stage (as shown in Figure 14.4) because these animals could not swim from one continent to another. Opposing geologists argued that land bridges could have existed in the past when ocean levels were lower. These land bridges would have allowed the fauna and flora to cross between continents.

3. Rock types on different continents matched each other

When Wegener put the continents together, he also found that bands of different rock types matched up, giving further weight to his theory.

4. Coal found in cold areas and evidence of glaciers found in the tropics

Coal only forms in hot and humid areas, and glaciers only form in cold areas, so how could there be coal in cold areas and evidence of past glaciers in regions that are now hot? Wegener concluded that this land could have once been part of the same landmass and in a different location.

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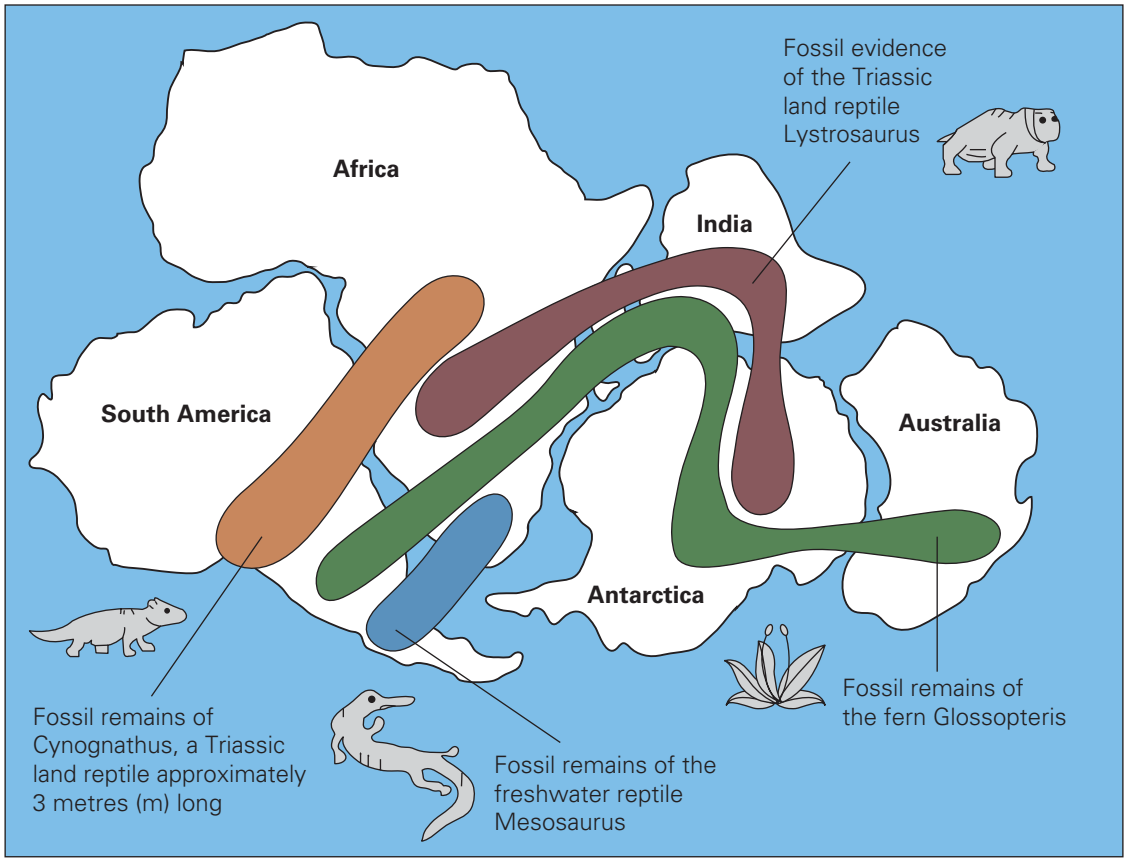


Figure 14.5 Wegener found that fossils on different continents matched up, supporting his theory of continental drift.

Despite all the evidence compiled by Wegener, he was unable to convince the scientific community at the time of the validity of his hypothesis. Alternative theories (like the land bridges) were proposed, and geologists questioned his credibility because he was a meteorologist and geophysicist known for polar climate research, and not a geologist. However, the main flaw of Wegener's hypothesis was that he had no explanation for the mechanism behind the movement of the continents.

The story of Alfred Wegener is a tragic one. In 1930, he and another team member were caught in a blizzard on an expedition in Greenland and did not survive. At the time, his hypothesis was still yet to be accepted by the scientific community.



Figure 14.6 Coal only forms in hot, swampy areas; glaciers only form in cold areas.

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Quick check 14.1

1. **Name** the scientist who is best known for proposing the theory of continental drift.
2. **List** the four different pieces of evidence he used to support his theory.
3. **Outline** why his theory was not accepted at the time.

Mid-ocean ridges, rift valleys and seafloor spreading

Around 20 years after the death of Alfred Wegener, evidence of geological change of the seafloor started to come to light that eventually was interpreted as support for the theory of continental drift. Most people before this time thought that the ocean floor was flat. The use of echo location (sonar) to probe under the sea was developed in the 1930s for military use. Sonar works by sending sound waves into the ocean; when they bounce back, they are picked up as an echo. The time they take to bounce back indicates the depth of that part of the ocean.

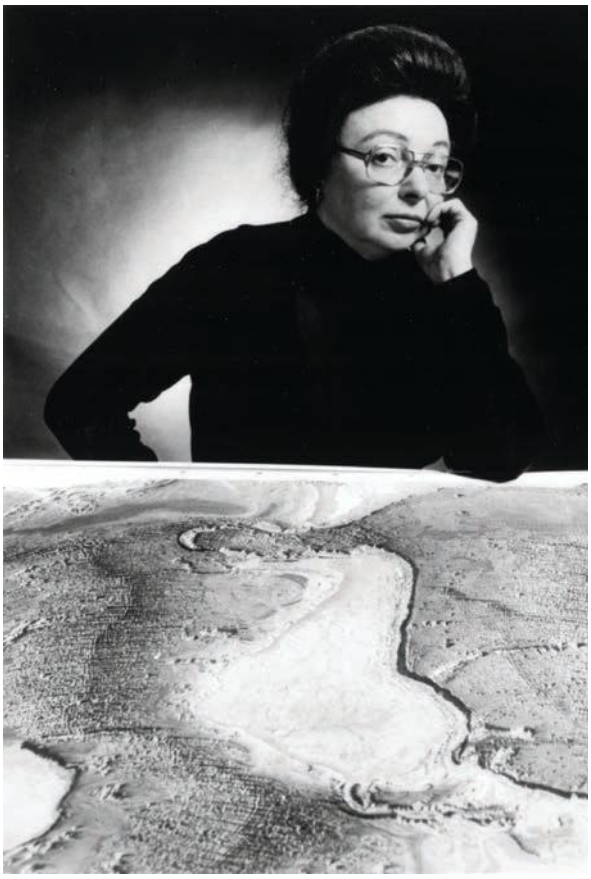


Figure 14.7 Geologist and oceanographic cartographer Marie Tharp used sonar data in the 1950s to map the Atlantic Ocean floor, revealing the Mid-Atlantic Ridge and discovering it had a rift valley.

The existence of sonar and its data was mostly secret until after World War II. Then it became available to geologists and oceanographers, and it revealed deep trenches, underwater mountain ranges and volcanoes. Geologist Marie Tharp was supplied with data from the mid-Atlantic. She became the foremost oceanographic cartographer (mapmaker) of her time, discovering that the Mid-Atlantic Ridge had an extraordinary and unexpected rift valley down its centre. This led to a revolution in geological knowledge of the seafloor.

Harry Hess, a geologist, became a US navy captain in the Pacific Ocean during World War II. His troop transport ship had an echo sounder, which allowed him to create profiles of the ocean floor, discovering ridges and submarine volcanoes. After the war he became a professor of geology at Princeton University. When he saw Marie Tharp's maps of the Mid-Atlantic Ridge, he realised that his profiles of the ocean floor in the Pacific was evidence of major geological changes, and he was the first to explain how ridges, rifts and the seafloor formed.

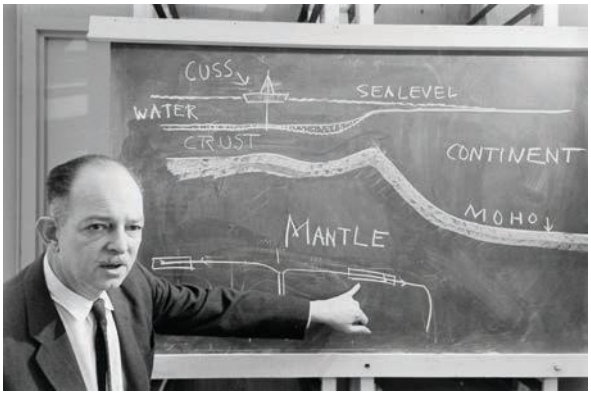


Figure 14.8 Harry Hess, a professor of geology who explained how the ocean floor and mid-ocean ridges and rifts formed

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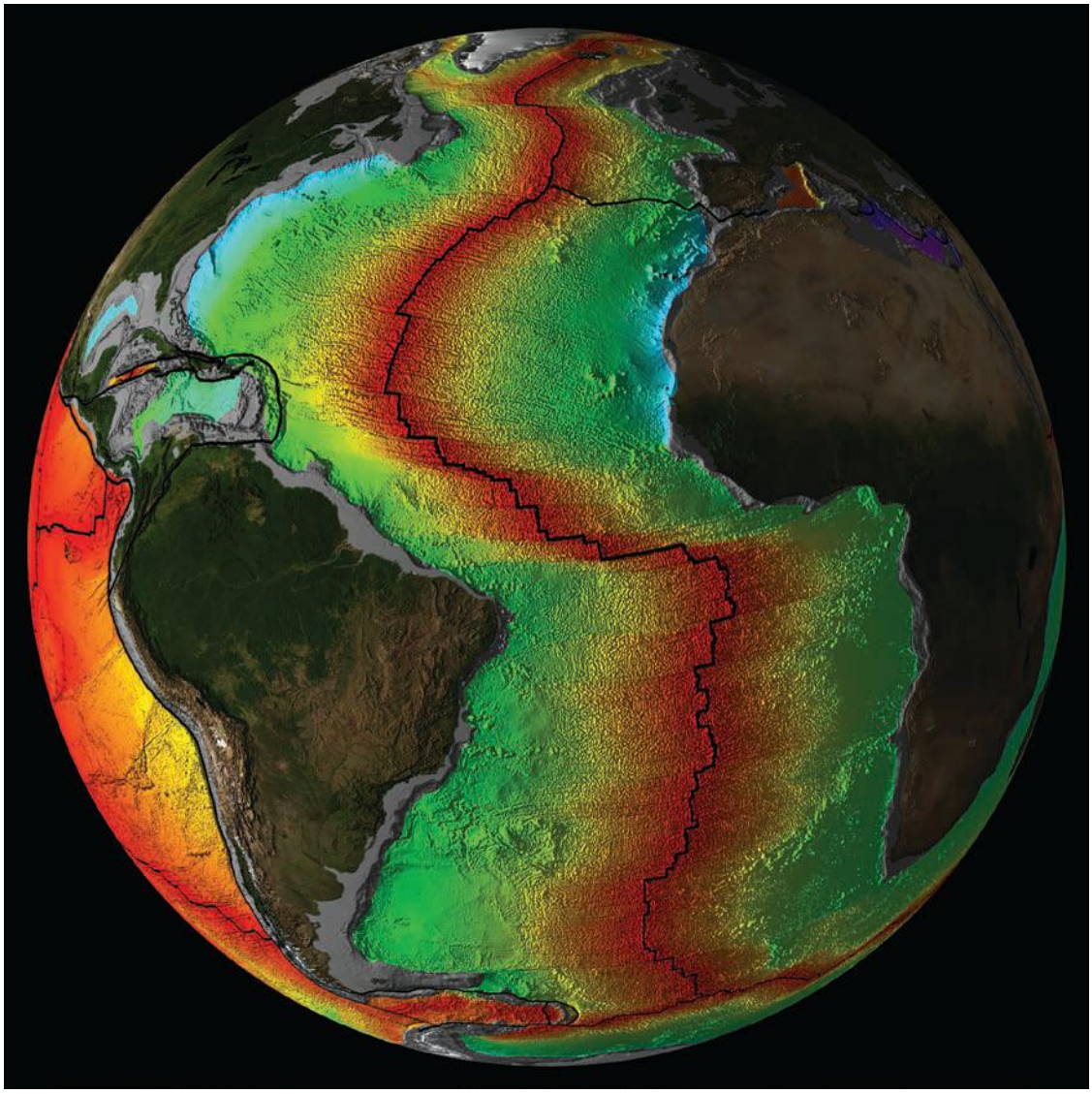


Figure 14.9 A map of the ocean floor. The Mid-Atlantic Ridge can be seen running down the centre between the continents.

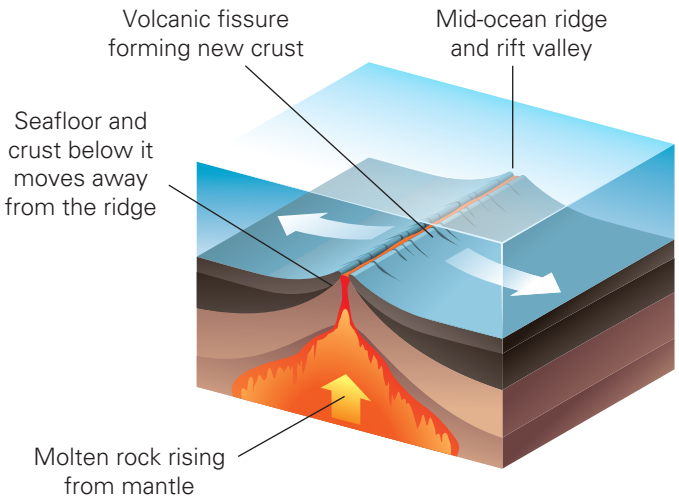


Figure 14.10 The seafloor is spreading as new crust is being formed from rising molten rock at volcanic fissures in the rift valley on top of a mid-ocean ridge.

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In his paper 'The History of Ocean Basins', published in 1962, Hess wrote that volcanoes or volcanic fissures (cracks) lining up along these ocean ridges bring up molten rock from under Earth's crust. This molten rock cools and forms new oceanic rock. As more and more oceanic rock is produced, the seafloor moves away from the ridges (Figure 14.10). Hess called this process **seafloor spreading**. This was a crucial piece of evidence to support Wegener's theory. If the two halves of an ocean floor are moving away from one another, then continents on either side of the ocean must be doing the same.

seafloor spreading a process by which new oceanic crust (outermost solid layer of the Earth) is produced as molten rock rises from below, causing the crust and seafloor to move away from ocean ridges

Hess also proposed that the old ocean floor was sinking in a process called subduction, forming ocean trenches. You will look at subduction in more detail in the next section.

Further evidence to support the idea of seafloor spreading comes from the age of the rocks on the seafloor, which shows a symmetrical pattern on either side of the ridge. If new rock is forming at the ridge and spreading out equally in opposite directions, you would expect that as you move further away from the ridge, the rock would increase in age. And this is precisely what has been found.

Advances in science 14.1

Journey to the bottom of the sea

The Challenger Deep, located in the Mariana Trench in the western Pacific Ocean, is the deepest known point in the Earth's oceans, measuring a depth of over 10 000 metres.



Figure 14.11 *Trieste II* was a deep-diving manned submarine built in 1964.

The first people to reach the bottom of the Challenger Deep were Don Walsh and Jacques Piccard. Having found the deepest part of the trench by blowing up TNT and timing how long it took them to hear the sound, they climbed into a steel cabin that was very cramped for two adults and descended. About 9400 m down, they heard a loud bang, but as there appeared to be nothing wrong, they carried on. Later they found out that a window had cracked.

Walsh and Piccard descended for nearly 5 hours, passing glowing creatures as they went. Finally, the cabin touched the ground, stirring the ocean floor beneath it. They waited for 20 minutes and then started the long ascent, which took 3 hours and 15 minutes, back to the surface.



Figure 14.12 Don Walsh (second from right) reached the bottom of the Mariana Trench in 1960.

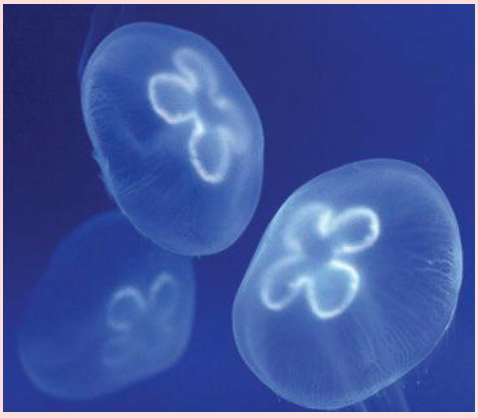


Figure 14.13 The only light that can be observed in the ocean depths is created by the animals that live there. This is called bioluminescence.

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Did you know? 14.1

Extreme exploration

In 2020, former NASA astronaut Kathryn Sullivan became the first person to both walk in space and descend to the deepest known point on Earth, after making the 11-kilometre ocean dive to the Challenger Deep. Her 3.5-hour spacewalk was in 1984.

Quick check 14.2

1. **Name** the ridge located in the Atlantic Ocean.
2. **Recall** the name of the technique that supplied the data that Marie Tharp and Harry Hess used to map the ocean floor.
3. **Describe** the process discovered by Harry Hess from seafloor mapping.

The Ring of Fire – distribution of volcanoes and earthquakes

There is another pattern that gives further clues about the tectonic plates. Most of Earth's volcanoes and earthquakes occur in a region surrounding the Pacific Ocean. This region is referred to as the Ring of Fire.

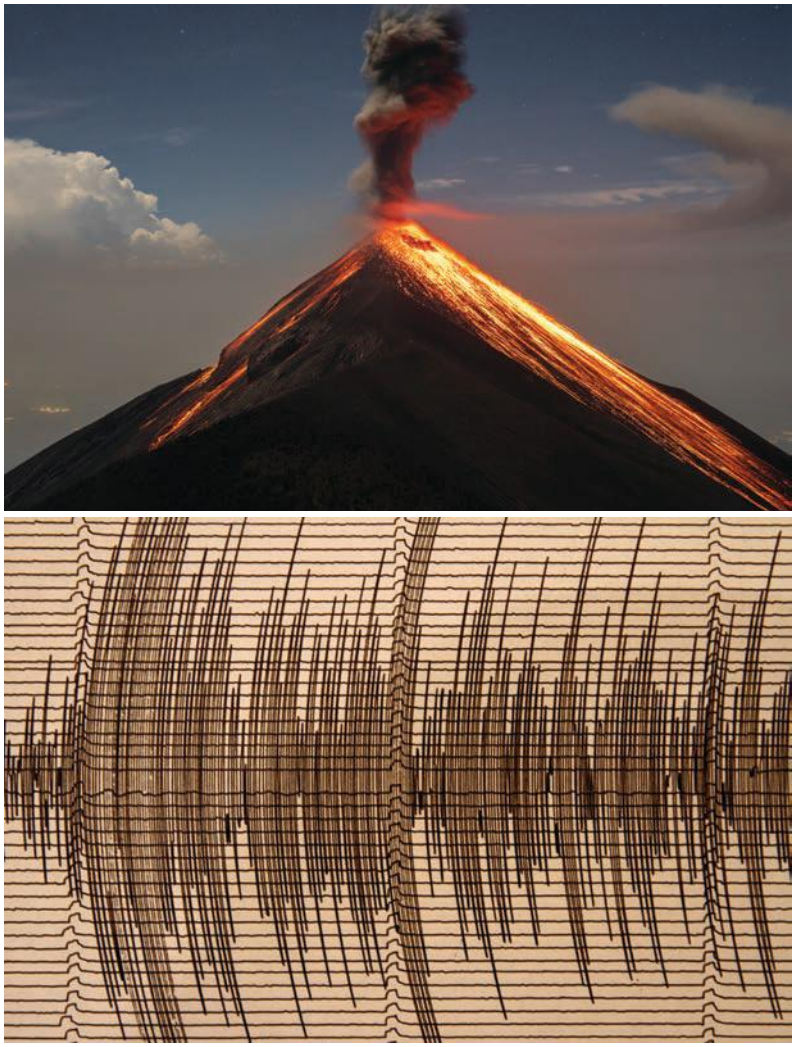


Figure 14.14 Volcanoes and earthquakes occur more frequently in the Ring of Fire than anywhere else on Earth.

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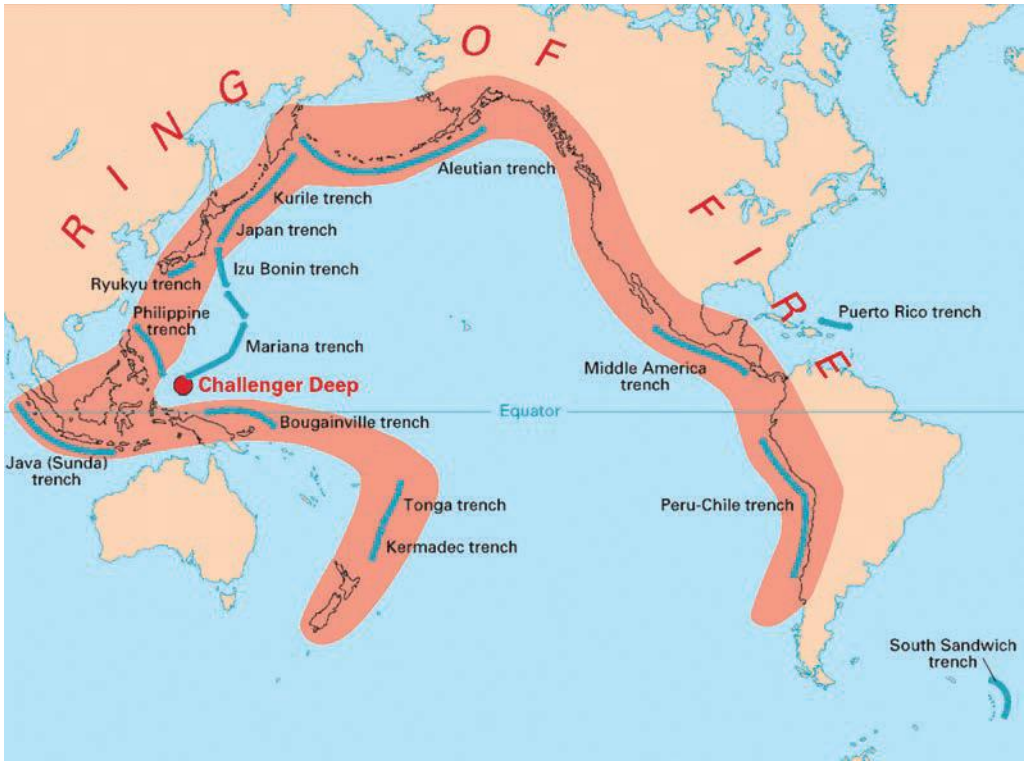


Figure 14.15 The Ring of Fire

Building on the theory of continental drift, scientists first proposed the theory of **plate tectonics** in the late 1950s and early 1960s. The theory tells us that Earth's surface is split into **tectonic plates**, gigantic slabs of rigid rock, which float on molten rock and form the Earth's surface. The pattern of increased volcanic and earthquake activity around the Ring of Fire coincides with the edges of these plates, known as **plate boundaries**. Seven major plates are currently recognised: the North American, Pacific, Eurasian, African, Australian, South American and Antarctic tectonic plates. They are called major plates because they are the largest ones. There are also eight minor plates and many microplates.

plate tectonics the theory that the Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

tectonic plates fragments of Earth's lithosphere that float on the asthenosphere

plate boundaries the edges where two tectonic plates meet

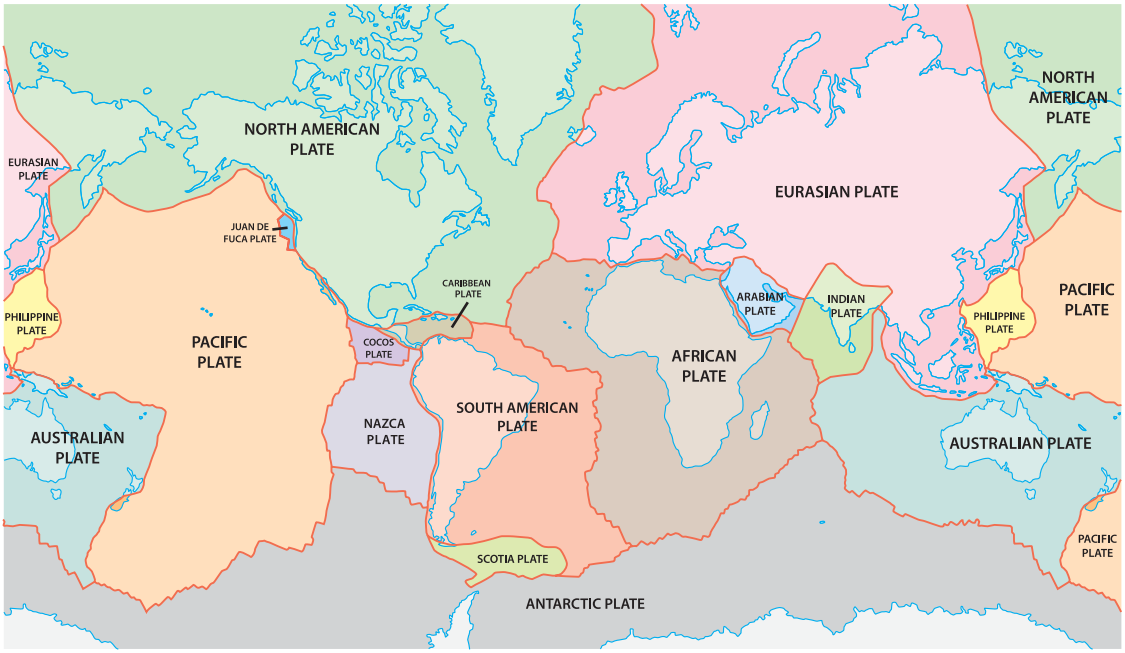


Figure 14.16 The major and some minor tectonic plates of Earth's surface

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Remember that Earth is a sphere, while this image is flat to fit the whole world on map. Compare the Antarctic plate on the flat map in Figure 14.16 to the globe in Figure 14.17.

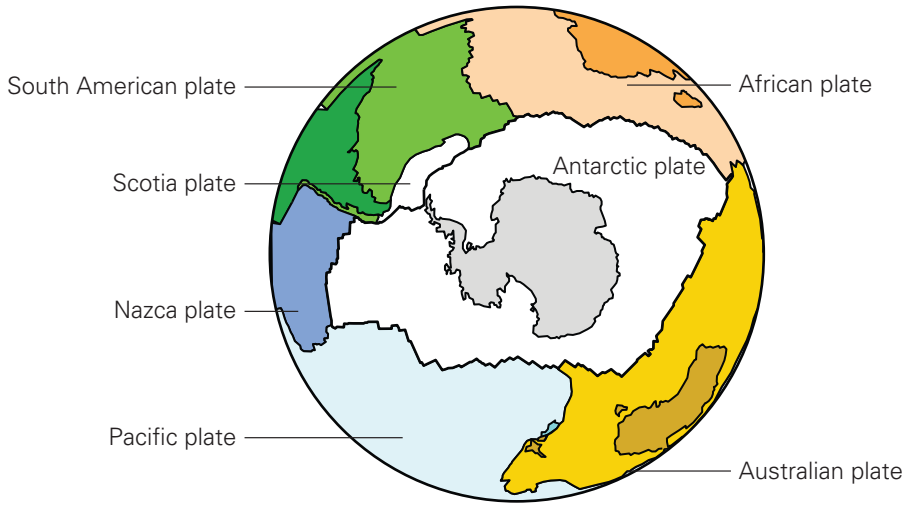


Figure 14.17 The major tectonic plates of Earth's surface shown on a globe viewed from the south

Cause of movement of tectonic plates

The tectonic plates are moving. This causes tectonic activity, such as earthquakes and volcanoes, along plate boundaries. Scientists can measure these movements to help predict where tectonic activity is most likely to occur.

VIDEO
Plate tectonics

WORKSHEET
Investigating tectonic plate movement

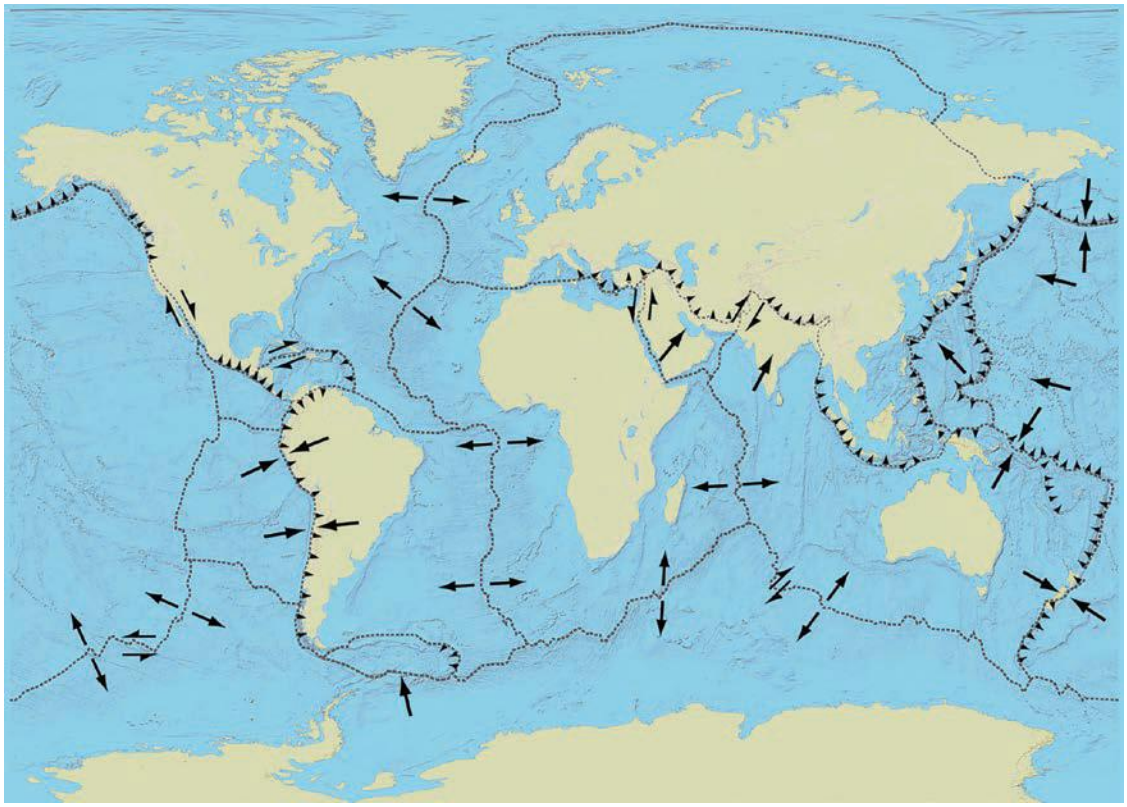


Figure 14.18 The major tectonic plates and their direction of travel. The small triangles on the lines indicate a convergent plate boundary.

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Advances in technology since Alfred Wegener proposed his theory have given us a lot of information that was not available at the time. This includes precise measurements of plate movement and detail about the structure of Earth. Even with all the evidence Wegener compiled, it seemed impossible that continents could move. He could not explain a mechanism that could cause the tectonic plates to move.

It wasn't until almost 1960, 50 years after Wegener proposed the idea of continental drift, that Harry Hess's seafloor spreading process provided the first evidence of a mechanism to drive plate movements. This inspired more research by a number of geologists who published more evidence, and by the late 1960s, scientists had accepted Wegener's theory. This mechanism is mostly a result of **convection currents** in the layers beneath the crust.

convection currents the movement of rocks within Earth's mantle due to temperature differences between the upper and lower layers

crust the solid outer layer of Earth that supports all life on Earth

mantle the layer of Earth underneath the crust that is made up of solid and semi-molten rock and surrounds the outer core

lithosphere the solid outer layer of Earth consisting of the crust and top layer of the upper mantle; it is split into giant slabs called tectonic plates

asthenosphere the softer layer of rock under the lithosphere

The layers of the Earth

Earth is made up of four layers: the **crust**, **mantle** , outer core and inner core. The inner and outer cores both contain heavy metals at very high temperatures, however the inner core is solid due to intense pressure, and the outer core is entirely liquid. The mantle is composed of solid and semi-molten rock and is divided into a lower and upper mantle. The crust is the solid outer layer. The **lithosphere** consists of the solid top layer of the upper mantle and the lower crust. The **asthenosphere** is the softer layer of hot semi-molten rock in the upper mantle, under the lithosphere.

The structural layers of the Earth are described in Figure 14.19.

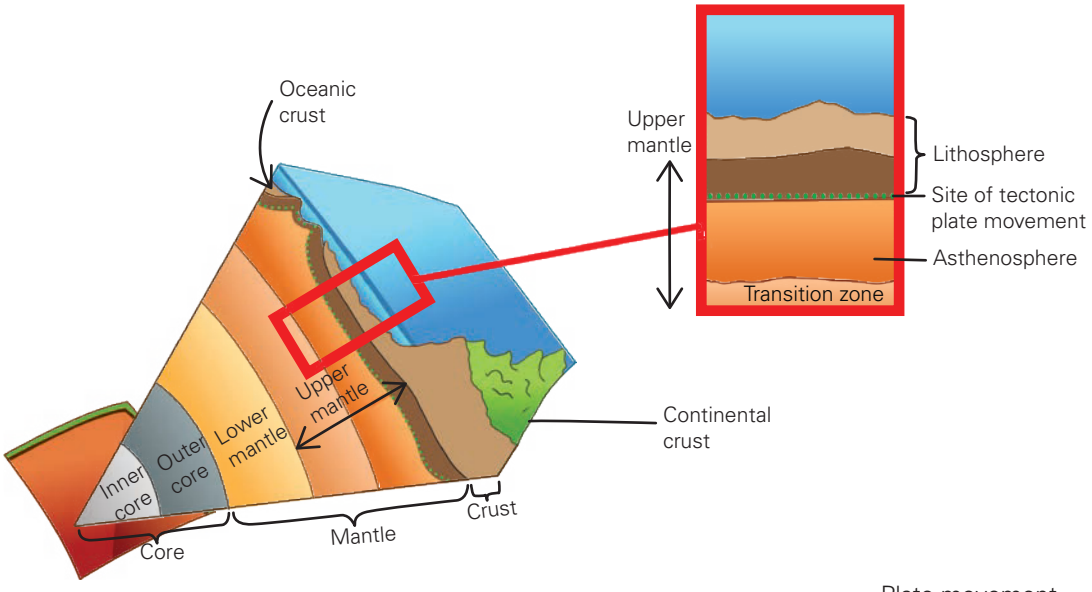


Figure 14.19 Earth's layers

The temperature increases as you move down through the mantle and get closer to the core. The heat created by the core heats the rock in the lower mantle, causing it to become less dense and rise towards the crust. As it rises towards the cooler surface, it begins to cool down and become denser. It is pushed aside by the hot rock that is still rising and falls back towards the core. This cycle of hot rock rising and cooler rock sinking is called a convection cycle and is caused by convection currents in Earth's lower mantle.

At the top of each convection cycle, the sideways movement of the cooling rock in the mantle causes the movement of the tectonic plates above it. Figure 14.20 shows what can happen when the sideways movements of rocks in the mantle are in opposite directions.

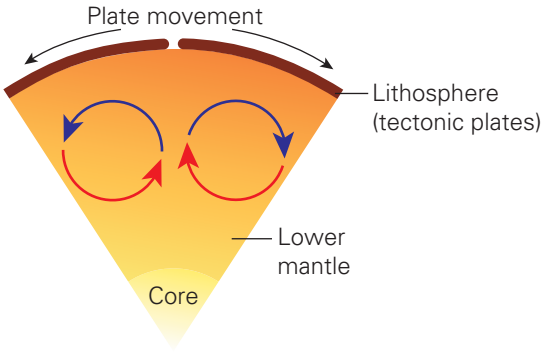


Figure 14.20 A segment of a cross-section through the Earth showing convection currents in the mantle, with heat rising from the lower to the upper mantle. The sideways movement of rock closest to the lithosphere (blue arrows) causes the tectonic plates to move in opposite directions, away from each other.

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WORKSHEET
Convection currents

Quick check 14.3

1. **List** the layers of the Earth from the surface to the centre.
2. **State** the name given to the giant slabs of rock that make up Earth's crust.
3. **Name** the seven major tectonic plates.
4. **Describe** the differences in structure between the rocks in the lithosphere and asthenosphere.
5. **Explain** why hot rock rises.
6. **Describe** how this movement of rocks in the mantle drives the movement of tectonic plates.

Practical skills 14.1

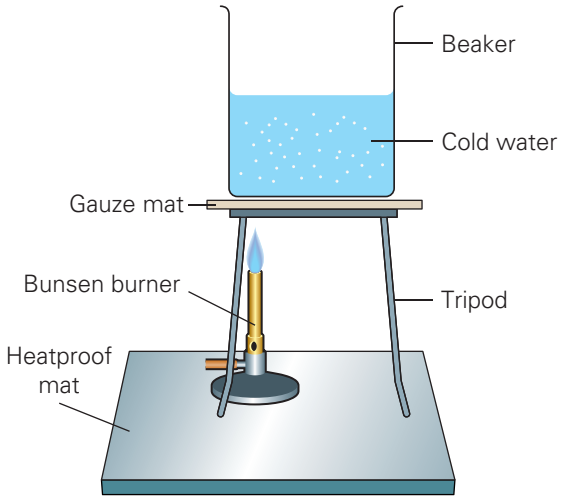
Observing convection currents

Aim

To observe convection currents.

Materials

- dark food colouring
- cold water
- 250 mL beaker
- ice cube tray
- Bunsen burner
- gauze mat
- tripod
- heatproof mat



Procedure

1. Mix 100 mL of water with some food colouring in a beaker (the darker the water, the better).
2. Pour this mixture into the ice cube trays and place the trays in a freezer until the water has frozen.
3. Half-fill a 250 mL beaker with cold water.
4. Set up your equipment as shown in the diagram.
5. Set the Bunsen burner to a blue flame and concentrate the heat on one corner of the beaker.
6. Drop an ice cube into the beaker and observe the water.

Results

Record your observations.

Discussion

1. Describe what happened to the ice cube when it hit the warm water.
2. Describe the distribution of the coloured water from the ice cube just after it had melted.
3. Explain what you observed.
4. Discuss what happened to the distribution of the coloured water from the ice cube as the Bunsen burner heated up the water.
5. Explain what you observed.
6. Describe and explain the appearance of the water at the end of the experiment.
7. Draw a labelled diagram to show what was happening to the water in the beaker.

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Plate boundary types

WORKSHEET
Plate boundaries

The direction of plate movement causes different types of plate boundaries to form. There are three types of plate boundaries: convergent (destructive), divergent (constructive) and transform (conservative). When two plates converge or move towards each other, crust is crushed and either pushed upwards to create mountains or pushed downwards at a subduction zone. When two plates diverge, or move apart, new crust forms in the gap growing between them. Tectonic plates can also slide or rub past each other. In this case, crust is neither created or destroyed, and thus this plate boundary is referred to as 'conservative'.

Table 14.1 summaries the three types of plate boundaries, the type of movement shown by each, and key features and examples of these from around the world.

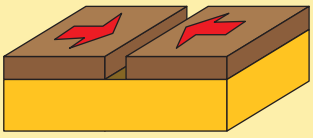
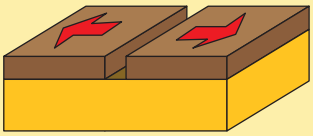
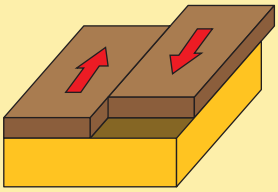
Type of boundary and movement	Diagram and what happens to the crust	Key features	Example
Convergent (destructive)	 Crust is destroyed	Mountains Trenches Subduction zones Volcanoes Earthquakes	Himalayan Mountain range
Divergent (constructive)	 New crust is created	Volcanoes Rifts Ocean ridges	Mid-Atlantic Ridge
Transform (conservative)	 Crust is conserved	Fault lines and earthquakes	San Andreas Fault, California

Table 14.1 A summary of each type of plate boundary. More detailed diagrams follow in the rest of this section.

Explore! 14.1

INVESTIGATION

The Chile Triple Junction

The Chile Triple Junction is located on the seafloor of the Pacific Ocean off the southern coast of Chile. Use your preferred search engine to answer the following questions.

1. List which three tectonic plates meet at the Chile Triple Junction.
2. Discuss why the triple junction is unusual.

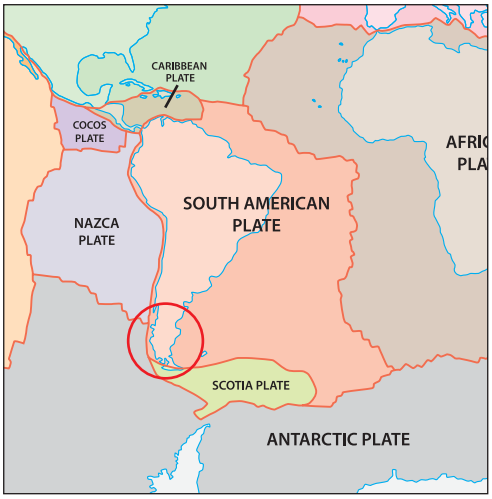


Figure 14.21 The Chile Triple Junction

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Convergent boundaries

Oceanic crust is thin and dense; in comparison, continental crust is thicker and less dense. So, what happens when plates with two different types of crust collide?

When an oceanic plate meets a continental plate

As the plate with the oceanic crust is denser than the plate with the continental crust, when they collide, the denser oceanic plate will sink underneath the continental plate in a process called **subduction**. As the oceanic plate sinks deeper and deeper into the mantle, it begins to melt, forming **magma**. This magma can rise up through the continental plate to form volcanoes. Mountains and deep ocean trenches also form at this type of destructive boundary. The Japan Trench is an example of this type of boundary (see Figure 14.23).

subduction the process in which the denser oceanic plate sinks underneath less dense continental plate

magma hot fluid rock found beneath the Earth's surface

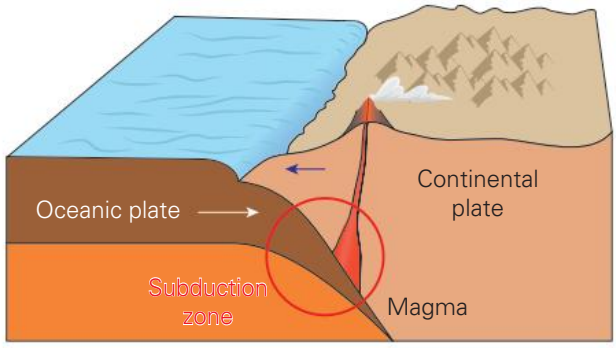


Figure 14.22 A subduction zone forms at an oceanic–continental convergent boundary when the denser oceanic plate subducts underneath the less dense continental plate. A deep ocean trench forms along the boundary where they meet.

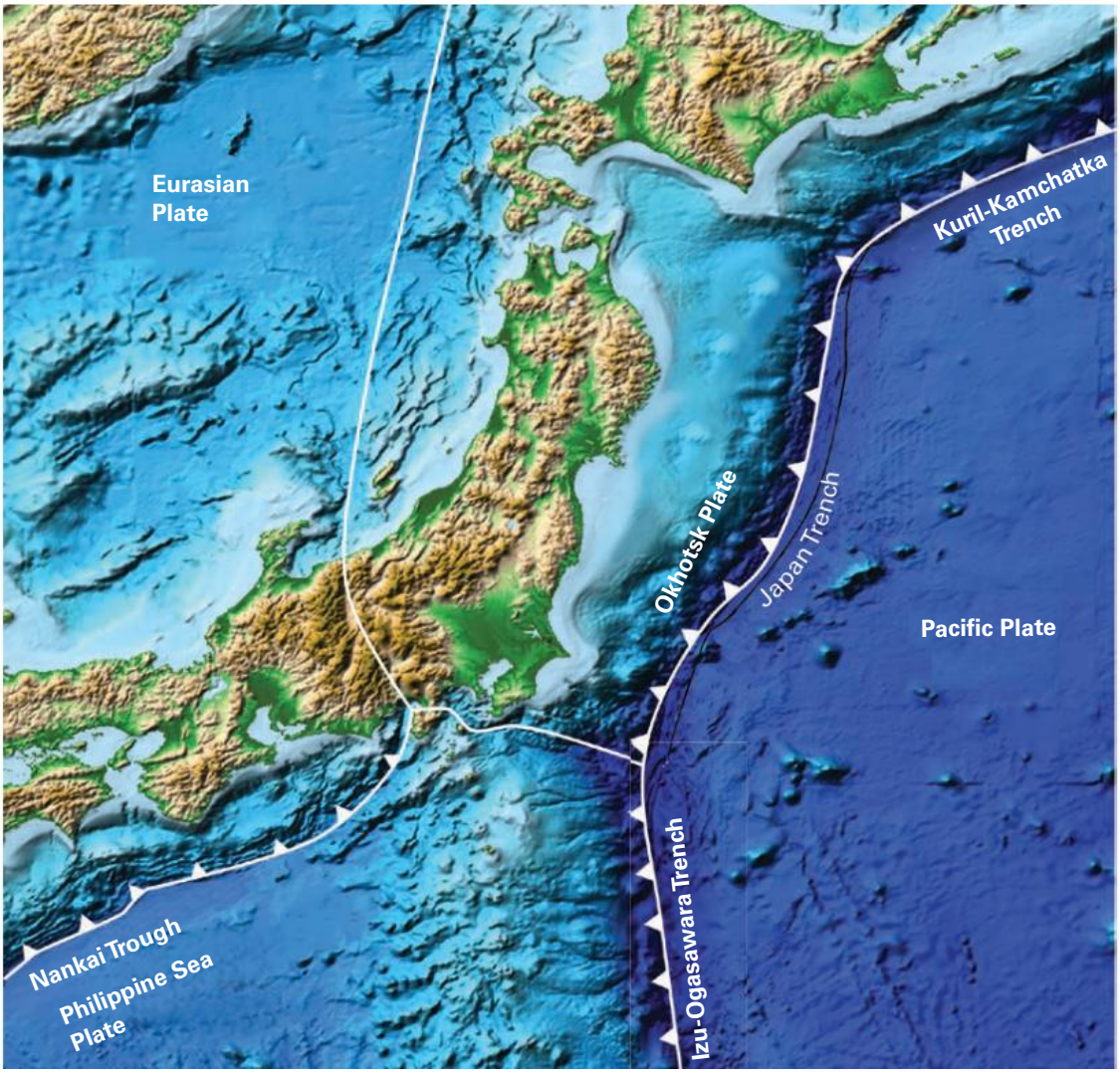


Figure 14.23 The Japan Trench is a deep-sea trench where the Pacific plate is being subducted beneath the Eurasian plate. Japan sits right on the edge of this trench, causing the country to experience earthquakes, volcanoes and tsunamis.

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When two continental plates meet

When two continental plates meet, both plates have the same density, so when they collide, subduction of the crust does not take place, although lower layers of the lithosphere may be subducted. Instead, the crust buckles and breaks down. The pressure of the collision forces the damaged crust upwards, eventually forming mountains such as the Himalayas.

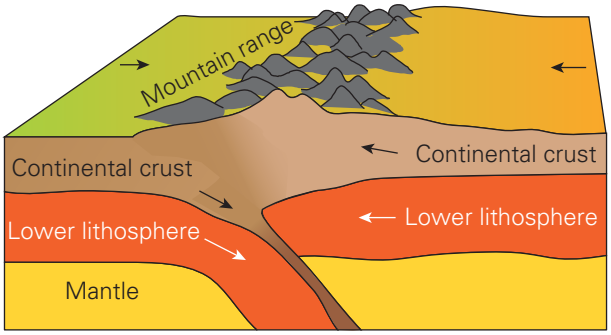


Figure 14.24 The formation of mountains when two continental plates collide



Figure 14.25 The Himalayan Mountain range, the highest in the world, is formed at a convergent plate boundary.

Did you know? 14.2

Growing mountains

As the Eurasian and Indian plates are constantly moving towards each other, Mount Everest – the highest mountain in the world at 8850 m tall – is getting taller each year, by 4 millimetres in fact. If your ambition is to climb Mount Everest, then you had better do it sooner rather than later if you do not want to have to climb even further!

When two oceanic plates meet

Usually when two oceanic plates meet, a subduction zone will be created and volcanic island arcs will form. Which one subducts depends on their relative densities and thickness, and the speed at which the plates are moving. Comparing Figure 14.26 with 14.22, you will see that they are similar, although the other way around – the subducting plates happen to be going in opposite directions. The formation of volcanoes in the converging oceanic plates is the same as in the oceanic–continenetal plate convergence; the cause is rising magma from the subducting plate melting. The difference in Figure 14.26 is that the volcanoes form underwater, and only the most active reach the surface and form an island.

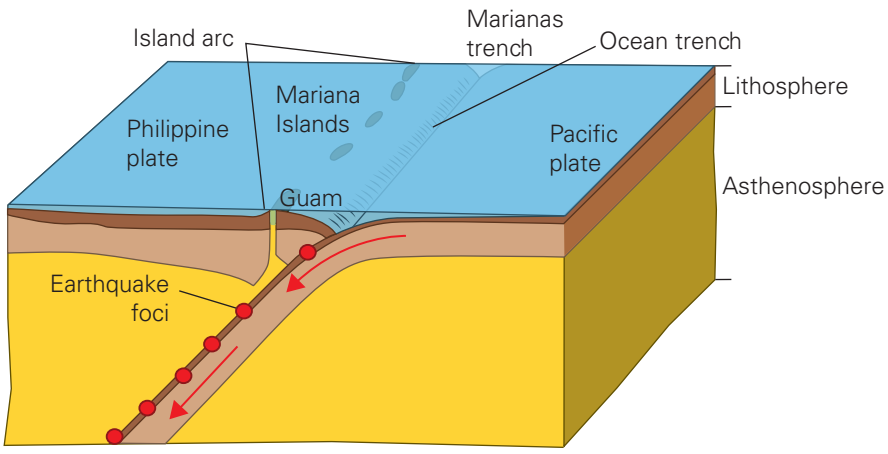


Figure 14.26 An island arc forming when two oceanic plates converge. The subducting plate melts, producing magma which rises and forms a volcano, building up a volcanic cone that reaches the surface of the ocean. The portion of the boundary shown is straight, but most boundaries curve, and so the resulting islands often lie in an arc.

VIDEO
Island hotspots

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Quick check 14.4

1. **State** the term which describes the action of one plate sinking underneath another.
2. **List** some of the features that can form at convergent plate boundaries.
3. **Discuss** why subduction does not take place when two continental plates collide.

Divergent boundaries

In the ocean (oceanic)

When plates move apart in the ocean, magma (molten rock) rises to fill the gap, gradually building more oceanic crust and forming mid-ocean ridges. As the magma reaches the cold surface of the sea bed, it quickly cools, forming igneous rock including pillow lava.



Figure 14.27 A University of Washington study shows how a volcano behaved during its spring 2015 eruption, revealing new clues about the behaviour of volcanoes where two ocean plates are moving apart, as at the Mid-Atlantic Ridge.

On land (continental)

When plates move apart on land, rift valleys are formed. In these rift valleys, the crust is getting thinner. Once a rift valley drops below sea level, it will eventually fill with water. This can form lakes or inland seas, which is how the Red Sea was formed. The rift valley can also join existing oceans. An example of this process is the East African Rift, where the Horn of Africa will eventually break away from the rest of Africa, forming a new island (see Figure 14.28).

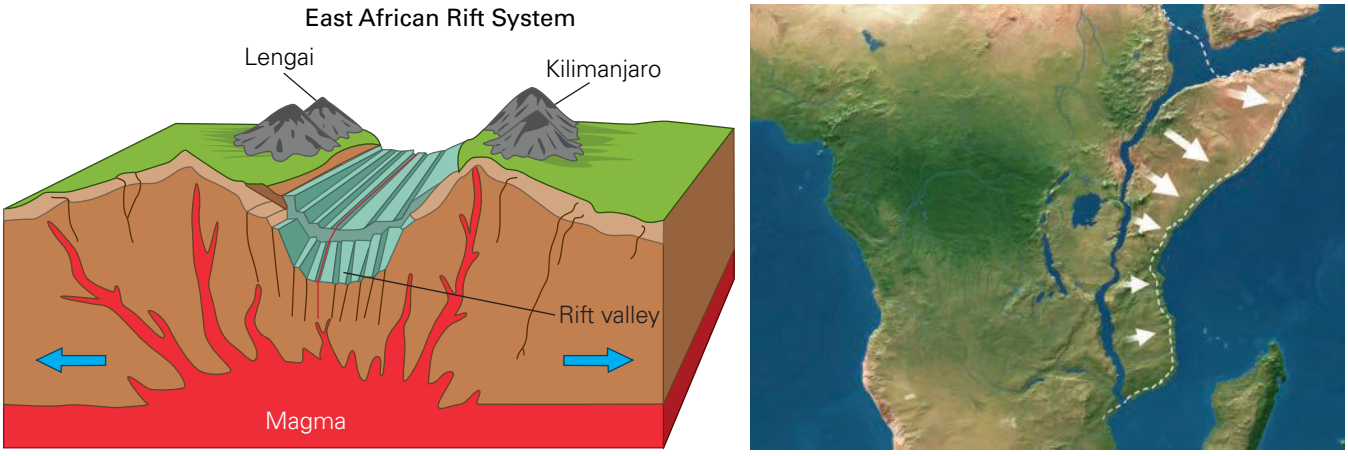


Figure 14.28 The East African Rift is an active rift valley which is breaking away a continental piece of Africa.

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Figure 14.29 New cracks are continuously appearing along the East African Rift. This one formed in Kenya in 2018.

Quick check 14.5

1. **Describe** the movement of plates at a divergent plate boundary.
2. **List** some of the features which can form at a divergent plate boundary.
3. **Explain** why divergent boundaries also known as constructive plate boundaries.

VIDEO
Causes of earthquakes

Transform boundaries

Tectonic plates can also slide or rub past each other. When plates move parallel to one another, but in opposite directions, a tremendous amount of force can build up due friction, which stops the plates from moving. When the force of the plate movement overcomes the friction that is stopping them from moving, the pressure is released, and violent surface earthquakes occur. Transform boundaries are also known as conservative boundaries as land is neither created nor destroyed. A well-known example is the San Andreas Fault. It lies between the Pacific plate and the North American plate slicing through California.



Figure 14.30 Location of the San Andreas Fault (red line)



Figure 14.31 The San Andreas Fault can be clearly seen from above. In built-up areas earthquakes along this fault cause a lot of damage.

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Forces in tectonic plate theory

Heat from within the Earth creates density differences in the mantle. There is a greater force due to gravity on cooler, denser rock compared to the less dense, hotter rock. Gravitational forces drive the convection currents.

It has been mentioned that mantle convection produces a sideways force, through friction, on the plates above, moving them. As shown in Figure 14.32, two other forces act on plates to cause their movement, and these are thought to be stronger than the convection/friction force.

Ridge push

The mid-ocean ridges are created by molten rock rising by convection at the volcanic fissures in the rift valley of the ridge. This rock piles up and the force of gravity pulls it down, but it can only move sideways, sliding away from the ridge and down until it flattens out. This force is called **ridge push**. It pushes the plate away.

ridge push
a force due to gravity at a mid-ocean ridge on a tectonic plate that pushes it away from the ridge

slab pull
a force due to gravity at a subduction zone on a tectonic plate that pulls it towards the subduction zone

Slab pull

At a subduction boundary, the force of gravity pulls the crust down into the mantle. The crust is colder and more dense than the mantle, and so it sinks, pushing less dense mantle and molten rock out of the way. Since the crust is solid, the sinking part pulls the horizontal part of the plate towards the subduction zone – this force is called the **slab pull**. It is the strongest of the three forces acting to move the plates. It also acts in the same direction as a ridge push.

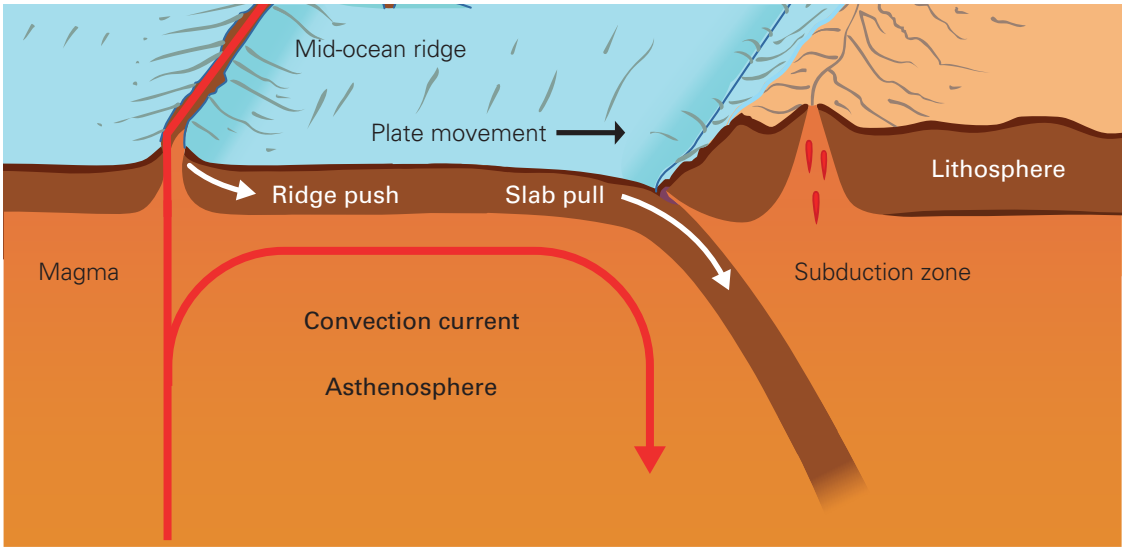


Figure 14.32 A section through the lithosphere and asthenosphere with an oceanic plate between a divergent boundary (a mid-ocean ridge) and a convergent boundary (subduction zone), showing the forces of ridge push and slab pull, the main forces that move the plate

WIDGET
Plate movement at boundaries

Quick check 14.6

1. **Describe** the movement of plates at a transform plate boundary.
2. **List** one of the characteristics of this type of boundary.
3. **Recall** why transform plate boundaries are also known as conservative boundaries.

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Oral histories of geological events

Aboriginal and Torres Strait Islander Peoples have deep and rich cultural histories that include detailed oral histories, including songs, stories and other cultural practices, that are passed down unbroken from generation to generation.

Many of these accounts provide evidence of earthquakes and volcanoes that have occurred well before the colonisation of the continent we now know as Australia.



Figure 14.33 A nineteenth-century drawing by artist Eugene von Guerard of the lake in the crater at the top of Budj Bim

Gunditjmara People hold and continue to share knowledge about four enormous giants that arrived in the southeastern region of the continent now known as Australia. While three of them departed to other parts of the continent, the fourth remained still and transformed into a volcano that came to be known as Budj Bim. The lava that spewed forth from the volcano was formed from the giant's teeth.

Recent Western scientific findings have uncovered evidence to support the timing of this account, which has been passed down for over 4000 years via the oral records of Gunditjmara and Bungandidj People (from neighbouring South Australia). The evidence indicates that Budj Bim, along with another nearby volcano, emerged roughly 37 000 years ago because of a swift succession of eruptions, and led to the formation of crater lakes in the region. This discovery suggests that the ancient knowledge could be the oldest story still in circulation today.



WORKSHEET
Researching examples of Indigenous Knowledge of geological change

Links to further examples of Aboriginal and Torres Strait Islander Peoples' Knowledge of geological change are given in the Interactive Textbook and teacher resources.

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Go online to access the interactive section review and more!

Section 14.1 review

Online quiz

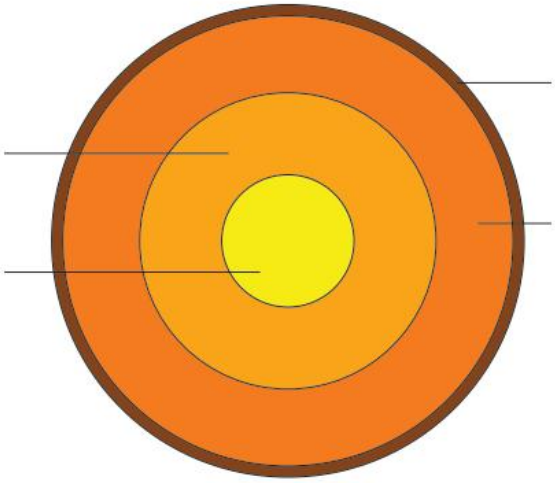
Section questions

Teachers can assign tasks and track results

Section 14.1 questions

Remembering

1. **Identify** the names of the three types of plate boundaries.
2. **State** the name of the mechanism which causes tectonic plates to move.
3. **Label** the following diagram showing the structure of the Earth.



4. **Match** the layer of the Earth (A–D) to its physical properties (1–4).

A. Crust	**1.** Made of metals (iron and nickel) Very hot temperatures Under intense pressure from the layers above so is a solid structure
B. Mantle	**2.** Made of dense, solid rock which flows in the hot temperatures
C. Outer core	**3.** Thinnest layer Supports all the life on Earth
D. Inner core	**4.** Made of metals (iron and nickel) Very hot temperatures Liquid

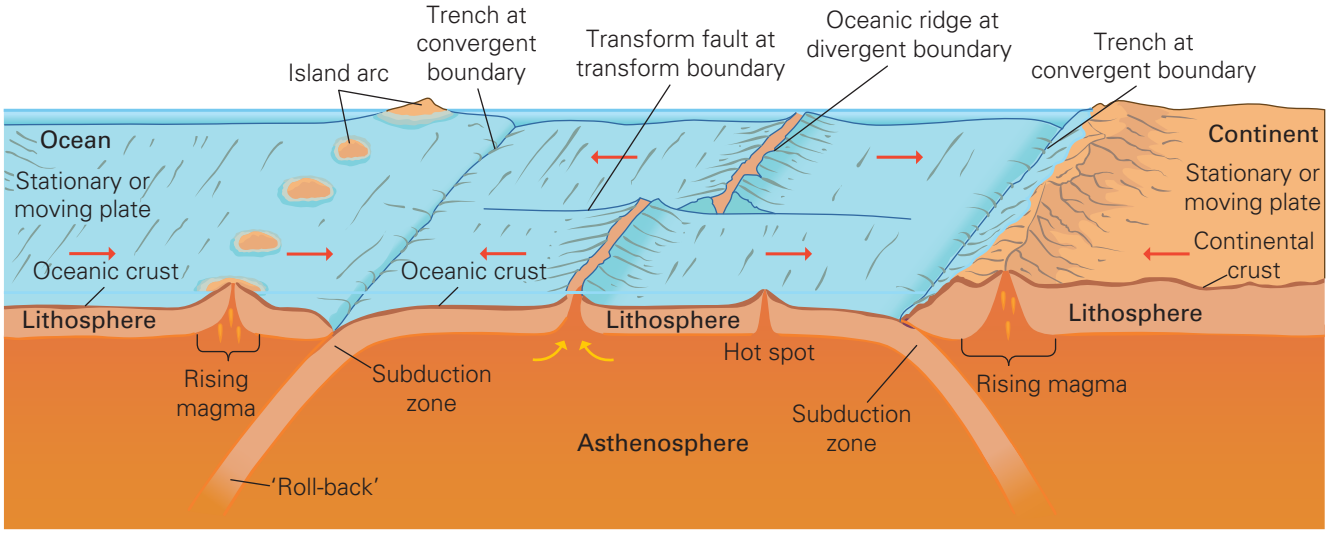
5. **Name** a real-life example of each of the three types of plate boundaries.

Understanding

6. **Describe** how temperature affects the structure of rocks in the mantle.

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7. Write a paragraph to **describe** two of the features of the diagram below.



8. At destructive plate boundaries, crust is destroyed. **Explain** why the overall amount of crust on the Earth has stayed the same despite this destruction.

9. **Outline** how magma forms at a subduction zone.

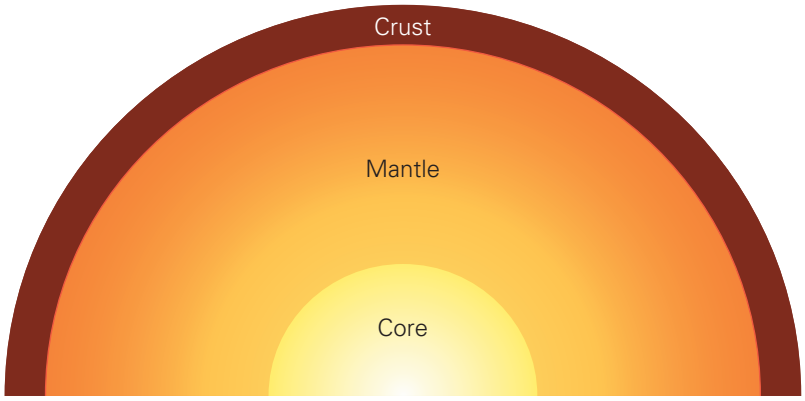
Applying

10. **Construct** a labelled diagram to show an oceanic plate subducting underneath a continental plate.

11. **Identify** the type of plate boundary where the following features would occur:

a. trenches
b. mountains
c. earthquakes
d. volcanoes
e. ridges
f. rifts
g. subduction zones.

12. Make a copy of the diagram below, and **model** by adding arrows and labels how convection currents in the mantle transfer heat and help to move tectonic plates.



Analysing

13. **Compare** and contrast oceanic and continental crusts.

14. **Analyse** why mountains and trenches may continue to increase in size.

Evaluating

15. **Propose** reasons why Australia does not experience significant amounts of tectonic activity.

16. **Propose** your own reasons why some tectonic plates move faster than others.

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14.2 Rocks

VIDEO
Igneous, sedimentary and metamorphic rocks

WORKSHEET
Formation of rocks

mineral
a naturally occurring chemical substance that is formed in the ground, with constant chemical composition, crystal structure and physical and chemical propertiesh

crystal
a substance with a specific chemical composition, in which the atoms are arranged in an ordered way to form a geometric shape

rock
a naturally occurring substance composed of minerals forming Earth's outermost layers, formed as part of the rock cycle

geology
the study of rocks and Earth's dynamic structure and the processes through which our planet (and other planetary objects) have formed

rock cycle
the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

Learning outcomes

At the end of this section, I will be able to:

1. describe the major processes of the rock cycle including melting and cooling, temperature and pressure, weathering and erosion, deposition, compaction and cementation.
2. consider the role of forces and heat energy in the formation of igneous, sedimentary and metamorphic rocks.
3. compare how quickly or slowly different rock formation processes can occur.
4. recognise how the law of superposition helps determine the relative age of rock strata.
5. describe investigations into or simulations of the observable properties of rocks and recall properties including crystal size and density.
6. model the formation of fossils including body, cast, trace, opalised and amber fossils.
7. explain how fossils can be used to date rocks and organisms.
8. recall the main chemical elements comprising Earth and compare them to those of one or more other planets.

Minerals, crystals and rocks

This section uses these three terms and it is important to distinguish them. **Minerals** have a specific chemical composition, like a compound. They are inorganic solids, meaning they occur naturally without having been made by living things. They have a **crystal** structure. A crystal is a solid in which the atoms or molecules are arranged in an orderly, repeating structure, which is why they often have geometric shapes. The crystals form when the material solidifies or comes out of solution. There are some mineral-like substances that don't form crystals, and they may be loosely called minerals, but their molecules are arranged randomly, as in opal or glass. **Rocks** are made mainly of minerals but can include some non-crystalline substances.

The rock cycle

The **geological** history of any given location determines the rock types found there. Rocks are made of minerals, and knowledge of where particular minerals can be found is necessary if we are going to use these resources – for example, to mine rocks containing resources like gold, silver, copper or iron.

There are three rock types based on how they are formed – igneous, metamorphic and sedimentary – and they can be recycled into each other by processes of:

- weathering and erosion followed by compaction and cementation
- heat and pressure
- melting and cooling.

This is illustrated by the **rock cycle**, shown in Figure 14.34.

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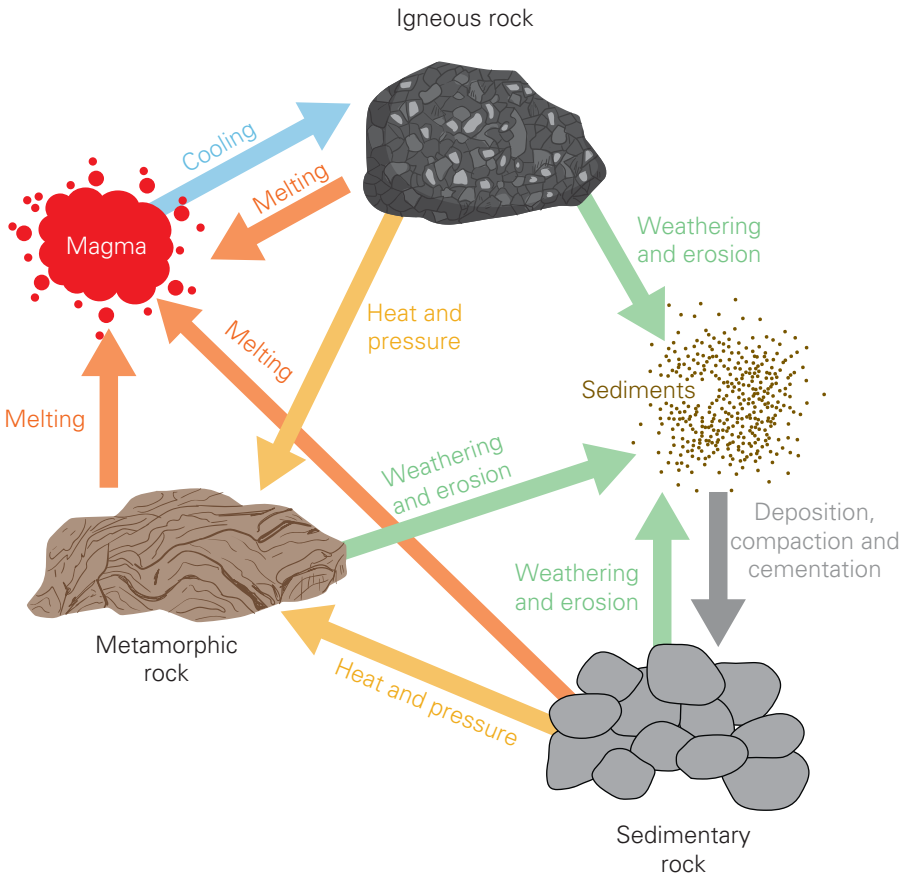


Figure 14.34 In the rock cycle, the three types of rock can change through the action of weathering and erosion, deposition, compaction and cementation, melting and cooling, and heat and pressure.

Melting and cooling



As you can see in Figure 14.34, the melting of rock to form magma (hot molten rock), and then the cooling of that magma, results in the formation of igneous rock. The process of melting takes place beneath Earth's crust at temperatures that can be as low as 500°C and as high as 1600°C. The process of cooling can happen below or on Earth's surface. An interesting characteristic of igneous rocks is that the minerals in them may form crystals. This is because when magma cools, crystallisation occurs. Below Earth's surface, magma takes a long time to cool, and the crystals formed in it are large. Magma that reaches Earth's surface is called **lava**. Because lava cools more quickly, the crystals formed are small and may even be microscopic.

lava
molten rock from inside Earth (called magma) that has reached the surface

Did you know? 14.3

'Igneous' and 'ignite' come from the same Latin word, *ignis*, which means 'fire'. This is an easy way to remember that igneous rocks are formed from hot magma.



Figure 14.35 'Igneous' comes from a Latin word meaning 'fire'.

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Quick check 14.7

1. **Name** the three types of rocks formed in the rock cycle.
2. **Describe** the roles melting and cooling play in the rock cycle.

INVESTIGATION

Explore! 14.2

What is a meteorite?

From time to time, rocks arrive on Earth from space in the form of **meteorites** that hit the ground. Conduct research to answer the following questions.

1. Describe the composition of meteorites.
2. Outline where meteorites originate from.
3. Propose whether meteorites pose a threat to life on Earth. Justify your argument using examples of meteorites that have struck Earth, and the aftermath.



Figure 14.36 An iron meteorite from space that collided with Earth

meteorite a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground

foliated appears banded or layered; has distinct repetitive layers or stripes

sediments sand, stones, etc. that slowly form a layer of rock

physical weathering the process of breaking down rocks into smaller pieces or particles, without changing the chemical composition

Heat and pressure

Rocks that are deep underground may be exposed to extreme pressure, high temperature or both. This can change the nature of the rock, often making it harder and denser. These processes create metamorphic rocks. Mudstone is a sedimentary rock made from mud. When it is exposed to high pressure and temperature it turns into slate, a metamorphic rock. If the temperature and pressure are increased again, it can become a schist, another type of metamorphic rock. Metamorphic rock is typically **foliated**, with elongated crystals.



Figure 14.37 Schist is formed when various rock types are subjected to high temperature and pressure.

Weathering

Weathering occurs when exposed rocks are broken down – for example, by ocean waves hitting a cliff face. Weathering breaks up large rocks into small particles called **sediments**. Types of weathering include physical weathering, chemical weathering and biological weathering.

Physical weathering is the breaking down of rocks into smaller particles by temperature, pressure or weather – for example, by extreme temperatures, high wind, snow, hail, rain and flooding. Ice is a very powerful agent in the weathering process because of a process known as 'freeze–thaw action'. In this process, water enters a crack in a rock and freezes. As it freezes, it expands with great force and widens the crack.

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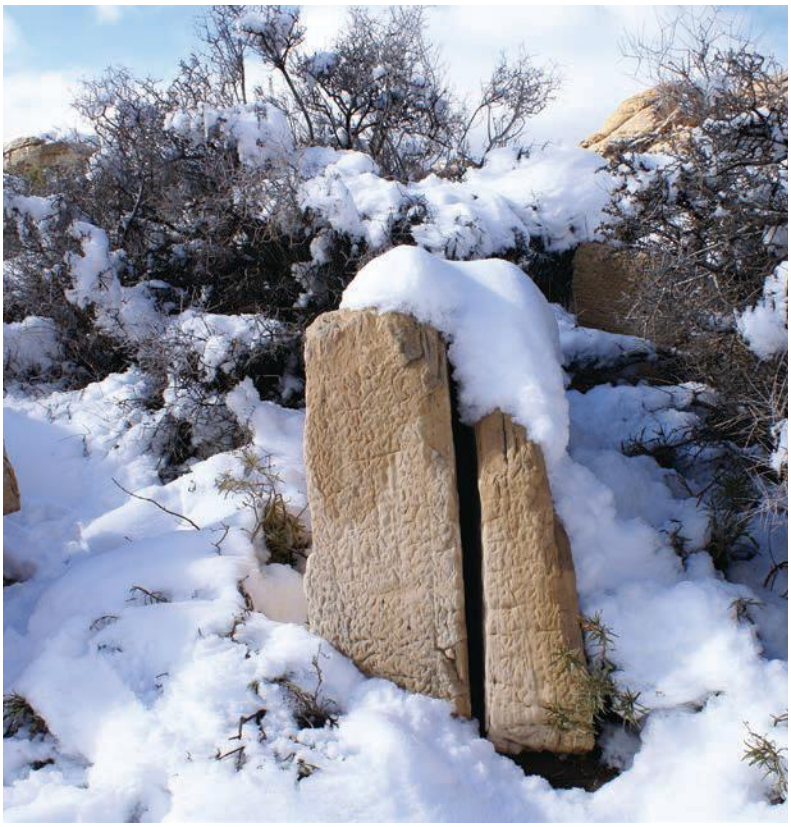


Figure 14.38 A rock split in two by freeze–thaw action

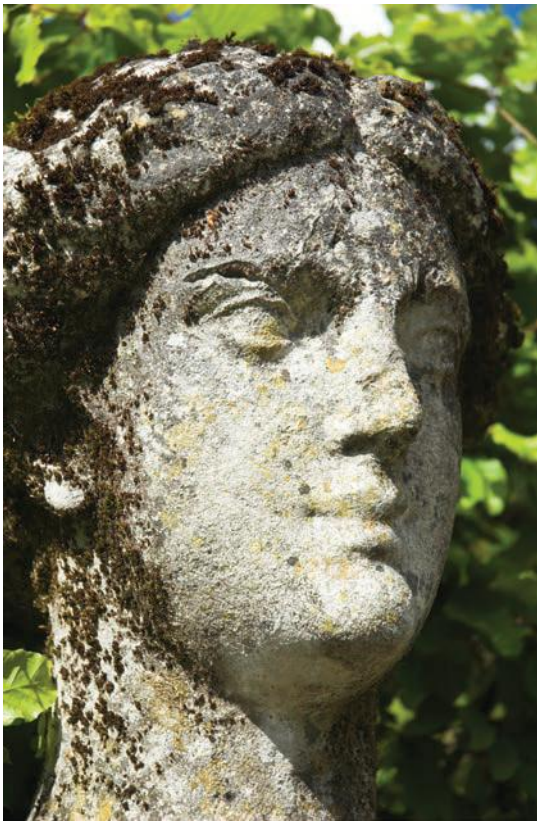


Figure 14.39 Chemical weathering of marble statues

This can happen many times, widening the crack slowly until eventually the rock breaks apart.

Chemical weathering occurs when rocks are slowly dissolved by substances (often pollutants) in rainwater that make it slightly acidic. It occurs relatively rapidly on limestone or marble, as these rocks react readily with acids.

chemical weathering the process in which rocks are broken down and chemically altered, via chemical reactions

Advances in science 14.2

Limestone mining in Kandos

Limestone was mined for around 100 years near the town of Kandos in the Central West region of NSW before the mine closed in 2011. The limestone from here was used to make cement that was sent all around the world to be used in such structures as roads, bridges, reservoirs, pipes, posts, paths, fences and buildings. Kandos also supplied the cement for the construction of the Sydney Harbour Bridge as well as the Opera House. Kandos is known as 'the town that built Sydney'.



Figure 14.40 An old cement silo

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Biological weathering is a form of physical weathering that occurs when rock is broken down into smaller particles by living things. For example, human feet can wear dips into the tops of stone steps, and plant roots grow into small cracks in rocks and make the cracks bigger (see Figure 14.41).

biological weathering the disintegration of rocks that is caused by living things

erosion the transport of rock fragments (that have resulted from weathering)



Figure 14.41 Biological weathering of rock caused by tree roots growing into the cracks

Quick check 14.8

1. **Distinguish** between the three types of weathering: physical, chemical and biological.

Erosion

Erosion occurs when rock that has been broken loose by weathering is transported or moved to a new location. It includes rocks or rock particles falling due to gravity, being carried away in the wind, or moved by waves, ocean currents, running water or even ice in a glacier.



Figure 14.42 These steps have been 'weathered' by people walking on them. The particles of stone have been washed away or eroded by the rain.



Figure 14.43 Ice in a glacier eroding the sediments beneath it

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The size of particles that can be carried is highly dependent on the way it is transported. Only small particles, such as sand, can be blown by the wind, but pebbles and even boulders can be transported in rivers and oceans. Glaciers can carry giant boulders trapped in the ice for many kilometres.



Figure 14.44 Conduct research to find out which process formed The Three Sisters in Katoomba.

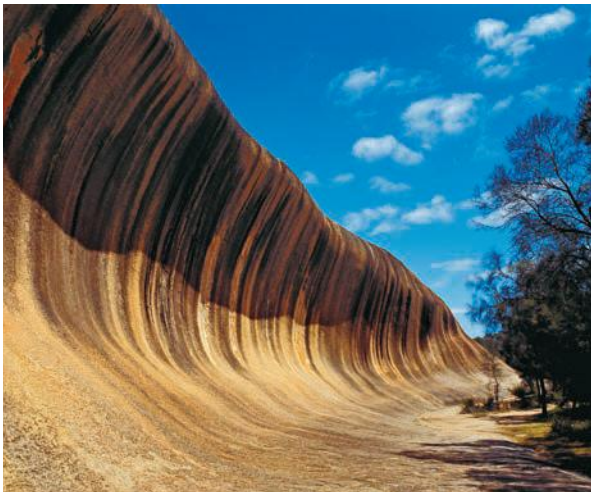


Figure 14.45 Wave Rock in Western Australia is made of granite that is more than two billion years old.

Try this 14.1

Erosion by wind

You will need the following materials:

- Petri dish
- water
- dry sand
- pebbles of various sizes (approximately 5–65 mm in diameter)
- drinking straw
- newspaper

Place the Petri dish on the edge of the newspaper. Moisten the bottom of the Petri dish with just a little bit of water before filling it with sand. Place five pebbles on top of the sand and spread them out evenly. Gently blow through the straw, away from the edge of the newspaper, so the sand lands on the newspaper and does not make a mess.

What do you observe? Which size particles were eroded by the 'wind' and which were not affected?

Deposition, compaction and cementation

Particles or sediments that are eroded come to rest when the wind or water moves more slowly or the ice melts. When the particles reach their destination, they drop, in a process called **deposition**. Often deposition occurs on ocean beds or lake beds. The particles are often deposited in visible layers, which become **compacted** or compressed by the weight of the layers above and **cemented** together. These processes finally form sedimentary rocks. Sometimes animal and plant remains are mixed in with the sediments and preserved as **fossils**. On the seabed, this process can continue in the same place for millions of years and can create layers of sediment many metres high.

deposition
the process that occurs when eroded particles stop moving and build up to form sedimentary rocks

compaction
the process of parts becoming closely positioned together, using very little space

cementation
the sticking together of sediment

fossil
the remains, shape or trace of a bone, shell, microbe, plant or animal that has been preserved in rock for a very long time

Quick check 14.9

1. **Distinguish** between weathering and erosion.
2. **Explain** the processes of deposition, compaction and cementation.

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Figure 14.46 Sedimentary rocks are very common, covering more than 70% of Earth's surface. Some contain fossils that are billions of years old. Note the different layers of sediment, all cemented together.

Practical skills 14.2

Deposits on a lakebed

Aim

To model and observe how sediments are deposited on a lakebed.

Materials

- soil
- sand
- gravel
- water
- jar with lid

Procedure

1. Add soil, sand and gravel to a jar, and mix them. Fill the jar halfway.
2. Add water until the jar is three-quarters full and put the lid on.
3. Make sure the lid is tight and shake the jar for one minute. How do you predict the particles will settle?
4. Observe how the particles settle. Time how long it takes for each layer to form.

Results

Draw a diagram representing the different layers and label them.

Discussion

1. Do the larger particles end up on the top layer or the bottom layer?
2. How long does each layer take to settle? Can you explain why this occurred?

Quick check 14.10

1. **List** the three different types of rock.
2. **Distinguish** between the three kinds of rock in terms of how they are formed.

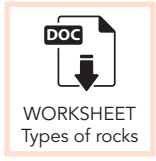
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Try this 14.2

Rock cycle poster

Make a poster of the rock cycle and annotate it with details of the different processes covered in this section. You are going to add to this poster in the next section, so make sure you leave space around the outside for extra information about the types of rocks.

Igneous rocks



WORKSHEET
Types of rocks

Beneath Earth's thin outer crust is molten and semi-molten rock called magma. When the surface crust becomes fractured, thin or weakened, molten magma can reach the surface and a volcano is formed. Igneous rocks are formed when lava cools quickly following a volcanic eruption, sometimes within minutes, or when magma cools and solidifies slowly underground in a magma chamber after it has been pushed close to the surface.

extrusive describes igneous rocks formed on Earth's surface; also called volcanic rocks

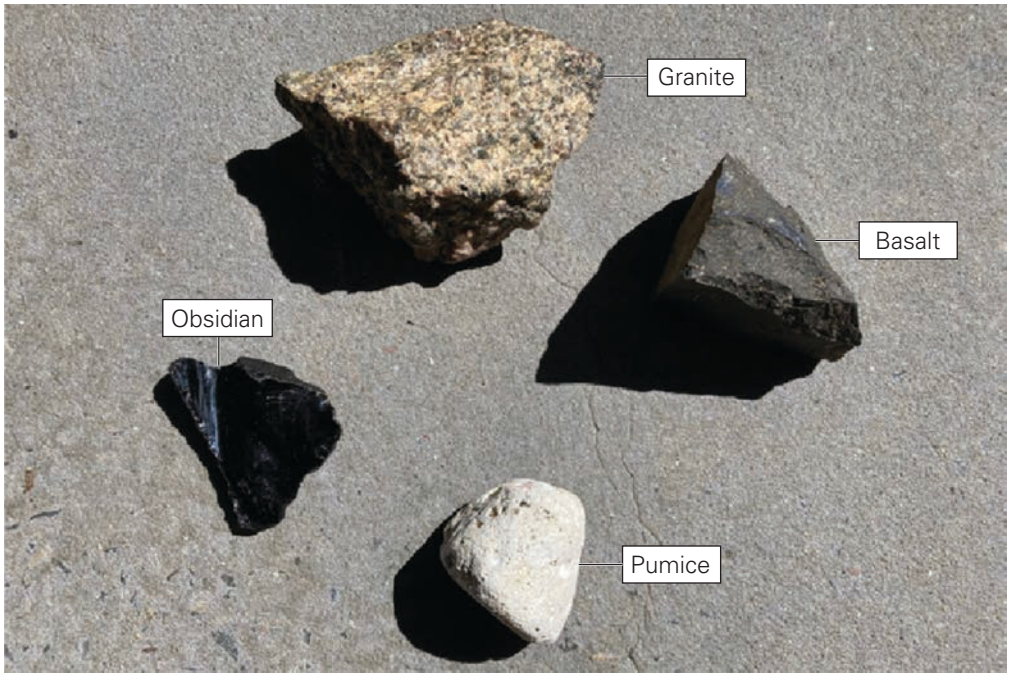


Figure 14.47 Some examples of igneous rocks

The crystals within igneous rocks can give information on how they were formed. The crystals may be anything from several centimetres long to visible only with a microscope. The size of the crystal gives a clue to how long the igneous rock took to cool and, hence, how close to the surface the rock was when it formed. When magma breaks through the crust and flows on the surface, it is called lava. The lava solidifies to form **extrusive** igneous rocks. Basalt, an igneous rock, has the interesting property of forming large hexagonal pillars as it cools. Pumice, also an extrusive igneous rock, floats on water! Obsidian looks like black glass, and due to its sharp edges it has been used as spear heads by indigenous cultures around the world.



Figure 14.48 Lava flows in Hawaii, cooling to form basalt, an igneous rock

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Figure 14.49 The columns or pillars of basalt found in Bombo Quarry near Kiama, NSW, are an example of magma flowing onto the surface, solidifying and forming igneous rock.



Figure 14.50 Basalt lava flows formed these rocks at Kiama blowhole approximately 260 million years ago. The blowhole itself is the result of much more recent erosion. It was first discovered by local Aboriginal Peoples, who named it Khanterinte.

intrusive describes igneous rocks formed underground; these are also called plutonic rocks and have larger crystals than extrusive rocks.

Another way for molten magma to form rocks is if it stops and cools before it gets to the surface and solidifies underground. This rock will cool more slowly and so there is more time for crystals to grow, which means the individual crystals are bigger. Igneous rock formed in this way is called **intrusive** or plutonic. Although this rock is hidden when it is formed, it can be exposed later when the layers above have been eroded. Granite is an example of a plutonic igneous rock formed beneath the surface of a volcano.



Figure 14.51 Granite has a distinctive mosaic of crystals of different colours. It has larger crystals because it cooled slowly. It is an intrusive igneous rock.



Figure 14.52 Granite is often used to make kitchen benchtops.

Quick check 14.11

1. **List** three examples of igneous rocks.
2. **Describe** in your own words how intrusive and extrusive igneous rocks are formed.
3. **Describe** the relationship between crystal size and the time the crystal takes to form.

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Investigation 14.1

Crystals and cooling rate

INVESTIGATION

Aim

To determine the effect that cooling rate has on crystal size formation.

Materials

- saturated potassium nitrate or magnesium sulfate
- beakers
- test tubes
- water
- ice
- hand lens

Planning

1. Write a rationale about crystal growth and the factors that can affect it.
2. Write a specific and relevant research question for your investigation.
3. Identify the independent, dependent and controlled variables.
4. Write a hypothesis for your investigation.
5. Write a risk assessment for your investigation.

Procedure

Using the materials, design an experiment to investigate how cooling rate affects the size of crystals of saturated potassium nitrate or magnesium sulfate.

Hint: To create crystals, you need to use a saturated solution of potassium nitrate or magnesium sulfate.

Results

Record your results. Consider different ways your results could be presented.

Discussion

1. Describe any patterns, trends or relationships in your results.
2. Explain any trends you have identified.
3. Identify any limitations in your investigation.
4. Suggest some improvements for this experiment.

Conclusion

1. Make a claim about the effect that cooling rate has on crystal size formation.
2. Support the claim by referring to your experimental observations.
3. Explain how your observations support your claim.

Metamorphic rocks

When rocks are subjected to very high temperature and pressure, they change into metamorphic rocks. The word metamorphic comes from Greek meaning 'transformed'; you might recognise 'morph' meaning to gradually change. The crystals inside these rocks may become deformed, and the chemical nature of the rock may change. Rocks that have been changed into metamorphic rock tend to be denser and harder than before. Under intense pressure, rocks may also become twisted and folded, as evidenced by the foliation patterns in them.

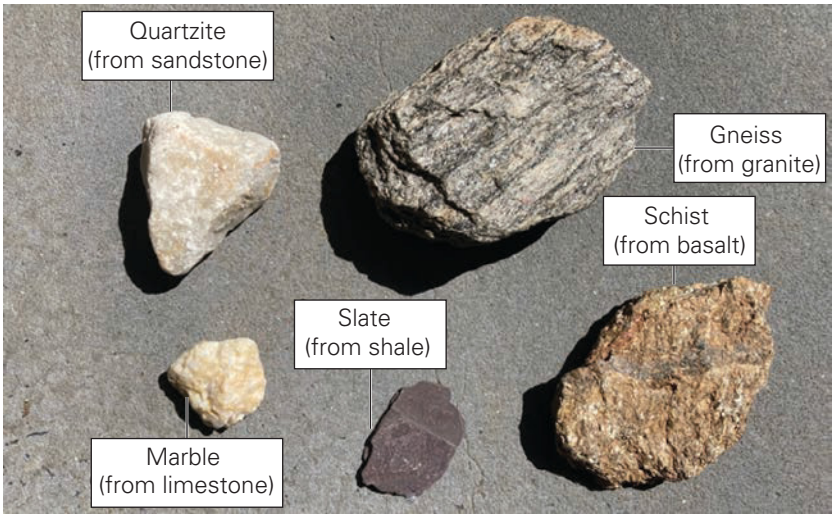


Figure 14.53 Some examples of metamorphic rocks

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VIDEO
Describe the three rock types

Over millions of years, buried metamorphic rocks can eventually make their way to the surface again. These rocks are found all over the world, and they constitute about 10% of Earth's surface. Because of their toughness, they are often used for building materials. For example, if limestone (sedimentary) is subjected to high pressure and temperature, it turns into marble (metamorphic). Marble is slightly denser and harder than limestone.



Figure 14.54 Marble is a metamorphic rock often used in bathrooms.

Can you think what marble is used for? Other common metamorphic rocks are:

- slate, which is metamorphosed shale (sedimentary)
- quartzite, which is metamorphosed sandstone (sedimentary)
- schist, which is a medium-grade metamorphic rock
- gneiss, which is the highest-grade metamorphic rock, forming under very high temperature and pressure.

INVESTIGATION

Explore! 14.3

Stone tools

Aboriginal and Torres Strait Islander Peoples have used a variety of rocks, such as basalt, sandstone, quartzite, chert and flint, depending on what is available on their particular Country. These rocks are then shaped and transformed into a variety of objects, such as grindstones, hammerstones, anvils, cutting tools and weapons. The techniques involved in creating stone tools require knowledge from the various disciplines of science. Conduct research to investigate the following questions.

1. Explain how having a knowledge of the geological, biological, chemical and physical sciences helps to create stone tools that are fit for the intended purpose.
2. Determine why the following rock types are used as the named tools in various Aboriginal and Torres Strait Islander cultures.
   a. The use of basalt as an axe head.
   b. The use of flint as a cutting tool.
   c. The use of limestone as a hammerstone.
3. Examples of techniques and methods are knapping, lithic reduction, percussion flaking, pressure flaking and grinding. Describe what each of these processes involves and how they help create stone tools from the raw material.



Figure 14.55 A young girl from Bow River grinds stone to a powder that will be used for artworks.

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Quick check 14.12

1. **Describe** how metamorphic rock is formed.
2. **Recall** three examples of a metamorphic rock and what components make up each one.

Sedimentary rocks

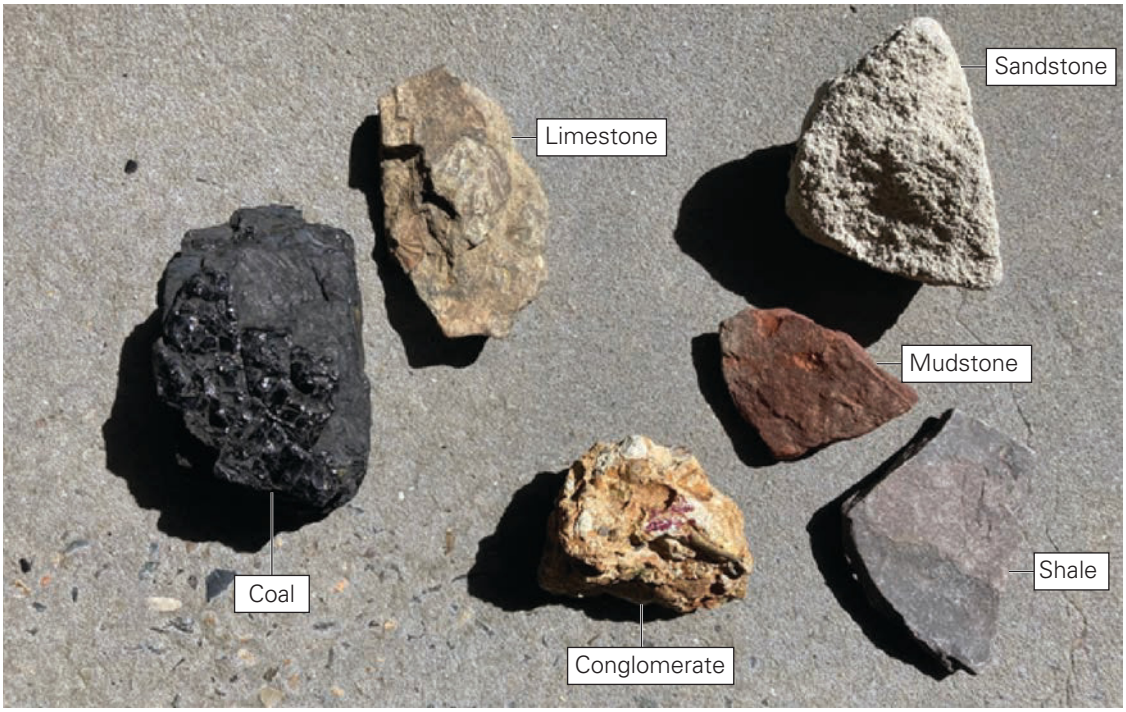


Figure 14.56 Some examples of sedimentary rocks

Weathering from waves, flowing water, wind, frost, rain, ice, chemicals and even living organisms can break down the surface of exposed rocks. The particles of weathered rock are eroded and carried away by water, gravity, wind or ice. Eventually, the particles can no longer be carried, and sedimentary rocks are formed when these particles or sediments are deposited, compacted and cemented together. Sedimentary rocks take thousands to millions of years to form. Uluṟu, in the Northern Territory, is 500 million years old (see Figure 14.57). The vertical ridges you can see were originally horizontal layers of sand and rock.



Figure 14.57 Uluṟu is an ancient sedimentary rock that holds great spiritual significance for the Aṉangu Peoples. It is tilted by nearly 90° by the movement of Earth's crust.

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The type of sedimentary rock formed depends on the size and composition of particles that are deposited. Sand is commonly found all over the world on beaches and at the bottom of rivers, lakes and the sea. The sedimentary rock formed from sand is called sandstone. It is a common building material because it is relatively easy to cut and is strong. Many of the early buildings in Sydney were built from sandstone mined locally from The Rocks area.



Figure 14.58 Sandstone blocks in Barangaroo

If the particles are smaller than sand grains, the sedimentary rock formed may be a shale or a mudstone. If the particles are of mixed sizes, containing large pebbles, as well as sand and mud, it is called a **conglomerate**.

conglomerate sedimentary rock composed of rounded rock fragments larger than 2 millimetres

Limestone is another sedimentary rock that is commonly found on Earth's surface. Like sandstone, it is also formed from sediment, but its composition is different to the quartz sand it is made from. It is formed from the shells and skeletons of sea creatures that collected on the seafloor. If the sediment is very fine, chalk is formed. These rocks contain calcium carbonate and can be identified by a simple test: when acid is placed on the surface, bubbles form. Chalk and limestone often contain fossils, and the age of the rock can be determined from the fossils it contains.

DOC WORKSHEET Identifying types of rocks

WIDGET A key to identify rocks



Figure 14.59 Sedimentary rock made from rounded pebbles is called a conglomerate.



Figure 14.60 Limestone often contains fossils.

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The law of superposition

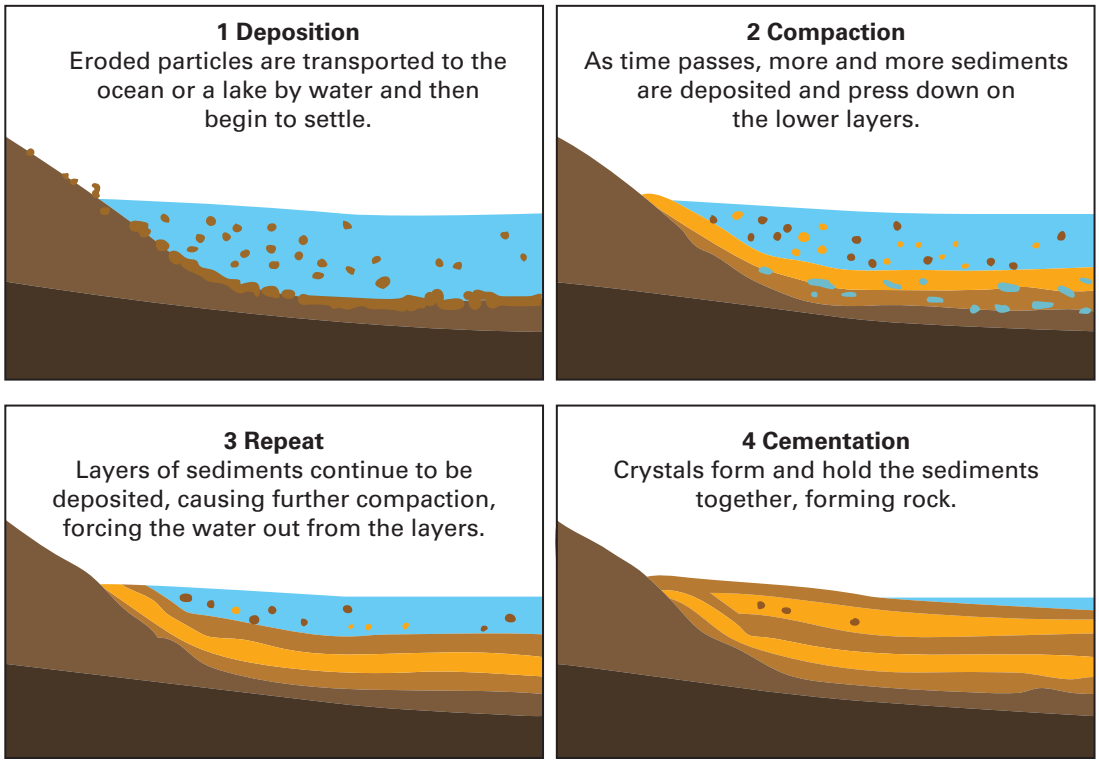


Figure 14.61 The formation of sedimentary rocks such as sandstone and mudstone

Figure 14.61 shows how a lot of sedimentary rocks are laid down in layers. We can see that the oldest rock would be at the bottom, as these layers were laid down first, and therefore the youngest rock layers would be on top. Geologists use this method to help give sedimentary rocks relative ages. This is called the law of superposition. By looking at the relative ages of sedimentary rocks, that is, the rocks' positions in a sequence, a geologist can estimate their ages.

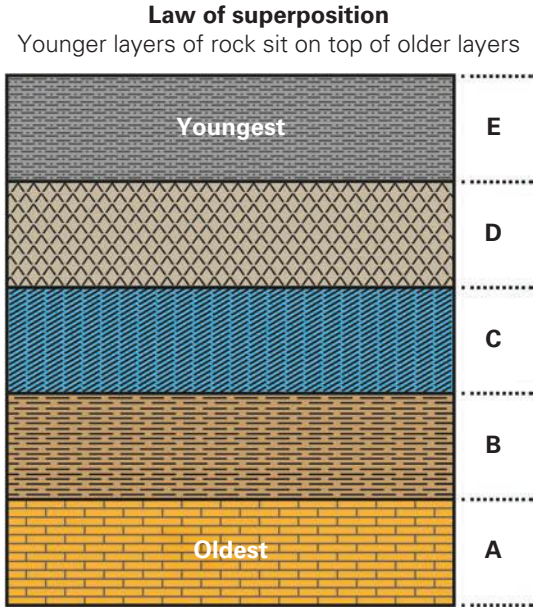


Figure 14.62 The law of superposition states that the oldest layers are at the bottom as they were deposited first.

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INVESTIGATION

Explore! 14.4

How is coal made?

Organic material from living creatures can also form sedimentary layers. Layers of plant material form coal, while oil is formed mostly from plankton. Although oil is a liquid, it is still sedimentary.

Use your preferred search engine to research the following questions.

1. List three different uses for coal.
2. Coal is a non-renewable resource. Are there any alternatives to coal for the uses you listed in the previous question?

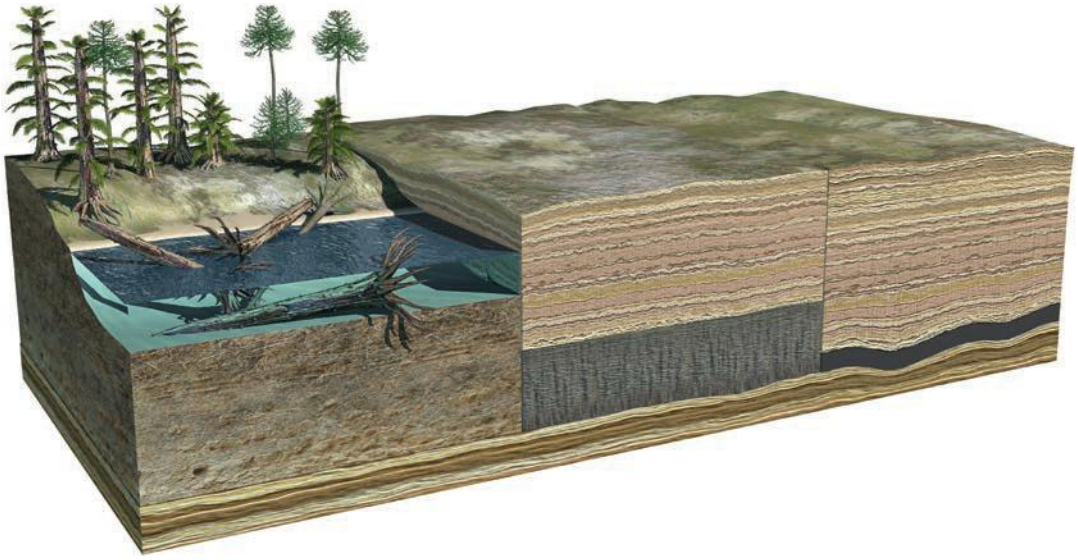


Figure 14.63 How coal is formed. Left: In the Carboniferous Period, trees died and formed a layer of wood. Middle: The wood was compressed by the layers of sediment which formed above. Right: The compressed wood was transformed by heat and pressure into coal.

Properties of minerals

Rocks are made of minerals. If you look closely at a piece of granite, you can see different colours. How many different colours can you see? Each one of these colours corresponds to a different mineral.

There are thousands of minerals. However, only 30 of them make up the majority of rocks. Minerals have a specific chemical formula and unique properties. The most common rock-forming minerals are quartz, calcite, mica, feldspar, amphiboles and pyroxenes. Some properties that can be used to identify minerals are colour, lustre, hardness, cleavage, streak and density (specific gravity).



Figure 14.64 The pink mineral in this sample of granite is feldspar (orthoclase), the white mineral is quartz, and the black minerals are pyroxene and biotite.

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Colour

The first thing you may notice about a mineral is its colour. And indeed, it is a distinguishing feature. But colour alone is not enough to identify a mineral as many minerals have variations in colour due to impurities or changes under high pressure and temperature.

Lustre

Lustre refers to how shiny the mineral appears, and whether it is translucent or opaque. Some terms to describe the lustre of a mineral include metallic, vitreous (also known as glassy), adamantine (also known as brilliant or diamond-like), silky, pearly and waxy.

Hardness

A useful method to help identify minerals, is to determine how hard the surface is. In 1812, Friedrich Mohs classified all minerals according to their ability to scratch each other, on a scale from 1 to 10.

The softest mineral, with a 1 on the Mohs scale, is talc, and the hardest is diamond with a 10. A mineral with a higher **Mohs scale** number can scratch any mineral with a lower number.



Figure 14.65 These minerals are all forms of quartz but appear as different colours, such as the purple amethyst in the centre.



Figure 14.66 A diamond has a hardness of 10 on the Mohs hardness scale.

Mohs scale
a scale from 1 to 10 that indicates the hardness of a rock

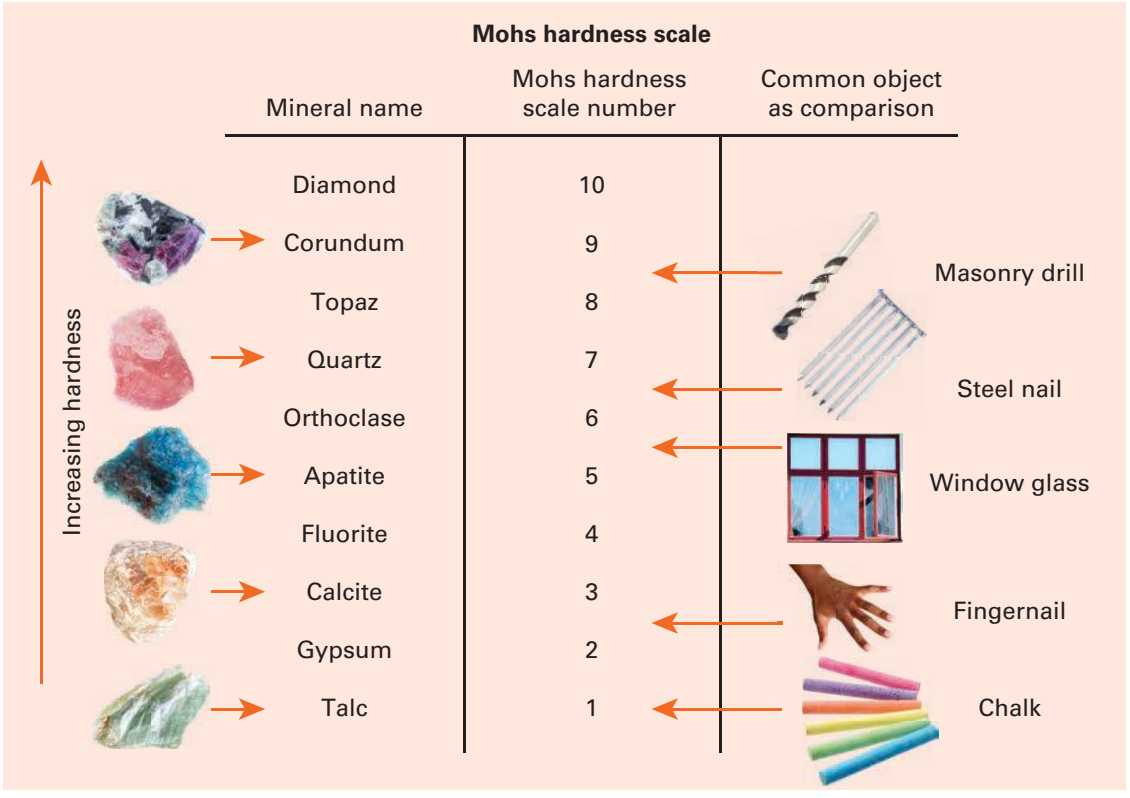


Figure 14.67 A table comparing objects of similar hardness on the Mohs hardness scale

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Cleavage

cleavage
the tendency of a mineral to break in a particular way because of its structure

Cleavage refers to the tendency of a mineral to break along specific planes of weakness in its crystal structure and hence break more easily in some directions than others. This gives some minerals a very distinctive shape.

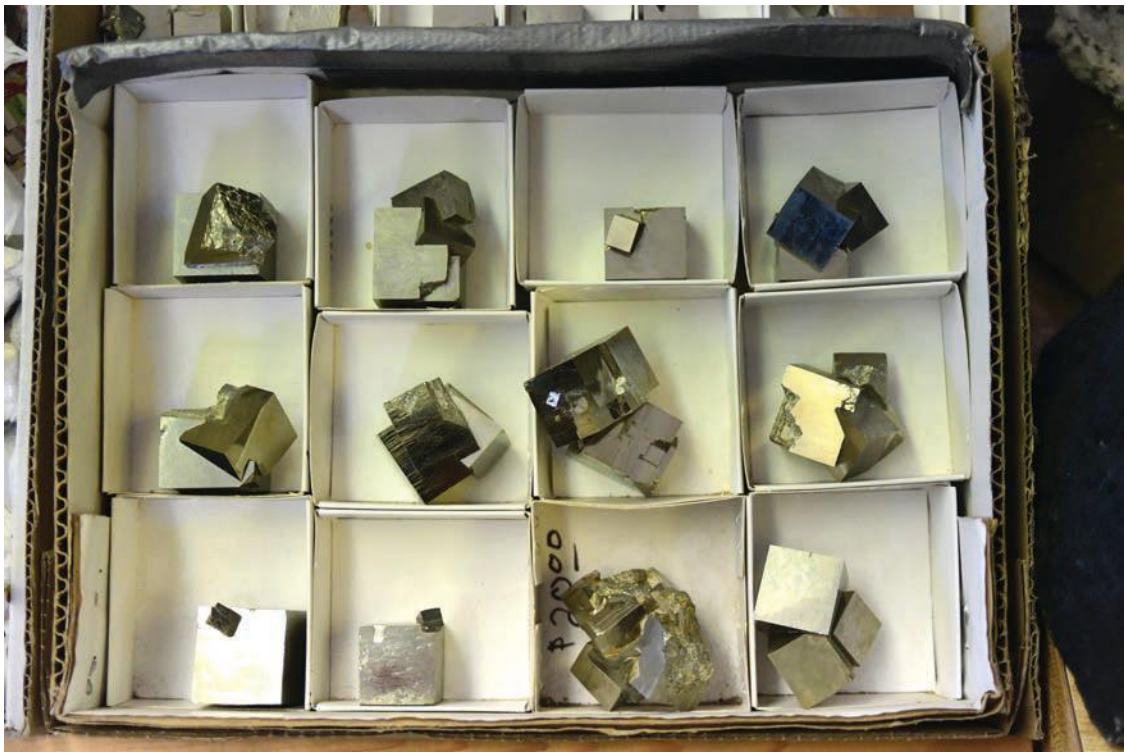


Figure 14.68 These pyrite samples are real! It is sometimes referred to as 'fool's gold' but can be easily distinguished from gold due to its distinctive cleavage.

Streak

Have you noticed when you pick up a rock and draw with it, the colour of the streak is not always the same colour as the mineral? The coloured streak a mineral leaves behind on a white ceramic tile is a more reliable indicator of its colour than the colour of its surface. For example, haematite is a dark-grey rock but has a reddish-brown streak.



Figure 14.69 Streak test on a haematite rock showing its streak colour

Density

streak test
a test used to help identify a mineral by scratching a rock on a hard ceramic tile

Every mineral has a specific density. This helps us identify the mineral. For example, if you wanted to know if your Olympic gold medal is pure gold or whether it is gold plated, you could find out its density. Gold has a very high density of 19.3 g/cm^3, whereas silver has a density of 10.5 g/cm^3.

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Did you know? 14.4

Eureka!

Archimedes's eureka moment was when he realised how he could prove the king's crown was made of gold without damaging it. He did this by submerging it in water to measure the volume of water it displaced to calculate the its density. He did find that the goldsmith was cheating the king by replacing much of the gold with silver, which is almost half the density of gold. Not good news for the goldsmith!



Figure 14.70 Archimedes's eureka moment!

Investigation 14.2

INVESTIGATION

How dense are different rocks?

Aim

To compare the densities of different rock types.

Materials

- 4 different types of rock (basalt, granite, sandstone and chalk)
- 10 mL measuring cylinder
- displacement can
- balance

Procedure

1. Draw the results table below.
2. Measure the mass of each rock type and record it in your results table.
3. Fill the displacement can with water.
4. Holding the 10 mL measuring cylinder at the spout of the displacement can, gently drop one of the rocks into the can.
5. Record the volume of water expelled in cubic centimetres (cm^3) in the results table. (Note: 1 mL = 1 cm^3.)
6. Repeat the above steps twice more with the same piece of rock, refilling the can before each procedure.
7. Following the same procedure, repeat for the other rock types.
8. Calculate the average volume of water expelled from the displacement can.
9. Using the formula below, calculate the density of each rock type.

$$\text{density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

Results

Type of rock	Mass (g)	Volume of water expelled (cm^3)			Mean volume (cm^3)	Density (g/cm^3)
		1	2	3		
Basalt						
Granite						
Sandstone						
Chalk						

continued ...

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Discussion

1. Organise the rocks from most to least dense.
2. Explain why the experiment was conducted three times for each rock type.
3. Explain why you should always measure at the bottom of the meniscus when measuring water levels.
4. Compare the density of each rock that you calculated to densities obtained from secondary sources on the internet. How close were you to those values?

Conclusion

1. Identify which rock was the most dense and which rock was the least dense.
2. Using your results, explain why oceanic crusts made of basalt subduct underneath continental crust made predominantly of granite at destructive plate boundaries.



Figure 14.71 Fossilised leaves in mudstone

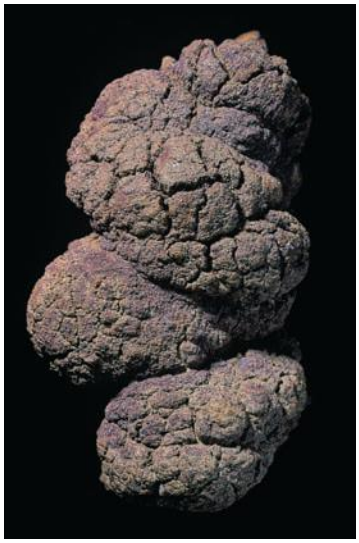


Figure 14.72 Coprolite is fossilised faeces. This could have come from a dinosaur millions of years ago!

Fossils

The bodies of different organisms may be deposited in sediment and form part of the sedimentary rock – this is how they become fossils. Groundwater containing dissolved minerals such as silica or calcite seeps into the remains. The minerals precipitate out of solution and crystallise over time, replacing the organic material entirely but retaining the shape of much of the organism's structure. In rare cases, the mineral which replaces the organic material is opal, a colourful type of silica. Such fossils are found in Lightning Ridge in New South Wales. Fossils can include footprints of animals or faeces (coprolites). Generally, fossils are only formed in rocks that start as sedimentary rocks. But rocks are always changing, and if the rock is later subjected to intense temperature or pressure, it may become metamorphic without the fossil being destroyed.

Fossils can be used to trace the history of life on Earth. Because sedimentary rocks form slowly, the passage of time is traced in their layers, with the oldest rocks at the bottom. Fossils found in the same layer must have lived at the same time in the same location, and so were part of the same ecosystem. Fossils found in different layers must have lived at different times, with newer fossils being found above older fossils. Evidence of extinction events can be seen when a certain type of fossil suddenly disappears. For example, by studying sedimentary rocks, it is known that all the dinosaurs became extinct at the same time, about 60 million years ago.

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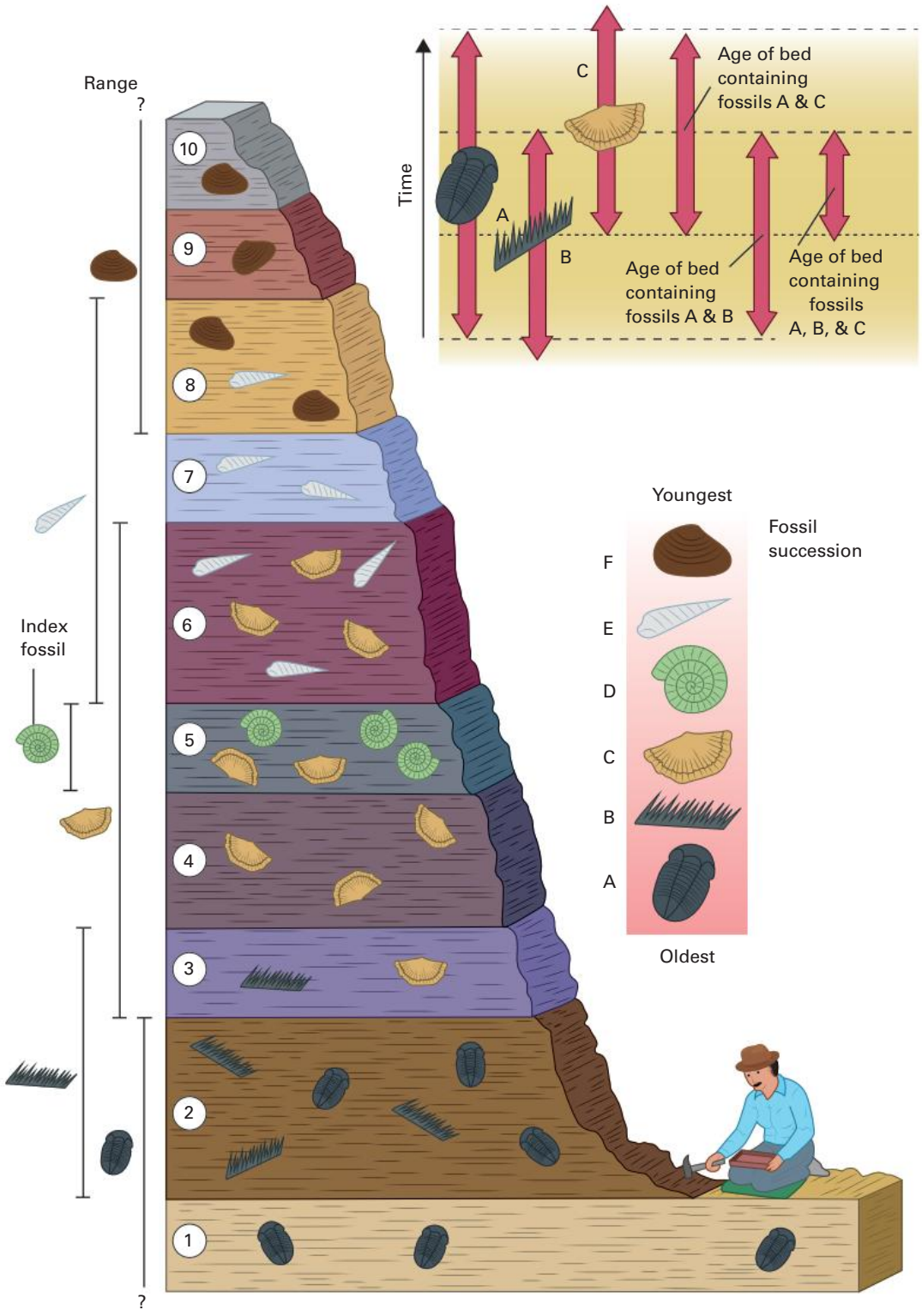


Figure 14.73 Fossils found in the same layer must have lived at the same time in the same location, and so were part of the same ecosystem.

Explore! 14.5

INVESTIGATION

Fossil formation

Use your preferred search engine to find out about the process of fossilisation.

1. Not all living things become fossils. Describe the conditions necessary for fossils to form.
2. Evaluate some things that scientists have learned from fossils.

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Types of fossils

There are various types of fossils, depending on how the impression was formed. Some common types are listed in Table 14.2.

Fossil type	Details	Images
Body	Parts of an organism, mainly hard parts like teeth, shells, bones, sometimes softer parts, and sometimes a whole organism, in which the original organic material has been replaced by minerals	 **Figure 14.74** Fossil fish from the Jurassic Period found in the Holzmaden Black Shale beds in Germany. It now consists entirely of minerals.
Mould	When a plant or animal decays in sediment, it may leave a hollow impression of itself.	 **Figure 14.75** The mould of an ammonite
Cast	When an animal or plant dies, its body creates a space in the sediment. This gap fills with minerals, such as silica, over time, and the shape of the animal is preserved as rock.	 **Figure 14.76** A fossilised trilobite, an extinct creature that once dominated life on Earth
Imprint	These fossils leave behind a two-dimensional (flat) print.	 **Figure 14.77** Leaves are pressed flat by the pressure in the sedimentary layers and all that is left is a dark area, like a shadow.
Amber	A whole organism is trapped in tree resin that hardens and fossilises as amber.	 **Figure 14.78** Whole-body fossils are found intact in a medium such as tree resin, which fossilises to become amber.
Indirect or trace	These fossils do not consist of part of the organism. They are indirect records of biological activities, such as footprints, teeth marks or burrow marks.	 **Figure 14.79** From a set of footprints, scientists can tell how fast the animal was moving, whether it was solitary or moved in groups, and how heavy it was.

Table 14.2 Six common types of fossils

Quick check 14.13

1. **Recall** how sedimentary rocks are formed.
2. **List** some examples of sedimentary rocks.
3. **Distinguish** between the five types of fossils discussed in this section.

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Advances in science 14.3

How did it become extinct?

The fossil record is the history of life as it is seen from fossils. It can tell us about groups of animals that are extinct, such as dinosaurs, and how animals and plants relate to each other. Unfortunately, the fossil record is incomplete because specific conditions are required for fossilisation to take place. Not all dead things become fossils.

Interpretation of the fossil record has always presented difficulties for palaeontologists (scientists who study fossils). For example, for many years it was believed that the extinction of dinosaurs was gradual, but in 1980 evidence was found of a meteor impact that is now thought to have caused the mass extinction. Also, disappearance from the fossil record does not always mean that a species is extinct; there may be many other reasons for its absence from the record.

Palaeontologists Steven Holland and Mark Patzkowsky designed computer models to aid the study of mass extinction and are using the models to more accurately decipher the fossil record. Their work is still in progress. However, it provides an initial guideline for analysis and assessment of extinction events.



Figure 14.80 Dinosaur tracks fossilised on the ground on the edge overlooking Bull Canyon. Sixty-six million years ago, a huge celestial object struck off the coast of what is now Mexico, triggering a catastrophic cooling period that eventually wiped out three-quarters of life on Earth, including the dinosaurs.

Try this 14.3

Summing up

Using the poster you began in *Try this 14.2*, annotate it with information about the three different rock types you have learned about, their characteristics and examples of each.

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VIDEO
Using rocks

INVESTIGATION

Explore! 14.6

Stone pigments

Aboriginal and Torres Strait Islander Peoples use paints, dyes and pigments originating from plant, animal and mineral sources.

1. Investigate one of these pigments and what rock (sedimentary/metamorphic/igneous) or mineral is used, as well as the chemical and/or physical processes involved:
   - red pigment
   - black pigment
   - white pigment
2. Fixatives can be applied to paints, enabling the pigment to bind to surfaces and increase the durability of the paintings. Name some fixatives used by Aboriginal and Torres Strait Islander Peoples.



Figure 14.81 Ground natural paints

Composition of Earth and other planets



Figure 14.82 The planets in our solar system, lined up according to their proximity to the Sun

The solar system was formed 4.6 billion years ago, including all of its planets. The four planets closest to the sun are called terrestrial planets. These are similar in composition and include Earth. Mercury is the richest in metals, while Earth, Venus and Mars all have roughly similar bulk compositions: about one-third of their mass consists of iron–nickel or iron–sulfur combinations; the remaining two-thirds are made of silicates (silicon and oxygen).

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The other four planets are referred to as gas giants. These mostly consist of lighter elements such as hydrogen and helium, although they also contain some heavier elements.

Asteroids are made of rock rich in metals and other elements. Some contain water in the form of ice. Asteroids sometimes collide with each other and break into smaller pieces. These are called meteors. Occasionally a meteor will collide with Earth. Once a meteor enters Earth's atmosphere, it is referred to as a meteorite. Smaller meteors will burn up in the atmosphere due to friction with air, but larger ones have landed on the surface of Earth. It is likely that the extinction of dinosaurs was caused by a such a cataclysmic event.

How do we know the composition of the other planets? By studying the motion of these planets, their mass can be calculated and hence also their density. Since we know the density of rock by studying our own planet, and we know the solar system and its planets formed at the same time, we can infer a lot about their composition.





Figure 14.83 Meteorites are smaller pieces of asteroids. Some of these have landed on Earth.

Explore! 14.7

INVESTIGATION

Mining asteroids

Use internet searches to find the latest investigation into mining asteroids. Work in teams to construct a PowerPoint presentation for your peers. Include reasons why mining should be conducted on asteroid, how this might be achieved, what are the minerals that can be mined and what we could use them for.

Section 14.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 14.2 questions

Remembering

1. **Name** the type of rocks formed during a volcanic eruption.
2. **Name** the type of rocks formed when sedimentary rocks change due to high temperature and pressure.
3. **Recall** what sedimentary rocks formed from pebbles are called.
4. **Name** five common fossil types.

Understanding

5. **Outline** how marble is formed and determine what type of rocks are involved.
6. **Explain** how the vertical layering of the rock forming Uluru indicates that Earth is ancient.

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Applying

7. Figure 14.84 shows a basalt columns rock formation at Fingal Head in northern NSW. Use what you have learned about igneous rocks to **explain** how this formation came to be.



Figure 14.84 A set of basalt columns at Fingal Head in NSW

Analysing

8. Examine the igneous rocks shown in Figure 14.85. **Identify** which one is intrusive and which one is extrusive. **Explain** your reasoning by first recalling the difference between intrusive and extrusive.

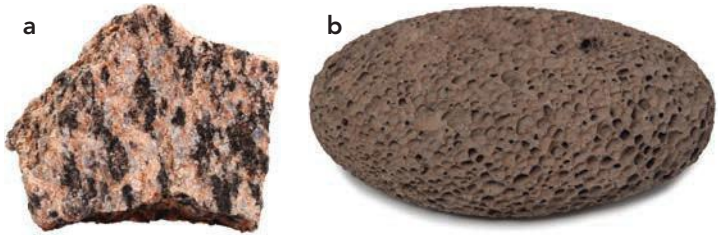


Figure 14.85 Types of igneous rocks

9. **Classify** the types of fossils shown in Figure 14.86.



Figure 14.86 Types of fossils

Evaluating

10. **Evaluate** why the water in the Macleay River (Figure 14.87) is brown. Use the following terms in your explanation: particles, sediment, weathering, erosion, deposit, rock.

11. 'A rock is clearly seen to be made of distinct and different layers. Therefore, it must be a rock, not a mineral.' **Evaluate** this statement and explain your reasoning.



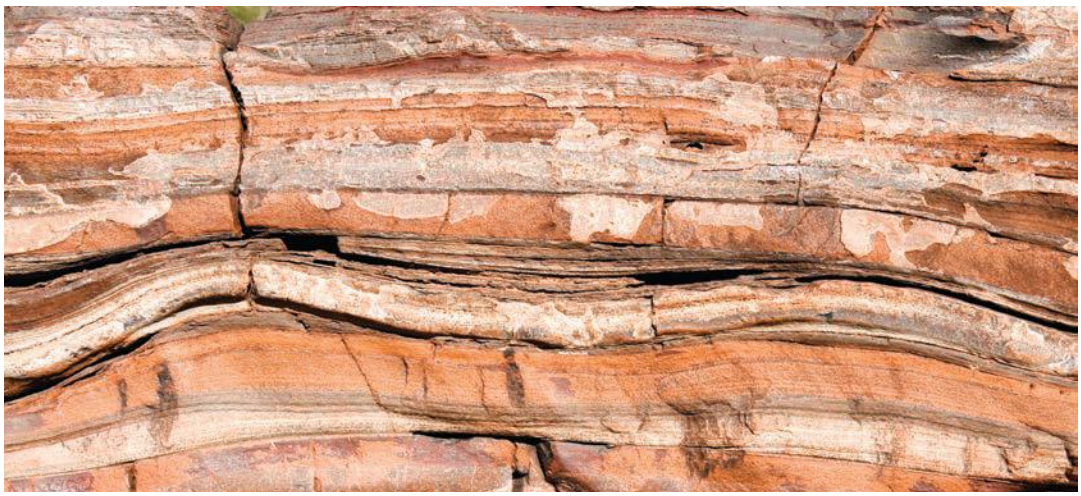
Figure 14.87 Brown water in the Macleay River near Kempsey, NSW

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Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
14.1	explain the evidence used in the development of the theory of continental drift and plate tectonics.	7
14.1	describe earthquakes and volcanoes as evidence of geological changes in the Earth's crust.	18
14.1	explain the relative significance of different forces involved in tectonic plate movement.	4
14.1	describe the forces and movement involved in three types of plate boundaries.	5
14.1	model interactions at plate boundaries.	2, 10
14.1	describe examples of Aboriginal and Torres Strait Islander Cultural accounts that provide evidence of earthquakes and volcanoes.	8
14.2	describe the major processes of the rock cycle including melting and cooling, temperature and pressure, weathering and erosion, deposition, compaction and cementation.	6, 11
14.2	consider the role of forces and heat energy in the formation of igneous, sedimentary and metamorphic rocks.	1, 15
14.2	compare how quickly or slowly different rock formation processes can occur.	6
14.2	recognise how the law of superposition helps determine the relative age of rock strata.	13, 16
14.2	describe investigations or simulations into the observable properties of rocks and recall properties including crystal size and density.	6, 12
14.2	model the formation of fossils including body, cast, trace, opalised and amber fossils.	9
14.2	explain how fossils can be used to date rocks and organisms.	16
14.2	recall the main chemical elements comprising Earth and compare them to those of one or more other planets.	14



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Scorcher competition

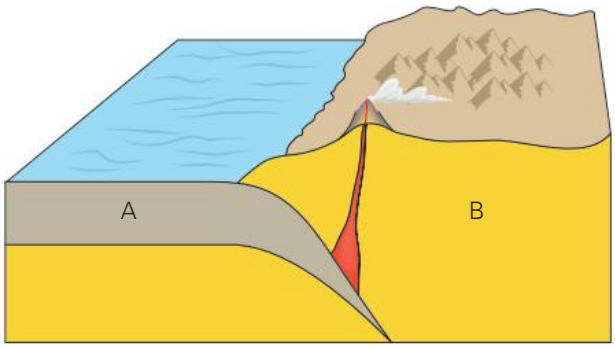
Review questions

Data questions

Review questions

Remembering

1. **Name** the two types of igneous rock.
2. **Recall** the differences in geology between a rock, a mineral and a crystal.
3. **Identify** which of the plates, A and B, at the subduction zone in the diagram is the continental plate and which is the oceanic plate, and state whether they are converging or diverging.



Understanding

4. **Explain** with the help of a drawing the forces that cause a tectonic plate to move.
5. **Describe** the three types of plate boundaries and how their movement affects the amount of crust present at each one.
6. **Explain** how differences in the processes that form the rocks schist and granite are reflected in the nature of their crystals.
7. **Describe** how Marie Tharp's topographic maps provided support for plate tectonic theory.
8. **Describe** an example of an Aboriginal and Torres Strait Islander Cultural account that provides evidence of earthquakes and volcanoes.
9. **Describe** the process of a body fossil forming and becoming mineralised.



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Applying

10. **Infer** whether the following effects indicate a constructive, destructive or transform plate boundary.
- **a.** No mountains form.
- **b.** Island arcs form.
- **c.** Crust is conserved.

11. Using the rock cycle, **describe** the process by which:
- **a.** igneous rock transforms into sedimentary rock
- **b.** metamorphic rock transforms into igneous rock.

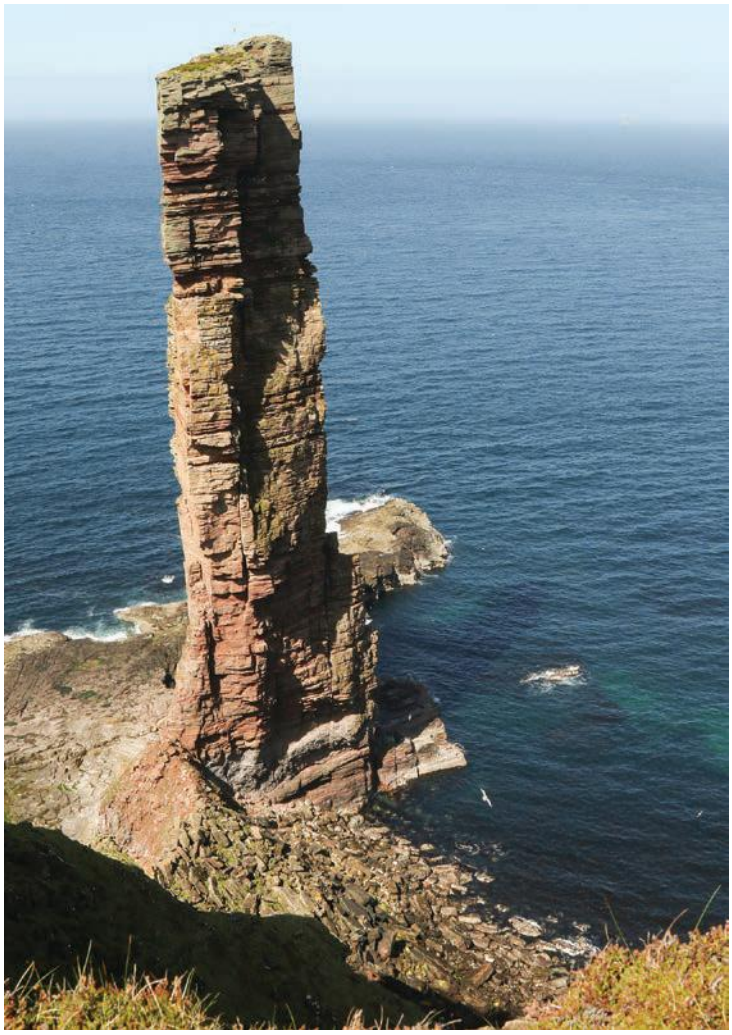
12. A rock is found to be made of a mixture of minerals with large crystal sizes. **Explain** what this tells us about how long it took the rock to form.

13. You are asked to examine rock strata in a specific location.
- **a.** Explain how you would determine the relative ages of the strata.
- **b.** You observe that the strata contain fossils. Explain how you would use the fossils to confirm the relative ages obtained in part **a**.

14. Two exoplanets (planets in another solar system) are detected. Studies indicate Exoplanet A is made mainly of metals and Exoplanet B is made mainly of helium. **Explain** which planets in our solar system each exoplanet is likely to resemble.

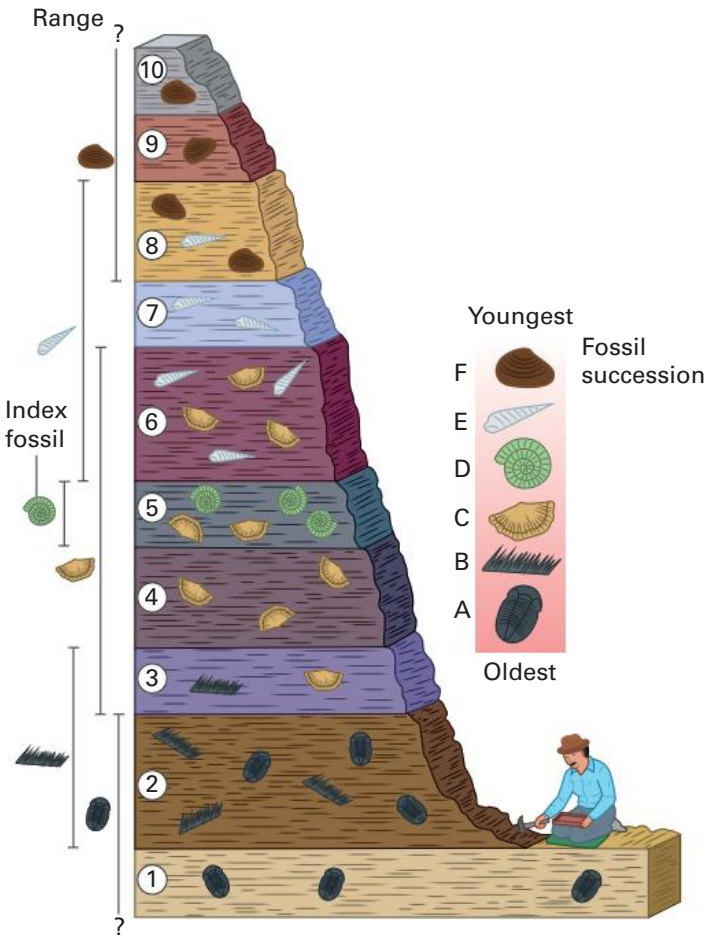
Analysing

15. **Infer** the geological processes that occurred to produce the formation shown in this image.



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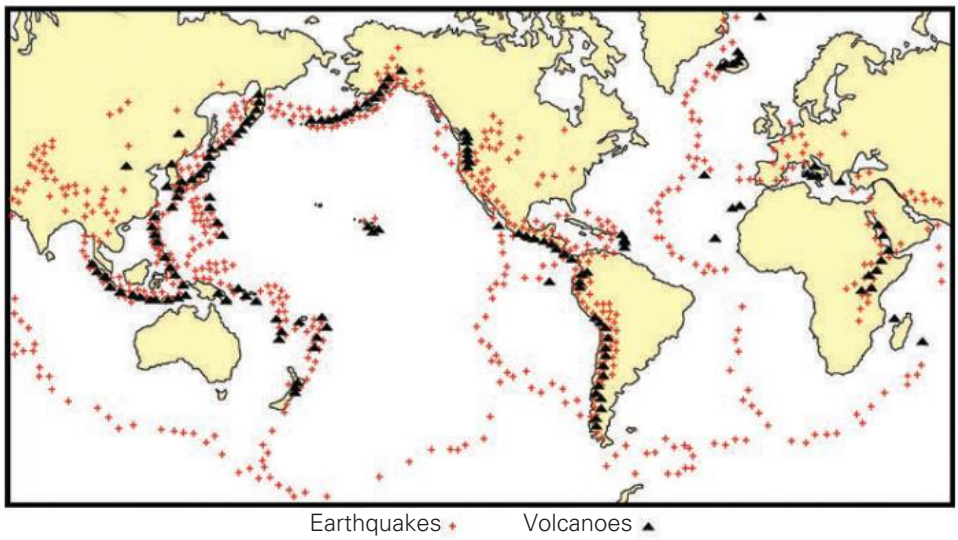
16. The diagram shows a geologist studying rock strata exposed in the walls of a canyon. He has found six fossilised organisms labelled from A to F in the strata, which are labelled from 1 to 10. The same strata are found over a wide region. Analyse which of these fossils would be the best to choose as a reference point for dating other fossils and strata in the region. **Justify** your choice.



Evaluating

17. Predict what you think will happen to Earth's continents in the next 100 million years.

18. Propose an explanation for the locations of global earthquake and volcanic activity shown in the map below.



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Data questions

New Zealand is a country that lies very close to a fault boundary and consequently experiences thousands of earthquakes a year. Earthquakes are categorised using the Richter scale, which measures earthquake magnitude on a scale of 0 to 10 (see Table 14.3). The magnitudes of 10 New Zealand earthquakes from 2010 to 2019 are presented in Table 14.4.

Richter scale	Observation
0.0–2.9	Not felt by humans
3.0–4.9	Felt by humans and not damaging
5.0–5.9	Small risk of damage to buildings
6.0–6.9	Moderate risk of damage to buildings
7.0–7.9	High risk of damage to buildings
8.0+	High probability of severe destruction

Table 14.3 Severity of earthquakes observed with the corresponding ranges of Richter scale values

Earthquake reference	Magnitude (Richter scale)
1	4.1
2	7.8
3	4.3
4	2.9
5	5.1
6	6.6
7	2.3
8	6.1
9	1.1
10	7.6

Table 14.4 The magnitude on the Richter scale of 10 earthquakes that occurred in New Zealand between 2010 and 2019

1. **Identify** the most severe earthquake recorded in Table 14.4.
2. **Determine** the earthquakes that had a high risk of damage to buildings.
3. The media are reporting a new earthquake in New Zealand that measures 6.5 on the Richter scale. **Identify** the likely observations relating to buildings in the area.
4. **Categorise** the earthquakes presented in Table 14.4 as 'not felt' or 'felt'.
5. **Identify** a trend in the Richter scale and severity of earthquakes.
6. Based only on the 10 earthquakes presented, **infer** whether there is a higher chance that an earthquake in New Zealand would not be felt or would damage buildings.
7. There are over 10 000 earthquakes a year in New Zealand. **Justify** whether your answer to Question **6** would be reliable.
8. The largest-magnitude earthquake ever recorded in New Zealand was 8.2 on the Richter scale, while the largest in Japan was 9.0. **Justify** whether it is possible to suggest that Japan is more at risk than New Zealand for severe earthquakes.
9. The media in New Zealand are reporting a mild earthquake that caused a tremor that did not damage buildings but moved furniture in buildings in the area. **Deduce** the magnitude of this earthquake on the Richter scale.

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STEM activity: Underground bunkers and asteroids

Background information

A bunker is a structure built underground for people to shelter or live in, protecting them from dangers above ground. For example, many homes in parts of the world that are prone to tornados have a bunker to protect the homeowners. During World War II, many major cities had huge bunkers built beneath them to protect residents from bombs.

DESIGN BRIEF

Design an underground bunker to survive the imminent impact of an asteroid!



Figure 14.88 A bunker provides protection from dangers above.

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Activity instructions

BREAKING NEWS: AN ASTEROID IS HEADING FOR EARTH!

Scientists have calculated that the asteroid will collide with Earth in 20 days. The impact will be so destructive that all humans will need to stay in bunkers underground for at least three months. Your team of engineers has been tasked with building an underground bunker for 10 people in your local area.

Suggested materials

- large plastic container
- soil and crushed rock
- cardboard
- ice-block sticks
- scissors
- sticky tape
- glue
- slotted masses/weights

Research and feasibility

1. Research the local rock formations in your area. Decide whether your bunker needs to be built underground or into local rock formations. You will need to research the common types of rock and the difficulty in excavating/drilling using the hardness scale for the rock type. You may need to consider other factors of the rock type that may be important when considering strength.
2. Also consider how you will access clean water, air and food in your underground bunker.

Design and sustainability

3. Decide as a group the volume of your bunker based on the number of people, and what your group believes are space requirements. Sketch proposed local area locations and a design for your bunker. Include annotations on your sketch for the bunker design, giving additional information on the thought processes behind it.
4. Discuss as a group how you can build a model of your proposed bunker for testing. Think about the type of local rock, your bunker shape, and how to make an effective model. Include in your discussion how you are planning to test your bunker to show its durability.

Create

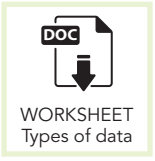
5. Build the model of your bunker, and then test it using varying weights or methods.

Evaluate and modify

6. Describe some of the difficulties you encountered while calculating and estimating the amount of space people will need to live in.
7. Did you need to make compromises about quality of life for the people living in your bunker, to save space? Explain how you came to your decisions.
8. Describe some modifications you could make to your bunker to withstand more force.
9. Evaluate the feasibility of constructing a bunker located within the rock type you have chosen.

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Appendix 1: Guide to Data Science 1



WORKSHEET
Types of data



DOCUMENT
Data Science index



WORKSHEET
Examine your digital footprint

In Stage 4 Science, Data Science can be taught alongside other focus areas or as an individual unit aligned to local contexts or student interests. This guide summarises the basic concepts required and provides links to relevant sections and practicals in other chapters.

Data

Data is the foundation of modern science and technology. It refers to all the observations and measurements collected during investigations. **Data science** investigates scientific questions that involve data to gain knowledge and improve insights. By analysing data, we can identify patterns, make predictions and develop new solutions to problems.

Data scientists are curious and ask questions about patterns and relationships in data. They use various techniques to collect and analyse this information, allowing them to draw conclusions, offer recommendations and develop models to explain and predict real-world phenomena.

Collecting and analysing datasets

In Chapter 1, Sections 1.4, 1.5 and 1.6 provide instruction in collecting, presenting and analysing data, including how to calculate and compare the mean and range of data to determine accuracy and reliability. The Data Science index in the Interactive Textbook lists practicals and activities involving analysing datasets and first-hand collection of experimental data.

Scientific inquiry and non-scientific approaches offer very different ways to understand natural phenomena, especially when it comes to the use of data. For example, iridology claims to diagnose medical conditions by analysing patterns in the iris. However, iridology lacks scientific validation. Its diagnostic methods are not based on data collection or statistical analysis, making it a **pseudoscience** – you will investigate pseudoscience further in Stage 5.

Evidence-based medicine relies on data from rigorous scientific studies and clinical trials. It uses statistical analysis to draw conclusions about the effectiveness of medical treatments. Data from these studies form the basis of medical decision-making, ensuring that treatments are based on scientific evidence.

data science
a field that uses statistical methods, algorithms and systems to extract insights and knowledge from data

digital footprint
the trail of data that is left behind by a person's interactions in the digital world

pseudoscience
a belief or practice that is presented as scientific but lacks reliable methodology or scientific validation

model
a simplified representation of a real-world system or phenomenon used to understand, analyse or predict its behaviour

Scientific models

In a scientific investigation, data can be collected in a variety of ways. It can be collected from experiments conducted in a laboratory, from fieldwork, or by using **models**. Scientists use various types of models to represent and understand different aspects of the world around us.

A model is a simplified representation of a real-world system or phenomenon that is used to understand, analyse or predict its behaviour. These models help scientists study complex systems and phenomena by simplifying them into more manageable forms. For example, models can represent the solar system, the structure of an atom or the way matter behaves at a particle level.

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Here are some examples of the types of models that are commonly used:

Model	Description	Application
Diagrams	Visual representations of a system or process like flow charts, graphs and charts that help illustrate relationships or patterns	A food web diagram can show how energy flows through an ecosystem.
Physical three-dimensional models	Tangible representations of objects or systems, built using materials such as clay, wood or plastic	Anatomical structures for education. Engineering prototype of new designs.
Computer **simulations**	Software that mimics the behaviour of a system over time based on adjustable variables	Climate models simulate Earth's climate system to predict future climate patterns. Geological models simulate the changes to the Earth's surface.
Mathematical formulas	Numerical representations that describe relationships between variables in a system; can be used to make predictions or analyse data	The formula for calculating the volume of a sphere is a mathematical model that describes the relationship between the radius of the sphere and its volume.



WORKSHEET
Analysing weather models

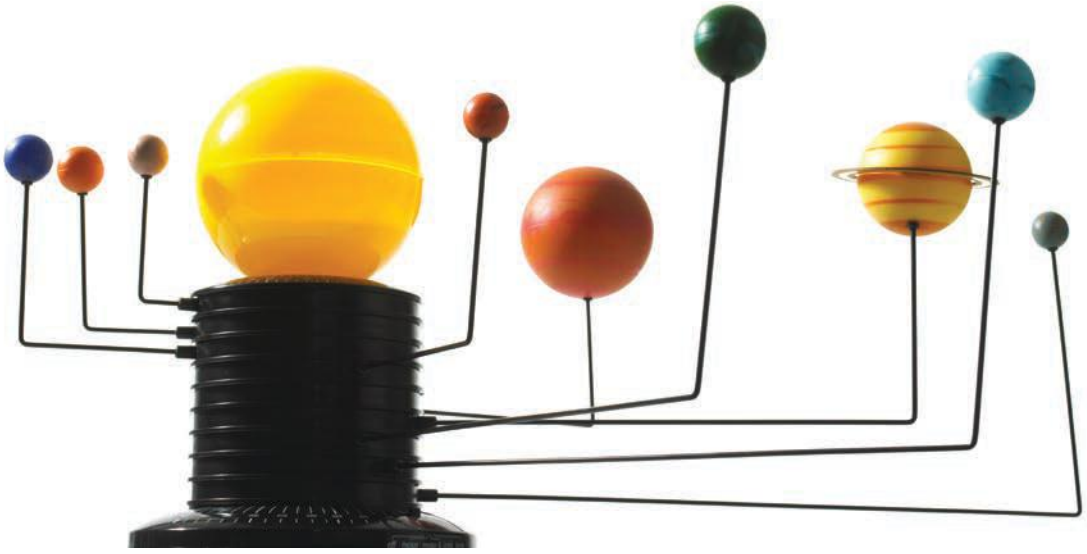
simulation
a computer program that uses a model to replicate the behaviour of a system over time

Developing and applying models

In Chapter 2, you learned how astronomers used observational data to develop our current model of the solar system. This model was based on the heliocentric theory – that is, that the Earth orbits the Sun – and was successful in predicting future observations, so that theory is now accepted.


VIDEO
The Big Bang theory

Models can be especially useful in developing theories about phenomena we cannot directly observe, such as the origin of the universe. Astronomers in the twentieth century, including Edwin Hubble, observed that all other galaxies are moving away from Earth, and galaxies further away from Earth are moving away faster. Based on these observations, Hubble and Georges Lemaître proposed a model of the universe where space itself was expanding. By extrapolating this expansion backwards in time, their model described the universe starting at a single incredibly hot and dense point – this is the Big Bang theory.



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Appendix 2: Guide to depth studies

In Stage 4 Science, you are required to complete at least two depth studies (one per year level). These studies provide an opportunity to explore scientific topics in depth and enhance your understanding of key concepts.

DOCUMENT Depth study checklist

DOCUMENT Depth study template

DOCUMENT Depth study ideas by chapter

Depth study topics

Your teacher may guide the class through specific depth studies, or you may work on a topic of your own choice. You may work individually or as part of a group. The only syllabus requirement is that it covers one or more of the Working Scientifically processes from Chapter 1.

NOTE

Throughout this textbook, you will see topics that are flagged with a lightbulb icon.

This icon indicates that the authors think the topic has potential to be explored further in a depth study.



DEPTH STUDY IDEA

Here are some examples of the different forms your depth study can take:

- **Profile of a species or material:** Research and create a detailed profile of a specific biological species (plant, animal, microorganism) or a material (like a mineral or synthetic substance). Include information about its habitat or source, properties, uses, adaptations, and role in its environment or applications.
- **Case study of a scientific organisation:** Investigate an organisation involved in scientific research or conservation, such as a research institute or a technology development centre. Examine its work, impact and contributions across different scientific fields, including biology, physics, earth and space science, and chemistry.
- **Design and conduct experiments:** Plan and carry out experiments that address questions or hypotheses. For example, you might test how light affects plant growth, investigate the effect of temperature on reaction rates or explore how different surfaces impact friction.
- **Literature review on a scientific topic:** Review existing scientific literature on a specific topic, such as the effects of climate change on ecosystems or the role of genetic mutations in diseases. Summarise the evidence and findings from various sources.
- **Investigate a health issue:** Research a health-related issue. For example, explore how chemical pollutants affect human health, the biological effects of radiation or the physical principles behind medical imaging technologies.
- **Group case study on a scientific topic:** Collaborate with your group to conduct a comprehensive case study on a topic that integrates biology, physics, chemistry, and earth and environmental science. Divide the work so that each student can focus on a specific aspect, such as the chemical properties of pollutants, their biological impact the physical principles involved or their effects on the environment.

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Presentation formats

Your depth study should be presented in a format that effectively communicates your findings. Possible formats include:

- essay
- report
- poster
- presentation
- speech
- video
- podcast.

Work with your teacher to determine the most appropriate format for your depth study.

Sample depth study: Investigating ecosystems

Here is a sample depth study focusing on ecosystems, integrating concepts from biology and environmental science. This example demonstrates how a comprehensive investigation can be conducted.
Note that this is only to be used as an example. Depth studies can cover a wide range of methods and presentations.

You are tasked with exploring how various factors impact ecosystems and the interactions between organisms within them. Your goal is to understand how changes in the environment affect ecosystems and their biodiversity.

Imagine you are working with a team of environmental scientists at a conservation organisation that monitors and restores local ecosystems. Your mission is to investigate the health of a local ecosystem, analyse the factors affecting its biodiversity and propose strategies for improvement.

This scenario-based depth study encourages you to explore the dynamics of ecosystems, understand the impacts of various factors on their health and develop practical strategies for conservation and improvement.

Method

1 **Define ecosystem health:** Develop a clear definition of ecosystem health. Explain key concepts such as biodiversity, stability and resilience. Discuss what constitutes a healthy ecosystem and why it is important.
2 **Investigate local ecosystems:** Choose a local ecosystem, such as a forest, wetland or grassland. Investigate its components, including the plant and animal species present, and the interactions between them. Study how these components contribute to the overall health of the ecosystem.
3 **Analyse factors affecting the ecosystem:** Research various factors that impact the ecosystem, such as:
   - Climate change: Examine how changes in temperature and precipitation affect the ecosystem's plant and animal species.
   - Pollution: Investigate the impact of pollutants (e.g. chemicals, waste) on the ecosystem's health and biodiversity.
   - Human activities: Study how activities like deforestation, urban development and agriculture influence the ecosystem.
4 **Conduct field observations:** Perform field observations or use available data to assess the current state of the ecosystem. Look for signs of stress or degradation, such as reduced biodiversity, invasive species, or altered water quality.
5 **Create a case study**: Develop a detailed case study of your chosen ecosystem. Include observations, data analysis, and a summary of how various factors are affecting its health. Provide examples of specific impacts, such as changes in species populations or habitat loss.

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6 **Propose conservation strategies:** Based on your findings, propose strategies to improve or restore the ecosystem. This might include actions such as:
   - Habitat restoration: Suggest ways to rehabilitate damaged habitats.
   - Pollution reduction: Recommend measures to reduce pollution and its impact.
   - Community engagement: Develop strategies to involve local communities in conservation efforts.

7 **Present your findings:** Summarise your investigation in a detailed report. Include descriptions of the ecosystem, the factors affecting its health and your proposed conservation strategies. Use diagrams, graphs and case studies to support your findings.

8 **Develop a presentation:** Prepare a presentation to share your results with the class. This could be in the form of a poster, a PowerPoint presentation or a video. Highlight the key aspects of your investigation and the importance of protecting ecosystems.



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Glossary

10% rule when energy is passed from one trophic level to another, only 10% of the energy will be passed on

abiotic relating to the non-living things in an ecosystem

abundance the number of individuals of a species within a community or ecosystem

acceleration the rate of change of speed of a moving object, measured as change in speed over time, with units such as metres per second per second (m/s/s); positive values mean speeding up and negative values mean slowing down (negative acceleration)

acceleration due to gravity acceleration experienced by a mass due to gravitational force of another mass; it is given the symbol *g*, and close to the surface of the Earth its rounded-up value is 10 m/s^2

accuracy how close a measurement is to the true value

air resistance the frictional force of the air

alloy a substance composed of two or more metals

alpha particle a positively charged particle released from the nuclei of some radioactive elements

alveoli the tiny sacs at the end of bronchioles in the lungs; the site of gas exchange with the capillaries

ammonia a poisonous substance that is produced when protein is broken down

annular eclipse an event when the Moon blocks the Sun, but the Moon is not at its closest point to Earth, so the outer edge of the Sun is still visible

anus the opening at the end of the digestive tract, through which solid waste leaves the body

aorta the largest vessel leaving the heart, from the left ventricle, carrying oxygenated blood to the body

apex predator a predator at the top of a food chain

apogee the point in the Moon's orbit when it is furthest from the Earth

aqueous solution a solution where the solvent is water

asthenosphere the softer layer of rock under the lithosphere

atom the smallest possible piece of any substance; it makes up all matter

atomic number the number of protons in the nucleus of an element, which determines the element's place in the periodic table

atrium one of the two upper chambers of the heart, the left atrium and right atrium

axes the horizontal and vertical lines used to frame a graph

bacteria very small prokaryotic organisms that have cell walls but lack membrane-bound organelles and a nucleus

balanced forces forces of equal magnitude in opposite directions will not change the motion of an object

bar/column graph a type of graph used to display the frequency of a qualitative variable (category)

bias when a source of information is influenced by personal opinion or judgement

biconcave concave on both sides

bilateral symmetry a form of symmetry where an organism's body can be divided into two identical halves.

bile a substance that helps break down fats; it is produced in the liver and stored in the gall bladder

binomial nomenclature a system of naming in which two names are used to identify an individual species of organism

biochemical reaction a chemical reaction that occurs within a living thing

biodiversity the variety of life that exists in an area

biological control the practice of introducing an organism into an ecosystem with the intention of limiting the spread of another organism

biological weathering the disintegration of rocks that is caused by living things

biology the scientific study of living organisms and their interactions with each other and their environment

bioluminescence a chemical reaction that produces light in living things

biomass the total mass of all organisms under consideration in an area or trophic level, which may refer to certain species or all organisms

biotic relating to the living things in an ecosystem

bladder the organ that stores urine

blood moon a name given to the Moon during a lunar eclipse while it is completely in Earth's shadow

boiling the rapid vaporisation of a liquid, which occurs when it is heated to a temperature called the boiling point

bolus a lump of partially digested food

bonds the forces that hold atoms together in molecules

bronchiole a smaller tube that branches off a bronchus and leads to the alveolii

bronchus (plural: bronchi) the large airways of the lung; two primary bronchi branch off the trachea, one main left bronchus to the left lung and one main right bronchus to the right lung

Brownian motion the random movement of particles in fluids and gases

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buoyancy the ability of an object to float on water or another liquid

buoyancy force the upward force experienced by an object that is partially or fully submerged in a fluid, e.g. water or air

caecum a pouch that forms the first part of the large intestine

calicivirus a disease that damages a rabbit's internal organs and can cause bleeding

capillaries the smallest blood vessels, one cell thick, and the site of gas exchange with cells

carbon dioxide a waste product produced in cellular respiration

carnivore an organism that eats only meat

causation the relationship between two variables where a change in one directly results in a change in the other

causal relationship a relationship between two variables in which changing one causes the other to change

cell membrane the barrier that separates the inside of the cell from the external environment

cell wall a rigid structure that surrounds each plant cell, shaping and supporting the cell

cellular respiration a process that occurs inside the mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

cementation the sticking together of sediment

centrifuge a device that uses fast circular motion to separate substances based on mass

characteristic a feature or quality of something

chemical change where one or more substances undergo a chemical reaction and a new substance is formed; mostly irreversible

chemical digestion a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

chemical potential energy the energy stored in the bonds between atoms

chemical weathering the process in which rocks are broken down and chemically altered, via chemical reactions

chemiluminescence a chemical reaction that produces light

chemistry the scientific study of the composition, properties and behaviour of matter

chloroplast a structure in a plant cell that contains chlorophyll and conducts photosynthesis

chromatography a technique to separate substances based on movement at different rates due to solubility

chyme a partially digested mass of food after it leaves the stomach

citizen scientist a member of the public that assists a professional scientist by voluntarily collecting data relating to the natural world

claim a statement or assertion that something is true or factual, which may require further investigation or evaluation to determine its validity

class the taxonomic ranking below phylum and above order

classification the grouping of similar objects or organisms together

cleavage the tendency of a mineral to break in a particular way because of its structure

closed system a system that allows exchange of only energy in and out of the system

commensalism a symbiotic relationship where one organism benefits and the other neither benefits nor is harmed

community a group of animals or plants that live or grow together

compaction the process of parts becoming closely positioned together, using very little space

compound a substance made up of two or more different types of atoms

compress squeeze or press to make smaller

concave a surface that curves inwards

concentrated a solution with a large amount of the solute

concentration the number of particles present in a given volume

condensation where heat is lost, causing a gas to become a liquid

condition the different levels of the independent variable

conductivity the ability of a substance to conduct or carry electricity or heat

conglomerate sedimentary rock composed of rounded rock fragments larger than 2 millimetres

consumer an organism that obtains food from consuming other organic material

continental drift the theory of how the continents on Earth have moved over millions of years

continuous data quantitative data points that have a value within a range; this type of data is usually measured

contraction the process of substances getting smaller: the particles of a substance move closer together as they cool

controlled variable a variable in an experiment that is kept constant so that it does not affect the observations of the independent variable

convection currents the movement of rocks within Earth's mantle due to temperature differences between the upper and lower layers

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convex a surface that curves outwards

correlated (of variables) two or more variables that change at the same time but without one causing the other (this relationship is called a correlation); usually because another (possibly unknown) variable is the cause; sometimes further research can turn a correlation into a causal relationship when the cause is discovered

corrosion the gradual and natural process of metals breaking down; an example is rusting

Cultural Lore the stories, customs, beliefs and spirituality of Aboriginal and Torres Strait Islander people, which are passed down through generations and act as a guide for everyday life

Crystal a substance with a specific chemical composition, in which the atoms are arranged in an ordered way to form a geometric shape

crystallisation solidification of a substance into a highly structured form

current the flow of electrons in a wire, which provides us with electricity

cytoplasm all the material inside the cell membrane, but outside the nucleus of eukaryotic cells, including organelles and other structures in a water-based fluid

cytosol the water-based mixture that fills the cell, containing different molecules; many chemical processes that happen within a cell occur in the cytosol

data information in the form of facts or statistics gathered to answer a question or for further analysis

data science a field that uses statistical methods, algorithms and systems to extract insights and knowledge from data

decantation the process of separating by using gravity, pouring the liquid off the bottom layer of solids

deceleration an alternative term for negative acceleration

decomposer an organism such as a bacterium or fungus that breaks down organic material

decomposition a reaction in which one substance breaks up into smaller ones

density how much matter (mass) is contained in a certain volume of a substance

dependent variable the variable that is measured during an experiment (as it responds to the independent variable)

deposition (matter) where a reduction in heat causes a gas to become a solid, without passing through the liquid state

deposition (rocks) the process that occurs when eroded particles stop moving and build up to form sedimentary rocks

detritivore an organism that feeds on dead or decaying organic matter

diaphragm a dome-shaped muscle that separates the chest and abdominal cavities; it contracts to draw air into the lungs

dichotomous key a tool used to identify organisms, where there are a series of questions with only two alternatives

differentiation the process by which stem cells become specialised

diffusion the movement of particles from an area of a high concentration of particles to an area of a low concentration of particles

digital footprint the trail of data that is left behind by a person's interactions in the digital world

dilute a solution with only a small amount of the solute

direct contact (type of force) a force that is applied to an object by touching and pushing or pulling it

discrete data quantitative data points that have whole numbers; this type of data is usually counted

dissolve cause to become mixed in a liquid so that it cannot be seen

dissolving the process where individual particles of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

distillation a technique to separate substances in a liquid using evaporation through boiling and condensation

DNA deoxyribonucleic acid, a chemical present in cells of living things that carries genetic information

domain the highest taxonomic rank above kingdom and even broader

double helix a description of the structure of DNA where two strands wind around each other like a twisted ladder

drag the frictional force of a liquid or gas

ductility the ability of a substance to be drawn into a wire

duodenum the first section of the small intestine, where many enzymes are secreted

ecological niche the role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment

ecosystem the interrelationship between living and non-living components of a specific area

ectothermic a cold-blooded organism that cannot regulate its internal temperature

efficiency the percentage of input energy that is converted to useful energy by a machine

egestion the process of removing undigested waste material from the body in faeces

elastic (material) able to return to its original shape when compressed, stretched or deformed

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elastic potential energy the energy stored when an elastic material is compressed or stretched

electrical energy the kinetic energy of moving electrons

electromagnet a magnet made by passing electricity through a coil of wire

electron a subatomic particle with a negative charge found outside the nucleus in all atoms

electron configuration the arrangement of an atom's electrons in the shells around the nucleus

electrostatic force an indirect force between positive and negative charges: opposite charges attract; like charges repel

element a substance made up of only one type of atom

embryo a fertilised egg in the early stages of growth and differentiation

endothermic a warm-blooded organism that can regulate its body temperature

endothermic reaction a chemical reaction that absorbs heat, causing a decrease in the surrounding temperature

energy the ability or capacity to do work

energy transfer the movement of energy from one place or object to another without changing form

energy pyramid a graphical representation that shows the amount of energy available at each trophic level in an ecosystem

energy transformation change or conversion from one form of energy to another, in line with the law of conservation of energy

environment the physical conditions in which an organism lives

enzyme a protein that speeds up chemical reactions in living organisms

epiglottis a flap of elastic cartilage that covers the opening of the trachea during swallowing, preventing food and liquids from entering the airways

equator an imaginary line drawn around the middle of the Earth, equidistant between the North and South poles

erosion the transport of rock fragments (that have resulted from weathering)

ethical relating to ethics, the field of considering what is right and wrong

eukaryote any cell or organism that possesses membrane-bound organelles and a nucleus

evaporation when heat causes liquid to become gas

excretion the process of removing metabolic waste from the blood via the liver, kidneys, lungs and skin

excretory system the body system that is responsible for filtering the blood and removing cellular waste products

exothermic reaction a chemical reaction that releases heat, causing an increase in the surrounding temperature

expansion the process of substances getting larger: the particles of a substance move further apart as they heat up

experiment a controlled situation where data is gathered to answer a question

extinction the complete disappearance of a species or group of organisms from Earth

extrapolation using existing data (such as a line of best fit) outside the original dataset to make a prediction

extremophile an organism that thrives in conditions of extreme temperature, pH or chemical concentration

extrusive describes igneous rocks formed on Earth's surface; also called volcanic rocks

fair test an experiment where all variables are kept constant except for the independent variable being tested

family the taxonomic ranking below order and above genus

field a region in space in which an object is affected by an indirect non-contact force

filtrate the substance that passes through the filter

filtration separating a mixture by passing through a filter

firestick farming the cool burning of areas of bush in stages, by the application of firesticks, to encourage new growth

first order lever a lever in which the fulcrum is between the load and the effort

flocculant a substance that causes particles to clump together

foliated appears banded or layered; has distinct repetitive layers or stripes

food chain a sequence of living things that shows their feeding relationship and the flow of energy between them

food web a group of interconnected food chains

force a push, pull or twist in a specific direction

fossil the remains, shape or trace of a bone, shell, microbe, plant or animal that has been preserved in rock for a very long time

freezing where heat is lost and a liquid becomes a solid

fulcrum the point on a lever where the arm pivots

function the job that an object does

gall bladder a small organ near the liver that stores bile and secretes it into the duodenum

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galvanisation the process of coating iron or steel in zinc to prevent corrosion

gas a substance that expands freely to fill space

genre a category used to group media such as music, art or books

genus the taxonomic ranking below family and above species

geocentric model a model where the Earth was the centre of the universe

geology the study of rocks and Earth's dynamic structure and the processes through which our planet (and other planetary objects) have formed

gravitational field the region around a mass where another object can experience its gravity or pull

gravitational potential energy a type of potential energy an object has due to its mass and height above the ground

group the vertical columns in the periodic table

guard cells specialised cells located on either side of a plant stoma that regulate gas exchange by opening and closing the stoma

habitat the place where an organism lives

haemoglobin the red pigment in blood that binds to oxygen, allowing red blood cells to carry oxygen

heat the effect of thermal energy in a material causing temperature to increase

heat transfer (thermal transfer) the flow of heat energy from matter at a higher temperature to matter at a lower temperature

heliocentric model a model with the Sun as the centre of the solar system

herbivore an organism that eats only plants

herbivory the consumption of plants

heterogeneous mixture a mixture that can be easily separated into its parts, and those parts keep their original properties

heterotroph any organism that obtains its nutrients by consuming other organisms

hierarchical where smaller groups are placed within larger groups, with no overlap between groups

holistic considering the whole thing rather than just the parts individually

homogeneous mixture a mixture where components are evenly distributed and all parts have the same properties

hypothesis a proposed explanation or an educated guess that can be tested through further investigation and experimentation

ileum the third section of the small intestine, where further food breakdown and nutrient absorption occur

independent variable the variable that is deliberately changed during an experiment

indicator (of physical or chemical change) a property that changes when a particular physical or chemical change happens, providing evidence of change and type of change

indirect non-contact (type of force) a force that is exerted by a field rather than by direct contact

inert a substance that does not easily react

inference to link an observation with past knowledge and assign meaning to the observation

insoluble substances that cannot dissolve

interdependence the dependence between different species in a community

interdisciplinary including more than one scientific branch or discipline

interpolation using existing data (such as a line of best fit) within the original dataset to make a reliable prediction

interspecific occurring between members of different species

intolerance an inability to eat a food without experiencing adverse effects

intraspecific occurring between members of the same species

intrusive describes igneous rocks formed underground; these are also called plutonic rocks and have larger crystals than extrusive rocks

invasive species an organism that is not native to an environment and causes harm to native organisms

invertebrate an animal that does not have a backbone

investigable question a research question that can be answered through completing an experiment

irreversible unable to go in the opposite direction

jejunum the second section of the small intestine, where food breakdown and nutrient absorption occur

joule the unit of energy or work done

kidneys a pair of organs that filter waste products from the blood and excrete them as urine

kinetic energy the energy of moving matter

kinetic transfer direct energy transfer through the motion of objects in collisions

kingdom the highest and broadest classification on the Linnaean taxonomic rankings

knowledge the understanding of information

koolamon also spelled coolamon, a carrying vessel, widely used by Aboriginal and Torres Strait Islander Peoples across Australia

large intestine the organ that is connected to the small intestine at one end and the anus at the other

lava molten rock from inside Earth (called magma) that has reached the surface

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law of conservation of energy the law that states that energy cannot be created or destroyed

leap year a year that happens every four years and has an extra day on 29 February

lenticels small slits on the trunks or branches of trees that allow gas exchange

light energy the energy of visible light, also used generally as an alternative term for radiant energy

line graph a type of graph used to display continuous data

liquid a substance that flows freely and takes the shape of its container but has constant volume and its particles are tightly packed

lithosphere the solid outer layer of Earth consisting of the crust and top layer of the upper mantle; it is split into giant slabs called tectonic plates

liver a large organ that has many functions, including the production of bile

lunar eclipse an event when a full moon becomes dark as it enters the Earth's shadow

lustre the ability of a substance to become shiny when polished

macroscopic visible to the naked eye

magma hot fluid rock found beneath the Earth's surface

magnetic field the area around a magnet where the magnetic force acts

magnetic force an indirect force between a magnet and another magnet or magnetic metal

malleability the ability of a substance to be bent or flattened into a range of shapes

mass the amount of substance in an object that never changes, measured in kilograms

matter anything that has mass and volume

mean the average of a set of data, calculated by adding up all the values in the set and dividing by the total number of values

mechanical advantage the ratio of the output force to the input force

mechanical digestion a series of mechanical processes that break food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

mechanical energy the sum of potential energy and kinetic energy

melting when heat causes a solid to become a liquid

melting point the temperature at which a specific solid melts

membrane-bound organelle an organelle that is surrounded by an outer covering made partly of oil/fat

meniscus the surface of a liquid in a container

mesopredator a predator in a mid-ranking trophic level, which usually hunts smaller animals

metabolic the chemical processes that occur within a living organism to maintain life, including breaking down substances to produce energy and building new molecules for growth and repair

metal a substance that is shiny, can conduct electricity, can be bent, is usually silver/grey and is ductile

metalloid a substance that has some of the properties of both metals and non-metals

metamorphosis the process of transformation from an immature form to an adult form

meteorite a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground

meter a measuring or recording instrument (do not confuse with metre, a unit of length)

microorganism an organism that can only be seen through a microscope

microscopic anything that can only be seen clearly with the use of a microscope

microvilli tiny projections on the surface of villi cells that increase surface area to enhance nutrient absorption

mineral a naturally occurring chemical substance that is formed in the ground, with constant chemical composition, crystal structure and physical and chemical properties

misnomer a wrong or inaccurate name

mitochondrion a structure in a cell that converts the energy from food into the form needed by the cell during cellular respiration

mixture a material made up of two or more different pure substances (compounds or elements) that are not bonded together

model a simplified representation of a real-world system or phenomenon used to understand, analyse or predict its behaviour

Mohs scale a scale from 1 to 10 that indicates the hardness of a rock

molecule two or more atoms joined together by strong bonds

motile able to move independently from one place to another

multicellular made of many cells

nectar a sweet liquid produced by flowers to attract pollinators

nephrons small filtering structures found in the kidney

net force the sum of all forces acting on an object

neuron a nerve cell

neutron a subatomic particle with a neutral charge found in the nucleus of an atom

non-metal a substance that is dull, cannot usually conduct electricity, is brittle and is not ductile

non-vascular not containing veins or specialised fluid vessels

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normal force the force applied by a surface on an object

Northern Hemisphere the half of the Earth north of the equator

nuclear energy potential energy stored in and released by the nucleus of an atom

nucleus (plural: nuclei) the central part of the atom containing its protons and neutrons

observe use senses and tools to gather information/data

omnivore an organism that is naturally able to eat both plants and animals

open system a system that allows exchange of energy and matter in and out of the system

orbit the curved path of a celestial object or spacecraft round a star, planet or moon

orbital period (of an orbit) the time taken to complete one orbit or revolution

order the taxonomic ranking below class and above family

organ two or more types of tissue acting together to perform a specific role

organ rejection when an organ transplant recipient's immune system recognises the organ as foreign and attacks it

organ transplantation the process of removing a donor organ and then surgically implanting it into a recipient to improve their organ function or replace a diseased organ

organelle a specialised structure in a cell that has a specific function or role

organism a living creature, such as a plant or an animal

origin the point (0, 0), where the horizontal axis and vertical axis intercept when both axes start from zero

outlier an extreme data value that is very different from the other data and could be the result of a faulty procedure

pancreas an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

Pangaea the supercontinent which has since broken into pieces and drifted apart

parallax error an error caused by not reading liquid measurements at eye level, which leads to measurements being too high or too low

parasitism a symbiotic relationship where a parasite benefits from living on or in a host (which is harmed)

partial eclipse an event when the Sun is partially blocked by the Moon

particle model all matter is made of particles that behave differently depending on whether they are solid, liquid or gas

penumbra the region in a shadow where the light is partially blocked

perigee the point in the Moon's orbit when the Moon is closest to the Earth

period the horizontal rows in the periodic table

peristalsis a wave-like contraction of the muscles of the digestive tract that pushes the food along

pharynx the throat region where the nasal cavity and oral cavity meet, leading into the trachea

phase of the Moon the bright area of the Moon and its shape when seen from Earth

phloem vascular tubes that transport sugars and nutrients throughout the plant

photons packets of energy that move at the speed of light and behave as particles and waves

photosynthesis the process by which green plants, some protists and bacteria convert light energy into chemical energy in the form of sugars using carbon dioxide and water, and releasing oxygen

phylum the taxonomic ranking below kingdom and above class

physical change when the physical properties of a substance change in some way, but no new substance is formed

physical property the way a substance or object looks and behaves under different physical conditions; a characteristic of a substance that can be observed and/or measured without changing it chemically

physical weathering the process of breaking down rocks into smaller pieces or particles, without changing the chemical composition

physics the scientific study of matter and energy, and their interactions with each other

plasma the yellow liquid component that makes up 55% of blood; it carries water, dissolved gases and chemicals

plate boundaries the edges where two tectonic plates meet

plate tectonics the theory that the Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

platelets tiny cell fragments that assist with blood clotting

pollination the process by which pollen, containing the male reproductive cells of a plant, is transferred from the male part of a flower to the female part of a flower

population all organisms of a particular species or group who live in one area

potential energy stored energy

precipitate the solid that forms when two clear solutions are mixed and undergo a chemical change

precision how close measurements are to each other

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predator an organism that obtains food by killing and consuming other organisms

prediction a statement of a testable expected outcome based on observation or scientific knowledge

pressure the amount of force exerted on a given area

prey an organism hunted and killed by another organism for food

primary consumer an organism that eats plants

producer an organism capable of producing food from photosynthesis

products the substances that are present at the end of a chemical reaction

prokaryote a unicellular organism that lacks membrane-bound organelles and a nucleus

protist a eukaryotic organism that is part of the kingdom Protista

proton a subatomic particle with a positive charge found in the nucleus of an atom

pseudoscience a belief or practice that is presented as scientific but lacks reliable methodology or scientific validation

pull to exert a force towards something

pure substance material that is made up of either one type of atom or the same groups of atoms (molecules or compounds)

push to exert a force away from something

pyramid of biomass a graphical representation that illustrates the total mass of organisms at each trophic level in an ecosystem

pyramid of numbers a graphical representation that shows the number of organisms at each trophic level in an ecosystem

qualitative a form of data that is a descriptive measurement

quantitative a form of data that is a numerical measurement

radial symmetry a form of symmetry where an organism's body can be divided into identical parts around a central axis

radiant energy the kinetic energy of moving photons

radioactive having or producing the energy that comes from the breaking up of atoms

random error an error that is caused by factors that cannot be easily controlled by the experimenter

range the difference between the largest and smallest values in a set

reactants the substances that are present at the beginning of a chemical reaction

reaction conditions conditions required for a chemical reaction to proceed

rearrange move things into a different order

rectum the second-last section of the large intestine; stores faeces

relationship (between variables) the link or association between two or more variables

reliability the consistency and repeatability of a measurement, experiment or test under the same conditions

reproducible able to be reproduced or copied

research question a question that can be answered practically through scientific investigation or through research

residue the substance that is left in the filter

reversible able to go in the opposite direction

revolution one complete orbit

rewilding the process of protecting an environment and returning it to its natural state, for example by bringing back wild animals that used to live there

ribosome a structure in a cell that reads genetic information to assemble proteins

ridge push a force due to gravity at a mid-ocean ridge on a tectonic plate that pushes it away from the ridge

rock a naturally occurring substance composed of minerals forming Earth's outermost layers, formed as part of the rock cycle

rock cycle the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

saliva liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

saturated a solution with the maximum amount of solute dissolved

scavenger an organism that feeds on dead animals that it has not killed itself

seafloor spreading a process by which new oceanic crust (outermost solid layer of the Earth) is produced as molten rock rises from below, causing the crust and seafloor to move away from ocean ridges

second order lever a lever in which the fulcrum is at one end and the load is between the fulcrum and the effort

secondary consumer an organism that eats primary consumers

sediments sand, stones, etc. that slowly form a layer of rock

sessile fixed in one place and not able to move

simple machine a basic mechanical device for applying a force and changing either its size or direction

simulation a computer program that uses a model to replicate the behaviour of a system over time

skin the biggest organ in the body, which forms a protective outer layer on a person

slab pull a force due to gravity at a subduction zone on a tectonic plate that pulls it towards the subduction zone

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solar eclipse an event when the Sun partly or completely disappears from view, while the Moon moves between it and the Earth

solid a substance that has a fixed shape and constant volume

soluble substances that can dissolve

solubility the ability of a solute to dissolve in a solvent to form a solution

solute the component of a solution being dissolved

solution a mixture where one substance is evenly dissolved in another

solvent the component in a solution capable of dissolving another substance

sound energy the kinetic energy of waves of vibration of particles moving through solids, liquids and gases

Southern Hemisphere the half of the Earth south of the equator

specialised cell a cell that has undergone structural changes that allow it to perform a specific task

species the most specific taxonomic ranking of a group of organisms

speed the rate of change of position of a moving object (called velocity when direction is specified), measured as change in distance over time, with units such as metres per second (m/s) or km/h

sphincter a muscle that surrounds an opening in the body and can tighten to close it, e.g. at the bottom of the oesophagus, leading into the stomach

state one of the distinct forms matter can exist in

static electricity a build-up then flow of electric charge

stem cell a cell that can develop into many different types of cells

stomata tiny pores (holes) in leaves that facilitate the entry and exit of gases such as oxygen and carbon dioxide

streak test a test used to help identify a mineral by scratching a rock on a hard ceramic tile

structure a physical part of an object

subatomic particle one of the particles that make up an atom

subduction the process in which the denser oceanic plate sinks underneath less dense continental plate

sublimation where heat causes a solid to become a gas, without passing through the liquid state

supersaturated a solution with more than the maximum amount of solute that is possible to dissolve; undissolved solute will be visible

surface tension the ability of water or another liquid to be cohesive (sticky) and resist a force or hold together

symbiosis a long-term close interaction between two organisms of different species

synchronous rotation occurs when one rotation of an orbiting body takes the same length of time as one orbit

systematic error an error that causes measurements to differ from the true result by a consistent amount, often due to faulty or uncalibrated equipment

systematic observations observations collected and recorded using scientific methods

syzygy the alignment in astronomy of three objects in a straight line

taxonomy a branch of science that groups and names organisms based on their relationships

tectonic plates fragments of Earth's lithosphere that float on the asthenosphere

telescope an optical instrument for making distant objects appear nearer and larger

temperature a measure of the average kinetic energy of the particles in a substance

tertiary consumer an organism that eats secondary consumers

the Dreaming the spiritual framework of Aboriginal and Torres Strait Islander cultures that explains the creation and interconnectedness of all things, existing beyond time and guiding relationships with land, community and culture

thermal energy the energy caused by vibration or movement of particles

third order lever a lever in which the fulcrum is at one end and the effort is between the fulcrum and the load

tissue a group of similar specialised cells that work together to carry out a specific function; different tissues make up organs

tissue engineering the combined use of cells and engineering to improve or replace biological tissues

tolerance the range of conditions that an organism can survive and function within

total eclipse an event when the Sun is completely blocked by the Moon

trachea the tube (reinforced with rings of cartilage, lined with cilia to remove foreign particles and mucus) that carries air down to the lungs; also known as the windpipe

transdisciplinary merging scientific and non-scientific disciplines such as social science and economics, and non-academic fields such as management, to address a broad issue

transition metals the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

transpiration a plant's loss of water through the stomata of its leaves

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trend a pattern in a graph that shows the general direction/ shape of the relationship between the dependent and independent variables

trendline/line of best fit a line drawn to show an average of plotted points

trial a run-through of an experimental method that is usually repeated several times, to obtain data that can be averaged, to reduce any effect of variables not being completely controlled

trophic level an organism's level or position in a food web; it is based on an organism's feeding habits, where producers occupy the first trophic level

twist to turn something

umbra the region in a shadow where the light is completely blocked

unbalanced forces A force of greater magnitude will cause the object to move or deform.

unicellular consisting of just one cell

urea a substance that is produced by the liver by breaking down ammonia

ureter the tube that leads from the kidneys to the bladder

urine a waste product from the body made of water, urea and other excreted wastes

useful energy the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it creates

vacuole a structure in a cell that stores water and nutrients

valence electrons the electrons in the outer shell of an element

variable a factor or condition that can be controlled, changed or measured in an experiment

vascular containing veins or specialised fluid vessels

vascular bundles a transport system in plants, made of xylem and phloem

vena cava the large vessel that returns deoxygenated blood from the body to the heart, emptying into the right atrium

ventricle one of the two lower chambers of the heart, the left and right ventricles

vertebrate an animal that has a backbone

vibrate move in a periodic (back and forth) motion

villi finger-like structures in the digestive system that have a high surface area and rich blood supply for absorption of nutrients

volume the space an object occupies

waning the period of about two weeks where the illuminated part of the Moon is decreasing from a full moon to a new moon

waste energy (or energy lost) the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy

waxing the period of about two weeks where the illuminated part of the Moon is increasing from a new moon to a full moon

weight the force of gravity on an object measured in newtons

word equation a chemical equation written using just the words for reactants and products, with an arrow indicating the direction of the reaction

work done when a force moves an object, work done, W, is the force in newtons, F, multiplied by the distance in metres, d, through which it moves ($W = Fd$); it is equivalent to the energy needed and has the same units (joules)

xenotransplantation transplanting organs from one species into another

xylem vascular tubes that transport water in one direction through the plant

zygote a fertilised egg cell

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