CAMBRIDGE

Interactive Textbook Included

sample pages

Uncorrected Sample Pages

Cambridge University Press © Shaw et. al, 2025
ISBN 978-1-009-59637-4
For more information please contact your regular Cambridge Education Resource Consultant or the Education Sales Assistant:

educationsales@cambridge.edu.au

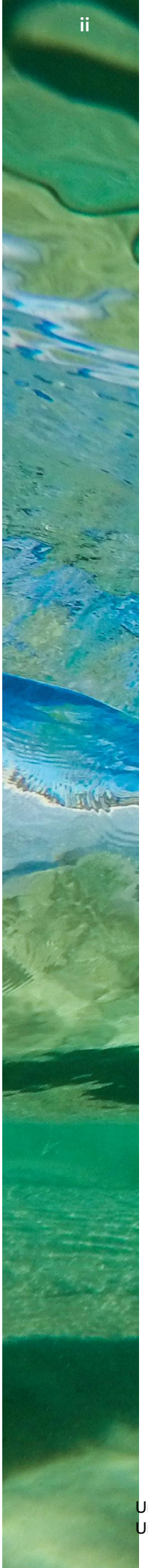
STAGE 5

Gemma Dale
Rachel Horton
Suzanne Wilson

Series consultant:
Simon Crook

Cambridge science

for the NSW Syllabus Second Edition



CAMBRIDGE
UNIVERSITY PRESS

Shaftesbury Road, Cambridge CB2 8EA, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India
103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press & Assessment is a department of the University of Cambridge.

We share the University's mission to contribute to society through the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org

© Cambridge University Press & Assessment

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press & Assessment.

First published 2021
Second Edition 2025

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

Cover and text designed by Shaun Jury
Typeset by Integra Software Services Pvt. Ltd
Printed in China by C & C Offset Printing Co., Ltd.

A catalogue record for this book is available from the National Library of Australia at www.nla.gov.au

ISBN 978-1-009-59637-4

Additional resources for this publication at www.cambridge.edu.au/GO

Reproduction and Communication for educational purposes
The Australian *Copyright Act 1968* (the Act) allows a maximum of one chapter or 10% of the pages of this publication, whichever is the greater, to be reproduced and/or communicated by any educational institution for its educational purposes provided that the educational institution (or the body that administers it) has given a remuneration notice to Copyright Agency Limited (CAL) under the Act.

For details of the CAL licence for educational institutions contact:

Copyright Agency Limited
Level 12, 66 Goulburn Street
Sydney NSW 2000
Telephone: (02) 9394 7600
Facsimile: (02) 9394 7601
Email: memberservices@copyright.com.au

Reproduction and Communication for other purposes
Except as permitted under the Act (for example a fair dealing for the purposes of study, research, criticism or review) no part of this publication may be reproduced, stored in a retrieval system, communicated or transmitted in any form or by any means without prior written permission. All inquiries should be made to the publisher at the address above.

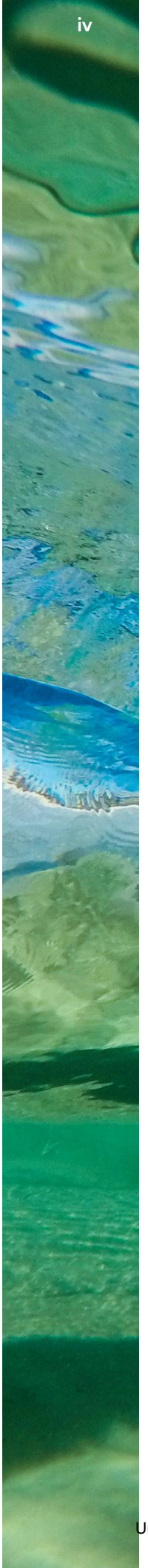
Cambridge University Press & Assessment has no responsibility for the persistence or accuracy of URLS for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate. Information regarding prices, travel timetables and other factual information given in this work is correct at the time of first printing but Cambridge University Press & Assessment does not guarantee the accuracy of such information thereafter.

Please be aware that this publication may contain images of Aboriginal and Torres Strait Islander people who are now deceased. Several variations of Aboriginal and Torres Strait Islander terms and spellings may also appear; no disrespect is intended. Please note that the terms 'Indigenous Australians' and 'Aboriginal and Torres Strait Islander peoples' may be used interchangeably in this publication.

Cambridge University Press & Assessment acknowledges the Aboriginal and Torres Strait Islander peoples of this nation. We acknowledge the traditional custodians of the lands on which our company is located and where we conduct our business. We pay our respects to ancestors and Elders, past and present. Cambridge University Press & Assessment is committed to honouring Aboriginal and Torres Strait Islander peoples' unique cultural and spiritual relationships to the land, waters and seas and their rich contribution to society.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



Contents

About the authors iii
About the cover vii
How to use this resource viii

Observing the universe

1 **Working scientifically** 2
1.1 Skills: Observing, questioning and predicting 4
1.2 Skills: Planning and conducting investigations 9
1.3 Skills: Processing and analysing data, and problem-solving 22
1.4 Skills: Communicating science 38

Forces

2 **Energy** 48
2.1 The law of conservation of energy 50
2.2 Calculating energy efficiency 58
2.3 Sources of energy 62

3 **Electrical energy** 86
3.1 Electrical circuits 88
3.2 Series and parallel circuits 104

Cells and classifications

4 **Homeostasis** 120
4.1 Body systems working together 122
4.2 The nervous system 131
4.3 The endocrine system 148

5 **Disease** 164
5.1 Infectious and non-infectious diseases 166
5.2 Protection against infectious disease 178
5.3 Disease transmission and management 191

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Solutions and mixtures

6 **Resources** 206
6.1 Minerals and resources 208
6.2 Aboriginal and Torres Strait Islander Peoples' use of resources 215
6.3 Environmental impact 220

7 **Bonding** 230
7.1 Stable electron configurations 232
7.2 Ionic bonding 237
7.3 Covalent bonding 244
7.4 Metallic bonding 247

Living systems

8 **Organic compounds and polymers** 256
8.1 Introduction to organic compounds 258
8.2 Reactions and uses of organic compounds 272
8.3 Polymers 282

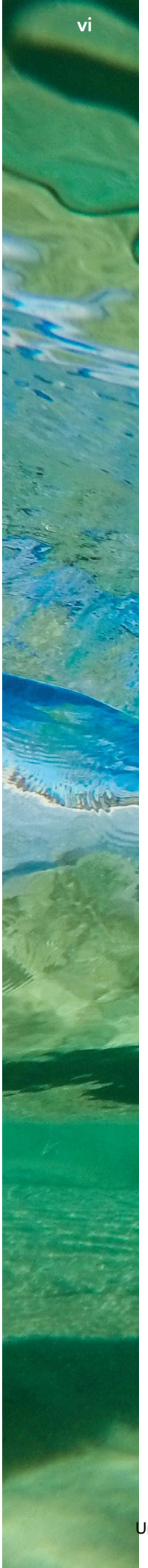
9 **Climate science** 292
9.1 Earth's climate and weather 294
9.2 The greenhouse effect 305
9.3 Climate change characteristics and effects 316

Atoms and the periodic table

10 **Sustainability and recycling** 338
10.1 Sustainability 340
10.2 Resource use and recycling 348

11 **Genetics** 368
11.1 DNA structure and function 371
11.2 Passing on genetic information 386
11.3 Patterns of inheritance 403
11.4 Changes in DNA 418

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



Change

12 **Evolution** 438
12.1 Evolutionary change 440
12.2 Natural selection and speciation 456
12.3 Developing the theory from evidence 472

13 **Chemical reactions** 498
13.1 Conservation of mass 500
13.2 Types of chemical reactions – synthesis and decomposition 507
13.3 Types of chemical reactions – displacement and neutralisation 511

14 **Rate of chemical reactions** 524
14.1 Measuring reaction rates 526
14.2 Factors affecting reaction rates 533

Reactions

15 **Nuclear reactions** 552
15.1 The Big Bang and the first elements 554
15.2 Radioactive decay 561
15.3 Uses of radioisotopes 565

Waves and motion

16 **Waves** 576
16.1 Properties of waves 578
16.2 Sound waves 586
16.3 Light waves 596

17 **Motion** 614
17.1 Analysing and describing motion 616
17.2 Graphing motion 627
17.3 Newton's laws of motion 643

Glossary 654
Index xxx
Acknowledgements xxx

Answers are available in the Interactive Textbook and the teacher resources.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 1

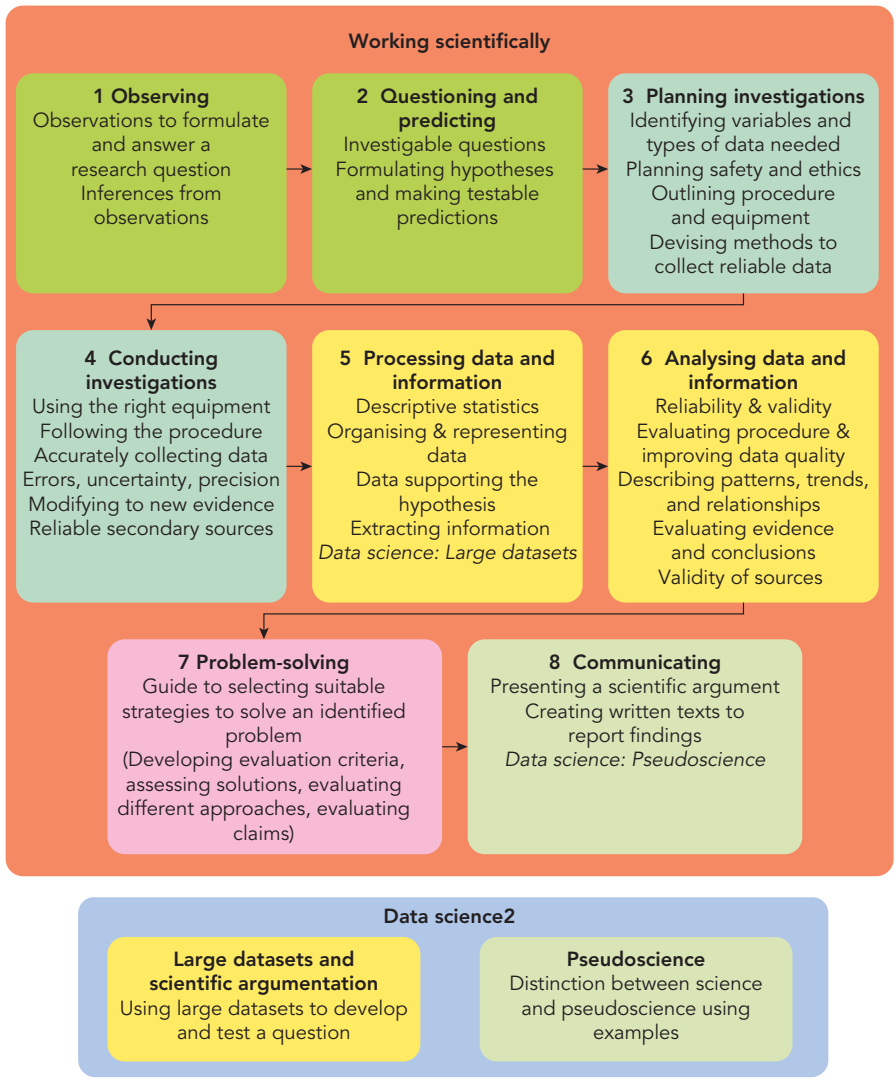
Working scientifically

Chapter introduction

Whenever you explore or question the world around you, you are working scientifically. Science involves asking questions about our world and seeking answers through a systematic approach. This chapter reviews the working scientifically skills sections of Chapter 1 in the Stage 4 resource, and extends them to Stage 5. You'll learn to formulate investigable questions and hypotheses using scientific reasoning and recognise the roles and types of variables in experiments. You'll also distinguish between quantitative and qualitative data, plan and conduct investigations while managing safety risks and systematically collect and process experimental data. You will consider the various methods used to organise and represent data, identify patterns and trends, before evaluating and concluding effectively. Finally, you'll explore how to clearly communicate your research and results to the broader community , and distinguish between genuine science and pseudoscience.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

absolute uncertainty
accuracy
bivariate analysis
calibration
confounding variable
controlled variable
correlated
dependent variable
extrapolation
fair test
hypothesis
independent variable
inference
interpolation
investigable question
mean
median
mode
outlier
parallax error
plagiarism
precision
prediction
primary data
pseudoscience
qualitative
quantitative
random error
range
reading error
relative uncertainty
reliability
repeatability
replicability
reproducibility
secondary data
sensitivity
SI units
systematic error
uncertainty
univariate analysis
validating
validity
variable
zero calibration error

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1.1 Skills: Observing, questioning and predicting

Learning outcomes

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

1. describe the skill of observing and relate it to working scientifically.
2. formulate questions and hypotheses that can be investigated scientifically.
3. make predictions based on scientific knowledge and observations.

Working scientifically skills

The skills introduced in the rest of this chapter occur throughout the textbook, particularly in the practical skills boxes in every chapter. This gives the choice of learning how to work scientifically by going through this chapter in one go, or by coming back to it as reference when each skill is encountered in a chapter on the science content.

A flow chart for using working scientifically skills in an investigation

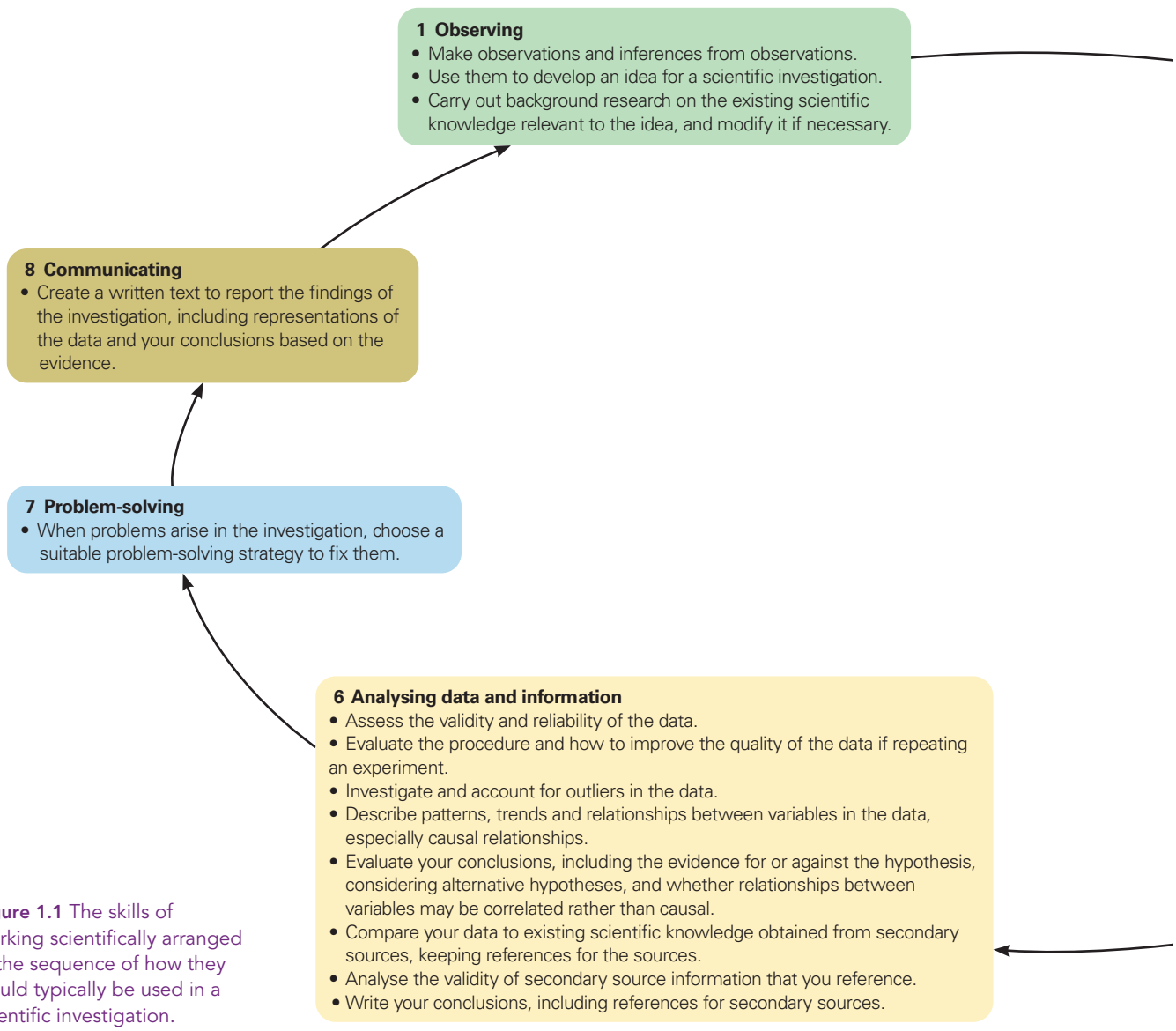


Figure 1.1 The skills of working scientifically arranged in the sequence of how they would typically be used in a scientific investigation.

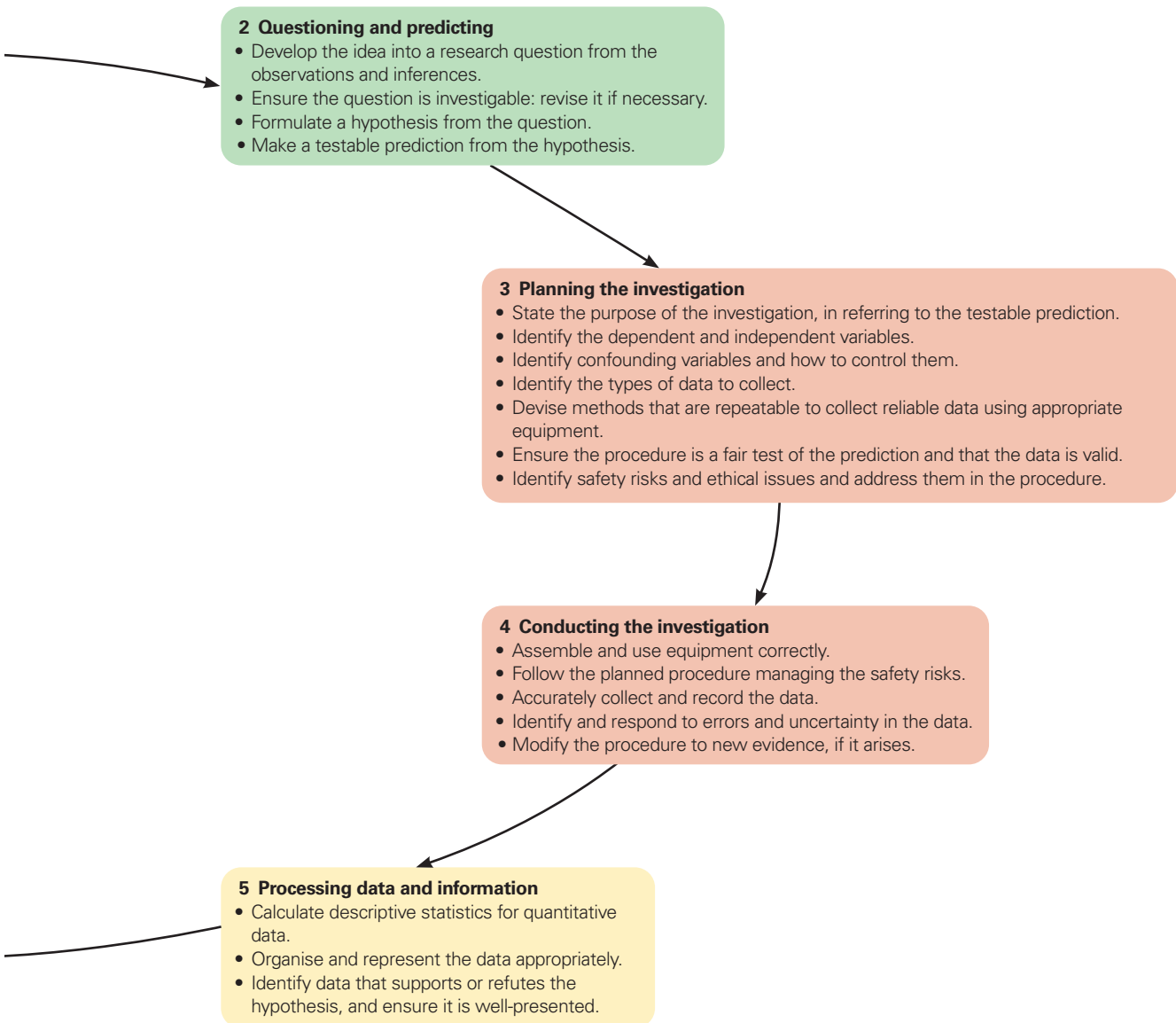
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Keeping track of the working scientifically skills

The online teacher resources include tables mapping the working scientifically skills against chapter contents and online resources, with the ability to monitor progress. In this way you can keep track of the skills you have learned and practiced.

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 scientific method, but all science is based on its principles. Figure 1.1 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.



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1 Observing

Working scientifically begins from observation. Observations are statements about information without any explanations or opinions, such as 'the sky is blue', 'the water is cold' or 'the leaf has a rough texture'. Recall from Stage 4 Science that descriptive observations like these are **qualitative**. Scientists may gather qualitative information using all their senses: sight, hearing, smell, taste and touch.

qualitative
a form of data that is a descriptive measurement

quantitative
a form of data that is a numerical measurement

Scientists may also count things or use instruments to gather **quantitative** quantified, as in 'the light from the sky has a wavelength of 450 nanometres', 'the water is 5°C', or 'the leaf has on average 1000 hairs per square centimetre'. Quantitative observations are generally more accurate but are not always possible. For example, measuring the number of hairs in a square centimetre is not always practical. Using equipment and making observations with precision is covered in the next section.

An observation generally starts a scientific investigation. A scientist notices something, wonders about it, and thinks about starting an investigation. Methodical and controlled observations made in the investigation or experiment then become data.

Inferences

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

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

Once observations are made, scientists use **inferences** to provide possible explanations for observations based on past knowledge. For example, if you observe that the sky is overcast, you might infer that it will rain soon. These inferences help in formulating **investigable questions** like, 'Can the onset of rain be predicted from daylight intensity measurements?' Other examples of investigable questions are 'Does light intensity affect the rate of photosynthesis in plants?' or 'Does the temperature of water affect how fast sugar dissolves?'

Figure 1.2 Light intensity will affect the growth of plants.

2 Questioning and predicting

Investigable and non-investigable questions

Investigable questions are those that can be answered through scientific investigation or experimentation. These questions are specific, measurable and testable. For example, 'How does light intensity affect the growth of plants?' is an investigable question because it involves a variable (light intensity) that can be manipulated and measured (plant growth). To answer investigable questions, you need appropriate resources, such as equipment, materials and time.

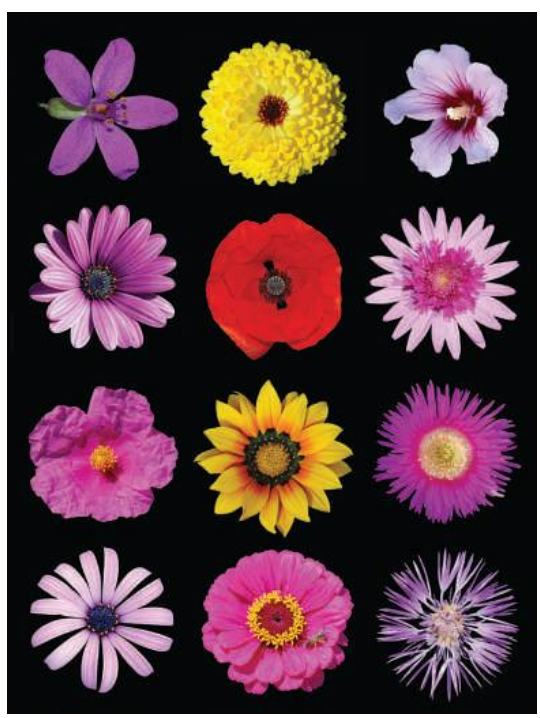


Figure 1.3 An example of a non-investigable question is 'What is the prettiest flower?'

On the other hand, non-investigable questions are those that cannot be answered through

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

experimentation. They might be too broad, subjective or not measurable, such as 'Why are plants important?' or 'What is the best type of music?' These questions might require background research or expert opinions rather than practical experiments.

When considering which type of question to ask, it's important to think about the resources you have available, such as access to equipment, time constraints and the feasibility of carrying out the investigation. This helps ensure that the question you choose is appropriate for a scientific investigation. An investigable question needs to meet the criteria outlined in Table 1.1.

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 1.1 The criteria for a question to be considered investigable

Quick check 1.1

1 **State** the purpose of formulating an investigable question.
2 **Provide** an example of a non-investigable question related to plant biology.
3 If you observe that a liquid is boiling, **recall** the type of inference you might make.

Background research on existing scientific knowledge

When you have an investigable question, before designing an experiment, it's important to see if similar questions have already been answered. Background research using secondary sources helps refine your question and ensure it hasn't been answered already. For instance, if you are investigating the effects of sunlight on plant growth, you might discover studies that give information about the optimal light conditions for different plant species. This step involves identifying keywords, developing specific research questions and searching for reliable sources of information. These will be covered later in the chapter.

Formulating a hypothesis and making predictions

Formulating a **hypothesis** and making **predictions** are key steps in scientific investigations. A hypothesis is an educated guess about the answer to the investigable question, based on existing knowledge, written as a testable statement. For example, if the investigable question is 'How does water affect the growth of plants?', then the hypothesis could be 'If plants receive more water, then they will grow taller'.

hypothesis an educated guess that can be tested through further experimentation

prediction a statement that describes what is expected to happen if the hypothesis is true

Predictions describe what is expected to happen if the hypothesis is true, guiding the experiment's design and data collection. For instance, 'Plants watered daily will grow 5 cm taller in a month compared to those watered weekly'.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The example above is a formal prediction made for an experiment. Predictions may also be made informally based on observations and existing scientific knowledge. For example, 'If I release a ball at the top of a straight ramp, it will roll down getting faster as it goes.'

Recall from your Stage 4 Science course that hypotheses can be formulated based on **variables**, specifically an **independent variable** and a **dependent variable**. The hypothesis is then stated using this format:

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)

'If the [*insert independent variable*] increases/decreases, then the [*insert dependent variable*] will increase/decrease.'

The prediction uses similar wording:

"If the [*insert independent variable*] is increased/decreased, then the [*insert dependent variable*] will increase/decrease.'

Examples of independent and dependent variables in hypotheses and predictions, and how to test them, are given in the next section.

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 **Define** 'inference'.
2 **Recall** the primary purpose of conducting background research before designing an experiment.

Understanding

3 **Explain** how the skill of observing relates to working scientifically.
4 **Describe** the purpose of the hypothesis in the scientific method.
5 **Explain** how a prediction relates to a hypothesis in scientific investigations.

Applying

6 **Write** a hypothesis where light intensity is the independent variable and plant height is the dependent variable.
7 **Compare** and **contrast** investigable and non-investigable questions with an example of each.

Analysing

8 **Formulate** a question that can be investigated scientifically, and a hypothesis, about how high a ball bounces when released from different heights above the ground.
9 **Write** a testable prediction based on the hypothesis that increasing the force applied to an object will cause it to accelerate faster.

Evaluating

10 You observe that a ball rolls further on a smooth floor than on a rough carpet. **Create** a hypothesis that could explain why the motion of the ball changes depending on the surface.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1.2 Skills: Planning and conducting investigations

Learning outcomes

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

1. describe the purpose of an investigation.
2. identify the IV, DV, controlled variables and data types needed.
3. select and justify investigation methods to collect reliable data.
4. identify safety risks and implement safe work practices.
5. identify and solve ethical issues.
6. select and use appropriate equipment including digital equipment to make observations with precision.
7. follow the planned method using equipment correctly to perform the investigation, identifying and responding to any errors.
8. accurately collect, record and organise data.
9. modify an investigation in response to new evidence.

WORKSHEET
Identifying variables and hypotheses

3 Planning investigations

The purpose of an investigation

The purpose of an investigation is to answer a research question through systematic data collection and analysis. This could involve understanding natural phenomena, testing the effectiveness of a new drug, or exploring environmental impacts. For example, an investigation into the effects of pollutants on local water quality aims to determine how different contaminants affect aquatic ecosystems. Clearly defining the purpose ensures that the investigation stays focused and relevant.

Identifying variables

In all investigations, we study variables. These were introduced and defined in the previous section. They are things we change and observe in an investigation, or things that affect what we observe. They may be quantities expressed as numbers or qualities that can be described, such as colour, texture or smell.

The independent variable is the factor that is deliberately changed to observe its effect, such as the amount of sunlight a plant receives. The dependent variable is what you measure to determine if it is affected by changes in the independent variable, such as the plant's growth rate. **Controlled variables** are the factors kept constant to ensure a **fair test** and isolate the effect of the independent variable, such as using the same type of soil and plant species.

Figure 1.4 Scientist conducting an experiment in the field

controlled variable
a factor that remains constant throughout an experiment to ensure that any changes observed in the dependent variable are solely due to the manipulation of the independent variable.

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

For example, in an experiment to test if the amount of water affects plant growth, the independent variable would be the amount of water given to the plants, while the dependent variable would

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

be the plant height measured. Controlled variables in this scenario might include soil type, plant species and light conditions, ensuring they remain constant throughout the experiment.

Confounding variables and validity of results

confounding variable
an external factor that can unintentionally affect the outcome of an experiment, making it difficult to determine whether changes in the dependent variable are caused by the independent variable.

univariate analysis
examining the characteristics of a single variable to understand its distribution and key features

bivariate analysis
investigating the relationship between two variables to determine how changes in one variable might affect the other.

It is also important to identify and account for **confounding variables**. These are factors that might unintentionally influence the results, preventing you from identifying the relationship between the independent and dependent variables. In this experiment, potential confounding variables could include variations in temperature, differences in soil moisture content or even pests affecting plant health.

Figure 1.5 Field studies in natural environments offer valuable insights into real-world conditions.

To state whether an experiment has provided 'valid' results, the experimenter must consider the influence of any loosely controlled variable or confounding variables, rather than how much data was collected. Results might be 'reliable' but not 'valid' if a confounding variable was not controlled in the method. It is important that scientists are very strict in controlling the controlled variables to ensure validity of their results. Reliability and validity are discussed at the end of this section in the context of using secondary sources.

Univariate and bivariate analysis

When designing an experiment, you should decide if you want to study one variable or the relationship between two variables. An experiment designed to understand a single variable is called **univariate analysis**. An example is measuring the height of plants given the same amount of water and light after a certain period in order to find the distribution of plant heights (how the data is spread out or arranged) and the mean plant height. An experiment designed to explore the relationship between two variables is called **bivariate analysis**. An example is the one given above, the experiment to test if the amount of water given (IV) affects plant growth (DV).

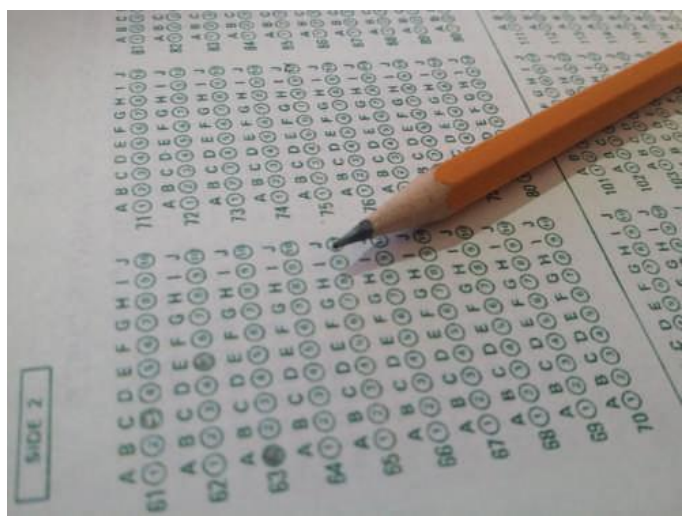


Figure 1.6 An example of univariate analysis is analysing the test scores of students in a class to provide insights into the average performance and the spread of scores. An example of a bivariate analysis is looking at the correlation between the number of hours studied and test scores to reveal whether more study time is associated with higher test performance.

To meet the data science requirement for this course, as noted in the data science appendix, you should conduct a univariate analysis and a bivariate analysis using large datasets. Guidance for this is given in the next section.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 1.1

Testing a hypothesis

Two students had the research question 'Does light intensity affect the length of a bean sprout growth?'

They were thinking of setting this experiment up under three different conditions: darkness, ambient light and a greenhouse setting.

Figure 1.7 Seed sprouts in a petri dish

1. State the independent variable for this experiment.
2. State the dependent variable for this experiment.
3. Write an appropriate hypothesis for this investigation using an 'If … then …' statement.
4. List four variables that must be controlled in this experiment.
5. What assumptions might have been made in this experiment regarding controlled variables?
6. How might the results of this experiment lead to further hypotheses and testing?

Identifying types of data to collect

Different investigations require different types of data. Qualitative data is descriptive, like noting the colour or texture of plant leaves, while quantitative data is numerical, such as measuring the height or number of leaves.

Choosing the right method to collect reliable data is also important. Fieldwork, such as observing animals in their natural habitat, can provide real-world data, whereas laboratory experimentation, like testing chemical reactions under controlled conditions, gives tighter control and more consistency. For instance, if studying the effect of fertiliser on plant growth, laboratory experiments can control environmental factors better than field studies.

Devising methods to collect reliable data in investigations

Consideration of the **validity** and **reliability** of data is important in planning an investigation and analysing the results. Validity is the answer to the questions 'Is this a fair test?' and 'Are all other variables controlled?'. The experiment should manipulate only the independent variable and measure only the dependent variable with all other variables kept constant. Validity therefore refers to how accurately the data represents the phenomenon it is intended to measure. By evaluating the validity of data, researchers can make informed decisions about the quality of the data and ensure that their conclusions and recommendations are based on accurate and reliable information.

Reliable experimental results are those that contain large **sample sizes** and have the properties of repeatability, replicability and reproducibility. Regarding sample size, imagine trying to decide if doctors should prescribe a new painkiller medication by asking one person if it reduced their pain. It would be unreasonable to make decisions about the healthcare of all Australians based on the opinions of one person!

validity
the extent to which an experiment is a fair test, with all relevant variables controlled, and appropriately addresses the research question, and accurately measures what it claims

reliability
how repeatable, replicable and reproducible the results are

sample size
the number of test subjects that are tested or observed in an experiment

Repeatability, replicability and reproducibility

Results from a single experiment may not be reliable as evidence for the research question. For example, it is difficult to perfectly control all controlled variables in an experiment, so a

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

repeatability how well the results match up when the same scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

replicability how well the results match up when a different scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

reproducibility how well the results match up when a different scientist repeats the experiment under different conditions to the original experiment, including different equipment and laboratory or field site

accuracy in experiments, how close a measurement is to the true value

single experiment may be influenced by some unknown variation. Therefore, scientists should ensure that they repeat their experiment under the exact same conditions multiple times, often called conducting multiple trials. If the results match well, the experiment is said to have high **repeatability**. It is also important to remember that an average calculated from many repeats is more reliable than a single measurement, or an average of fewer repeats.

Results should also be replicable (have high **replicability**), which is when another scientist carries out the experiment using the same method and equipment as the original experiment and gets similar results.

Finally, results should be reproducible (have high **reproducibility**), which is when another scientist carries out the experiment using a different method and equipment as the original experiment and still gets similar results.

	Repeatable	Replicable	Reproducible
Consistent results from:	Same person and lab, same method	Different person and lab, same method	Different person and lab, different method

Table 1.2 The difference between repeatability, replicability and reproducibility

If experimental results are repeatable, replicable and reproducible, scientists can be confident that their results are reliable.

Even if your experiment is valid and reliable, it may not be accurate if your equipment or procedure is wrong. **Accuracy** in experiments is how close a measurement is to the true value. But how can we know what that is? If we are measuring something that has a published value, we can compare our value to that. When something is measured for the first time though, scientists don't know what the true value is until it has been reproduced. Scientists aim for high accuracy so their results can be trusted and compared with others.

Quick check 1.2

1 **Recall** if you would use qualitative or quantitative data to describe the colour of a plant's leaves.
2 **Name** an example of a controlled variable in an experiment testing the effect of light on plant growth.
3 **Define** a confounding variable.

Outline the procedure and equipment needed

The procedure is the method for carrying out the investigation. It is a series of things that you do in order to collect the data. They should be written down as numbered steps, in sufficient detail that another person could follow the procedure. To create a procedure, first you must understand exactly what you have to do to carry out the experiment and collect the data. You must also have decided on the equipment and materials you need. Then you should imagine yourself going through the sequence of steps, writing them down as you do so. For guidance, look at the *Practical skills* boxes in the following chapters, such as *2.1 Jumping paper frogs* or *3.1 Investigating resistance*. If you are working in a group, a good tip is for each student to write their own procedure, then to compare and discuss them to compile the final version.

The procedure, equipment and materials needed must all be considered together.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Identify and manage safety risks and ethical issues

In any scientific investigation, you must identify any potential risks to ensure the safety of all participants. Risks can include physical hazards, such as exposure to harmful chemicals, or environmental hazards, such as impacting local ecosystems. For example, when conducting fieldwork in a river to study water quality, risks might include slippery surfaces, strong currents and the presence of dangerous wildlife.

Implementing safe work practices involves wearing appropriate personal protective equipment (PPE) such as gloves, safety glasses and lab coats when handling hazardous materials and adhering to safety protocols to minimise the risk of accidents.

Figure 1.8 Proper use of personal protective equipment, such as radiation protection suits, is necessary to maintain safety while handling hazardous materials.

Managing risks includes having emergency procedures in place, such as knowing the location of safety showers and eye wash stations. By addressing potential risks and following safety guidelines, the likelihood of accidents and injuries is reduced.

Ethical issues

Ethical considerations must also be considered, especially when working with living organisms or human subjects. Ensuring that no harm comes to participants and obtaining informed consent are fundamental ethical principles.

Figure 1.9 Effective risk management involves ensuring that emergency procedures, like the location of eye wash stations, are well known and accessible.

Explore! 1.1

Ethical issues in science experiments

Research the following ethical issues and write 1–2 sentences for each summarising why they should be considered in conducting investigations in science.

1. Honesty and integrity in scientific research
2. Respect for people who are the subjects in a science investigation
3. Observe privacy and consent
4. Respect for living organisms
5. Environmental responsibilities
6. Following regulations and safety guidelines
7. Ethical uses of technology and AI
8. Scientific responsibility to society

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4 Conducting investigations

Assemble and use appropriate equipment

Selecting suitable materials and technologies is essential for the success of any investigation. Choosing high quality and appropriate tools, such as using a pH meter for accurate acidity measurements, ensures reliable and valid results.

Figure 1.10 Proper setup and handling of equipment, as demonstrated in scientific experiments in challenging environments like the Snowy Mountains, are crucial for obtaining accurate results.

Accurately assembling, constructing and manipulating equipment will improve any investigation. This involves setting up experimental apparatus according to detailed instructions and ensuring all components function correctly. For example, when assembling a circuit for an electrical experiment, the wires must be connected properly, and the power supply must be compatible with the components used.

Manipulating equipment with precision, such as adjusting the flame of a Bunsen burner or calibrating a digital scale, ensures experimental conditions are consistent and reliable. **Calibration** is the process of adjusting equipment to ensure its measurements are accurate and consistent. This procedure involves comparing the measurements from the equipment with known standards or reference values and making necessary adjustments to correct any discrepancies.

calibration
adjusting measuring equipment against a known standard value to ensure its accuracy

Figure 1.11 Equipment used to calibrate volumetric glassware

Ensuring all equipment used is correctly calibrated will allow for better replicability and reproducibility by other scientists and using large sample sizes improves reliability as there is a smaller chance of error. Random or systemic errors, such as in taking readings on glassware or in reflex time to stop a stopwatch, can reduce reliability, particularly the replicability and reproducibility of results. This is another reason why repeating the experiment multiple times is important and errors can be made less impactful by averaging results. Proper use and maintenance of equipment can also enhance the accuracy of results and prolong the lifespan of the tools and materials used.

Following the planned method

Following the planned procedure methodically is important for experimental validity. This involves following the step-by-step instructions outlined in the experimental design and being vigilant for any deviations or errors that may occur. If an error is identified, such as an unexpected change in temperature or a malfunctioning piece of equipment, it is important to pause the experiment, assess the situation and take corrective action. This may involve recalibrating equipment, repeating certain steps, or adjusting the procedure to account for the error. Documenting any deviations and

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

the actions taken to address them is important for maintaining the integrity of the investigation and providing a clear record for future reference.

Quick check 1.3

1 **Outline** what you should do if you identify an error during an experiment.
2 **Recall** an example of personal protective equipment (PPE) that should be worn when handling hazardous materials.
3 **Describe** why is it important to select high-quality and appropriate tools for an investigation.

Accurately collect and record data

Systematically and accurately collecting and recording data involves using appropriate methods and tools to gather data and ensuring all measurements are carefully taken and recorded, and are consistent. For example, when measuring the growth rate of plants, it is important to use a consistent method, such as measuring from the base to the highest point of the plant at regular intervals. With fieldwork, documenting the conditions under which the data was collected, such as the date, time and environmental factors, could also provide valuable information when later interpreting the results.

Figure 1.12 Recording data promptly and accurately in a structured format, such as a lab notebook or digital spreadsheet, helps prevent errors and omissions.

Identifying and responding to errors and uncertainty

Measurements are almost never perfect. The accuracy of any measurement will always be limited by the apparatus being used, the skills of the person collecting the data, the method being used and the environment where the experiment is being carried out. Whenever we do an experiment, we are attempting to determine the 'most true' data, but we will normally find variation in the results.

So, what are the possible reasons for the different values seen in our data? Mistakes are avoidable problems made by the person collecting the data, such as selecting the wrong piece of equipment or writing down results incorrectly. Although these are possible, a careful scientist should not make mistakes and would not include them in any report.

Errors are the difference between the results of experimental measurements and the true or reference values involved. They are not the same as mistakes.

Systematic errors

Systematic errors arise from measured values that are either consistently larger or smaller than the true value of your data if equipment is used in the same way. Systematic errors can be minimised by careful experimental design, including calibrating measuring instruments correctly. Some examples are given below:

- **Instrument effects.** These are caused when a measuring instrument is faulty or has not been calibrated correctly. For example, if a scale used to measure a mass was not properly calibrated, so that all the readings were 3.00 g greater than they should be, then all the measurements of mass would be consistently overestimated by 3.00 g. This would lead to a systematic effect because the data is all wrong by the same amount each time a measurement is taken. A **zero-calibration error** occurs when the initial value shown by a measuring instrument is not zero when it should be zero.

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

zero calibration error
a measuring instrument giving a non-zero reading when the true value should be zero

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

For example, a scale may show 0.001 g, even when nothing is being weighed.

- **Environmental effects.** These are caused by external factors such as temperature or humidity. For example, the measurements taken using a metal ruler will differ depending on the temperature. In low temperatures the ruler will contract, whereas in warmer temperatures it will expand. This means that all the measurements taken under those particular conditions would always be lower or higher than the correct value.
- **Observation errors.** These are caused by undertaking the wrong observations or reading instruments incorrectly. For example, a **parallax error** may occur when the observer's eye is positioned at an angle to the measurement markings, causing the data to be either larger or smaller than the correct value.

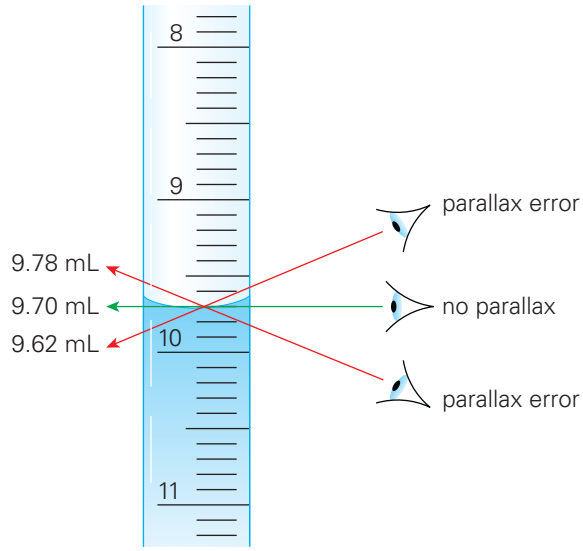


Figure 1.13 The position where there is no parallax is the correct eye level for reading the measurement.

parallax error a measurement taken that is not the true value due to the position of the object along various lines of sight

random error error caused by limitations of the measurement device or the observer that does not follow a regular pattern

reading error a reading or measurement that is not the true value

uncertainty the doubt that a measured value is the true value

Choosing the best equipment and using a method that avoids systematic errors will improve the accuracy of the experiment. For example, you could use an electronic timer system to record measurements at given time intervals rather than rely on a human to use a hand-operated stopwatch.

Random errors

Even if careful experimental design removes systematic errors, **random errors** will remain that will affect the accuracy of a measurement. These are caused by limitations of the measurement device and the observer and are equally likely to be positive or negative because they do not follow a regular pattern. They can be caused by the experimenter's inability to obtain the same measurement in the same way to get the same result. You may measure the mass of a piece of magnesium ribbon three times using the same balance and produce slight variation in your results: 1.36 g 1.38 g and 1.39 g.

Reading errors

Reading errors can also occur when a measurement falls between two measurement markers. An observer would have to estimate the true value, and this would differ between observers. It is likely that half of the results obtained would be estimates that are too large and half would be too small. These effects are an unavoidable part of doing experiments and can affect result precision, but the resulting error can be reduced by repeating the experiment many times and taking average values.

Uncertainty

Due to random and systematic effects in the experimental process, there will always be a margin of doubt about any of your results– the **uncertainty** about the measurement. But how big is this margin? We have looked at how these can arise, but we need to be able to quantify them. This happens through estimating the uncertainty of any measurement. There are two ways to do it, described next.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Absolute uncertainty

The first way is to state a range or interval around a measured value which quantifies the likelihood that a repetition of our experiment will produce a new result that would lie within this interval.

The notation for a measurement and its uncertainty should take the following format (remember to add the appropriate units):

measured value ± *uncertainty*

where ± means 'give or take'. This tells us the **absolute uncertainty**.

absolute uncertainty the size of the range of values within which the actual 'true value' of a measurement probably lies

The following rules are often used to determine the absolute uncertainty in a single measurement when using either an analogue scale or digital measuring instrument:

- The uncertainty in an analogue scale measuring instrument is equal to the smallest increment of the instrument divided by two.
- The uncertainty in a digital measuring instrument is equal to the smallest increment of the instrument.

However, if we take multiple measurements to calculate a mean, we can estimate the absolute uncertainty by calculating half the range.

Uncertainty = $\frac{1\text{ V}}{2}$ = 0.5 V

Uncertainty = 0.1 V

Uncertainty = $\frac{100\text{ g}}{2}$ = 50 g

Uncertainty = 0.001 g

Figure 1.14 There are different rules for single measurements using analogue (left) or digital (right) instruments. Remember to include units!

For example:

- You measured the mass of different magnesium ribbon pieces as 1.36 g, 1.38 g and 1.39 g.
- The mean of these readings is $\frac{1.36 + 1.38 + 1.39}{3}$ = 1.38 g.
- The range can be calculated by maximum value − minimum value = 1.39 − 1.36 = 0.03 g.
- The uncertainty is calculated by taking half the range = 0.5 × 0.03 = 0.015 g.
- You can then include this uncertainty when communicating your results:
- Mass = 1.38 ± 0.02 g.
- The mass of the magnesium can therefore be expected to be between 1.36 and 1.40 g.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Relative uncertainty

relative uncertainty the ratio of the absolute uncertainty to the reported value, often expressed as a percentage

The uncertainty of any measured value can also be expressed as a percentage or as a ratio. This is **relative uncertainty**. This is calculated by dividing the absolute uncertainty of the result by the result itself. The relative uncertainty can be more useful than the absolute uncertainty because it puts your experimental data into perspective. For example, if you made an error in measuring the length of your eraser, it would be more noticeable than if you made the same error when measuring the table. Relative uncertainties do not have units, unless the uncertainty is multiplied by 100 where it is reported as a percentage.

Consider this example:

- You measured the length of your table (80.0 cm) using a metre rule.
- The absolute uncertainty is ±0.05 cm.
- This uncertainty can then be included when communicating your results:
- Length = 80.0 cm ± 0.05 cm.
- The relative uncertainty is calculated by $\frac{0.05}{80.0} = 0.000\,625$.
- This can then be reported as a percentage by multiplying by 100:
- Percentage uncertainty = $0.000\,625 \times 100 = 0.0625\%$.

Now compare this result to measuring your eraser:

- You measured the length of your eraser (5.0 cm) using a metre rule.
- The absolute uncertainty is ±0.05 cm.
- This uncertainty is then included when communicating your results:
- Length = 5.0 cm ± 0.05 cm.
- The relative uncertainty is calculated by $\frac{0.05}{5.0} = 0.01$.
- This can then be reported as a percentage by multiplying by 100:
- Percentage uncertainty = $0.01 \times 100 = 1\%$.

The example above illustrates the importance of considering both absolute and relative uncertainty when reporting measurement results. While the absolute uncertainty is the same for both the table and eraser measurements, the relative uncertainty is significantly higher for the eraser due to its smaller size.

Uncertainty when measuring length

When we measure length, we normally use a ruler or a tape measure. These are scale measuring instruments, so the uncertainty should be equal to half the smallest increment of the instrument. The smallest division of a ruler you probably have is one millimetre, producing an uncertainty of 0.5 mm or 0.05 cm.

If you were measuring the length of an eraser, you would place the eraser so it was aligned at zero on your ruler, so there is an additional ±0.05 cm error at that end. Therefore, the total error for a centimetre ruler is 0.05 cm + 0.05 cm = ±0.1 cm.

Which uncertainty should be recorded?

Often, you will be completing an experiment that uses equipment and involves recording multiple measurements. The accuracy of your investigation should consider the unit in which you are measuring the dependent and independent variables, as well as the precision of the instruments you are using (Figure 1.15). You should always record the largest source of uncertainty.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

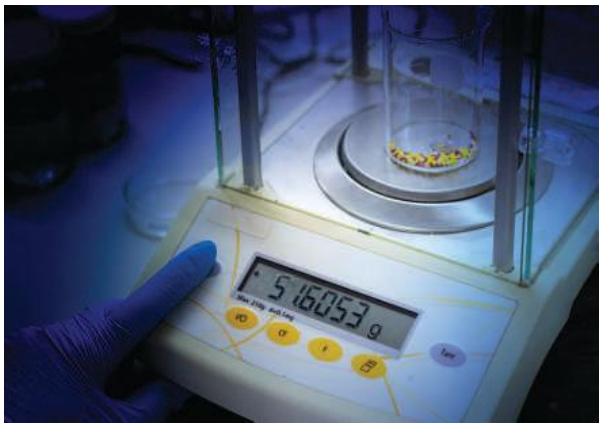


Figure 1.15 Measurement tools vary in their precision.

Experimental precision

Experimental **precision** refers to how closely repeated measurements agree with each other. For example, let's say you record the mass of a product of a chemical reaction in grams (g) and you repeat the experiment four times, getting results of 1.54 g, 1.55 g, 1.55 g and 1.54 g. The data shows low variation from the mean (it is clustered tightly) and can be said to be precise. Note that, even though this data is precise, it is not necessarily accurate. Precision does not give us an indication of how 'true' the data is; that is, how accurately it matches the actual values. The reading of values on glassware such as burettes and measuring cylinders can sometimes affect precision, particularly when the experimenter needs to estimate a value between graduated markings.

precision
how closely repeated measures agree with each other

sensitivity
the smallest change in a value that an instrument can detect or measure

In science, we distinguish the **sensitivity** of a measuring instrument from precision. Sensitivity refers to the smallest change in a value that the instrument can detect or measure, whereas precision refers to the consistency of the readings.

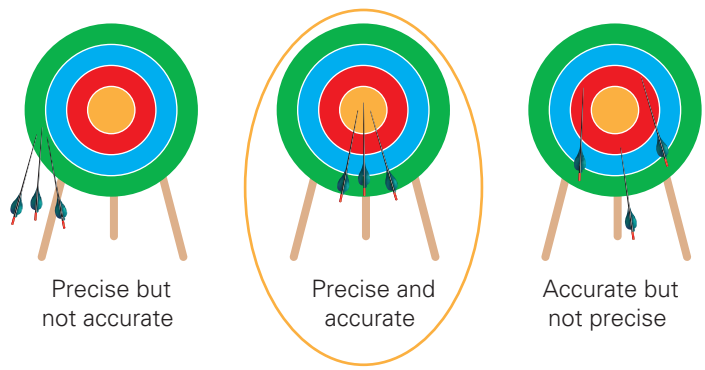


Figure 1.16 A faulty piece of measuring equipment might consistently give wrong values, like the target on the left. This measurement would be precise, but the results are inaccurate and do not measure what they claim to measure; therefore, they have low validity. Note that there are some diagrams that use this dartboard analogy for the broader term 'reliability' but it is best restricted to showing the more specific term 'precision'.

Quick check 1.4

1 **Outline** how a systematic error could affect your experimental results.
2 **Explain** the difference between experimental accuracy and precision.
3 **State** the sort of uncertainty that each of the following scenarios represents.
   a A measuring tool is incorrectly calibrated and regularly underestimates the mass.
   b A measuring tool is not very precise and the temperatures vary by approximately 0.5°C in either direction.
4 Describe how the effect of relative uncertainty can be reduced.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Modifying an investigation to new evidence

Investigations often need modification in response to new evidence. If initial results suggest an unexpected trend, the hypothesis or experimental design might need adjustment. For example, if testing how different fertilisers affect plant growth and discovering that one fertiliser unexpectedly stunts growth, you might need to investigate further into the chemical composition of that fertiliser and its effect on the plants.

Using reliable secondary sources

When evaluating secondary sources, especially online content, you should develop and apply criteria such as the author's qualifications, the accuracy of information and the presence of supporting evidence to determine the validity and reliability of the content. Reliable sources are usually written by experts, such as scientists or scholars and are published in reputable journals, books or websites. Look at the date of publication to ensure the information is current, as outdated data might no longer be accurate. Consider the purpose of the source: is it meant to inform, persuade or sell something? Be wary of bias, which can distort the facts. Cross-referencing information with other credible sources can help verify accuracy.

Figure 1.17 *Nature* is one of the most cited scientific journals, making it one of the most respected academic journals globally.

The principles for evaluating the validity and reliability of secondary source data are the same as for **primary data**, i.e. the data that you and your class have collected, as covered above.

primary data data that researchers collect themselves for a specific purpose; obtained from observations, experiments, surveys or interviews

secondary data information that has already been collected and analysed by others that is used to support or inform new research.

Be sure to record the correct references of secondary sources you use, as you will need to state them in any reports or science communications where they are acknowledged. Referencing secondary sources is covered in more detail in the last section of this chapter.

Explore! 1.2

Scientific publishing crisis

Scientific knowledge is verified through rigorous processes such as hypothesis testing and peer review. Hypothesis testing involves proposing a testable explanation and conducting experiments to gather data that supports or refutes the hypothesis, while peer review ensures that other experts critically assess the research methods and findings before publication.

However, these verification processes are being undermined by a growing global crisis in scientific publishing. In 2023, over 10 000 sham research papers were retracted, exposing the widespread issue of fraudulent studies largely driven by shadow organisations known as 'paper mills'. These paper mills produce fake research to advance the careers of young scientists, often with journal editors bribed or infiltrated by these groups. The result is a rise in retractions, which have increased from just over 1000 in 2013. This scandal undermines scientific progress and threatens credible research, making it difficult for scientists to base their work on trustworthy findings.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 1.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 1.2 questions

Remembering

1 **State** what is meant by experimental accuracy.
2 **Name** one reason why it is important to follow planned procedures in an experiment.
3 **Define** the term 'controlled variable'.

Understanding

4 **List** the types of variables commonly identified in a scientific experiment.
5 **Explain** why it is necessary to use appropriate tools and methods when collecting data.
6 **Explain** why it is important to identify and account for confounding variables in an experiment.

Applying

7 **Apply** the working scientifically skills to outline the steps you would follow in an experiment testing the effect of different fertilisers on plant growth.
8 If you notice that your digital scale is giving slightly different readings for the same weight, **identify** what you should do.
9 When measuring the growth rate of plants, **plan** how your method should be consistent.

Analysing

10 **Compare** the effects of using a hand-operated stopwatch versus an electronic timer system on experimental accuracy.
11 If repeated measurements of a chemical reaction's mass are very close but consistently slightly off from the true value, **infer** what this means.

Evaluating

12 **Discuss** why documenting conditions such as date, time and environmental factors is important for data collected 'in the field' outdoors compared to data collected in the laboratory.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1.3 Skills: Processing and analysing data, and problem-solving

WORKSHEET
Plotting data

Learning outcomes

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

1. calculate a range of descriptive statistics.
2. use a range of representations to organise data and information.
3. extract information from a range of sources.
4. use large datasets to develop and test a question (from *Data science 2*).
5. Assess data validity and reliability.
6. describe relationships between variables, identify data which supports or refutes hypotheses, and evaluate evidence and conclusions.
7. evaluate investigation procedure and improve the quality of data.
8. select and implement problem-solving strategies.

mean
the average value, found by adding all the numbers together and dividing by the count of numbers

median
the middle value in an ordered dataset, or the average of the two middle values if the set has an even number of observations

mode
the most frequently occurring value in a dataset

range
the difference between the highest and lowest values in a dataset

SI units
the standard international system of units used for measuring physical quantities, ensuring consistency and uniformity in scientific and technical communication globally

5 Processing data and information

Organising data effectively is a necessary step before interpreting results which allows you to draw accurate conclusions in scientific investigations. Good organisation starts with how and where you record the data, such as in a clear and logical results table or spreadsheet. Care taken to make the observations and write or type them accurately will produce good data. However, datasets, especially large ones, often require data cleaning, which includes removing duplicates, addressing missing values and correcting errors to maintain data quality.

Calculating descriptive statistics using SI units

Summary statistics, also called descriptive statistics are used to summarise and describe the key features of a dataset. These include the **mean**, **median** and **mode**, which provide a central value for comparison; and measures of variability, such as the **range**, which shows how spread out the data is. For instance, in an experiment measuring plant growth under different light conditions, calculating the mean growth rate for each light condition offers a central value for comparison, while the range reveals the variability within each condition. Using **SI units**, like metres (m) for length and kilograms (kg) for mass, ensures consistency and facilitates straightforward comparison and interpretation of results.

Worked example 1.1

Calculating the mean, mode, median and range

Violet decides to determine how light affects plant growth. She creates three groups that consist of 10 plants and records their growth rates (measured in cm/week) in the following table.

Group	Light conditions	Growth rate (cm/week)
A	Plants grown under natural sunlight	5, 6, 7, 5, 6, 8, 7, 5, 6, 7
B	Plants grown under LED lights	7, 8, 7, 8, 9, 8, 7, 8, 9, 7
C	Plants grown under fluorescent lights	4, 5, 4, 5, 6, 5, 4, 5, 6, 4

She calculates the mean, mode, median and range for each group.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Group	Mean	Mode	Median	Range
A	$= \frac{5 + 6 + 7 + 5 + 6 + 8 + 7 + 5 + 6 + 7}{10}$ = 6.2	5, 6, 7 (All appear three times each, so there are multiple modes.)	To find the median, arrange the values in ascending order: 5, 5, 5, 6, 6, 6, 7, 7, 7, 8. Since there is an even number of observations, the median is the average of the fifth and sixth values. median $= \frac{6 + 6}{2}$ = 6	= 8 – 5 = 3
B	$= \frac{(7 + 8 + 7 + 8 + 9 + 8 + 7 + 8 + 9 + 7)}{10}$ = 7.8	7, 8 (Both appear four times each.)	Values in ascending order: 7, 7, 7, 7, 8, 8, 8, 8, 9, 9. median $= \frac{(8 + 8)}{2}$ = 8	= 9 – 7 = 2
C	$= \frac{4 + 5 + 4 + 5 + 6 + 5 + 4 + 5 + 6 + 4}{10}$ = 4.8	= 4, 5 (Both appear four times each.)	Values in ascending order: 4, 4, 4, 4, 5, 5, 5, 5, 6, 6. $= \frac{5 + 5}{2}$ = 5	= 6 – 4 = 2

There are many benefits of analysing summary statistics. They help in recognising patterns within the data, making it easier to communicate these patterns to others as they provide a clear summary of the dataset. In this example, it becomes easier to compare the growth rates of plants under different light conditions. For example, Group B shows the highest growth rates, suggesting it performed best under the given conditions, likely due to LED lights. Group A shows more variability in growth, while Group C has the lowest mean growth rate.

Representing the data

A variety of representations can be used to organise and present data, including graphs, keys, models, diagrams, tables and spreadsheets. Examples are shown in the figures below.

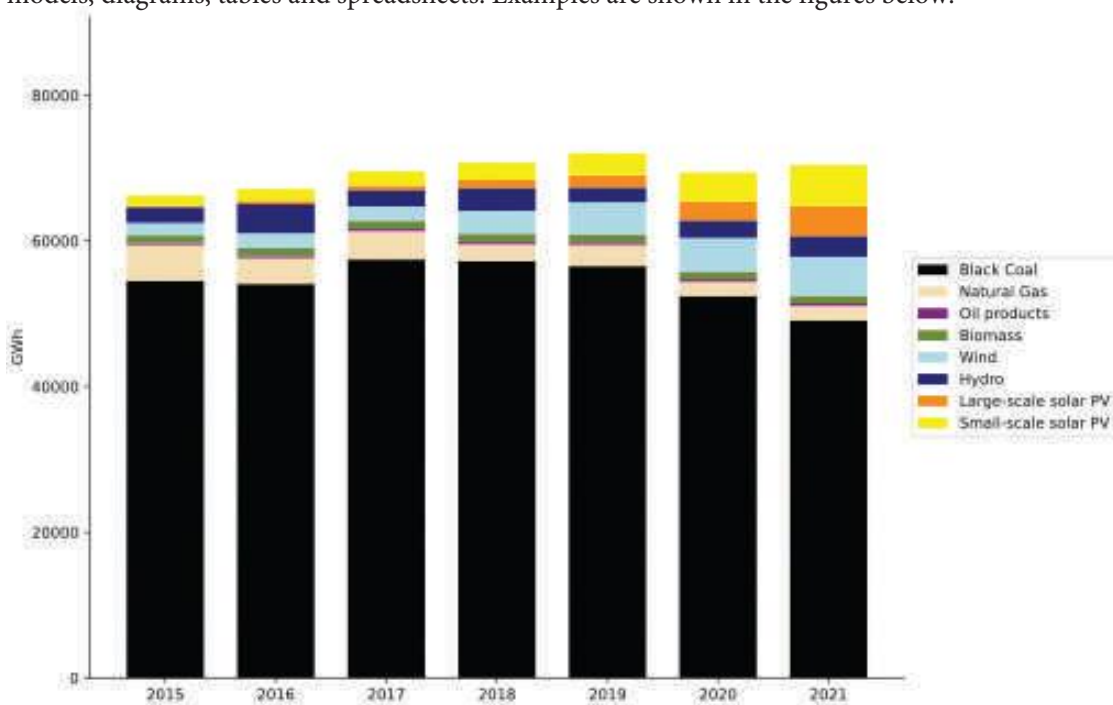


Figure 1.18 Bar graphs are ideal for displaying comparisons in the size of different groups, or changes over time. This is a segmented bar graph: the total energy production for each year shown in each column is subdivided into energy sources, so we can see how much each source contributes and how that changes over time.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

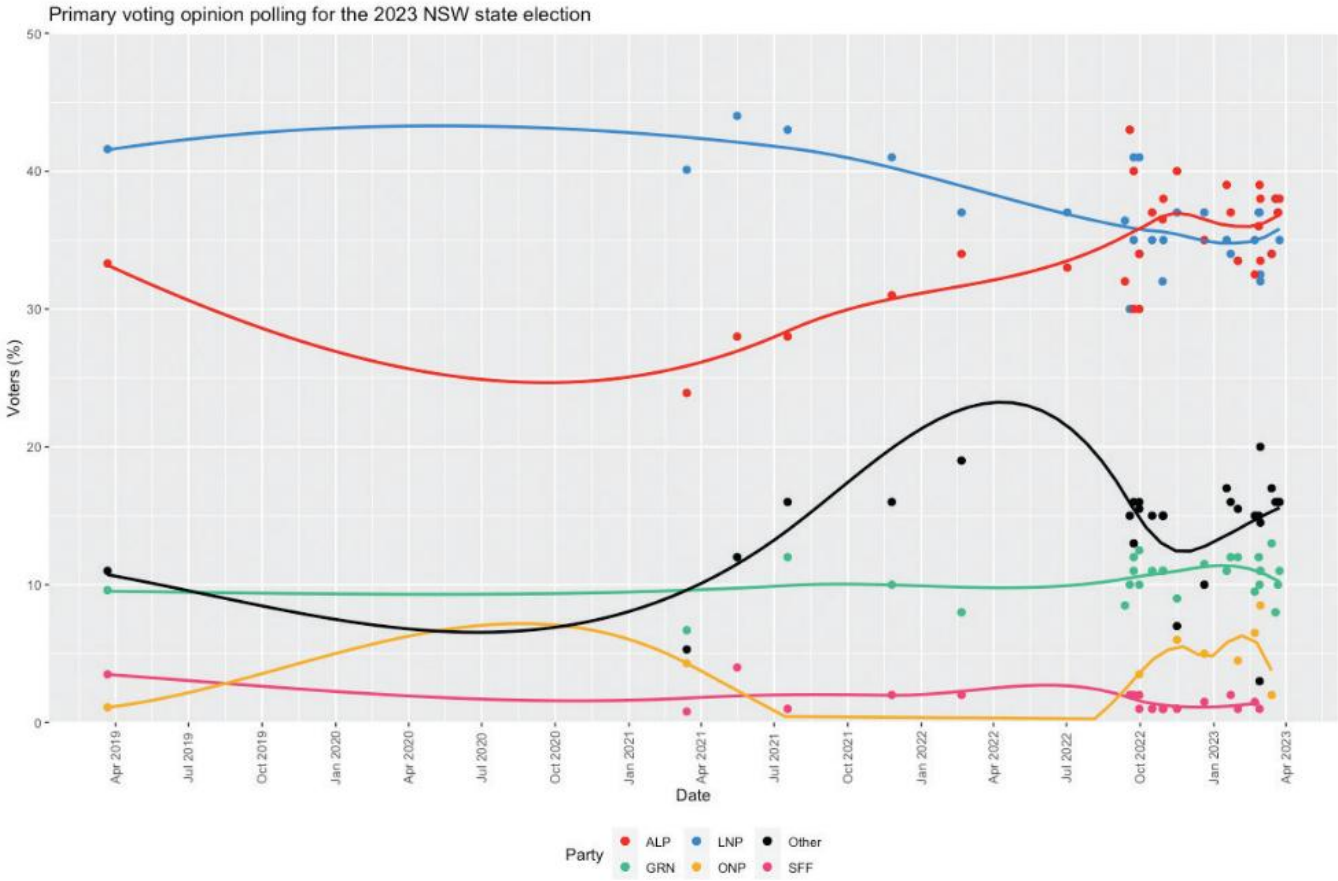


Figure 1.19 Line graphs are ideal for displaying changes over time, or changes in the DV (plotted on the vertical y-axis) as the IV changes (plotted on the horizontal x-axis). Line graphs may plot one set of values of the DV, or several – there are 6 sets in this example, one for each political party.

Figure 1.20 Pie charts are good for displaying proportions or percentages of subgroups (the slices) that make up a total (the whole pie). They are commonly used for displaying groups in a population, or subtotals of money spent or planned in a budget, as shown here.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

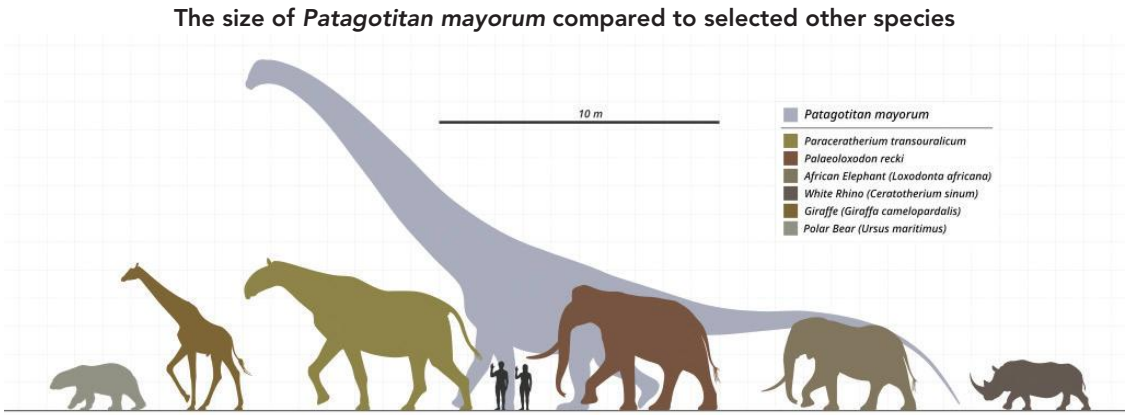


Figure 1.21 Diagrams and infographics are good for comparing the size of things – size in the diagram represents size of the actual thing. Here `size' means physical size but it could be a different value. For example, these animals could be sized according to the area of land required to feed each individual.

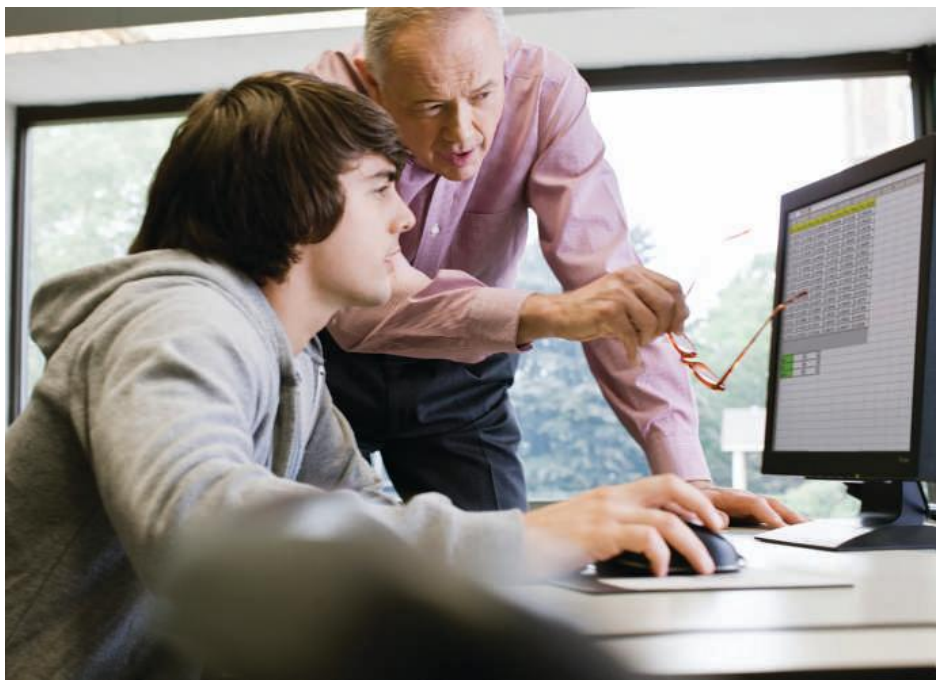


Figure 1.22 Tables and spreadsheets are essential for organising large datasets and performing calculations efficiently. Using these tools allows scientists to present their data clearly and effectively, facilitating better understanding and communication of their findings.

Quick check 1.5

1 **List** three common tools or representations used to organise and present data.
2 **Explain** how the mean and range of a dataset summarise the data's central value and variability (how spread out the values are).

Try this 1.2

Descriptive statistics

Consider the following data set: 17, 14, 18, 21, 21, 19, 12, 20, 16.

1 Calculate the mean, median, mode and range of the data.
2 Put the data into a spreadsheet software and explore how you can determine the mean, median, mode and range of the data using the software's features and functions.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Data that supports a hypothesis

The purpose of collecting data is to support or refute a hypothesis. Identifying which is closely related to skill *6 Analysing data and information* and so is discussed there, later in this section.

Selecting and extracting information from a range of sources

In order to do background research on your investigation question, or to answer an investigation question that is based on existing information and data, you need to extract information from a range of sources. These include texts, diagrams, flow charts, tables, databases, graphs and multimedia resources. You need to have an understanding of the purpose of these representations of data and why they are used. You should also have a clear idea of what you are looking for – writing down your purpose or objective. Then you can follow this procedure to extract information from the source:

1. Identify the purpose of the source, the kind of information it conveys, and how it helps you.
2. 'Scan' (quickly look through) the source to get an overview – read just its titles, headings, diagrams, labels and captions.
3. Look for and read any introductions, summaries or conclusions that provide more detail on its purpose and importance.
4. Find patterns or relationships that relate to what you are looking for, especially descriptions of changes, trends, comparisons, and cause and effect relationships.
5. Write notes in your own words summarising the key points, saying what the source shows, what you can learn from it, and what conclusions you can draw.
6. Imagine explaining the information in the source to someone else – if you can do this, you have understood it.

Using available large datasets to develop and test a question

As noted earlier in this section, and in the data science appendix, you need to use a large dataset for an investigation. Examples of large datasets are given below, and a worksheet is provided in the Interactive Textbook to guide you through such an investigation.

WORKSHEET
An investigation using a large dataset

Large datasets are collections of huge amounts of information. These can sometimes contain gigabytes or even petabytes of data (one petabyte of data is equivalent to taking over 4000 digital photos every day for your entire life!) These datasets can come in different forms, like numbers in a database, structured files, or unstructured data such as texts, images and videos. Large datasets are important in many fields because they are based on very large samples, sometimes containing all existing data, and are therefore a more accurate representation than a small dataset. In addition, they help us understand complex information, make better decisions and discover new trends and patterns that lead to improvements and innovations.

Table 1.3 highlights how data is collected and used across different fields.

Sector	How data is collected and used
Healthcare	Patient data is collected and analysed to enhance diagnostic accuracy, develop personalised treatment plans and inform healthcare policies, leading to improved patient outcomes.

Figure 1.23 Medical sensors continuously collect data

Table 1.3 Data collection across different fields

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Sector	How data is collected and used
Online platforms	Social media and e-commerce sites gather extensive user data to personalise content, improve user experiences and optimise marketing strategies based on user behaviour and preferences.

Figure 1.24 Algorithms process huge amounts of data to personalise the content being shown.

Climate science	Environmental monitors and satellites continuously collect data. These large datasets facilitate advanced studies in climate science.

Figure 1.25 Weather stations continuously measure temperature, humidity, wind speed and air pressure to give real-time weather updates.

Government	Public records maintained by government institutions provide vast datasets on demographics, health and economic conditions, which inform public policy-making, improve public services and monitor social trends.

Figure 1.26 Birth, death and marriage registers stored in archive

Business	Businesses use large datasets to streamline operations, optimise decision-making and enhance customer experiences, increasing efficiency and profitability.

Figure 1.27 Data is used to guide warehouse workers, helping them make informed decisions that improve operations by streamlining workflows and optimising inventory management.

Table 1.3 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Sector	How data is collected and used
Agriculture	Modern farming relies on data collected from various sources like satellite imagery, soil sensors and weather stations. This data helps farmers monitor crop health, optimise irrigation, manage pests and predict yields.
Space exploration	In space exploration, data is gathered through satellites, telescopes and space probes. This data is used to study planetary systems, monitor cosmic phenomena and explore the potential for life beyond Earth.
Nuclear science	In nuclear science, data is collected from particle accelerators, nuclear reactors and radiation detectors. This data is used to study atomic interactions, develop nuclear energy technologies and ensure safety in nuclear facilities.

Figure 1.28 The Commonwealth Scientific and Industrial Research Organisation (CSIRO) provides datasets related to environmental science, agriculture and climate change. Recent research led by CSIRO and NSW Department of Primary Industries, has identified the most profitable and least risky cropping rotations for southern NSW. The study, spanning from 2017 to 2023, found that diverse canola-cereal and legume systems offer increased profitability and reduced risk compared to traditional methods. This research is guiding growers to optimise crop management for better productivity and profitability.

Figure 1.29 NASA hosts extensive datasets on space exploration, earth sciences and atmospheric conditions.

Figure 1.30 The Australian Nuclear Science and Technology Organisation (ANSTO) offers datasets on materials science, nuclear research and radiation. This includes data from the Open Pool Australian Light-water (OPAL) reactor, which is a key facility for nuclear experiments.

Table 1.3 *(continued)*

Quick check 1.6

1 **Describe** the advantages of large datasets over smaller ones.
2 **Name** an example of how large datasets are used in a specific sector.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6 Analysing data and information

Assessing data validity and reliability

Data validity and reliability has been introduced under skill *3 Planning investigations* because the experimental design should take into account how you ensure a valid test and reliable data. When you analyse the data from the experiment you should assess its validity and reliability, and address ways to improve the quality of the data in your conclusions.

Checklist of ways to assess the validity of data – did you:

- use clear methods and follow procedures exactly
- change only the independent variable, ensure all others except the independent variable are controlled
- avoid bias – not change results to fit expectations
- compare results with scientific theories or previous studies.

Checklist of ways to assess the reliability of data – did you:

- use as many test subjects as possible (have a large sample size) especially if they are people or other living things or materials that tend to have natural variability
- calibrate equipment to make sure that it gave accurate readings
- use higher precision instruments (such as digital thermometers rather than conventional liquid thermometers)
- use consistent methods especially in measuring techniques
- take multiple readings – repeat measurements – and see if they are consistent
- check for systematic errors – look for consistent mistakes in measuring or recording data
- identify other errors and uncertainty
- check for outliers (see following item)
- compare results with others in the class
- compare results with published values (actual values).

Evaluating the procedure and improving the quality of the data

Notice that most of the items in the checklist above relate to the procedure that you followed – the experimental method. Assessing the data also allows you to evaluate the method. Improving the method to put right any deficiencies will also improve the data the next time, or in experiments with similar methods. The assessment and improvements to be made should be included in your report on the experiment.

The checklists above apply to primary data that you collect, and to secondary source data that you investigate or rely upon.

Investigating outliers

Outliers are anomalous data values that do not appear to fit with the other recorded values. These values are often situated a long way from the mean and may represent an experimental error, such as error in reading the scale or a fault in measuring equipment.

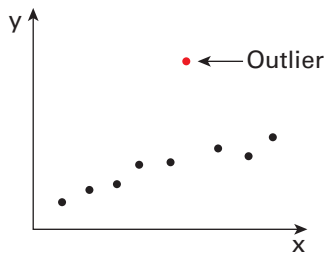


Figure 1.31 Outliers are often easily spotted in graph form.

outlier
anomalous data value that does not seem to fit the rest of the data

It is important that outliers are investigated and accounted for in the discussion of your results. Sometimes, repeating the experiment eliminates the outlier, but you need to mention that this has occurred. The most common causes of outliers in a dataset within the scientific laboratory are:

- data entry errors (human miscalculation)
- measurement inaccuracies (instrument error).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Outliers can easily be spotted when data is graphed. There will often be a large gap between an extremely high or low value and other observations, indicating that it differs greatly.

Quick check 1.7

1 **Define** the term 'outlier'.
2 **Describe** whether a dataset with several outliers will give accurate results.
3 **Define** validity.
4 **Describe** how validity can be evaluated.

Describing patterns, trends and relationships between variables

Identifying patterns and trends in data is necessary to understand the underlying phenomena in scientific investigations. Patterns refer to regularities or repeated sequences in data, while trends indicate a general direction in which data points move as a variable changes. Often they describe the same thing. This discussion applies to bivariate data, when the dependent variable is plotted against the independent variable. Graphing data allows scientists to visualise relationships between variables (or the lack of them) easily, so it is generally the best representation of the data to use. However, other kinds of diagrams and tables can also be used effectively.

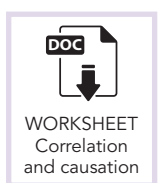
Identify data which supports or refutes a hypothesis

An investigation should be a valid test of a prediction from a hypothesis. This is usually in the form that if the IV is changed, the DV will change in a specified way. If it does, then the data supports the hypothesis. If it does not, the data refutes the hypothesis. Sometimes though the results are not clear, such as when your prediction was for an increase in the DV, but it is so small it could have arisen by chance. Scientists have ways to measure whether a change in the DV is significant, but these are not part of this course. If the hypothesis is supported or refuted, then questions or solutions to problems that are based on it are refuted as well.

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

Relationships between variables

The relationships between variables should be identified and described by examining how changes in one variable affect another. For instance, in a study examining the effect of fertiliser on plant growth, the amount of fertiliser used (independent variable, on the horizontal *x*-axis) and the height of the plants (dependent variable, on the vertical *y*-axis) are the key variables. A positive relationship might be observed if increased fertiliser leads to taller plants, while a negative relationship would occur if the fertiliser harmed the plants. No correlation may be observed with some plants if the added fertiliser had no effect. Recall the meaning of **correlated** and correlation from Stage 4.



WORKSHEET
Correlation and causation

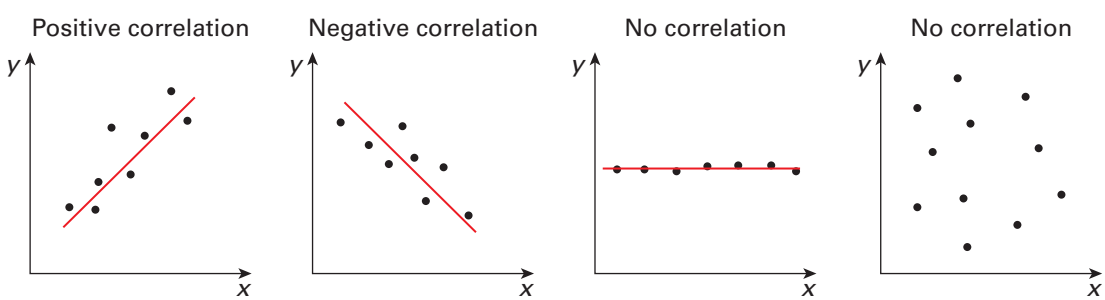


Figure 1.32 The relationship between two variables can be positive, negative or have no correlation. The latter can be shown by a flat plotline or line of best fit, meaning the DV was not changed by changes to the IV, or no correlation can be shown by data to which a line can't be fitted. This may suggest that the DV changed due to a confounding variable.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 1.3

Understanding causal and correlational relationships

A causal relationship implies that one variable directly affects another. This means that changes in the independent variable cause changes in the dependent variable. Establishing causality often requires controlled experiments where researchers can manipulate the independent variable and observe the resulting changes in the dependent variable.

A correlational relationship indicates that two variables are related, but it does not imply causation. In other words, while the variables may move together in a predictable pattern, this relationship does not establish that one variable causes the other to change. Correlation can be positive (both variables increase or decrease together) or negative (one variable increases while the other decreases).

Figure 1.33 Increased ice cream sales correlate with more drowning incidents. However, this is due to higher temperatures driving both more ice cream consumption and increased swimming activity, which raises drowning risks.

A common misunderstanding is assuming that correlation implies causation. There are many examples where a correlation exists between two variables, but the relationship does not imply that one variable causes the other. Other factors, often unmeasured or less obvious, might be influencing both variables. Figures 1.33 to 1.35 show examples.

Figure 1.34 Increased umbrella sales correlate with more rainfall. The correlation is due to umbrellas being purchased in response to rain rather than causing it.

Figure 1.35 Taller individuals might earn more on average, but this correlation is likely influenced by social and economic factors rather than height directly affecting income.

Interpolation and extrapolation

Interpolation involves estimating values within the range of observed data points, while **extrapolation** involves predicting beyond the observed range. Note the conventional usage of *estimation* within the range (interpolation) and *prediction* outside the range (extrapolation). For example, if a graph shows a linear

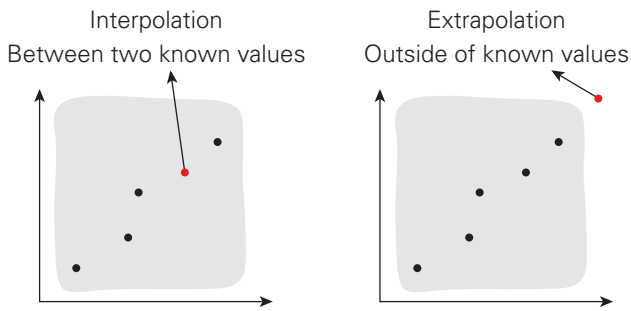


Figure 1.36 Interpolation and extrapolation

interpolation the method of estimating unknown values within the range of known data points

extrapolation predicting values outside the range of known data points based on the existing trend

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

increase in enzyme activity with temperature up to 40°C, interpolation can estimate enzyme activity at 35°C and extrapolation can predict activity at 45°C. These techniques are valuable for making informed predictions and understanding trends beyond the collected data. They can be used in the discussion of your results and in your conclusions. Predictions from interpolation and extrapolation can also be used in further research.

Quick check 1.8

1 **Outline** how you would test the hypothesis that adding the recommended amount of lawn fertiliser makes the lawn greener compared to no fertiliser, and what data would refute the hypothesis.

2 A straight ramp 1.5 m long with a mechanism to adjust the angle of slope to the horizontal is set up on a laboratory bench. An electronic timing system is set up to record the time it takes for a ball to roll from top to bottom. Average speed is calculated from average time and distance is 1.5 m. The results are shown in the table.

Ramp angle (°)	Average time (s)	Average speed (m/s)
10°	2.25	0.67
20°	1.70	0.88
30°	1.20	1.25
40°	0.95	1.58

Describe the relationship between speed and ramp angle shown by this data.

3 **Graph** the data in Question 2 and use interpolation or extrapolation to **predict** the speed of the ball at ramp angles of 25° and 50°.

Try this 1.3

Using data to make decisions

In today's world, making informed decisions based on data is an essential skill, whether it involves managing resources, implementing new strategies, or assessing the impact of changes. In groups, select an example below and work collaboratively to analyse the data, draw conclusions and make evidence-based decisions. As you explore your scenario, think critically about the potential outcomes of your decisions and the broader implications they may have.

Water usage in school

- Gather and analyse water usage data in your school.
- Identify high-consumption areas.
- Propose water-saving strategies.
- Assess the implications of implementing these strategies.

School recycling program

- Collect data on waste recycling vs. landfill disposal.
- Evaluate the effectiveness of the current recycling program.
- Recommend improvements based on the data.
- Consider environmental and behavioural implications.

Study strategy effectiveness

- Introduce a new study strategy.
- Analyse pre- and post-implementation test scores.
- Determine if the study strategy improved performance.

continued

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

- Decide if the strategy should be adopted schoolwide.
- Discuss the potential impact on student study habits.

Screen time vs. academic performance

- Survey screen time and collect academic performance data.
- Analyse the correlation between screen time and grades.
- Make recommendations on managing screen time.
- Consider the effects on health, wellbeing and academic outcomes.

Tuck shop price change impact

- Analyse tuck shop sales data before and after a price change.
- Identify trends in student purchasing behaviour.
- Make decisions about future pricing strategies.
- Evaluate the impact on student nutrition and tuck shop revenue.

Evaluating evidence and conclusions

When you have collected bivariate data in an investigation, you need to analyse whether it supports or refutes the hypothesis, which should be in the form that a change in DV causes or is correlated with a change in IV. The clearest way to do this is to graph the DV (vertical axis) against the IV (horizontal axis) and refer to the section on correlation to see if the graph shows positive correlation, negative correlation or no correlation. You can then conclude whether the data supports or refutes the hypothesis, or whether it is inconclusive or what the degree of uncertainty might be. Remember to consider whether there are alternative conclusions, such as the change in the DV being due to another variable that was not controlled. You should also comment if there is a causal relationship, and if so, what the causal mechanism might be. This is where scientific knowledge comes in, knowledge of other evidence-based arguments that support your findings. Guidance on writing a conclusion is given in the next section.

The same principles apply when you develop evidence-based arguments using data from secondary sources rather than your own data.

Analysing the validity of secondary source information

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.

secondary data information that has already been collected and analysed by others that is used to support or inform new research.

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.

It is important to ensure that the secondary data is relevant to the investigation question or claim. This means carefully reviewing the data and assessing its quality, reliability and validity. Validity in secondary sources can be evaluated by considering several factors.

Consider the:

- credibility of the data by examining if it is from a reputable source and whether it provides references to support its claims
- currency of the information to ensure that it is recent and relevant

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

- objectivity of the source by examining if it has a particular bias that may influence the information presented
- methodology used to ensure that there were no potential sources of bias or error in the data collection process
- consistency of the information compared with other sources of information to identify any inconsistencies.

Try this 1.4

Evaluating headlines

In 2018, a research paper was co-written by William McAuliffe, a psychology PhD student, in the esteemed journal *Nature Human Behaviour*. The paper suggested that people tend to become less generous over time when making decisions in an environment where they lack knowledge or interaction with others.

However, the university's press department may have sought to increase the study's appeal to news outlets by exaggerating its findings. The press release announcing the study's publication carried the headline 'Is big-city living eroding our nice instinct?'

Consequently, various media outlets picked up the story, with headlines such as 'City life makes humans less kind to strangers' and 'Big city living "switches off human instinct to be nice"'. However, these interpretations of the study were inaccurate, as it was conducted in a lab, not a city, and only measured investment behaviour rather than overall kindness.

When reading reports of scientific studies in the media, it is important to evaluate the methods used by scientists to conduct their research to ensure the validity of the headlines. Here are some steps you can take when evaluating these factors.

1 Read beyond the headline. The headline of an article is designed to grab your attention, but it may not provide a complete or an accurate summary of the study. Read the full article to get a better understanding of the research and the methods used.
2 Check the source. Look for reputable sources of information, such as **peer-reviewed** scientific journals.
3 Look for replication. Scientific findings should be replicated by other researchers before they are accepted as true.
4 Check the sample size. Studies with larger sample sizes are generally more reliable than studies with small sample sizes.
5 Check the methodology. Look for studies that use rigorous methods to control for confounding variables and minimise bias. **Randomised controlled trials** are generally considered the best.
6 Look for limitations. No study is perfect, and there may be limitations to the methods used or the findings reported. Look for studies that acknowledge their limitations.

Your teacher will provide you with headlines and the scientific report they are based on. Research the methods used by scientists in the provided studies and evaluate the validity of the headlines written in the media.

peer review
a process where work is examined and approved by experts before being published

randomised controlled trial
a study design that randomly assigns participants to either an experimental group or a control group; the only expected difference is the variable being studied

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 1.4

Using data to validate scientific findings

Data is important in **validating** scientific discoveries. The larger the dataset, the better. For example, Gregor Mendel, known as the father of genetics, conducted experiments with pea plants. He carefully recorded the traits of thousands of plants, which helped him discover the laws of inheritance. By analysing his large sets of data, Mendel was able to confirm his genetic theories.

validating checking if something is accurate, correct or reliable

Similarly, the astronomer Vera Rubin studied how galaxies rotate. She used large amounts of data to show that galaxies were behaving in a way that couldn't be explained by visible matter alone. Her work provided strong evidence for the existence of dark matter, a groundbreaking discovery in astronomy.

Figure 1.37 Vera Rubin using a telescope in 1963

Figure 1.38 In climate science, huge amounts of data are collected from weather stations, satellites and ocean buoys. Scientists analyse this data statistically to create and validate models that predict climate change patterns.

7 Problem-solving

A scientific investigation is an extended exercise in problem-solving. The skills of working scientifically are directed towards answering an investigable question, which can be regarded as a problem to solve. The scientific method can be considered as a type of problem-solving method.

The following points are a guide to problem-solving to use during this course, to help with carrying out investigations, answering questions, doing activities and writing reports.

1. **Select strategies suitable for an identified problem**
   - Analyse the issue is and break it into smaller parts.
   - Draw diagrams to help see the problem more clearly.
   - Choose a strategy from step-by-step approach or trial and error.
   - Draw up a plan for your chosen strategy and put it into action.
2. **Develop evaluation criteria for the problem**
   Evaluation criteria are rules to judge the success of the solution. Start by writing down the purpose of the solution, then break it into criteria that will measure the success of the solution.
3. **Assess the solution using the evaluation criteria**
   Ask questions like:
   - Did the solution meet the criteria?
   - Was it efficient?
   - Could it work in different situations?
   - What changes might help it work better next time?
   - Modify the solution and reassess, repeating until it meets all criteria.

Uncorrected sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4. **Use causal relationships**
   Analyse whether cause and effect is part of how the problem is framed or is part of the solution, or both. If it is there may be a model (like a graph or diagram, or a formula that can be used to predict an outcome.
5. **Evaluate different approaches to solve the problem**
   There are usually several ways to solve a problem. Look at the advantages and disadvantages of each approach to choose the most practical one.

A worksheet is provided in the Interactive Textbook with a worked example of problem-solving using these points, and a problem is then provided to solve.

Another aspect of scientific problem-solving is using scientific knowledge and findings from investigations to evaluate claims. There are many claims made in social media and on the internet and in other media, especial in relation to products. Scientific knowledge and working scientifically skills enable you to separate facts from opinions and to test claims. For example, there may be a claim that a certain energy drink makes you run faster. You could design an investigation to test this claim.

Go online to access the interactive section review and more!

Section 1.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 1.3 questions

Remembering

1 **Define** the following terms: mean, mode, median and range.
2 **Recall** why large datasets are useful.
3 **State** what a trend is in a dataset.
4 **Define** an outlier in a dataset.

Understanding

5 **Explain** why it is important to use SI units in scientific data presentation.
6 **Describe** where the independent and dependent variables should be placed on a graph.
7 **Explain** the difference between correlation and causation.
8 **Describe** how systematic error differs from random error.

Applying

9 **Calculate** the mean, median, mode and range of the following dataset: [10, 12, 12, 14, 15, 16, 18].
10 **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]
11 **Convert** four minutes and 16 seconds to seconds.
12 **Describe** the relationship in a dataset that shows a positive correlation between hours studied and test scores.
13 **Calculate** the mass and absolute uncertainty of an object that you weigh three times and obtain values of 14.95 g, 5.00 g and 5.05 g.

Analysing

14 **Analyse** the effects of excluding outliers from a dataset on the mean and range.
15 An investigation finds a correlation between the number of people who carry umbrellas and the number of traffic accidents. **Propose** why this correlation might be misleading when considering causality.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Evaluating

16 **Assess** the appropriateness of using interpolation and extrapolation for making predictions from experimental data. What are the limitations of these methods?

17 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 color	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.

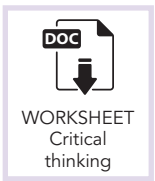
b **Decide** which column would be used as the dependent variable.

c **Propose** the independent variable in this experiment.

18 **Evaluate** the reliability of a measurement where a digital scale consistently reports a weight 0.02 g higher than the known true weight of an object. What steps should be taken to improve measurement accuracy?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1.4 Skills: Communicating science



WORKSHEET
Critical thinking

Learning outcomes

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

1. present scientific arguments using evidence, and scientific language and terminology appropriate to purpose.
2. create written texts to communicate scientific investigations.
3. recognise that scientific texts attempt to persuade the reader to adopt a scientific perspective.
4. identify and distinguish pseudoscience from science and investigate an instance of pseudoscience in popular media (from *Data science 2*).

8 Communicating

Presenting a scientific argument

Effective science communication is essential in today's world, where understanding scientific concepts and findings is necessary for informed decision-making. Science communication involves presenting complex ideas and data clearly and accurately, ensuring that your message is both accessible and engaging to your audience. Whether you are explaining a new scientific theory, detailing the results of an experiment or constructing a persuasive argument, it is important to communicate effectively.

When doing scientific research, it's important to gather and use information from many different places. This can include reading texts, looking at diagrams and flow charts, studying tables, databases, graphs and even watching videos or using interactive tools. For example, if you're studying how pollution affects a local ecosystem, you might need to gather data from scientific articles, environmental reports and databases. Diagrams can help you understand processes, while tables and graphs can show important numbers and trends. Videos and other multimedia resources can provide extra information and context.

Creating scientific texts

Once you have all this information, the next step is to combine it to make a strong argument. This means looking for patterns, common ideas and linking everything together to support or challenge an idea. For example, if several studies show that pollution harms marine life, you can use this combined information to argue for better pollution control measures. Being able to find, understand and put together information from different sources is important for understanding your research topic and making evidence-based conclusions.

When presenting your scientific arguments, you should use evidence and correct scientific language. Your evidence is the data that you collected through your investigation and is used to support your claims. For instance, if you are explaining how plants grow faster with more sunlight, you should provide data from experiments and use terms like 'photosynthesis', 'hypothesis' and 'variables'.

Tailoring your language to your audience – whether they are classmates, teachers or the general public – is also something that needs to be considered. For a scientific audience, detailed and technical language is appropriate, while a more general audience might require simpler explanations.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 1.39 You should consider your audience when choosing how to present information.

Quick check 1.9

1 **Describe** what might happen if scientific concepts are not communicated clearly.
2 **Recall** the role evidence plays in scientific arguments.
3 **Outline** how you can check if your science communication is effective.

Writing a conclusion for a scientific investigation

Drawing valid conclusions requires applying scientific concepts to interpret the data accurately. For instance, understanding the principles of photosynthesis can help explain why increased light exposure enhances plant growth. Conclusions should be directly supported by the evidence collected during the investigation and you should also support or refute your hypothesis. This involves comparing the observed results with the expected outcomes based on the hypothesis.

Figure 1.40 If a hypothesis states that increased sunlight will enhance plant growth, data showing higher growth rates in plants exposed to more sunlight would support the hypothesis. Conversely, if the data shows no significant difference or a decrease in growth, it would refute the hypothesis.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Write a reference list

When you use information from other sources in your work, it's important to give credit to the original authors. This is done by using an accepted referencing style. Referencing shows where you got your information from and allows others to check your sources.

WORKSHEET Writing a conclusion and reference list

There are several common referencing styles you might use. For example, the APA (American Psychological Association) style involves putting the author's last name and the year of publication in parentheses when you mention their work in your text. At the end of your document, you create a reference list with all the details about each source, like the author's name, the title of the work and the publication details. An example of writing a conclusion and a reference list is given in the worksheet.

plagiarism the process or practice of using another person's idea or work and pretending that it is your own

Using the correct referencing style is important for several reasons. It helps you avoid **plagiarism** by giving proper credit to other researchers. It also allows others to verify your sources and check the information for accuracy. Proper referencing shows that you respect intellectual property and follow academic standards. Always make sure to use the style required by your school and be consistent throughout your work.

Explore! 1.5

Persuasive texts

Scientific texts often aim to persuade readers to adopt a specific perspective. Authors do this by presenting strong evidence and using authoritative language and recognising this can help you critically analyse scientific literature. In the early 20th century, several scientific articles and adverts were published to persuade readers that smoking cigarettes had health benefits. The authors used authoritative language, referring to 'studies' and 'clinical trials' that supposedly showed positive effects of smoking.

However, these studies were funded by tobacco companies and the authors positioned themselves as experts by using medical terminology and referencing doctors who endorsed smoking.

Figure 1.41 Some cigarette adverts suggested smoking could aid in weight loss.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

As a reader, you should identify the perspective and consider any potential biases. In this case, the funding from tobacco companies likely influenced the research and its presentation.

Over time, further research has conclusively showed the severe health risks associated with smoking, including lung cancer and heart disease, disproving the earlier claims.

Figure 1.42 More recently, experts are informing people about the dangers of e-cigarettes.

Science vs. pseudoscience (*Data science 2*)

Science and **pseudoscience** might seem similar on the surface but look closely and they are quite different. Science is based on evidence and follows a systematic method to understand natural phenomena. Scientists make observations, form hypotheses, conduct experiments and analyse results to reach conclusions. This process is repeatable and transparent, allowing others to verify findings. For example, the theory of gravity was developed through careful observations and experiments.

pseudoscience knowledge or claims that appear to be scientific but do not follow the rigorous methods of science, often based on beliefs or opinions rather than evidence, and which are not are not testable or reproducible

Pseudoscience, on the other hand, refers to claims that appear to be scientific but do not follow the rigorous methods of science. These claims are often based on beliefs or opinions rather than evidence and are not testable or reproducible. For example, astrology claims that the positions of stars and planets influence human behaviour, but it lacks scientific evidence and does not use a reliable method to support its claims. Pseudoscience may sound convincing, but it does not hold up to scientific scrutiny.

Pseudoscience often appears in popular media, making it accessible to a wide audience. Television shows, movies and websites sometimes present pseudoscientific ideas as if they were factual, which can be misleading. Social media platforms also contribute to the spread of pseudoscience. Influencers and online communities can quickly share and popularise unverified claims, such as conspiracy theories about vaccines or climate change denial. These platforms often lack the checks present in scientific peer review, allowing pseudoscientific ideas to spread.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Pseudoscience often presents alternative ideas and claims to science. In communicating science it is therefore necessary to distinguish it from pseudoscience by reference to the scientific method and by arguing from evidence. Table 1.4 gives more examples of pseudoscience.

Pseudoscience example		Science
Astrology suggests that the positions of celestial bodies at the time of a person's birth can affect their personality and future.		Despite its popularity, astrology has no scientific basis and does not use reliable evidence to support its claims.
Cryptozoology is the study of animals whose existence has not been proven by science, like Bigfoot, Yeti, the Chupacabra or the Loch Ness Monster.		These creatures are often reported in stories and sightings but lack scientific evidence to confirm their existence.
Flat Earth theory is the belief that Earth is flat.		This belief ignores the extensive scientific research and evidence from astronomy, physics and global navigation supporting the spherical shape of the Earth.
Water witching, or dowsing, is a practice where people claim to locate underground water using a stick or rod.		Scientific tests have repeatedly shown that dowsing is no more effective than random chance, yet some still believe in its validity.
Homeopathy claims that highly diluted substances can treat various ailments.		Scientific studies have shown that homeopathy is no more effective than a placebo.

Table 1.4 Examples of pseudoscience with corresponding scientific view

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 1.5

Unmasking pseudoscience

Your teacher will provide you with a piece of media that makes a scientific claim. This could be from news websites, YouTube, social media platforms, or other popular sources. You'll analyse the claim using a critical thinking checklist provided below.

Critical thinking checklist

Use this checklist to guide your analysis.

- **Source reliability:** Who is making the claim? Is it a credible and reputable source?
- **Evidence:** Is there empirical evidence supporting the claim? Are sources of evidence cited? Has evidence been distorted or selected to fit the claim, while contrary evidence is ignored?
- **Reproducibility:** Can the claim be tested and reproduced by independent researchers? Can the claim be disproven if it were false?
- **Peer review:** Has the claim been subjected to peer review by the scientific community?
- **Logical consistency:** Does the claim fit the known laws of science?
- **Anecdotal evidence:** Does the claim rely heavily on personal anecdotes or testimonials, instead of scientific data?

Discussion

In small groups, present your findings and determine whether the claims you investigated are scientific or pseudoscientific. Then have a class discussion where each group will share their findings and reflect on the impact of pseudoscience in popular media. Write a short reflection on what you've learned about pseudoscience and its presence in the media. Discuss how this new awareness might influence your future media consumption.

Figure 1.43 Some TV programs explore ghost hunting or psychic abilities, presenting them as real phenomena, despite the lack of scientific evidence.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Acknowledging and communicating Aboriginal and Torres Strait Islander Knowledge

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. Contemporary science uses rigorous methods of observation, experimentation and analysis to develop an understanding of the natural world.

Acknowledging and identifying the relationship between Aboriginal and Torres Strait Islander Peoples Knowledges and contemporary science promotes a more inclusive and collaborative approach to knowledge production. This is known as working 'both ways' or combining traditional knowledge with contemporary 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' Knowledge, it is important to be culturally responsive and respectful, maintain cultural protocols and avoid any offensive narratives, language or images. Culturally responsive and respectful practice includes avoiding appropriation of knowledge and culture, such as making 'dot paintings' or copying the sound of the didgeridoo. Cultural protocols include respecting that in most language groups, females do not play didgeridoos. Generally, it is wise to seek permission from the relevant Aboriginal and Torres Strait Islander Peoples or 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. Further advice is available in the online resources.

Go online to access the interactive section review and more!

Section 1.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 1.4 questions

Remembering

1 **Define** science communication.

Understanding

2 **Explain** why using various sources of information is important in scientific research.

Applying

3 **Identify** how diagrams and graphs can be used to support a scientific argument.

Analysing

4 **Analyse** how biases in scientific studies might influence the interpretation of results.

Evaluating

5 **Assess** how you can determine if a scientific claim in a media source is reliable or pseudoscientific.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		**Linked questions**
1.1	describe the skill of observing and relate it to working scientifically.	
1.1	formulate questions and hypotheses that can be investigated scientifically.	
1.1	make predictions based on scientific knowledge and observations.	
1.2	describe the purpose of an investigation.	
1.2	identify the IV, DV, controlled variables and data types needed.	
1.2	select and justify investigation methods to collect reliable data.	
1.2	identify safety risks and implement safe work practices.	
1.2	identify and solve ethical issues.	
1.2	select and use appropriate equipment including digital equipment to make observations with precision.	
1.2	follow the planned method using equipment correctly to perform the investigation, identifying and responding to any errors.	
1.2	accurately collect, record and organise data.	
1.2	modify an investigation in response to new evidence.	
1.3	calculate a range of descriptive statistics.	
1.3	use a range of representations to organise data and information.	
1.3	extract information from a range of sources.	
1.3	use large datasets to develop and test a question (from Data science 2).	
1.3	assess data validity and reliability.	
1.3	describe relationships between variables, identify data which supports or refutes hypotheses, and evaluate evidence and conclusions.	
1.3	evaluate investigation procedure and improve the quality of data.	
1.3	select and implement problem-solving strategies.	
1.4	present scientific arguments using evidence, and scientific language and terminology appropriate to purpose.	
1.4	create written texts to communicate scientific investigations.	
1.4	recognise that scientific texts attempt to persuade the reader to adopt a scientific perspective.	
1.4	identify and distinguish pseudoscience from science and investigate an instance of pseudoscience in popular media (from *Data science 2*).	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive chapter review!

Scorcher competition | Review questions | Data questions

Review questions

Remembering

1. **Define** with examples the following terms: systematic error, random error, uncertainty and outlier.
2. **Describe** how to accurately measure volumes of liquid using a measuring cylinder.
3. **Define** data validity and reliability.
4. **List** the steps in a general problem-solving strategy.

Understanding

5. **Select** and **justify** investigation methods to collect reliable data on the growth rates of four different types of plant.
6. **Identify** the safety risks of an experiment to measure the boiling point of a solution and **outline** the safe work practices to use in carrying out the experiment.
7. Referring to the dependent variable (DV) and independent variable (IV) in an experiment, **explain** in general terms what experimental result would support the hypothesis that the value of the IV determines the value of the DV.
8. **Outline** in general terms how a scientific text would attempt to persuade the reader to adopt a scientific perspective.

Applying

9. **Describe** the purpose of a scientific investigation that you have completed.
10. **Identify** the IV, DV, controlled variables and data types needed in an experiment to investigate whether giving plants different amounts of daylight per day affects their growth.
11. **Select** appropriate equipment to make observations of the maximum mass of salt that will dissolve in 1 kg of distilled water at 20°C.
12. **Calculate** the mean, range, and median of the following data, which is the time in seconds for a reaction to take place, conducted 10 times:
    29, 33, 27, 25, 31, 35, 30, 26, 28, 32
13. **Select** a representation for the following data and then create it:

Time (minutes)	0	1	2	3	4	5	6	7	8
Temperature (°C)	90	82	76	70	65	61	58	55	53

14. **Outline** a scientific argument that Earth is a sphere and not a flat disc.
15. **Write** a report of a recent science practical that you have carried out.

Analysing

16. **Formulate** a question and hypothesis about factors that affect plant growth that can be investigated scientifically
17. **Predict** what will happen to the growth of two sets of plants A and B over a month where A is given 14 hours of daylight per day and B is given 10 hours of daylight per day.
18. Students set up beakers each containing 500 mL of water at different temperatures and use stopwatches to measure how long it takes 10 g of sugar to dissolve at each temperature. When the results are analysed and discussed, it emerges that students stirred the water at different rates with different sizes of spoons, which affects the rate of dissolving. **Propose** a modification to the investigation procedure to control this effect.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

19. **Use** Australian Bureau of Statistics population data for Australia to test the question: 'The population of Australia grew faster in percentage terms in the 1960s compared to the 2010s'.
20. In an investigation of how light intensity affects the growth of plants, eight plants each received different intensity of artificial light in a closed room. However, the measurements of the plants' growth did not support the hypothesis that the greater the light intensity the more the plants would grow. **Propose** changes to the procedure to improve the quality of data.

Evaluating

21. **Identify** the ethical issues involved in an investigation to survey your classmates' use of social media and **propose** measures to solve these issues
22. **Select** an example of a pseudoscience and **compare** and **contrast** its claims with those of scientific explanations of the same data.
23. **Find out** from an Internet source how long on average it takes for plastic bags to break down in the environment. **State** the source and **explain** why you think it is reliable.

Data questions

A New South Wales scientist designed an experiment to show how the temperature at which water boils changes at different heights above sea level. The scientist did this by boiling water while on a hike up Blackfellows Hill in New South Wales' Kosciuszko National Park. The mountain is 1611 m high. The scientist used the same volume of water in the same beaker, the same heating apparatus and the same thermometer to measure the temperature. The results are presented in Figure 1.44.

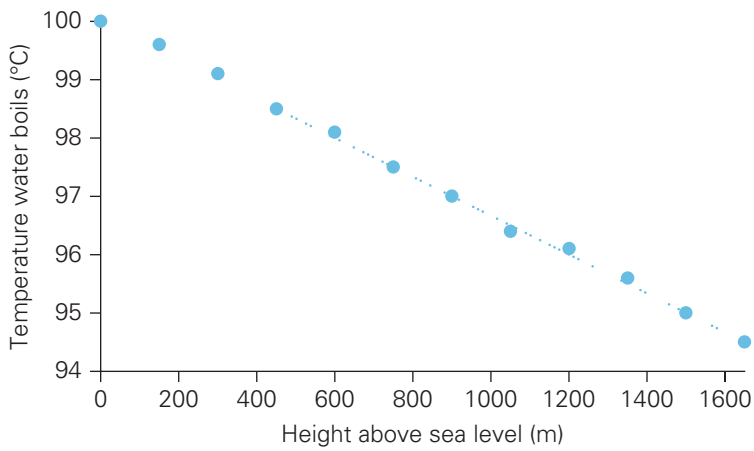


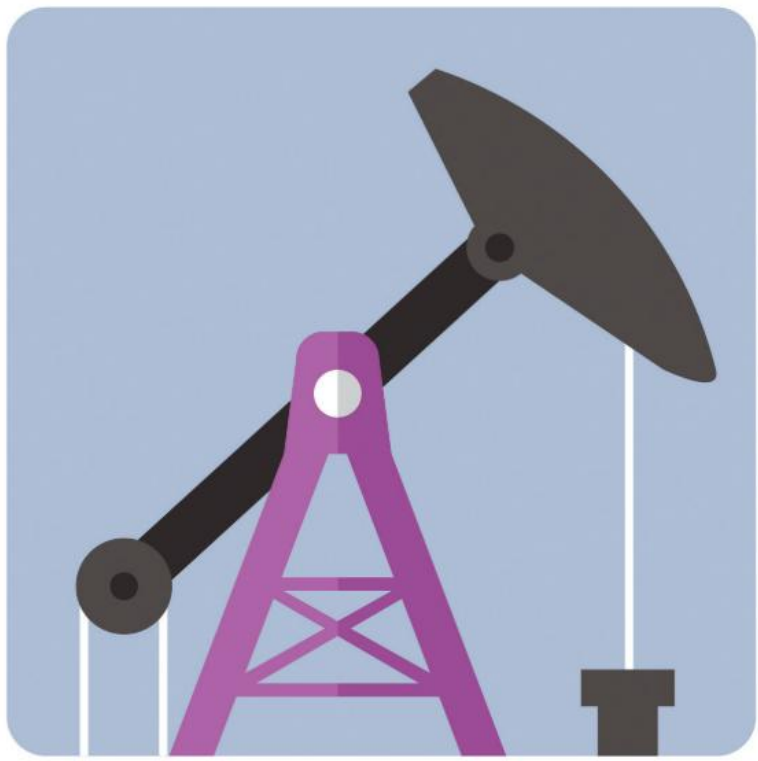
Figure 1.44 The different temperatures that water boils at different heights above sea level on Blackfellows Hill, Kosciuszko National Park

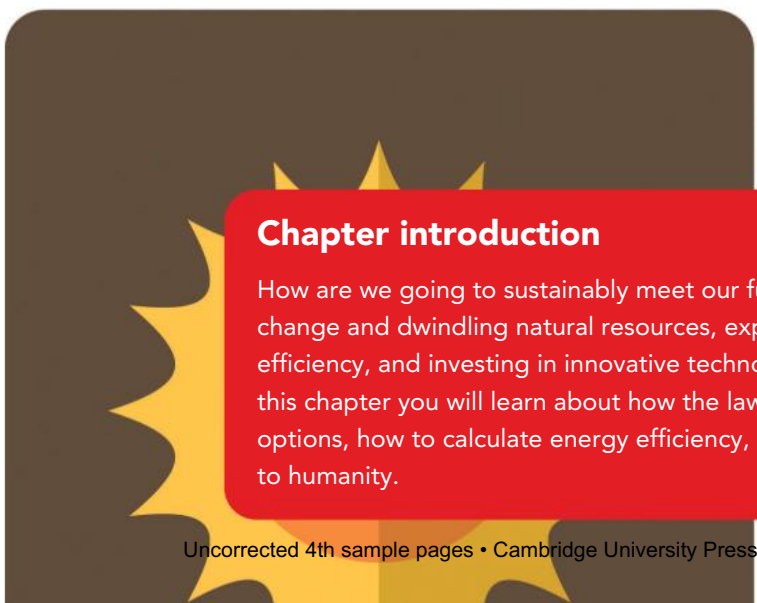
1 **Identify** two controlled variables in this experiment.
2 **Use** the graph to determine the independent variable in the experiment.
3 **Calculate** the range in the data presented.
4 **Identify** the trend in water boiling temperature as height above sea level changes.
5 **Analyse** the data points and identify any outliers that should be removed from the trend line.
6 From the trend line, **infer** the temperature of boiling water at 700 m above sea level on Blackfellows Hill.
7 **Justify** that the linear trend line is a reliable fit for the data.
8 **Extrapolate** the data to estimate the height above sea level that would allow water to boil at 94°C.
9 Mountains in the Alps in Europe can be twice the height of Blackfellows Hill above sea level. **Predict** the temperature that water would boil at on a 3300 m peak in the Alps.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 2

Energy



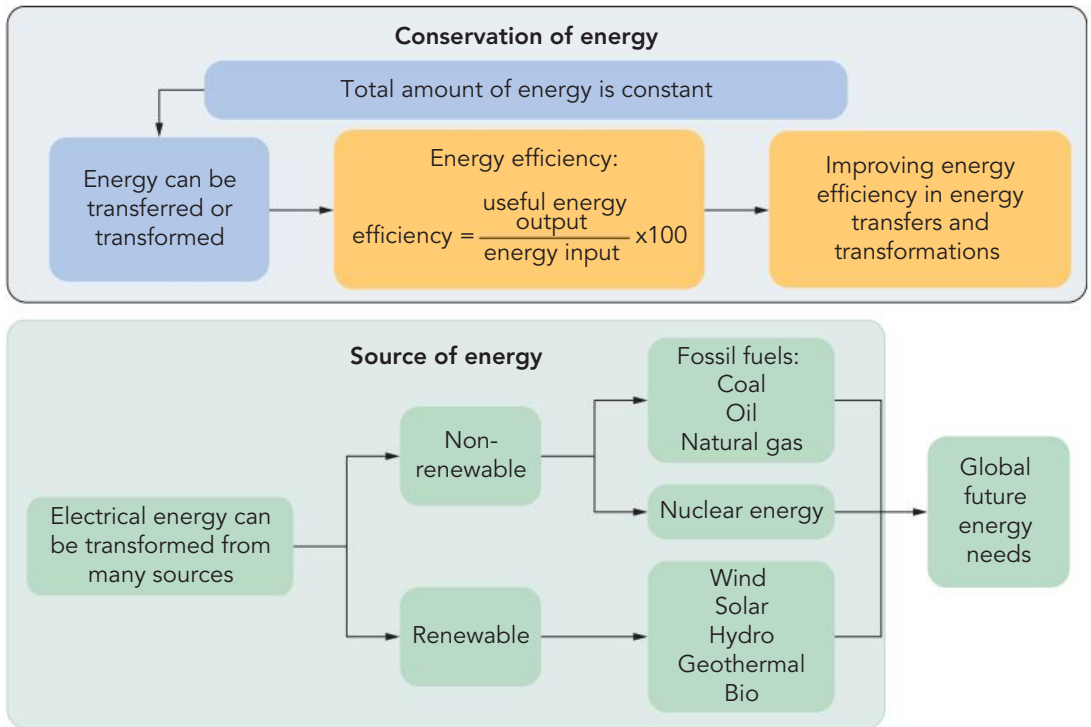


Chapter introduction

How are we going to sustainably meet our future energy needs? As we face the challenges of climate change and dwindling natural resources, exploring renewable energy sources, enhancing energy efficiency, and investing in innovative technologies need to be addressed as a matter of urgency. In this chapter you will learn about how the law of conservation of energy defines and limits our energy options, how to calculate energy efficiency, and the various sources of energy that are available to humanity.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

efficiency
fossil fuel
geothermal energy
hydroelectric power
input energy
non-renewable
output energy
sustainable
useful energy
waste energy

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2.1 The law of conservation of energy

WORKSHEET
Energy transfers and transformations

Learning outcomes

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

1. understand the law of conservation of energy.
2. perform calculations to show how total energy is constant in transfers and transformations in a closed system.

The law of conservation of energy states that energy cannot be created or destroyed, it can only change form. This implies that the total amount of energy is constant, it stays the same, however it is present in different forms. When an object fall to the ground, it has less gravitational potential energy than it had before it fell, but it did gain kinetic energy as it fell, the when it landed that energy may have been transformed into elastic potential energy and then back to kinetic as it bounced, but not as high as before because some energy was lost as heat or sound or deformation of the object. The energy is not really lost, is it? It is now in the environment. So, the object and its environment are part of the system.

This is the reason that when you swing a pendulum it can never swing back higher that the release point. This would violate the law of conservation of energy. To cause the pendulum to swing higher energy would have to be *added* to the system. This energy would need to come from somewhere. Say you pushed the swing then you added energy, and now you are part of the system, so the total energy is still constant.

Figure 2.1 A swing can never swing back higher than the release point (unless pushed!).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

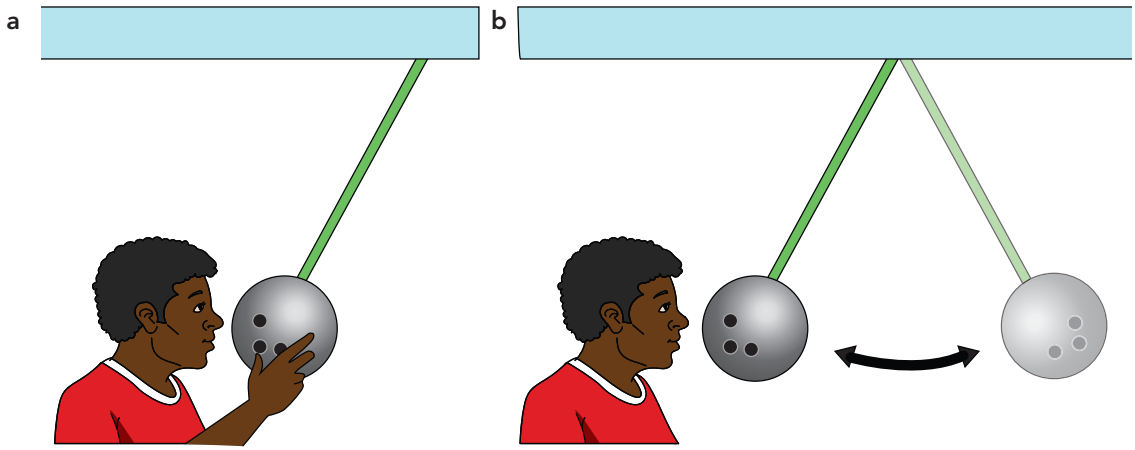


Figure 2.2 A common demonstration of the law of conservation of energy. **(a)** A heavy pendulum is brought to the experimenter's nose and released. **(b)** When it swings back, it stops just short of the face as its total energy has not increased. As shown in his YouTube video, MIT's Professor Walter Lewin demonstrates that physics can be frightening (search for 'Simple Pendulum Experiment Walter Lewin Lecture #shorts').

Let's consider the example involving a swinging pendulum:

1 **Initial State:** At the highest point of its swing, the pendulum has maximum gravitational potential energy (GPE) and minimum kinetic energy (KE). The total energy (E) of the system can be expressed as:

$$E = \text{PE} + \text{KE}$$

2 **During the swing:** As the pendulum swings downwards, potential energy is converted into kinetic energy. At the lowest point of the swing, the pendulum has minimum potential energy and maximum kinetic energy. The total energy at this point is still the same:

$$E = \text{GPE}_{\text{max}} + \text{KE}_{\text{min}} = \text{GPE}_{\text{min}} + \text{KE}_{\text{max}}$$

Since:

$$\text{KE} = \frac{1}{2}mv^2$$

where m is mass in kilograms (kg) and v is velocity in metres per second (m/s), and:

$$\text{GPE} = mgh$$

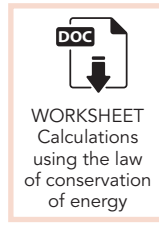
where m is mass in kg, g is acceleration due to gravity, and h is height in metres (m), then:

$$E \text{ (total energy)} = \frac{1}{2}mv^2 + mgh$$

Despite the transformation of energy from potential to kinetic, the total energy remains constant:

$$E_{(\text{initial})} = E_{(\text{final})} = E_{(\text{total})}$$

Recall the unit of energy is the joule (J) . The worksheet in the Interactive Textbook gives further examples.



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 2.1

The law of conservation of energy in a pendulum

Consider a 2 kg pendulum released from rest at a height of 5 m above its lowest point.

Calculate the maximum velocity of the pendulum.

Working	Explanation
$m = 2$ kg $h = 5$ m	Identify the values given in the question.
At its highest point PE = mgh. PE = $2 \times 9.81 \times 5$ $= 98.1$ J	Identify equation needed to answer the question and substitute the relevant values into the equation.
Kinetic energy (KE) at the highest point is 0 J since the pendulum is momentarily at rest.	At rest, mean $v = 0$ m/s initially.
Total energy (E) at the highest point: $E_{initial}$ = PE + KE $= 98.1 + 0$ $= 98.1$ J	Recall the law of conservation of energy and identify the relevant equation.
At the lowest point, the height $h = 0$, means PE = 0 J.	Identify the values given in the question.
Using the law of conservation of energy: KE = $E_{initial}$ − PE $= 98.1 - 0$ $= 98.1$ J	Substitute the relevant values into the equation.
KE = $\frac{1}{2}mv^2$ $v = \sqrt{\frac{2KE}{m}}$ $= \sqrt{\frac{2 \times 98.1}{2}}$ $= 9.9$ m/s	Identify equation needed to answer the question, rearrange and substitute the relevant values into the equation.

Elastic potential energy and the law of conservation of energy

The same principles can be applied to elastic potential energy of a spring or elastic. The equation is given by:

$$\text{EPE} = \frac{1}{2}kx^2$$

where EPE is the elastic potential energy (also may be represented as E_e), measured in J; k is the elasticity constant, which is an indication of the object's stiffness; and x is the linear length that it has been expanded or compressed relative to its equilibrium position, measured in m.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 2.2

Elastic potential energy

A bow has an elasticity constant of 2000 N/m. It is stretched by 30 cm.

a How much elastic potential energy does the bow store?

b How much kinetic energy does the arrow gain if it follows horizontal trajectory?

c If the arrow was aimed directly upwards and has a mass of 100 g, how high would it go?

Figure 2.3 A stretched bow stores elastic potential energy.

Working	Explanation
a elastic potential energy	
k = 2000 N/m x = 30 cm = 0.30 m	List the relevant data that has been provided. Remember to convert cm into m.
EPE = $\frac{1}{2}kx^2$	Recall the definition of elastic potential energy and the equation.
EPE = $\frac{1}{2}$ × (2000 N/m) × (0.30 m)^2	Substitute the relevant data into the equation.
EPE = 90 J	Solve the problem, giving an answer with appropriate units.
b kinetic energy	
Using the law of conservation of energy the arrow can only gain 90 J of kinetic energy	If it was released aimed upwards it would also gain gravitational potential energy. In this case, the sum of KE + GPE would equal 90 J.
c height of arrow	
KE + PE = 90 J 0 + mgh = 90	At the very top of its flight the velocity would be zero before it changes direction and falls back to the ground.
m = 100 g = 0.1 kg	List the relevant data that has been provided. Remember to convert g into kg
$h = \frac{90}{0.1 \times 9.8}$ = 91.8 m The arrow would reach a height of 91.8 m before falling back down.	Identify equation needed to answer the question, rearrange and substitute the relevant values into the equation. Conclude by answering the question in words.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 2.1

Jumping paper frogs

Aim

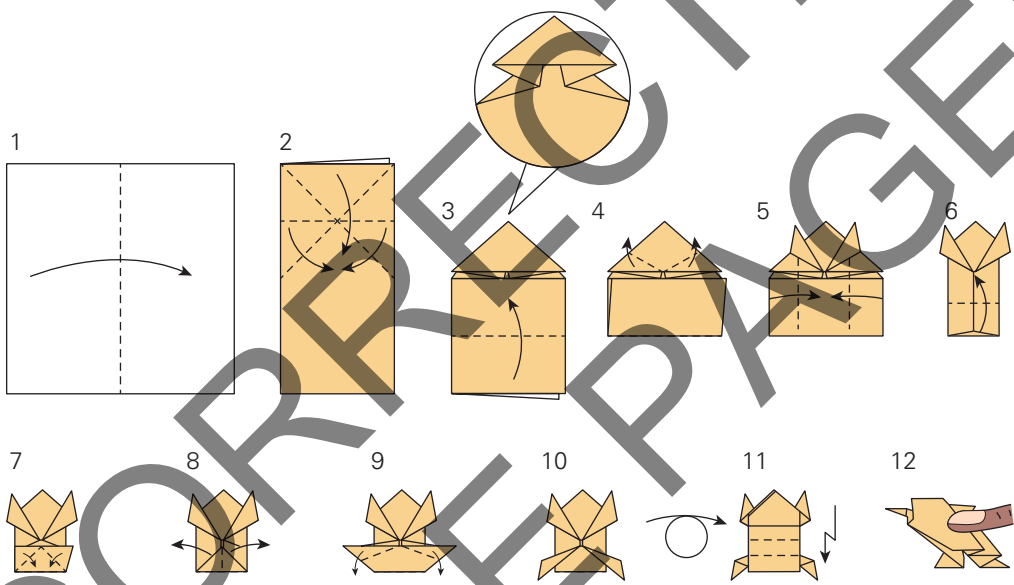
Create an origami frog to demonstrate the conversion of elastic potential energy to kinetic energy and gravitational potential energy.

Materials

- origami paper
- ruler

Procedure

1 Use the following steps to create your own jumping frog.



2 Press down on your frog to make it jump and record both the height and distance it jumped.

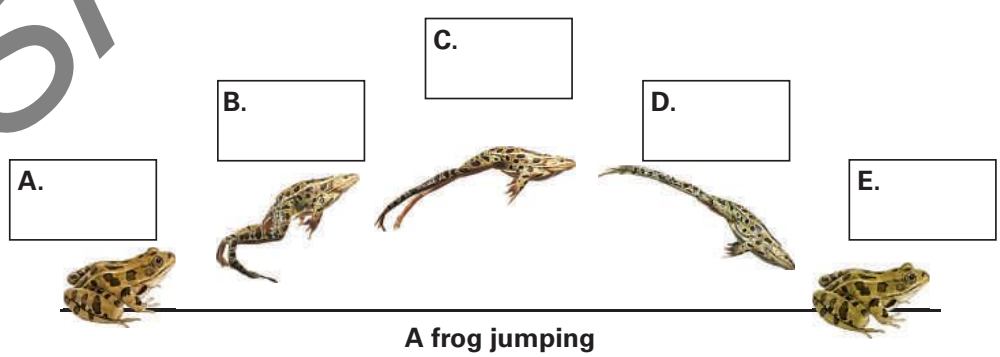
3 Explore ways to change the amount of energy your frog has so it can jump different heights and/or distances.

Discussion

1 Where does the energy that enables your frog to move come from?

2 Complete the illustration below by indicating the form of energy (kinetic, gravitational potential or elastic potential) possessed by the frog at different stages of its jump.

3 Discuss the total energy of the system by considering the energy before, during, and after the jump.



A frog jumping

UNCORRECTED SAMPLE PAGES

Quick check 2.1

1 **State** the law of conservation of energy.
2 **Describe** the energy transformations in a pendulum.

Efficiency of energy transfers and transformations in flight

VIDEO Energy transformations in a hot air balloon

Flight is indeed a great achievement, and it requires considerable energy. Let's investigate the efficiency of the energy transfers and transformation. How much of the input energy results in flight?

Investigating a hot air balloon

The operation of a hot air balloon involves two energy changes. When the hot air balloon first takes off, chemical potential energy is stored in the form of natural gas (in the gas cylinder in the basket of the balloon). When the gas is burned, it releases thermal energy, which heats the air in the balloon. The air in the balloon expands as it warms up, and this makes the air inside the balloon lighter and less dense than the air around the balloon. The balloon then rises, due to buoyancy forces, gaining kinetic energy and gravitational potential energy as it gains altitude.

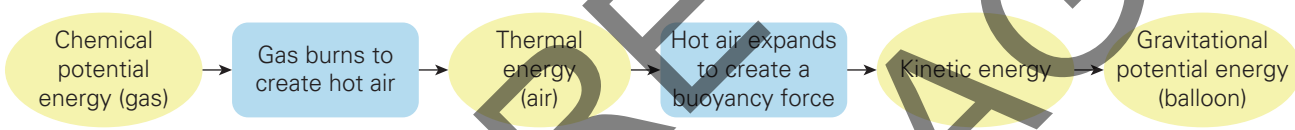


Figure 2.4 Energy flow diagram for a hot air balloon

Figure 2.5 A hot air balloon flying over the Hunter Valley in NSW. The balloon converts chemical energy to thermal energy, then kinetic energy as it moves, then gravitational potential energy as it gets higher.

Explore! 2.1

INVESTIGATION

Energy efficiency of a hot air balloon

Research how much of the thermal energy (a form of kinetic) of the hot air in the balloon is transferred to kinetic energy of the balloon. Use specific keywords in your search to find numerical data on the amount of fuel and the amount of energy it provides to lift a hot a balloon a certain height and stay airborne for a specific time. Present you finding in a poster discussing efficiency of energy transfers and transformations.

UNCORRECTED SAMPLE PAGES

Investigating an aircraft taking off

Sometimes a machine can convert a source of energy into two forms at the same time. When an aircraft takes off, it starts moving slowly from one end of the runway and then accelerates under full power until it leaves the ground at the other end. When it first starts its take-off, the jet has chemical potential energy stored in the form of aviation fuel in its tanks. The fuel is ignited in the jet engines to create a force that accelerates the aircraft along the runway, gaining kinetic energy as it does so. When the aircraft reaches sufficient speed, it lifts off and gains gravitational potential energy as it rises into the air.

Look closely at the picture of the aircraft taking off, and you can see that the air behind the aircraft's engines is blurred. This is because it is at a high temperature, heated by the energy produced by the aircraft's engines, and that energy should be added to the energy flow diagram. Aircraft are also very noisy when taking off, so sound energy is also produced.

Figure 2.6 An aircraft converts chemical potential energy to kinetic energy and gravitational potential energy.

In Figure 2.7, the approximate percentages of the two forms of waste energy have been added to the flow diagram for the jet aircraft. These can be included if they are known. Remember, the total amount of **input energy** must exactly equal the total **output energy** when **waste energy** is included.

input energy the energy that a machine or device uses as its source of energy

output energy the energy that a machine or device provides or wastes

waste energy the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy and sound

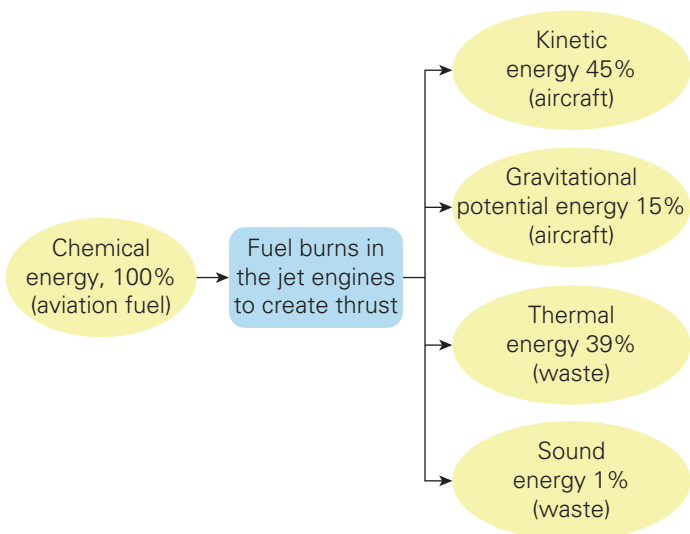


Figure 2.7 Energy flow diagram for a jet aircraft taking off

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

In this example, the useful energy is kinetic energy (45%) and gravitational potential energy (15%), which adds up to 60%. This means that 60% of the energy input is converted to useful energy and the efficiency rating of the aircraft's engines is 60%. The other 40% is wasted through thermal and sound energy.

Section 2.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 2.1 questions

Remembering

1 **Recall** the energy transformations that occur when bouncing a rubber ball.
2 **Describe** the difference between an energy transfer and an energy transformation.

Understanding

3 Using the law of conservation of energy, **explain** why a light globe gives off thermal energy.
4 **Describe** the energy transformation that occurs in a pendulum swing.

WIDGET Energy forms and transformations

Applying

5 **Calculate** the height from which of a pendulum of mass 20 kg is released so that its maximum velocity at its lowest point is 10 m/s.
6 If a spring stores 90 J of elastic potential energy when extended by 10 cm, **calculate** the spring constant.

Analysing

7 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.

Evaluating

8 Cars are energy inefficient. State the input form of energy and the useful and wasted forms of energy. **Propose** some other forms of transport that are more energy efficient.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2.2 Calculating energy efficiency

WIDGET
Energy conversion flow diagrams

Learning outcomes

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

1. understand and calculate energy efficiency in energy transfers and transformations.
2. explain how energy efficiency can be improved.

efficiency
a measure of the ability to produce useful energy

useful energy
energy that can be used for a specific purpose

The **efficiency** of a system, in terms of its ability to convert energy, is a measure of its ability to produce useful energy. **Useful energy** is defined as energy that can be used for a specific purpose. In the example of a bouncing ball, kinetic energy and elastic potential energy are useful forms of energy, since they enable the bounce. In contrast, in a bouncing ball, heat (the ball gets warmer) and sound (noise of the bounce)energy are by-products of the energy conversion (that is, wasted energy). Wasted energy is usually lost to the environment and typically cannot be used to do work.

Recall from Stage 4 that a Sankey diagram is a useful way to visualise energy conversions including useful and waste energy. The worksheet in the Interactive Textbook will help you revise them.

WORKSHEET
Energy conversions with Sankey diagrams

Energy efficiency is usually expressed as a percentage and can be calculated using the following equation:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

Worked example 2.3

Efficiency

What is the efficiency of a light globe if 75 J of energy is put in but only 12 J of light energy is produced?

Working	Explanation
Useful energy output = 12 J, energy input = 75 J	List the relevant data that has been provided.
$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\% \times 2$	Recall the definition of efficiency energy and the equation.
$\text{efficiency} = \frac{12\ \text{J}}{75\ \text{J}} \times 100\% \times 2$	Substitute the relevant data into the equation.
efficiency = 16%	Solve the problem, giving an answer with appropriate units.

INVESTIGATION

Investigation 2.2

Investigating the efficiency of bouncing balls

Aim

To calculate and compare the efficiencies of balls that bounce.

Background information

Different factors can affect a ball's efficiency. For example, temperature, inflation level of the ball, surface area and the material that a ball is made from can all have an impact.

Useful formula

$$\text{percentage efficiency} = \frac{\text{final potential energy}}{\text{initial potential energy}} \times 100$$

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Materials

As chosen by students but most likely to include:

- a variety of balls
- equipment to measure the height of the bounce
- other equipment as requested

Planning

1 Identify the independent variable from the clue in the aim and describe the different groups that will be set up for the experiment.
2 Define the dependent variable (calculated) and how it will be measured.
3 Define the controlled variables and describe how these will be managed to prevent any controlled variables from affecting the measurements.
4 Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.

Procedure

Design a method

1 Design a method that will allow you to calculate the efficiency of a variety of balls that bounce by measuring the rebound height.
2 Complete a risk assessment, considering at least two significant risk.

Test and modify the method

3 Test out your original method using a trial run to collect data.
4 Adjust steps in the method to address any issues identified.

Undertake your modified method

5 Follow the steps in your method to collect multiple trials of data.
6 Make note of any issues that may need to be discussed in your evaluation.

Results

Calculate the percentage efficiency for each of the balls you tested.

Discussion

1 Compare the efficiency of the different types of balls. Justify your response using data.
2 Identify which bouncy ball is the most efficient.
3 Discuss how this data can be related to energy transformation and wasted energy.
4 How much variation in the measurement was observed between different student groups within the class?
5 Were other variables that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning with data.
6 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments. Include calculations such as confidence limits that would help validate your findings.
7 Write out an improved version of the method based on the answers to the above evaluation questions. Include instructions on how to control variables for validity.

Improving energy efficiency

Improving energy efficiency in energy transfers and transformations reduces energy consumption and minimises environmental impact. One effective method is the use of thermal insulation, which helps to retain heat within buildings, reducing the need for additional heating in winter and preventing overheating in summer which reduces the need for cooling with air conditioners. Thermal insulation uses materials to prevent heat transfer via conduction, convection and radiation. It involves using poor thermal conductors, materials that block convection currents, like solid foam with isolated air bubbles, and reflective materials that reduce radiation heat transfer. This can be achieved through insulating walls, roofs and floors, as well as by using double-glazed windows.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Another effective way to improve efficiency is the selection of energy-efficient appliances and lighting, such as LED bulbs, which consume significantly less electricity compared to traditional incandescent bulbs while providing the same level of brightness. This is because very little of the energy supplied is transformed to waste heat. Using energy-efficient appliances (the star rating system helps inform your purchase) and ensuring regular maintenance can prevent energy wastage. Implementing smart thermostats and energy management systems can also optimise energy use by adjusting settings based on occupancy and usage patterns.

INVESTIGATION

Explore! 2.2

Reducing energy consumption and improving energy efficiency in the home

Choose one household energy use in Australia from Figure 2.8. Conduct research to propose how the energy usage can be reduced and how energy efficiency can be improved.You could also refer to Table 2.1 for amount of electricity used in typical Australian homes.

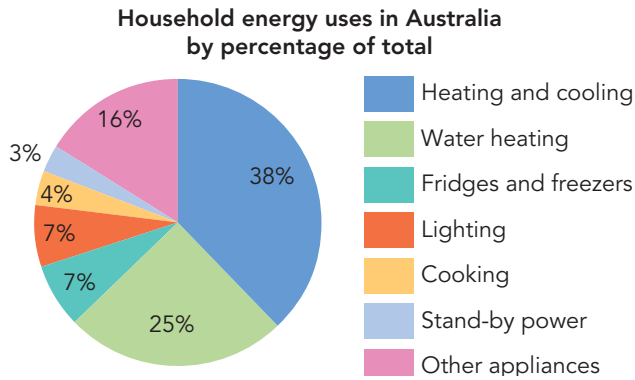


Figure 2.8 A break-owand of household energy use in Australia

Number of people in the house	Electricity used: kilowatt-hours (kWh) per year
1	5000–6500
2	6000–8000
3	7500–10 000
6 or more	12 000–16 000

Table 2.1 Amount of electricity used in a typical Australia home based on number of people in the home. The unit kilowatt-hour is a unit of energy used in electricity meters and bills, equal to a power of 1 kilowatt running for 1 hour. 1 kWh = 3.6 MJ.

Go online to access the interactive section review and more!

Section 2.2 review

Online quiz | Section questions | Teachers can assign tasks and track results

Section 2.2 questions

Remembering

1 **Define** the term 'useful energy' in your own words.
2 **State** what usually happens to wasted energy.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

3 A car has an energy efficiency of 35%. **Explain** what this means in terms of energy.

4 Incandescent light globes convert 10% of their input energy into light energy, while LEDs (light-emitting diodes) convert 60% of their input energy into light energy. **Determine** which type of light globe is more energy efficient.

5 As Jane slides down a playground slide, the amount of kinetic energy that she gains is less than the amount of gravitational energy that she loses.

- **a** **Predict** where the missing energy goes.
- **b** **Consider** what Jane can do to minimise the amount of wasted energy.

Applying

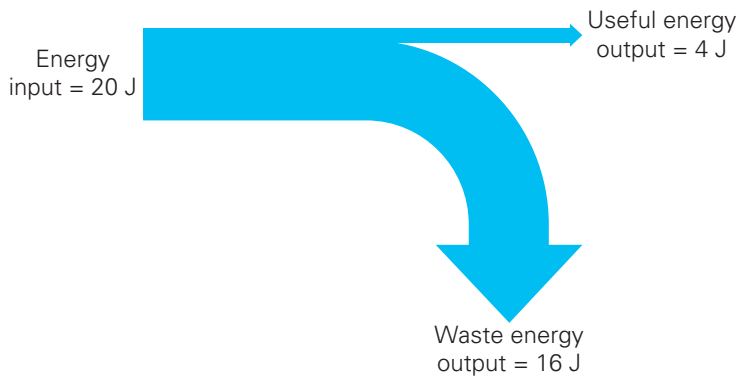
6 An organism uses 500 J of chemical potential energy stored in its body to produce 125 J of kinetic energy to climb a tree. **Calculate** the organism's efficiency.

7 A cyclist used 1000 kJ of energy riding to work. Of this, 250 kJ was transformed into kinetic energy to move their muscles. The other 750 kJ was transformed into heat. **Calculate** the energy efficiency of the cyclist.

Analysing

8 A kettle has an energy efficiency of 89%. **Calculate** how much electrical energy is required to produce 1068 J of thermal energy.

9 The Sankey diagram below is of a light globe.



- **a** **Identify** the useful energy output that the light globe is designed to produce.
- **b** **Describe** the effect that the wasted energy has on the surrounding air.
- **c** **Calculate** the efficiency of this light globe.

Evaluating

10 **Explain** how the law of conservation of energy still applies to a system despite energy being 'lost' during a transformation.

11 On cold days, some of the heat transferred from a hot car engine is used to warm the air inside the car. **Describe** the effect that this has on the overall efficiency of the car engine. Justify your answer.

Figure 2.9 Car heater used to warm a driver's hand

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2.3 Sources of energy

WORKSHEET
Sources of energy

VIDEO
Australian renewables

Learning outcomes

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

1. identify different energy sources.
2. describe how electricity is produced from different energy sources.
3. evaluate the advantages and disadvantages of renewable and non-renewable energy sources.
4. evaluate ways to optimise energy use.
5. identify trends in energy use and predict future demand.
6. explain why alternative sources of energy are needed.

Production of electrical energy

Recall that the law of conservation of energy states energy cannot be created or destroyed, however it can change form. To produce electrical energy, energy must come from somewhere else. Solar panels transform light energy into electrical energy. Most other sources rely on a generator. A generator transforms kinetic energy into electrical energy. Wind, hydroelectric, thermal, nuclear, coal, oil and gas, and bioenergy all transform or transfer various forms of energy into kinetic energy. This kinetic energy is transferred to a turbine which then rotates. This rotation provides relative movement between electric and magnetic fields inside a generator. This in turn transforms the kinetic energy into electrical energy. Studies in senior Physics explore how a generator works.

Figure 2.10 A dynamo demonstrates how kinetic energy is transformed into electrical energy.

A dynamo demonstrates how kinetic energy can be transformed into electrical energy; by turning the handle, your input of kinetic energy results in rotation of the copper conducting coil between a strong magnet. This results in a small light globe lighting up. The kinetic energy of turning the handle has been transformed into electric energy, The same transformation of energy occurs in some small torches where the motion of the lever operates the torch as seen in Figure 2.11.

Figure 2.11 A dynamo torch uses a lever and gears to transform kinetic energy into electrical energy to power the light globe.

Now, if you want to make a lot of electrical energy, for example to meet the power needs of a whole city, you will need a lot of solar or kinetic energy. Let's have a look at the source of energy used to make enough electrical energy to meet our energy needs.

renewable
can be produced as quickly as it is used

Methods of electrical energy production that do not use up natural resources or will never run out, such as solar and wind, are called **renewable** energy sources. Other energy sources, such as coal, oil and gas, are not renewable. Once these sources are used, they cannot be replaced within a human lifetime, and as such, once they run out, they are effectively gone forever.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Another major consideration in choosing an energy source is the effect it has on the environment. Some methods of energy production, such as burning coal, create pollution that damages the environment. In addition, when wood, oil, gas or coal is burned, greenhouse gases, which have the potential to cause climate change, are created. Methods of energy production that are non-polluting or have a small effect on the environment are called **sustainable**.

sustainable causing little or no damage to the environment and therefore able to continue for a long time

The demand for energy has increased steadily since the Industrial Revolution 300 years ago, and it is still increasing today as more countries become industrialised. Scientists are constantly looking for ways to make the production of energy more efficient and to reduce its effect on the environment.

Australia is a lucky country. It is rich in natural resources. The map below shows coal, oil and natural gas resources. Australia also has the third largest deposits of uranium, which is the fuel used in nuclear power station. Australia is also a large continent with access to a lot of solar, wind and water (for hydroelectric and tidal energy sources) and some geothermal energy.

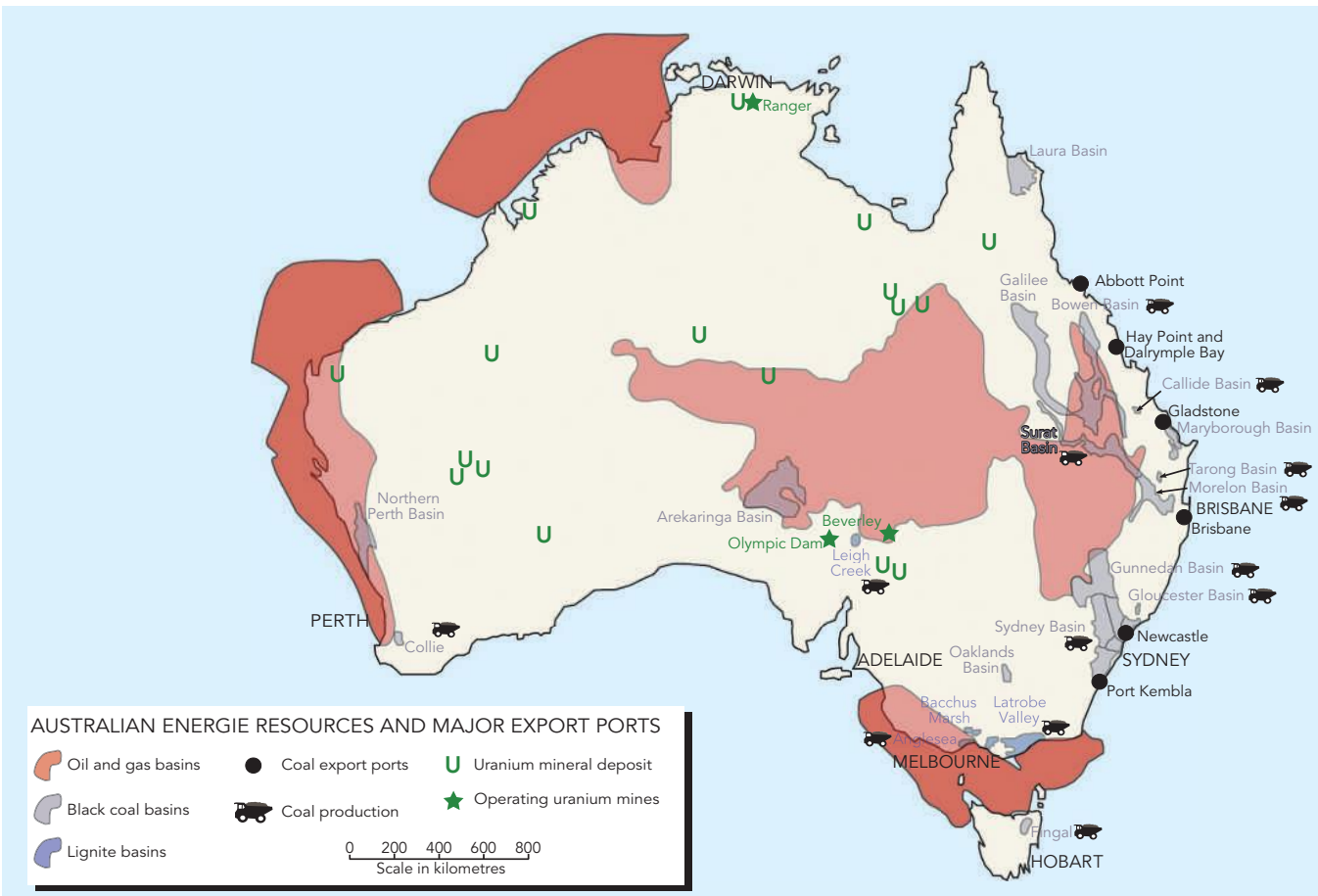


Figure 2.12 Australia is rich in natural resources.

Coal, crude oil and natural gas

Coal, crude oil and natural gas are **fossil fuels**. Most deposits of coal formed 300 million years ago during the Carboniferous Period. This was 100 million years before the dinosaurs, when the Earth was warm, wet and covered with giant forests. Eventually the forests died and layers of sand, which later turned into rock, covered the dead trees. Deep underground and under high temperature and pressure, the remains of the forest trees changed into coal. Petroleum and natural gas are formed in a similar process from marine life deposited deep on the ocean floor and buried under high pressure. Oil and gas are fluids and will move through porous rock until it reached a ceiling of impermeable rock, called the cap rock. The oil or gas is trapped there.

fossil fuel a non-renewable energy source such as oil, coal or natural gas

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The energy originally came from the Sun. By the process of photosynthesis plants absorbed the sun's energy and stored it in chemical bonds. When we burn coal, oil or gas, these chemical bonds are broken, and energy is released.

non-renewable existing in limited quantities that cannot be replaced after they have all been used

Coal, oil and natural gas are **non-renewable** resources. When they have all been used up there will be none left. It takes millions of years to form, but we burn them much more quickly than they are formed, so eventually we will runout.

To create electricity, fossil fuel power plants burn these high-carbon fuels generating heat to convert water into steam. This steam then drives large turbines to produce electricity.

Figure 2.13 Mount Piper Power Station is a coal powered power station with two steam turbines with a combined generating capacity of 1400 MW of electricity. It is located near Portland, in the central west of New South Wales.

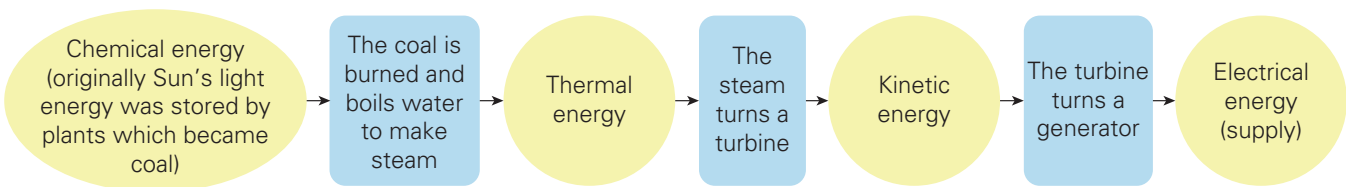


Figure 2.14 Energy flow diagram for a coal-fired power station

We could just burn wood to create heat to boil water to make steam to turn a turbine, but you would need a lot more! Figure 2.15 shows the energy content of various high-carbon fuels.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

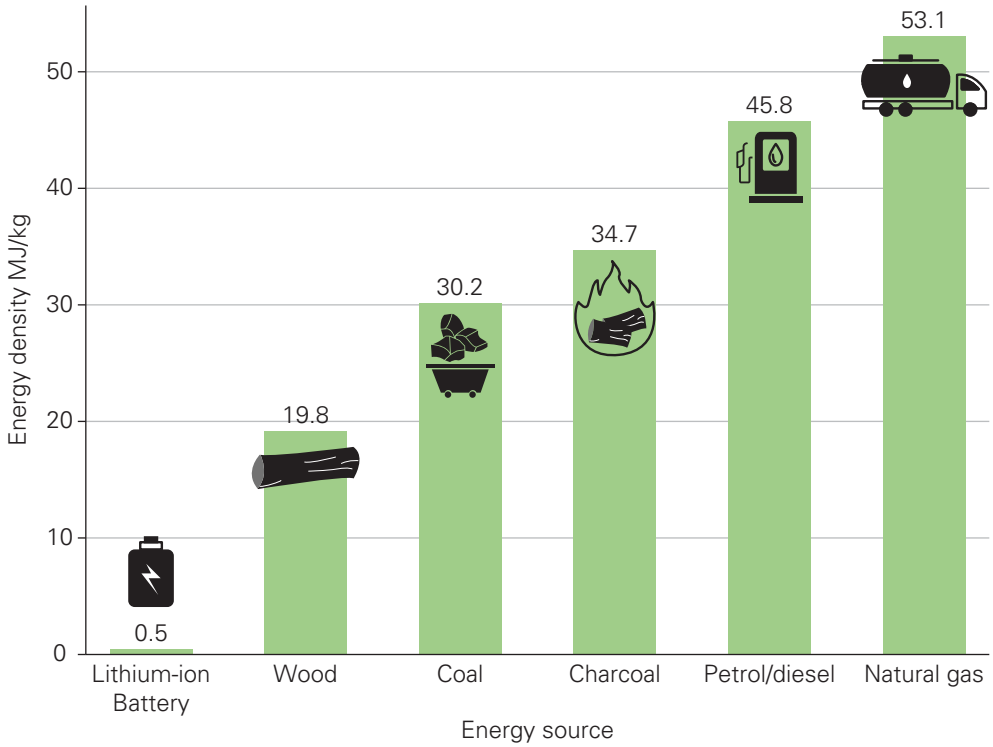


Figure 2.15 Graph showing the energy density (energy in MJ/mass in kg) of a variety of carbon fuelscompared to a lithium-ion battery

We have already mentioned that burning fossil fuels releases carbon dioxide into the atmosphere. Carbon dioxide is a greenhouse gas, it absorbs heat energy, contributing significantly to global warming. This source of energy from fossil fuels is non-renewable and not sustainable. So why do we still use it? To answer this question, we also need to consider economic factors. Since the Industrial Revolution 300 years ago, technology has progressed, giving us many different options for energy resources. However, as the infrastructure already exists for burning fossil fuels, it is economically viable to continue using this source of energy. Let's look at some alternative sources of energy.

Try this 2.1

Research task: Energy efficiency of burning fossil fuels

Aim

Research and evaluate the energy efficiency of different fossil fuels.

Research

1 **Identify different fossil fuels:** Research the main types of fossil fuels – coal, oil, and natural gas.
2 **Energy transfers:** Investigate how energy is transferred when each fossil fuel is burned. Identify the different forms of energy produced (e.g., thermal energy, mechanical energy, electrical energy).
3 **Energy losses:** Examine the types of energy lost during the combustion process. Consider losses in the form of heat, light, and sound energy, and how they affect overall useful energy produced.

Analyse

1 **Efficiency comparison:** Create a table comparing the energy efficiency of coal, oil, and natural gas. Include information on energy transfers and the types and amounts of energy lost for each fuel.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2 **Case studies:** Find and summarise real-world examples of energy efficiency in power plants using each type of fossil fuel. Discuss how they manage energy losses and what measures they take to improve efficiency.

Conclude

Critical evaluation: Based on your research, write an evaluation of the energy efficiency of burning fossil fuels. Which fuel is the most efficient in terms of energy transfers and minimal energy losses? Are there any technologies or methods that can improve efficiency?

Present

1 **Create a presentation:** Summarise your findings in a three-minute presentation. Use visuals such as graphs, tables, and images to support your points.
2 **Q&A session:** Be prepared to answer questions from your peers and teachers about your research and conclusions.

Nuclear energy

Unlike all other forms of energy production, nuclear energy does not rely ultimately on the Sun. Instead, the fuel comes from radioactive materials, mainly uranium, found within the Earth's crust. These materials were inside the Earth when it formed, around 4.5 billion years ago. The mass of fuel required is a tiny fraction of that required to run a coal-burning power station to produce the same amount of energy. For this reason, although the materials used in nuclear power generation are not renewable, it is unlikely that the world will ever run out of nuclear fuel. Nuclear power stations do not release greenhouse gases.

There are over 400 nuclear reactors across the world. Australia has the third-largest deposits of uranium in the world and exports it to other countries which rely on nuclear power to meet their energy needs. Most of Australia's energy comes from coal and natural gas.

Figure 2.16 In addition to over 400 nuclear power plants, another 56 are planned to be commissioned by 2030.

Nuclear power plants generate electricity by triggering the fission of uranium-235 isotopes. When these isotopes are bombarded by neutrons, they split, releasing a significant amount of energy in the form of heat. This heat is then used to convert water into steam, which drives large turbines to

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

produce electricity. This is similar to the way fossil fuel power plants operate, but the heat source is different, and a lot less fuel is required to produce much more energy.

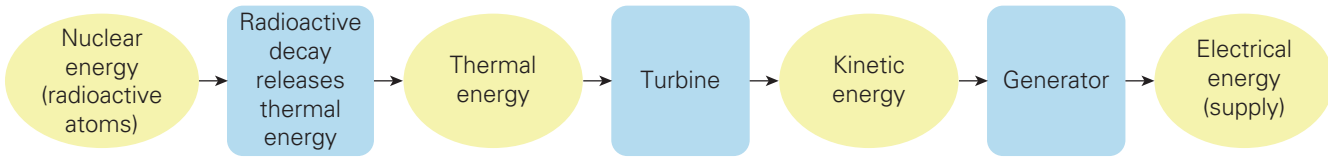


Figure 2.17 Energy flow diagram for a nuclear power station

Did you know? 2.1

Australian uranium

Australia is the world's third-largest uranium producer, after Kazakhstan and Canada. All the uranium mined in Australia is exported, because there is no nuclear power plant here to use it. However, there is a nuclear reactor at Lucas Heights on the outskirts of Sydney, operated by the Australian Nuclear Science and Technology Organisation (ANSTO). It is used for research and nuclear medicine purposes. It produces radioactive isotopes used for diagnostic medical imaging, specifically technetium-99. It also produces irradiated silicon through a process known as neutron transmutation doping. This is also critical to our modern day lives, as irradiated silicon has an enhanced ability to conduct electricity and is essential for products like solar panels and high-powered computer chips used by the electronics industry across Europe and Asia. The reactor is also used for a technique called neutron scattering. Metals appear opaque in an X-ray, but with this process the internal structure of metal can be seen, just like the internal structure of the body is seen in an X-ray. This is useful for detecting structural weaknesses in airplane propellers and railway tracks for example.

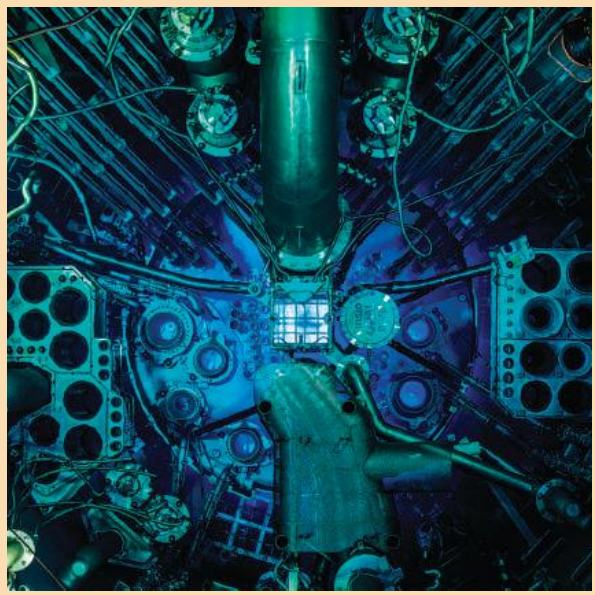


Figure 2.18 This is an image of the bottom of the OPAL reactor pool in Lucas Heights in Sydney. The pale square in the middle contains the uranium fuel rods. The items like silicon to be irradiated are in the various circular chambers placed around the fuel rods.

Although nuclear energy has the potential to supply the world's energy needs when fossil fuels start to run out, there are also some potential issues. One of these is public perception of the safety of reactors. Although safety incidents involving nuclear reactors are rare, their potential consequences can be severe, leading to widespread environmental damage, long-term health effects for nearby populations, and significant economic impacts. This underscores the importance of stringent safety measures, rigorous regulatory oversight, and continuous improvements in reactor technology to minimise risks and ensure public safety. The waste products of nuclear power remain radioactive for many hundreds of years, meaning that finding suitable locations to store nuclear waste is a contentious issue.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

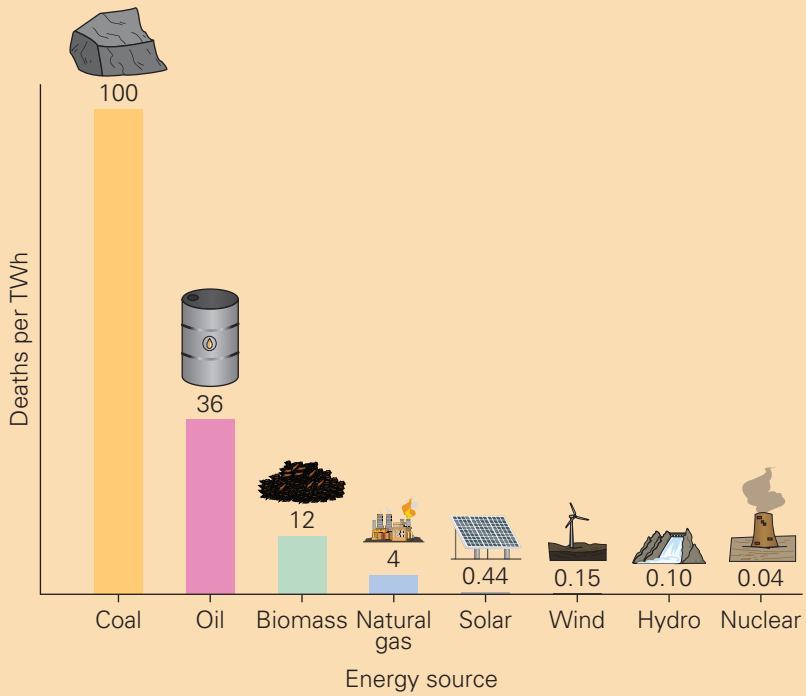


Figure 2.19 In spite of the negative public perception of the risks of nuclear power, in terms of safety, it is responsible for a very low number of deaths per terawatt-hour (TWh) of energy produced (1 TWh = 1 billion kWh).

Did you know? 2.2

Nuclear fusion

The future of nuclear power may well lie in nuclear fusion rather than fission. The energy from our sun is from fusion, in fact every star! Elements lighter than iron on the periodic table release large amounts of energy when they are formed, that is when smaller nuclei are fused together. The smallest nucleus is hydrogen, this is the fuel required for a fusion reactor. Hydrogen is readily available in water. Decomposition of water releases the hydrogen which can, under very high temperature and pressure, be fused with each other to form helium. Fusion releases enormous amounts of energy which can be used to heat water and produce steam to rotate a turbine to provide kinetic energy for a generator to transform into electrical energy. And this process, unlike fission reactors, does not produce any radioactive nuclear waste. Fusion could generate four times more energy per kilogram of fuel than fission (of Uranium in current nuclear power plants) and nearly four million times more energy than burning oil or coal.

The first ever fusion reactor is under construction in France. It is called the International Thermonuclear Experimental Reactor (ITER). Strong magnetic fields are used to confine superhot plasma (plasma is state of matter distinct from solid liquid and gas that consists of positive ions and free-moving electrons). Australia (Australian National University and ANSTO) is also involved in the project to provide technical expertise.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

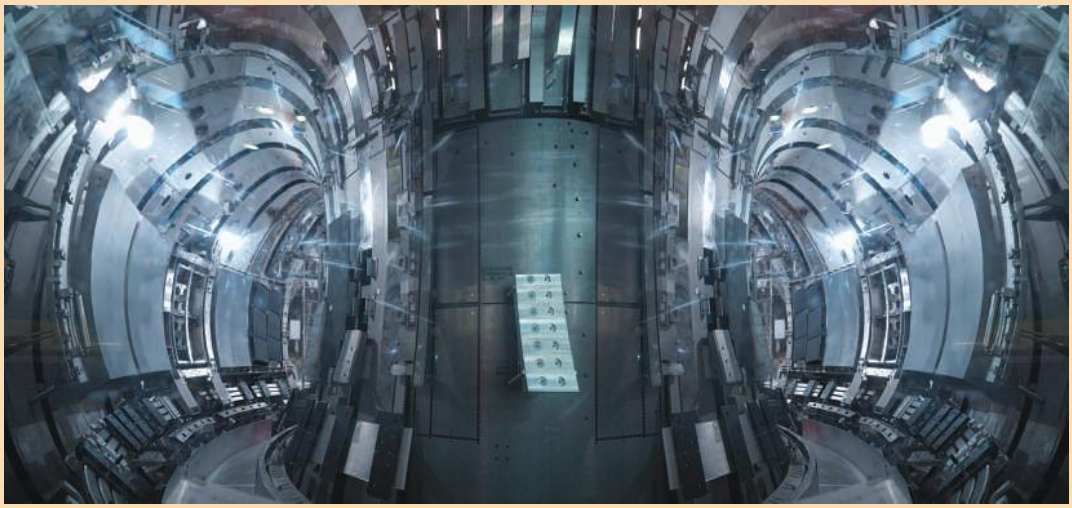


Figure 2.20 A fusion reactor is a toroid (donut) shape to contain the superhot plasma using magnetic fields.

Figure 2.21 The ITER international fusion project is unique for its international collaboration model.

Quick check 2.2

1 **Define** the term 'non-renewable' in your own words.
2 **Recall** the types of non-renewable energy sources used in Australia.
3 **State** how and why the demand for energy has changed over the years.
4 **Recall** how both nuclear power plants and fossil fuel power plants generate electricity.

Wind energy

Wind energy is a renewable energy source in which electrical energy is generated using large wind turbines, usually built in groups called wind farms. The advantage of wind energy is that once the wind turbine has been built, wind energy is free, non-polluting and available at night unlike solar energy. The main disadvantage is that it depends on the availability of the wind. For this reason, the energy that wind turbines produce is intermittent and must be combined with a storage capability, such as a battery, to provide a continuous energy supply. The technology to improve the efficiency of the batteries while, critically, also ensuring the environment is protected is a field of ongoing research.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 2.22 Crudine Ridge Wind Farm is located on Wiradjuri Country, 45 km south of Mudgee. The wind project became fully operational in 2022, producing enough electricity to power more than 75 000 homes and prevent 266 000 tonnes of carbon emissions annually. The wind farm is supplying clean energy to corporate partners such as Nestle Australia and Sydney Airport.

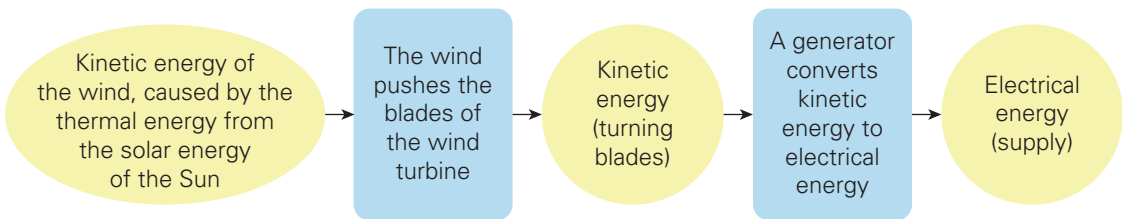


Figure 2.23 Energy flow diagram for a wind turbine

Solar energy

Solar energy is a renewable energy source. Solar panels are used to convert the energy in sunlight directly into electrical energy and can also supply energy to provide hot water. This does not require the use of turbines. The advantages of solar panels are that the energy they produce is free once the initial cost is met, and they are non-polluting to use. When solar panels are combined with storage batteries, they can provide a constant supply of energy, as the batteries store energy during the day and release it at night. As is the case with wind energy, there is a field of ongoing research to improve battery efficiency and ensure protection of the environment.

Figure 2.24 Solar panels, such as those used in the 102 MW solar plant near Nyngan, western NSW, convert sunlight into electricity.

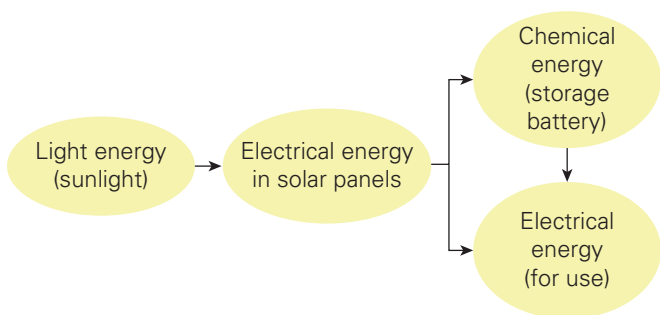


Figure 2.25 Energy flow diagram for a photovoltaic solar panel with a storage battery

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Hydroelectric power

Hydroelectric power is generated by using the gravitational potential energy of water held in dams to drive turbines that generate electricity. The water's gravitational potential energy is transformed into kinetic energy as it falls, the waters kinetic energy is transferred to the turbines at the base of the dam, or far below it as shown in Figure 2.26. These turbines turn generators that convert this kinetic energy into electrical energy.

hydroelectric power
a renewable source of energy harnessing the gravitational potential energy of water to generate electrical energy

Some countries are well suited to hydroelectric energy generation. Norway, for example, generates around 95% of its energy in this way. In Australia, hydroelectric energy accounts for around 6% of total energy production. The biggest single producer of hydroelectric power in Australia is the Snowy Mountains Scheme.

Figure 2.26 Part of the hydroelectric Snowy Mountains Scheme showing a dam creating a storage reservoir, with pipes taking water to turbines in the power station below. The scheme took 25 years to build, it was completed on time and on budget in 1974. In 2024, the Snowy 2.0 project is expanding and building a huge power station complex that will house equipment capable of generating 2200 megawatts of renewable energy deep underground at Lobs Hole in the Snowy Mountains.

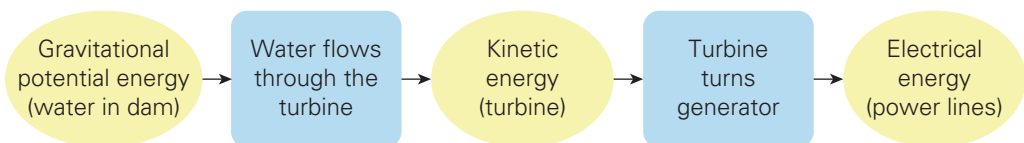


Figure 2.27 Energy flow diagram for hydroelectricity generation

In planning and construction of dams, an environment impact study is imperative to maintain the health of the local ecosystem, as diverting waterways has a significant effect on aquatic habitats, water quality, and the overall biodiversity of the region. Drought can also affect the production of energy as the system depends on the height of the water above the turbines. The higher the water, the more gravitational potential energy can be converted to kinetic energy. However, if there is a lack of rain the levels may be low for extended periods of time, during which less power can be generated. Dams also need to have contingency plans in case of floods to protect both the dam and any settlements and structures below it.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Geothermal energy

geothermal energy
thermal energy that originates from inside the Earth

Geothermal energy is heat generated within the earth. It is both sustainable and renewable. Where the Earth's crust may be fractured or thin, it is possible to drill down to find rocks hot enough to boil water. Cold water is pumped down to this hot rock. The water boils, producing steam, which is brought to the surface and used to move turbines to generate electrical energy.

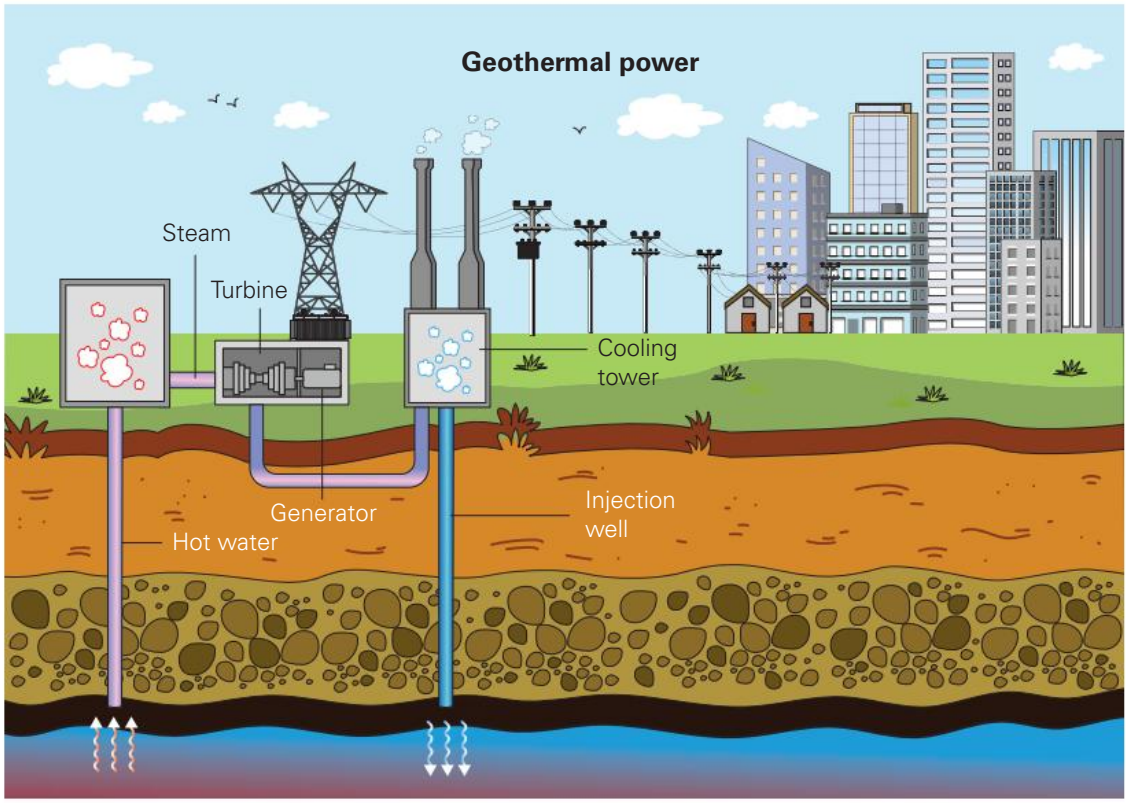


Figure 2.28 Geothermal energy uses heat energy to heat water into steam that turn turbines to generate electricity.

Figure 2.29 The Wairakei Power Station in New Zealand uses geothermal energy to produce electricity.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Australia has the potential for geothermal energy resources, but currently no geothermal power plants are operating in Australia. There are some geothermally heated pools, accommodation and horticultural facilities but no power generation. Research is ongoing into the production of hydrogen from geothermal energy to obtain 'green' hydrogen for both domestic consumption and export, driven by large industries' efforts to decarbonise their energy sources.

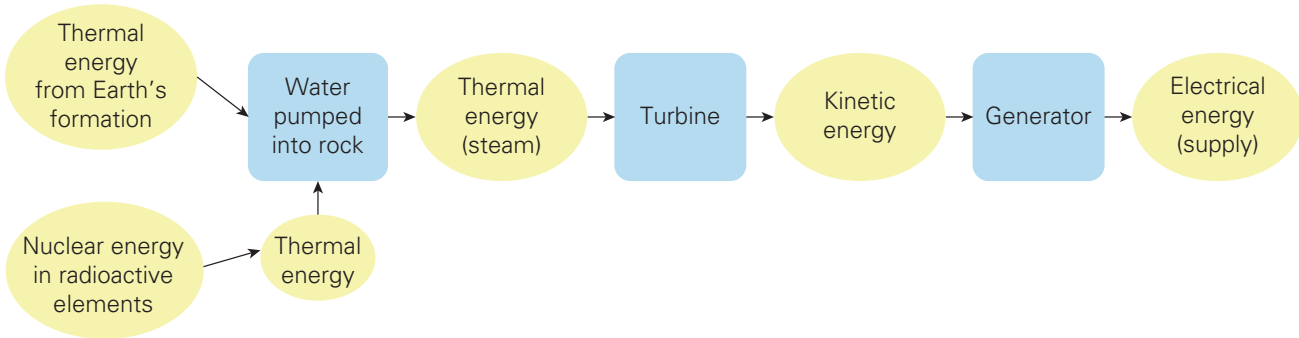


Figure 2.30 Energy flow diagram for geothermal energy

Explore! 2.3

Providing technology to remote communities

Approximately one in five Aboriginal and Torres Strait Islander People are located in remote and isolated parts of Australia. Providing access to basic services such as electricity and clean water in these areas is very difficult, let alone modern technology such as mobile phone and internet coverage. Despite these difficulties, individuals remain in these areas as they have a connection to the land.

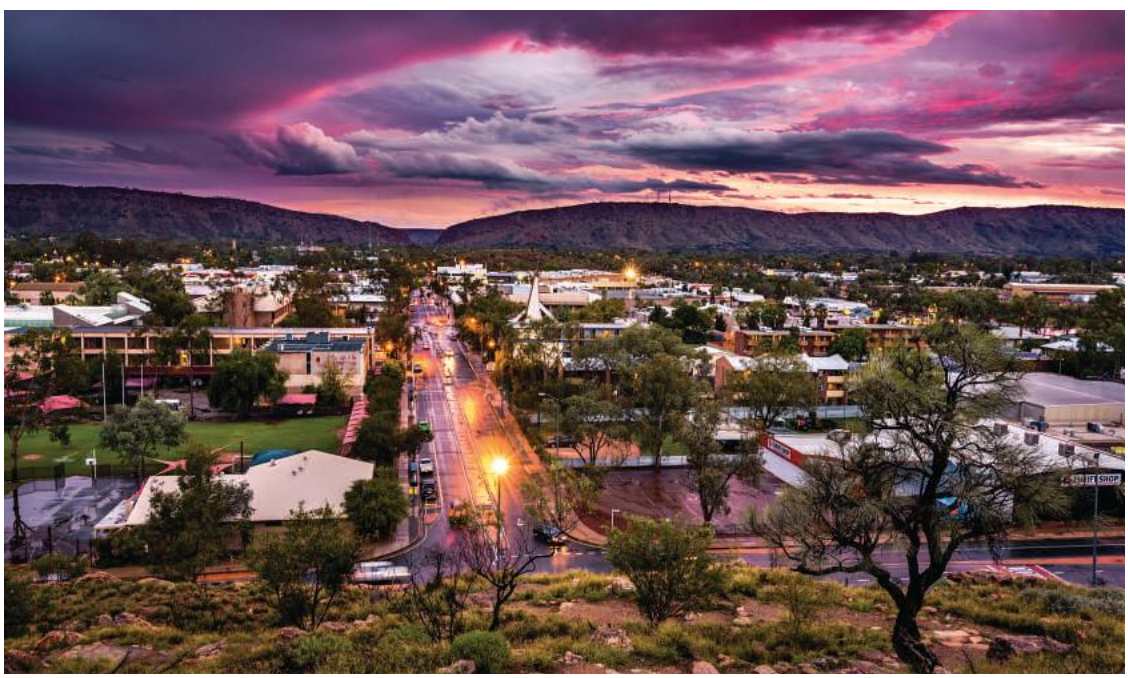


Figure 2.31 Around 10% of Alice Spring's energy is generated from renewables. The challenge is serving communities that are as far as 130 km from the town.

1 Research what is being done to provide basic modern services to remote communities, including any new technology such as solar thermal collectors and battery banks.

2 What are the economic and ethical implications of providing these services to small groups of people at such remote locations?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Bioenergy

Biomass and biogas are both derived from recently living organic materials and can be used to produce electricity. Biogas consists of a mixture of gases produced from decomposed organic matter (manure is a great source of biogas) or biomass (plants are farmed for this purpose). Remember fossil fuels are actually very old biomass, and the energy is trapped in the chemical bonds of the carbon-rich molecules. The energy in bioenergy is stored in organic matter in the same way. However, biomass as an energy source is considered carbon neutral. Why is this so? The reason is time, fast growing crops are farmed, while they grow plants absorb carbon dioxide from the atmosphere, once they are harvested and the energy is released by burning the organic material the carbon dioxide is released back into the atmosphere. Meanwhile the next crop has been planted and is absorbing carbon dioxide from the atmosphere as it grows. The cycle continues, repeatedly absorbing and releasing carbon dioxide, keeping its overall amount in the atmosphere constant.

It is a useful source of energy to compliment other renewable sources such as solar and wind, which currently do not provide sufficient energy and whose availability fluctuates at night or if there is little wind.

Figure 2.32 Willow is a short rotation woody crop harvested on a three-to-four-year cycle and used as a biofuel crop.

Figure 2.33 Compressed organic material like wood, plant materials and even animal dung biomass can be used for renewable bioenergy generation on a large scale.

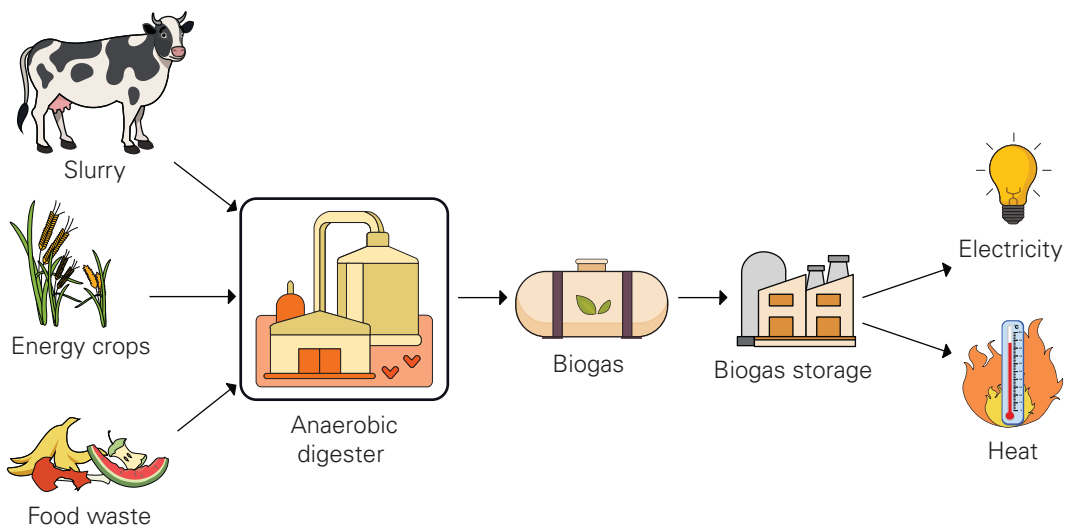


Figure 2.34 Biogas can be collected from any decomposing organic material and burned to ultimately produce energy in the form of heat or electricity.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Biogas is also burned to produce heat to boil water to produce steam to transfer kinetic energy to a turbine, which turns a generator that transforms the kinetic energy to electrical energy.

Advances in science 2.1

Algae-based solar cells

These solar cells utilise the photosynthetic properties of microorganisms such as algae to convert light into electric current that can be used to provide electricity.

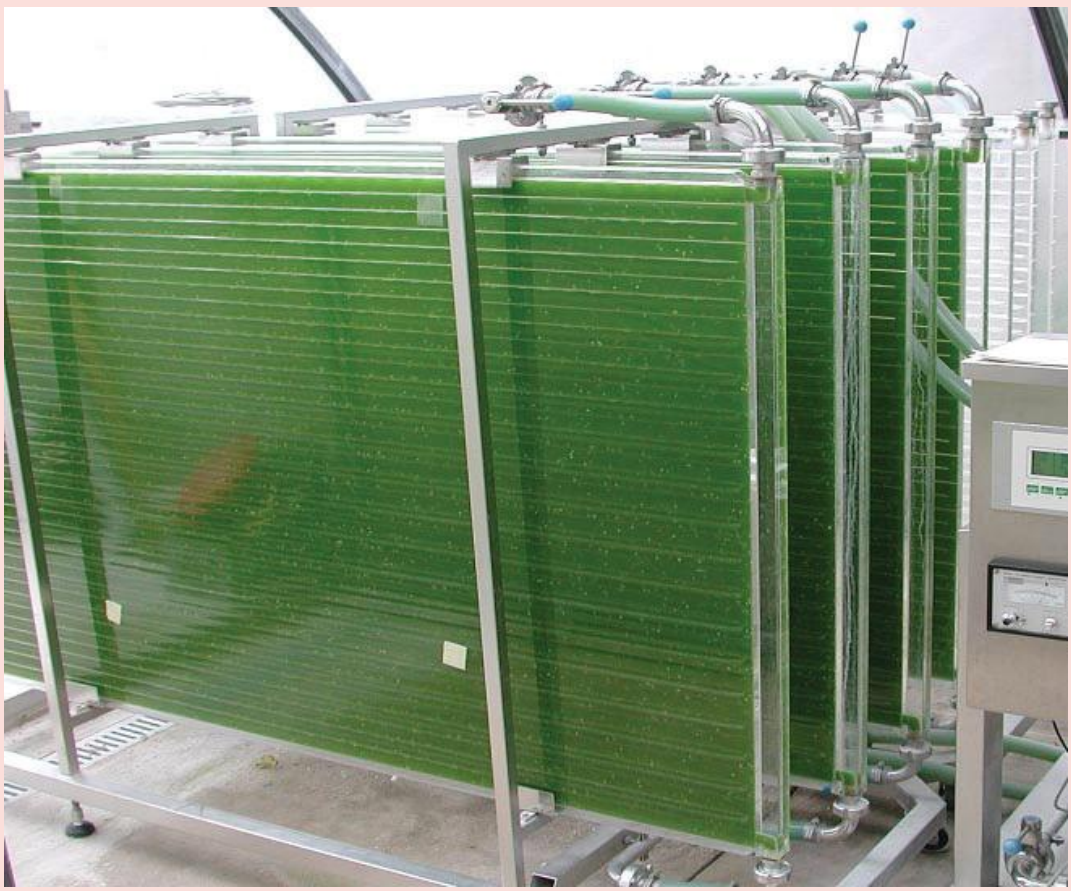


Figure 2.35 Algae-powered fuel cells, known as biophotovoltaics or biological solar cells, are an environmentally friendly approach to harvesting solar energy. They use the photosynthetic properties of microorganisms like algae to convert light into electric current.

Explore! 2.4

Turning waste into energy

A lot of energy in modern life goes unused in the form of food scraps and animal wastes. A UK-based company is trying to change that by harnessing the power of detritus (waste material). Use the website of SeaB Energy (a UK company that converts organic waste into energy) to answer the following questions.

1 Why is food and animal waste such an issue for the world and the environment?
2 Explain how SeaB Energy's two main products, the Muckbuster® and the Flexibuster®, work.
3 Draw a flow diagram showing the energy transformations that would occur in harnessing energy from food and animal waste.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Advances in science 2.2

The power of evaporation

A key challenge for current renewable energy resources is intermittency. Wind turbines and solar photovoltaic cells, for example, only produce power when wind and sunlight, respectively, are available. To power the electrical grid from renewable energy sources, we need a stable supply of energy, and we also need to store that energy to keep up with periods of high demand.

Water in nature is in constant transformation, and because water covers 70% of Earth's surface, the water cycle involves enormous amounts of energy, which is a potential resource. Up until now we have been able to harness energy from water falling from the clouds or from a height, but researchers at Columbia University in the United States looked for a way to harness the energy involved in evaporation of water – and they found it!

Figure 2.36 Evaporation from lakes and oceans is an untapped energy source that could be the solution to our inconsistent power supply.

In 2015, the researchers discovered a way to harness the process of evaporation to create a seemingly endless, controllable, renewable energy resource. The secret to their discovery was the property possessed by bacterial spores whereby they expand when exposed to water and contract as they dry out. This expansion and contraction is similar to that of muscle movement and can be controlled by adjusting the humidity.

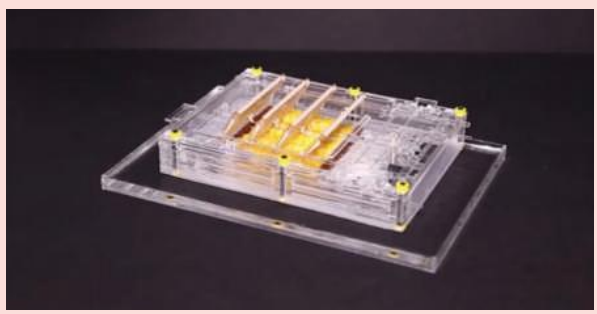


Figure 2.37 The evaporation engine floats on the surface of water and creates a piston-like back-and-forth movement as the water evaporates from the surface.

The scientists used their research findings to create an evaporation engine using material coated with bacterial spores that behaved like muscles. The evaporation engine sits on the water surface, and as moisture from the water enters the device it changes the shape of the muscles. The movement of these muscles was coupled to shutters, which allow moisture to escape when they are open. Because the moisture escapes, the muscles dry out and contract. This closes the shutters, so the humidity builds up again – and the cycle of the engine continues.

The advantage of this renewable resource is that you can store up the moist air and release it in a controlled fashion over time. This gives you a continuous power output that can keep up with our power demands.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Summarising advantages and disadvantages of renewable and non-renewable sources

From the descriptions of energy sources in this section you will be able to evaluate the advantages and disadvantages of each. Table 2.2 provides a concise summary.

Energy source	Advantages	Disadvantages
RENEWABLES		
Solar energy	• No carbon emissions • Sustainable and inexhaustible • Low operational costs	• High initial investment costs • Efficiency depends on location and weather • Requires large areas for panels • Energy storage solutions needed for nighttime and cloudy days
Wind energy	• No carbon emissions • Sustainable and inexhaustible • Low operational costs • Can be installed onshore and offshore	• High initial investment costs • Efficiency depends on wind availability • Visual and noise impact • Requires energy storage solutions for calm period when no wind
Hydropower	• High efficiency • Reliable and consistent energy supply • Low operational costs • Provides flood control and water storage benefits	• High initial infrastructure costs • Environmental impact on aquatic ecosystems • Limited to suitable geographic locations • Potential displacement of communities
Geothermal energy	• Reliable and consistent energy supply • Low emissions • Small land footprint • High efficiency	• High initial drilling and infrastructure costs • Limited to regions with geothermal activity
Biomass energy	• Utilises waste materials • Reduces landfill use • Carbon neutral if managed sustainably	• Can produce emissions and pollutants • Requires large areas for biomass cultivation • Competition with food production • High transportation costs for biomass materials
Algal biomass	• High growth rate and productivity • Can be cultivated on non-arable land • Absorbs CO_2 during growth • Can be used for biofuel production	• High initial research and development costs • Requires large volumes of water • Harvesting and processing can be energy-intensive • Potential ecological impacts if not managed properly

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

NON-RENEWABLES		
Coal	• Reliable energy output • Established technology and infrastructure • Abundant supply in many regions • Low initial infrastructure costs	• Significant greenhouse gas emissions • Environmental degradation from mining • Health impacts from air pollution • Finite resource leading to depletion
Natural gas	• High efficiency and lower emissions compared to coal and oil • Reliable and flexible energy supply • Established infrastructure • Lower operational costs	• Still produces greenhouse gas emissions • Risk of leaks and explosions • Finite resource
Oil	• High energy density • Reliable and established technology • Supports a wide range of applications beyond electricity generation	• Significant greenhouse gas emissions • Environmental risks from spills and drilling • Finite resource • Price volatility and geopolitical risks
Nuclear energy	• High efficiency and reliable source • Low greenhouse gas emissions during operation • High energy density • Established technology	• High initial infrastructure and decommissioning costs • Long-term radioactive waste management • Small risk of devastating disasters • Public concerns are challenges

Table 2.2 A summary of the advantages and disadvantages of renewable and non-renewable sources or energy

Global future energy needs

As the global population and its rapidly developing new technologies increases, so too does energy demand (Figure 2.38).

Future energy needs are significantly influenced by increasing global electricity demand, particularly from data centres and the requirements of servers hosting artificial intelligence applications. The International Energy Agency (IEA) projects that electricity demand from data centres will more than double between 2025 and 2030. To meet these future energy needs sustainably, it is important to optimise how we currently use energy and explore alternative energy sources. This involves improving energy efficiency, adopting new technologies and implementing policies that support sustainable energy practices.

We can optimise current energy use through several strategies by improving energy efficiency in buildings, transportation, and industrial processes. This can be done by upgrading insulation, using energy-efficient appliances, and adopting smart grid technologies that optimise electricity distribution and consumption. Additionally, promoting behavioural changes, such as reducing energy waste and encouraging the use of public transportation, can contribute to more efficient energy use. Governments and organisations also implement policies and incentives to support energy efficiency initiatives and investments in renewable energy infrastructure such as solar panels.

Analysing historical data on energy consumption can provide valuable insights into past trends and help predict future energy demands at state, national, and global levels. For instance, data may

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

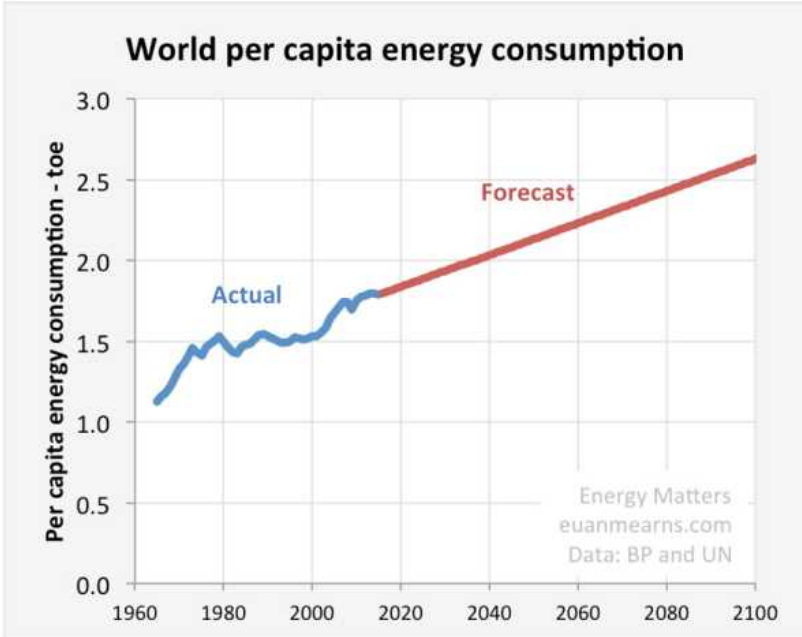


Figure 2.38 World per capita energy consumption forecast to 2100 using a straight line (red) extrapolated from the historic actual figures 1964 – 2018 (blue). The unit of energy in this graph is a 'toe' or tonne of oil equivalent. 1 toe ≈ 41.9 GJ (gigajoules).
Source: https://euanmearns.com/global-energy-forecast-to-2100/

reveal patterns in energy use related to economic growth, technological advancements, and policy changes. By examining these trends, policymakers and energy planners can forecast future energy needs and develop strategies to address them.

Actual global electricity generation from fossil fuels, renewables and nuclear for 2010 to 2020 ('history') is shown in Figure 2.39. The amount generated from these sources is then forecast up to 2050 ('projections').

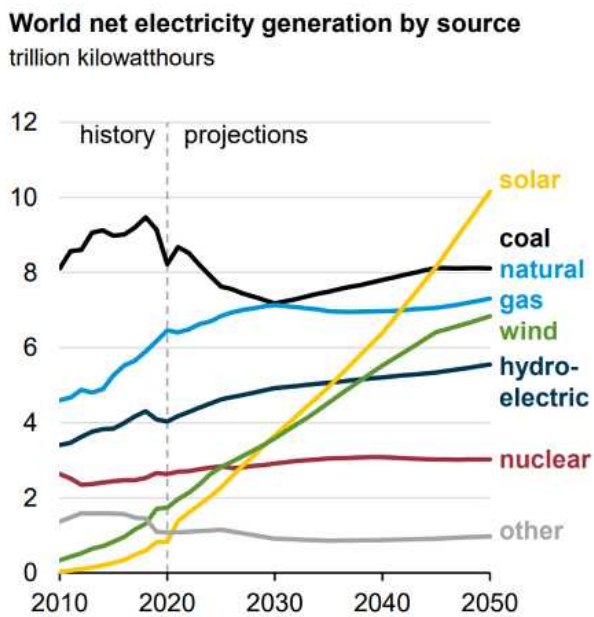


Figure 2.39 World total electricity generation by source, with forecasts up to 2050 based on the 2010--2020 history. The unit of energy in this graph is a kilowatt-hour (kWh), a unit typically used in electricity meters and bills. 1 kWh = 3.6 MJ.
Source: https://euanmearns.com/global-energy-forecast-to-2100/

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The development of alternative energy sources is driven by several factors. Firstly, the environmental impact of fossil fuels, including greenhouse gas emissions *and* pollution, necessitates a shift towards cleaner energy options. Renewable energy sources, such as solar, wind, and hydropower, offer sustainable alternatives that can reduce carbon footprints and mitigate climate change. Secondly, the finite nature of non-renewable resources, such as coal, oil, and natural gas, underscores the need for sustainable energy solutions to ensure long-term energy security. Lastly, advancements in technology and decreasing costs of renewable energy systems make them increasingly viable and competitive with traditional energy sources. Technology is quickly developing solutions for energy storage as the batteries are currently the most environmentally damaging aspect of renewable energy sources.

The threat of climate change means that there is an urgent need to find cleaner, renewable alternatives to fossil fuels that do not contribute extensive amounts of greenhouse gases with potentially devastating consequences to our planet.

Explore! 2.5

Stabilization wedges

There are many ways carbon emissions can be reduced or eliminated to mitigate the magnitude of climate change. The Stabilization Wedges Game, developed by the Carbon Mitigation Initiative at Princeton University, demonstrates the scale of the greenhouse gas problem and possible steps that can be taken over the next 50 years.

As a class or in a small group, visit https://cmi.princeton.edu/resources/stabilization-wedges/the-wedges-game/. Play the game.

In addition to the questions asked during the game, consider the following:

1 Do you think the game provides an accurate demonstration of the problem and solutions? Why or why not?
2 The game was developed in 2004 and originally explored scenarios in 2054. Are we currently closer to the 'ramp' or the 'flat path'?

Go online to access the interactive section review and more!

Section 2.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.3 questions

Remembering

1 **List** the fossil fuels used to provide energy in Australia.
2 **Recall** approximately how many years ago coal deposits were formed.
3 **State** some sources of energy that harness water.
4 **Describe** the main reason behind switching to renewable energy sources.

Understanding

5 **Explain** how energy is produced using thermal energy from the Earth.
6 **Draw** an energy flow diagram for a hydroelectric power station.
7 **Explain** the difference between the terms 'renewable' and 'sustainable'.
8 **Explain** why nuclear energy is not considered renewable.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

9 **Explain** how non-renewable energy sources are causing global warming.
10 **Explain** why each of the renewable sources of energy is considered 'renewable'.

Applying

11 **Construct** a table with columns to summarise the advantages and disadvantages of each method of producing energy.
12 Make two lists and **order** each from best to worst. Make one list that ranks energy sources for addressing environmental concerns and another that ranks energy sources for producing the most economical energy.
13 Use your answer to Questions 11 and 12 to **design** a plan combining a variety of energy sources to ensure both continued energy production and protection of the environment to ensure sustainable energy production practices.

Analysing

14 Consider the Sun's role in life on Earth. **Explain** why there would be no life on Earth without the Sun.
15 Some people use wood-burning stoves to heat their homes. **Conclude** whether this source of energy is renewable and/or sustainable. Explain your answer.

Figure 2.40 A wood-burning stove

Evaluating

16 **Suggest** one drawback of using solar energy as an energy source.
17 **Suggest** two reasons why coal may not be suitable as a long-term energy source.
18 **Suggest** why inner-city trains and trams are powered by electrical energy.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
2.1	understand the law of conservation of energy.	
2.1	perform calculations to show how total energy is constant in transfers and transformations in a closed system.	
2.2	understand and calculate energy efficiency in energy transfers and transformations.	
2.2	explain how energy efficiency can be improved.	
2.3	identify different energy sources.	
2.3	describe how electricity is produced from different energy sources.	
2.3	evaluate the advantages and disadvantages between renewable and non-renewable energy sources. .	
2.3	evaluate ways to optimise energy use.	
2.3	identify trends in energy use and predict future demand.	
2.3	explain why alternative sources of energy are needed.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Data questions

Solar panels are used across Australia to convert the energy provided by sunlight into electricity. The electricity produced by a typical commercial solar panel in NSW throughout a sunny day is shown in Figure 2.41. The efficiency and price of six different solar panel models is also shown in Table 2.3.

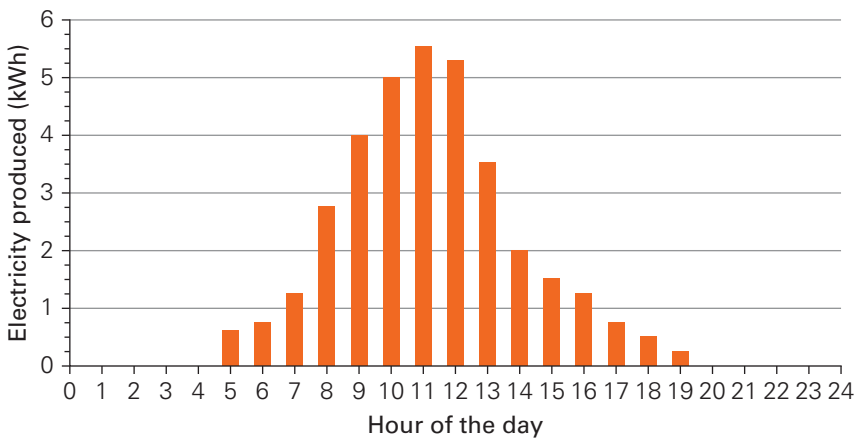


Figure 2.41 Electricity produced, in kilowatt-hours, by a typical commercial solar panel throughout a sunny day

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Solar panel model	Efficiency (%)	Estimated price ($/m²)
A	46	> 2 000 000
B	44	> 1 000 000
C	37	> 100 000
D	22	120
E	17	80
F	15	70

Table 2.3 Efficiency and cost of different solar panel models

1 **Identify** the time of the day the solar panel presented in Figure 2.41 produces the most electricity.
2 **Calculate** how many hours per day the solar panel can produce electricity.
3 **Identify** the pattern of electricity production throughout a sunny day.
4 Refer to Table 2.3 and **identify** the trend between the efficiency of a solar panel and the price per square metre.
5 **Infer** whether the cost of a solar panel is directly proportional to the efficiency.
6 **Deduce** why electricity is not produced between midnight and 4 a.m. and again between 8 p.m and midnight.
7 **Predict** the effect on the data in Figure 2.41 if the weather was an overcast and rainy day.
8 A domestic household owner in NSW would like to install solar panels on the roof of their home. The owner would like a solar panel with an efficiency above 20% to cover 3 m². **Deduce** the type of solar panel and the lowest price that the homeowner could pay for these requirements.
9 Based on the general shape of the data presented in Figure 2.41, **justify** why the angle at which the solar panel is oriented on a roof is important for a higher electricity production.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Wind power

Background information

Wind power has been used for generations as a method of generating usable energy. Wind turns the turbine and generates mechanical energy, which has been used for many things over the years. From providing energy to pump water from a reservoir to electricity generation, wind power has many uses, and a major benefit is its ability to be generated in remote areas.

DESIGN BRIEF

Design a wind turbine capable of lifting an object.

Activity instructions

In groups you will design and construct a simple wind turbine capable of lifting weights from the floor up to bench height. Your turbine must be efficient in its energy conversion and sustainable in its design.

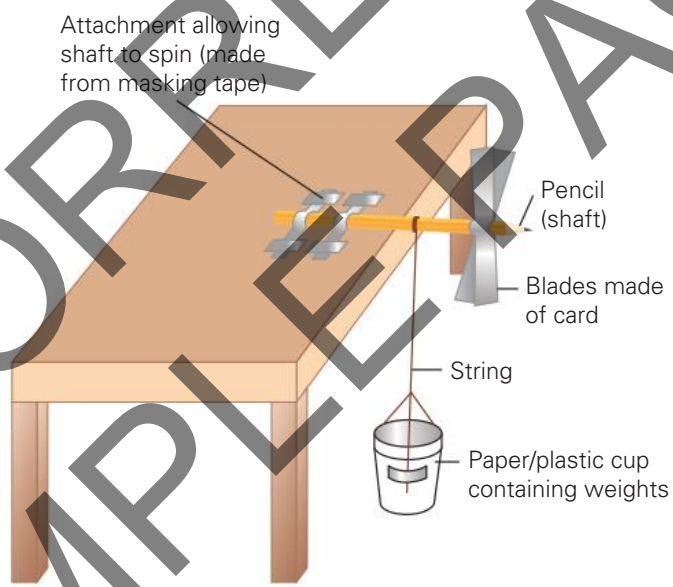


Figure 2.42 You can build ideas around this basic design.

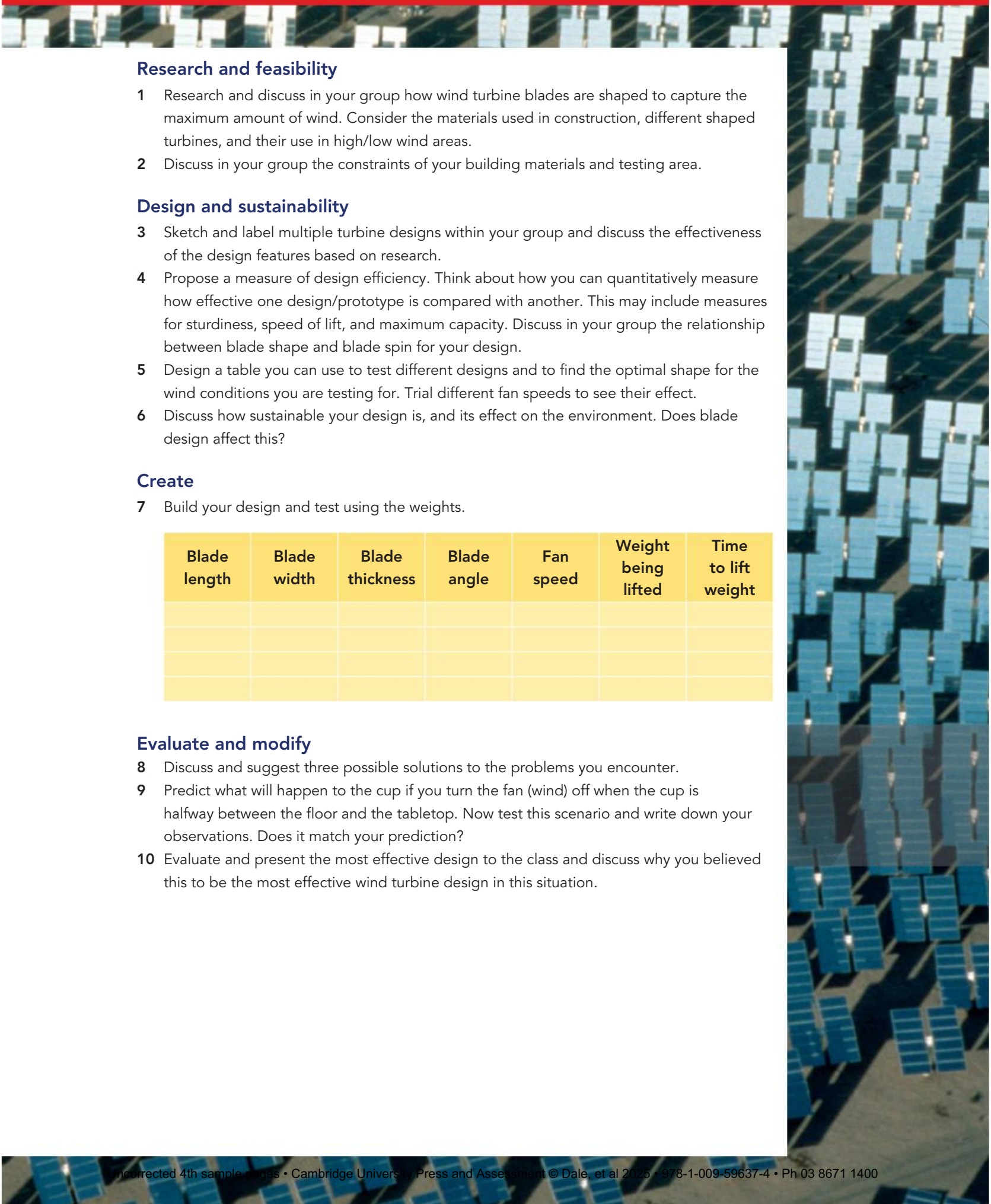
Suggested materials

- a medium-sized fan (to simulate a constant flow of wind)
- cardboard (different thicknesses if possible)
- masking tape (optional)
- string
- pencils
- scissors
- paper or plastic cup for carrying the load
- weights (you can use Lego® characters as well)
- electronic scale (optional)

UNCORRECTED SAMPLE PAGES

FPO

sample pages • Cambridge University Press and Assessment © [illegible] et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



Research and feasibility

1 Research and discuss in your group how wind turbine blades are shaped to capture the maximum amount of wind. Consider the materials used in construction, different shaped turbines, and their use in high/low wind areas.

2 Discuss in your group the constraints of your building materials and testing area.

Design and sustainability

3 Sketch and label multiple turbine designs within your group and discuss the effectiveness of the design features based on research.

4 Propose a measure of design efficiency. Think about how you can quantitatively measure how effective one design/prototype is compared with another. This may include measures for sturdiness, speed of lift, and maximum capacity. Discuss in your group the relationship between blade shape and blade spin for your design.

5 Design a table you can use to test different designs and to find the optimal shape for the wind conditions you are testing for. Trial different fan speeds to see their effect.

6 Discuss how sustainable your design is, and its effect on the environment. Does blade design affect this?

Create

7 Build your design and test using the weights.

Blade length	Blade width	Blade thickness	Blade angle	Fan speed	Weight being lifted	Time to lift weight

Evaluate and modify

8 Discuss and suggest three possible solutions to the problems you encounter.

9 Predict what will happen to the cup if you turn the fan (wind) off when the cup is halfway between the floor and the tabletop. Now test this scenario and write down your observations. Does it match your prediction?

10 Evaluate and present the most effective design to the class and discuss why you believed this to be the most effective wind turbine design in this situation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

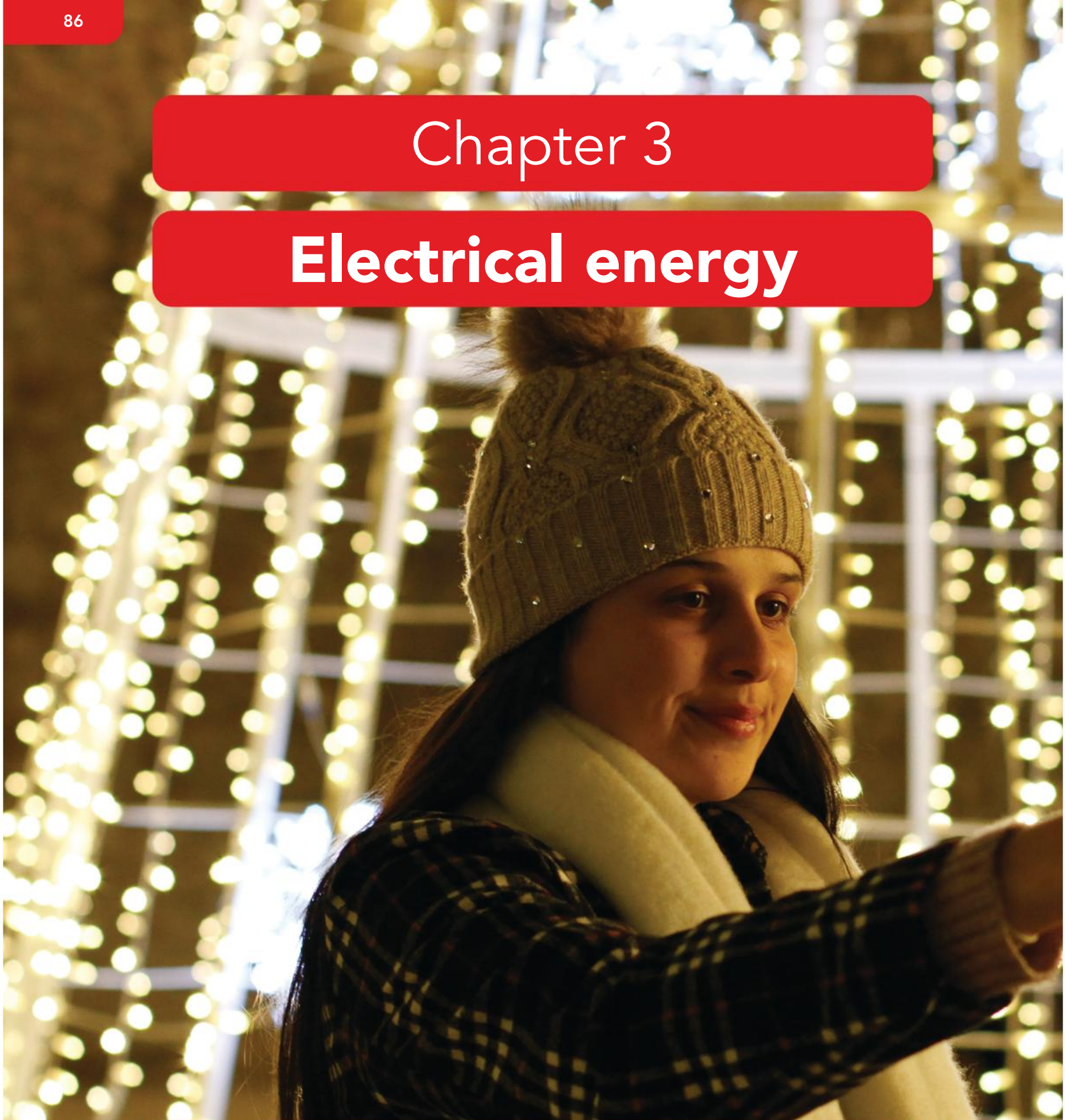
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 3

Electrical energy

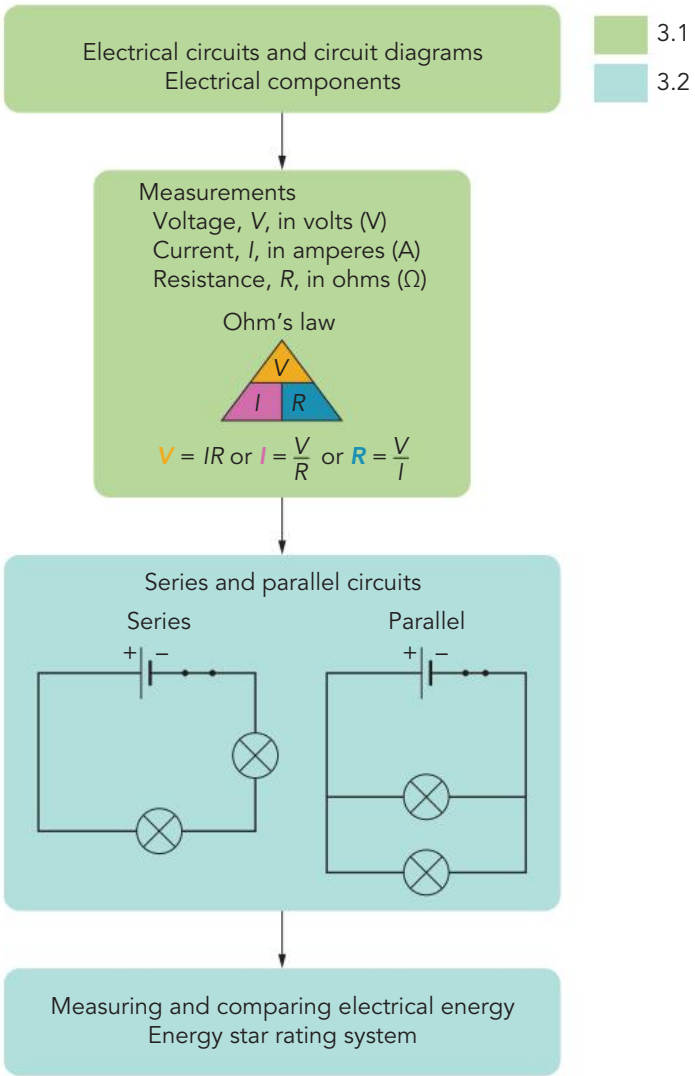


Chapter introduction

So much of what modern life depends on requires electrical energy. A constant supply of electricity to power our devices and appliances requires a lot of energy. An understanding of how electrical energy works is essential to maximise its use efficiently and safely. Let's have a look at how electrical circuits are used to transform energy to meet our needs.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

ammeter
ampere
battery
cell
circuit breaker
conductor (electricity)
coulomb
earthed
electrocution
fuse
insulator
load
ohm
Ohm's law
parallel circuit
residual current device
resistance
series circuit
voltage
voltage drop
voltmeter

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

3.1 Electrical circuits

WORKSHEET
Simple circuits

VIDEO
Electricity

Learning outcomes

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

1. draw and identify complete circuits.
2. construct circuits that contain multiple components.
3. measure voltage and current in series and parallel circuits.
4. understand how Ohm's law ($V = IR$) describes the relationship between voltage (V), current (I) and resistance (R).

Electricity is a form of kinetic energy because it is the flow of charge. It is generally the movement of the negatively charged electrons that results in a current. Electricity can also flow in liquids where ions are free to move. In either case a current can only flow when there is a circuit or path for the flowing charges to follow.

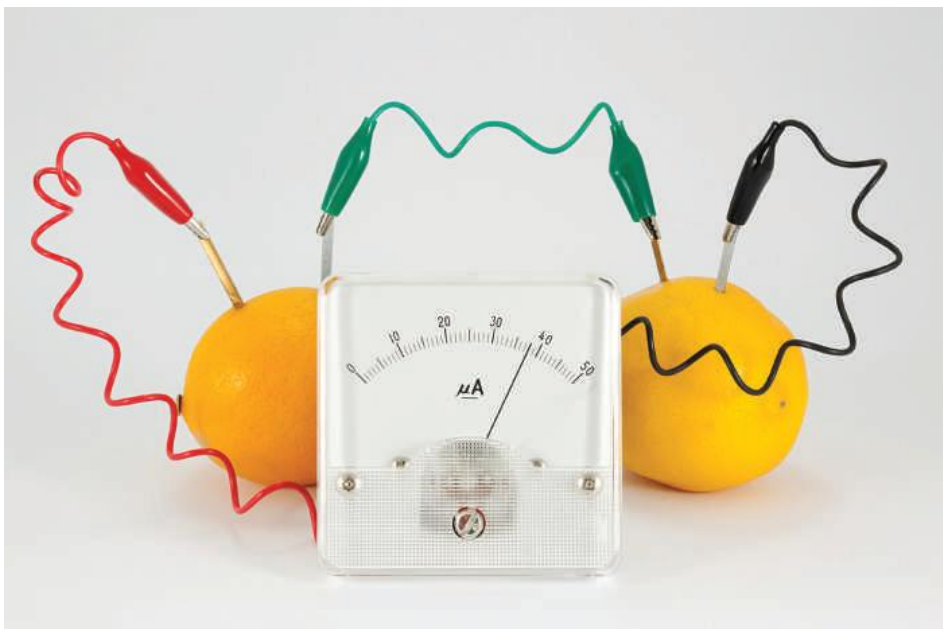


Figure 3.1 Current is a measure of the flow of charges.

You have probably played the board game where winning meant you had to have exceptionally steady hands for removing the 'organs' of a patient with surgical precision. Whenever you missed and touched the edges, a buzzer would sound. This occurred because you completed an electrical circuit. Without a complete circuit the no current flows and the buzzer does not sound.

An electrical circuit always has these three components:

- a power source (provides energy to electrons – for example a battery or power pack)
-

  connecting wires (conducting material to provide a path for the moving electrons to complete the circuit).

load
a device that transforms electrical energy to another form energy in a circuit

However, if you connected a power source to wires without a load, it does not last long! This is called a short circuit, a high current will flow and damage the wires and the battery, they could become very hot, start smoking, and melt. In fact, electrical fires are sometimes caused by a short circuit.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 3.1

Electric dexterity test

Set up a simple circuit with a light globe (or buzzer) and a battery as shown. For the conducting wire, bend a metal coat hanger into a complex line with bends and loops, and attach one end to the battery.

Use a second coat hanger to make a hook, connecting it to the light globe or buzzer.

Test your steady hand and skill at completing the circuit without setting off the buzzer or light!

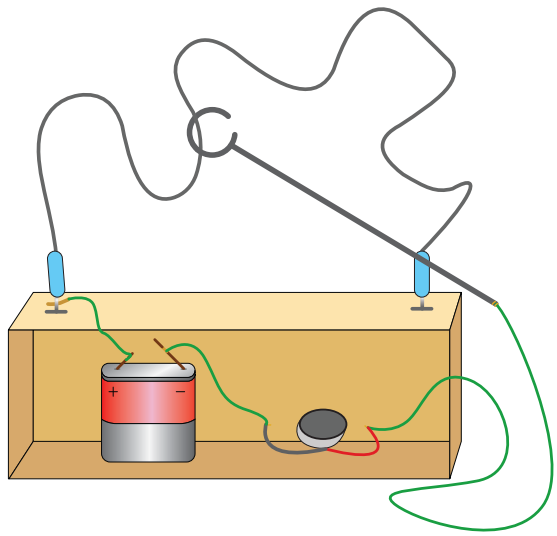


Figure 3.2 Simple circuit set-up

Electrical circuit components

Power source

The **cell** or **battery** is the power source of a circuit. It supplies the energy to the electrons, which are then pushed around the circuit. When the two terminals are connected via a circuit, electrons flow from the negative to the positive terminal. An everyday battery, like you might have in a torch, is an electrochemical cell (something that derives electrical energy from chemical reactions). You may have noticed a battery is labelled with the voltage it supplies, for example 9 V battery provides more energy than a 3 V battery. The voltage supplied by a battery is the potential difference between its positive and negative terminals. This voltage indicates how much energy the battery can provide to move electric charges through a circuit. Schools are often equipped with power packs similar to the one shown Figure 3.3, with a dial to choose the voltage setting you require, up to 12 V. The use of these power pack lowers risk as it limits the energy supplies to 12 V and has a built-in fuse which will disconnect the circuit in case of a high current (for example a short circuit). If the fuse does not act immediately, turn off the power if you detect overheating wires.

Figure 3.3 A typical school lab power pack that can supply AC and DC current at 12 V.

cell
a single electrical energy source that produces a current

battery
a portable source of power

Load

A load is a component – a resistance – of an electrical circuit that transforms energy. Electrons moving through a circuit carry energy from the power source to components that can transform that energy into other forms of energy as the electrons pass. For example, in incandescent light globes, the energy being carried by the electrons is transformed into light and thermal energy.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Only a small amount of the energy is transformed into light energy – around 96% is wasted as thermal energy. Incandescent light globes, which are not very energy efficient and waste about 90–95% of the energy supplied, can get quite hot! In contrast, light emitting diodes (LEDs) are tiny light globes that transform electrical energy into light energy much more efficiently than incandescent light globes, with about 60% of the energy lost as thermal energy. The lifespan of LEDs is also much longer than that of incandescent light globes. LEDs are often used in appliances such as watches, microwaves, calculators, traffic lights and TV screens.

Advances in science 3.1

Electric cars

There are many reasons why electric cars are becoming more mainstream worldwide. They do not release any exhaust gases and have the potential to dramatically reduce air pollution in large cities. They are quiet and efficient. An electric car powered by rechargeable batteries uses electric motors to drive all four wheels. These motors can also become efficient electrical generators when the car is braking. This 'regenerative' braking system can recoup up to 60% of the car's energy of motion and turn it back into electricity!

Additionally, electric cars are being designed so that their batteries can be fully or partially recharged by renewable resources, such as domestic solar energy. There is no point driving an environmentally friendly electric car if you are charging up with electric power produced by highly polluting coal-fired power stations!

Figure 3.4 Fast charging an electric car. The 85-kWh battery pack has a mass of 540 kilograms (kg) and contains 7104 lithium-ion battery cells in 16 modules.

Circuit diagrams

The circuit in Figure 3.5 shows a battery pack connected to a light globe with connecting wires and a switch. When the switch is pressed down, it completes the circuit, so electrons can flow from the negative terminal of the battery through the circuit and back to the positive terminal.

Circuits are represented in the form of a diagram in which each symbol represents a different electrical component. Figure 3.6 shows the circuit from Figure 3.5 in the form of a circuit diagram using symbols.

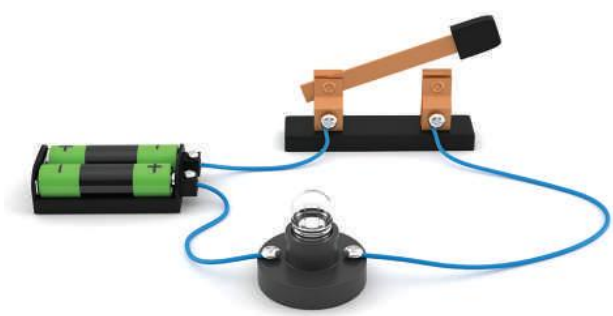


Figure 3.5 A simple circuit can be made with a power source, light globe and switch.

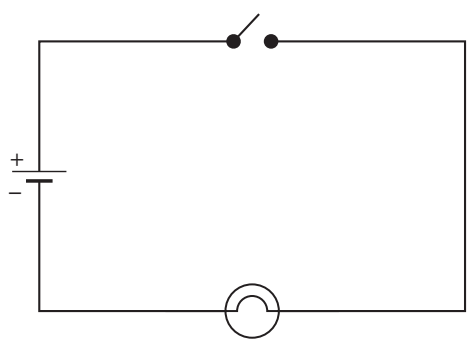


Figure 3.6 To create a diagram of the simple circuit shown in Figure 3.5, join the symbols for a power source, a light globe and a switch together with straight lines that represent the wires.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Advances in science 3.2

Crystal circuits

In 2017, scientists found a way to engrave an electrical circuit into a crystal. By accident, physicists from Washington State University found that if a crystal is heated and then left exposed to light, it can conduct electricity. A circuit can be engraved into the crystal using a laser.

Even better, it was found that the circuit can be erased by heating it on a hot plate. This means the circuits can be erased and reconfigured numerous times, like the drawings on an Etch a Sketch.

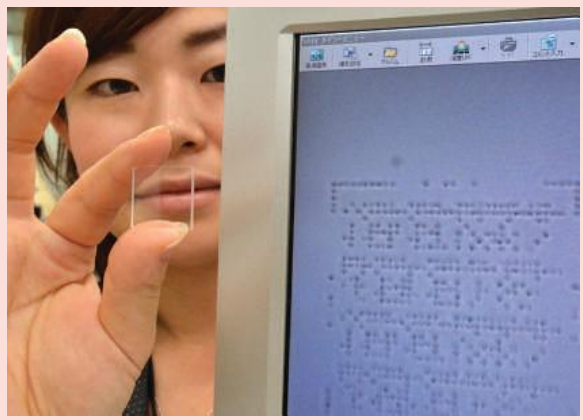


Figure 3.7 Laser beams create dots on glass in order to store data.

An electrical circuit in a crystal would be transparent, opening up opportunities to embed electronics in windows.

Circuit symbols

You have already seen some common electrical components and their circuit symbols above (battery, load and connecting wires). Table 3.1 shows several other useful electrical components and their circuit symbols.

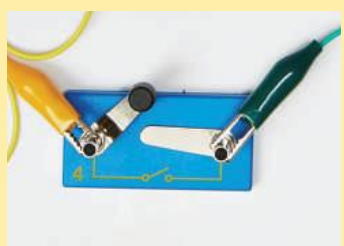
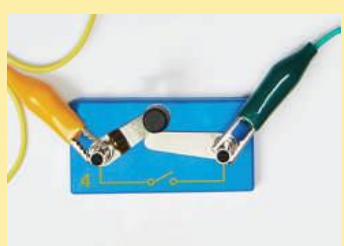
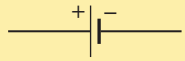
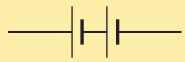
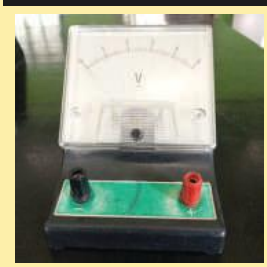
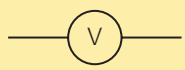
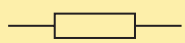
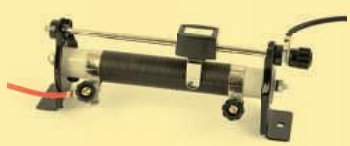
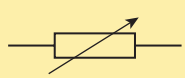
Component	Image	Symbol
Connecting wire		
Switch open		
Switch closed		

Table 3.1 Some common electrical components and their circuit symbols

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Component	Image	Symbol
Cell		
Power supply or battery pack		
Ammeter		
Voltmeter		
Load: light globe		
Load: resistor		
Load: variable resistor or rheostat		

ammeter
a device for measuring electric current

voltmeter
a device for measuring voltage (potential difference) between two points on an electric circuit

Table 3.1 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Drawing circuit diagrams

A circuit diagram is a representation of an electrical circuit using universally accepted symbols. Circuit diagrams should always be drawn with a ruler and pencil. All lines should be straight and joined at right angles.

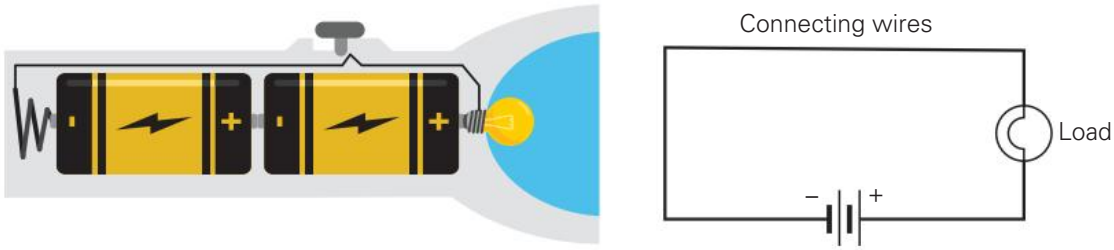


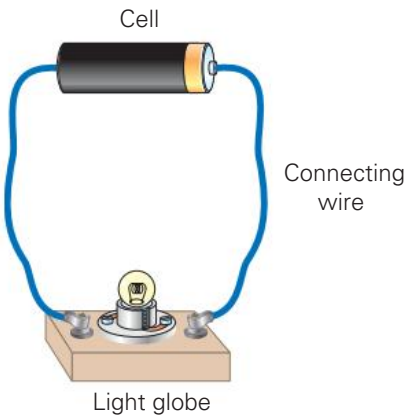
Figure 3.8 The left-hand drawing shows the inside of a torch, but you use a simplified diagram like the right-hand one to represent the circuit. The batteries are the energy source, and the light globe is the load. Can you think of one component that needs to be added to the diagram?

Try this 3.2

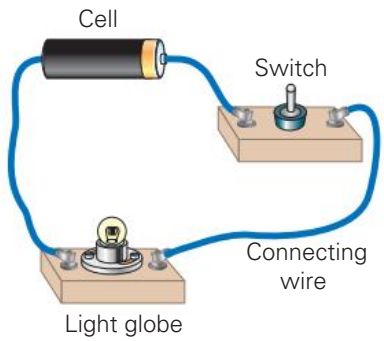
Drawing circuit diagrams

Draw circuit diagrams for the following circuits.

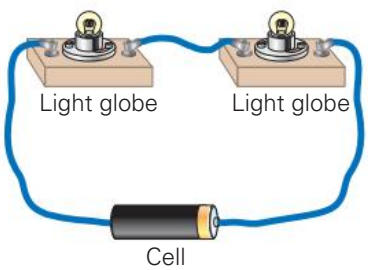
a



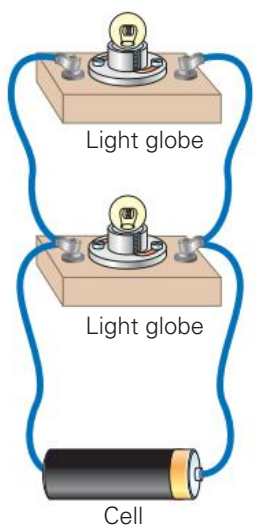
b



c



d



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 3.1

1 **List** five components that could be included in a circuit.
2 For the list from Question 1, **draw** the circuit symbol for each.
3 **Explain** why circuit diagrams are used.
4 **List** the rules that apply to drawing a circuit diagram.

Voltage

voltage
a measurement of how much energy each charge carrier is given

Voltage is the 'push' that sends electrons around the circuit. It is supplied by the power source of a circuit and is a measurement of how much energy is given to the electrons (charges). Because electrons are so small, a unit of charge is more than a billion billion electrons. A 1.5 V battery supplies 1.5 joules (J) of energy per unit of charge. Components such as light globes and speakers transform the energy supplied by charges into light, heat and sound. The voltage of a battery is usually standardised for its particular purpose. Car batteries used for starting petrol cars are virtually all standardised at 12 V. In Australia, power points supply 230 V. Some appliances contain a transformer that reduces the voltage to a more suitable number. For example, your laptop charger has a black box on the charger lead, this box will have text that indicates the change from 230 V (input) to whatever the device requires (output). Look closely and you will find it.

Figure 3.9 Adapters like this one convert a higher voltage into a lower one.

Voltage is measured in volts (V) using a voltmeter. A voltmeter can measure the voltage provided by the power supply or the voltage drop across components of the circuit. In a circuit, a voltmeter must be connected to the start and the end of the component whose voltage you are measuring so as to measure the voltage drop **across** the component as shown in Figure 3.11. This is called connecting in **parallel** to the circuit, which will be explained in the next section.

parallel circuit
a circuit in which several branched for current to flow where each component is connected to the battery

Current

Current is the movement of electrons around a circuit. If voltage is the push, then current is the thing that is pushed–the charge. The electrons flow from the negative terminal to the positive terminal (referred to as electron flow or electron current). However, the current in circuit diagrams is shown as going in the opposite direction; that is, from the positive terminal to the negative terminal of the power source. This is called conventional current, and follows the direction defined in the 1700s (before they knew about electron flow!)

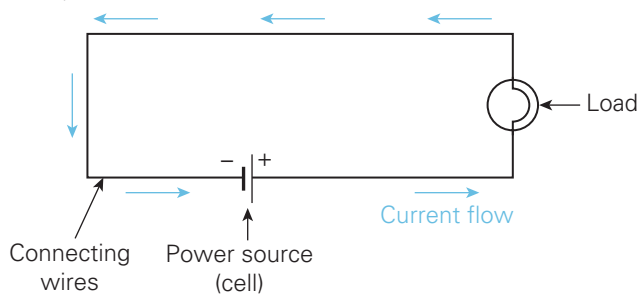


Figure 3.10 Conventional current is indicated in this simple circuit as flowing from the positive terminal to the negative terminal of a cell. The connecting wires are drawn as straight lines.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

It is possible to measure the rate at which charge passes any point in a circuit. Imagine being able to see the electrons moving along a conductor carrying an electric current. You could count the number which pass any particular point in 1 second and use that number as a measure of the current (in electrons per second).

The unit of current is defined this way: 1 **coulomb** (C) of charge transferred per second is 1 **ampere** (A), or amp for short. A coulomb can be defined as the amount of charge transferred in 1 second with a current of 1 amp. You can increase the electric current flowing through a circuit by increasing the voltage or energy supplied to each charge.

coulomb
unit of electric charge; the amount of charge transferred in 1 second with a current of 1 amp

ampere
The flow of 6.242×10^{18} electrons per second

To measure the current in specific locations of a circuit, an ammeter is used. An ammeter is connected in line with the power source and load to measure the current **through** a circuit as shown in Figure 3.11. This is called connecting in **series** with the circuit. This figure also shows a voltmeter connected in parallel in the circuit. Connections in series and parallel are explained in the next section.

series circuit
only one path for the current to flow

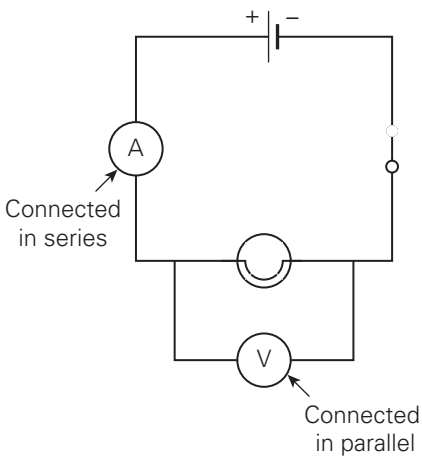


Figure 3.11 Ammeter (A) connected in series, measuring current through a circuit, and a voltmeter (V) connected in parallel measuring voltage across the load

Figure 3.12 When building a circuit, ammeters need to be placed in series and voltmeters need to be placed in parallel.

Quick check 3.2

1 **Define** the following terms in your own words.
- **a** Voltage
- **b** Voltage drop
- **c** Voltmeter
- **d** Current
- **e** Ampere
- **f** Ammeter

2 How does current differ in a circuit when the switch is open and closed? **Explain** your answer.

Resistance

The **resistance** in an electric circuit is how difficult it is for the current to flow through a material or component. Imagine resistance as being like a choke point in the circuit resisting the flow of charge (current) and opposing the push of the voltage. Resistance is measured using the unit **ohm**. The unit symbol for ohms is the symbol for the last letter in the Greek alphabet, omega, represented by Ω.

resistance
the degree to which a substance resists the flow of an electric current through it

ohm
the unit of resistance

Figure 3.13 Digital multimeters can measure current, voltage and resistance.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Conductors

conductor (electricity) a material that allows electric current to flow easily

Materials through which current can flow easily have a low resistance and are called **conductors**. Metals are a good example of conductors. Factors that affect the resistance of a wire include the:

- thickness of the wire. A thinner wire forces the electrons through a smaller space, meaning more collisions are likely to occur with other electrons and the atoms of the lattice. Therefore, the thinner the wire, the greater the resistance.
- length of the wire. The longer the wire, the more obstacles in the metal lattices slowing the current.
- temperature of the wire. If the temperature of a metal is elevated, the atoms in the lattice begin to vibrate more vigorously as they gain thermal energy, this increased movement increase the collision with the travelling electrons and therefore increases the resistance.
- type of material.

Some metals are much better at conducting electricity than others. This is due to how tightly the elections are bound to the atoms, as well as the geometry of the lattice arrangement of the atoms in the metal. Copper is an excellent conductor of electricity. It is used in electrical wiring, electrical motors, telecommunications and electric cars. Gold is also an excellent conductor of electricity; however, due to its cost it is used in small amounts in critical electronic components such as computer chips and spacecraft electronics.

Did you know? 3.1

Saving lives

A defibrillator is a device that treats life-threatening heart problems by delivering a measured dose of electric current to the heart. When the heart does not beat as it should, blood is not circulated around the body. To get the heart pumping, an electric shock is delivered to the heart. An automatic external defibrillator (AED) can be used by untrained people and significantly improves survival rates in people having a heart attack.

Figure 3.14 An AED can increase the chance of survival during a heart attack.

Insulators

insulator a material through which current cannot flow easily

Some materials have such high resistance that they block electric current almost completely. Such materials are called **insulators**. Examples of good electrical insulators are various plastics, glass, ceramics, wood and rubber.

Variable resistors

Fixed resistors are used in circuits to control the amount of current that flows, while variable resistors can be adjusted and are used to control the volumes on stereos and televisions, or the brightness of the lights through the use of dimmer switches. These variable resistors may have a slider or dial that can be used to adjust the resistance and therefore the current in the circuit.

A light-dependent resistor (LDR) is a special type of variable resistor because its resistance changes depending on the amount of light falling on it. As light intensity increases, resistance decreases. LDRs are used in light-sensitive electronic circuits and act as light-sensitive switches; for example, they are used for lights that turn on automatically when it gets dark.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Thermistors, another special type of variable resistor, act in the same way except that their resistance changes as the temperature increases or decreases. Thermistors regulate the temperature in air conditioners and refrigerators using the relationship between voltage and resistance.

Explore! 5.1

Electrical engineering as a career

Electrical engineering is a career that deals with the principles of electricity, electronics and electromagnetism. One of the jobs of electrical engineers is to maintain the delivery of power to homes and businesses; that means maintaining power lines and transmission towers. Power lines are the most efficient way to transmit large amounts of electrical energy. You may notice that power lines are bare – the air insulates them. However, utility poles and transmission towers need insulation. Conduct some research to answer the following questions.

1 Identify the material used in insulators for high-voltage power transmissions.
2 Some electric utilities have begun converting to polymer composite materials for use in some types of insulators. Identify what these are made of and deduce why they are useful as an alternative to other insulators.

Figure 3.15 This electrical engineer is carrying a high-voltage electrical insulator ready for installation.

Quick check 3.3

1 **Define** the term 'resistance' in your own words.
2 **Compare** a conductor and an insulator and give an example of each.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Ohm's law

Georg Simon Ohm was a German physicist who, through his research first published in 1827, observed that electric current had direct proportionality with the voltage applied across some conductors; that is, if you double the voltage, you double the current. There was also inverse proportionality between resistance and current; that is, if you double the resistance, you halve the current. This relationship is known as **Ohm's law**, where R is the resistance in ohms (Ω), V is the voltage in volts (V), and I is the current in amperes (A).

Ohm's law the law that states there is a direct proportionality between the voltage applied across some conductors and the resultant electric current

$$V = IR \text{ or } I = \frac{V}{R} \text{ or } R = \frac{V}{I}$$

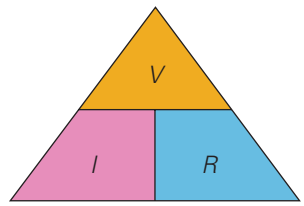


Figure 3.16 The Ohm's law triangle describes the relationship between voltage, current and resistance.

For example, if you have a circuit with a 2.5 V power source and a 1 Ω resistor, the current would be $I = \frac{2.5 \text{ V}}{1 \text{ Ω}} = 2.5 \text{ A}$. If the resistor is changed to having 2 Ω resistance while keeping the voltage the same at 2.5 V, then the current is decreased to $I = \frac{2.5 \text{ V}}{1 \text{ Ω}} = 1.25 \text{ A}$.

Recall that resistance is how difficult it is for electrons to travel around a circuit. So, if you increase resistance, the current must decrease.

$V = IR$ is a linear relationship. V is directly proportional to I and will be represented by a straight line on a graph. If we rearrange this formula to $R = \frac{V}{I}$, we can see that resistance is inversely proportional to current. If voltage is kept constant, then the greater the resistance, the smaller the current. This makes sense because greater resistance means there are more obstacles for the current flow, so the current flow decreases. Conversely, the lower the resistance the higher the current flow, such as is the case in a short circuit. If we draw a graph of the relationship with current on the horizontal axis and voltage on the vertical axis, then the gradient of the line will give us resistance. Remember that the gradient is equal to rise over run.

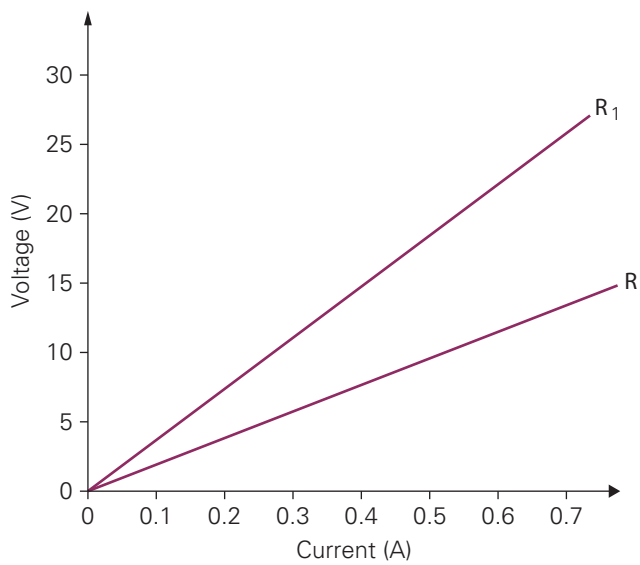


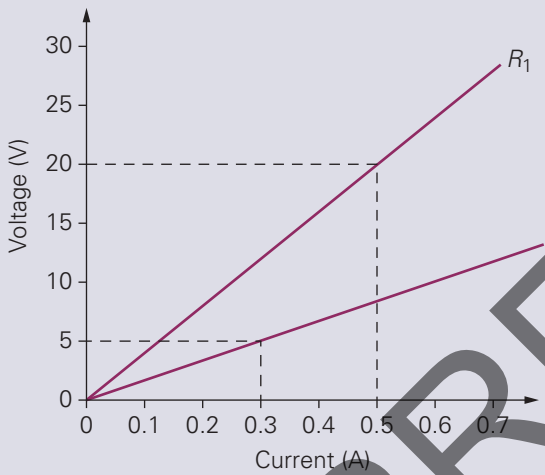
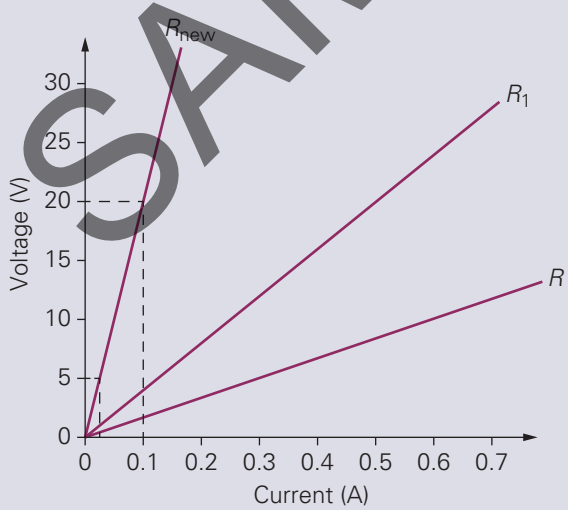
Figure 3.17 The resistance of R_1 is greater than the resistance R and therefore has a steeper gradient.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 3.1

Calculating resistance

1 Using the graph in Figure 3.17, calculate the resistance of resistor R_1 and resistor R.
2 The resistor in this circuit is replaced with 200-Ω resistor. Find the current when a voltage of 20 V is applied.
3 Assuming this conductor from part **b** obeys Ohm's law, add this line to the graph. Use the graph to predict the current if the voltage is reduced to 5 V and indicate this on the graph.

Working	Explanation
a resistance of resistor R_1 and resistor R	
 $R_1 = \frac{20}{0.5} = 40\ \Omega$ $R = \frac{5}{0.3} = 16.7\ \Omega$	Find the gradient of each line. The gradient is given by rise over run. Be careful, in this case the line goes through the origin but that is not always the case.
b current with a 200-Ω resistor and a voltage of 20 V	
$V = 20\ V$ $R = 200\ \Omega$	Identify the values given in the question.
$V = IR$ $I = \frac{V}{R}$ $= \frac{20}{200}$ $= 0.1$ A	Identify equation needed to answer the question and substitute the relevant values into the equation.
c current with a 200-Ω resistor and a voltage of 5 V, from the graph	
	If asked to use the graph, always indicate on the graph how you obtained your value. Using the graph the value for the current if the voltage is reduced to 5 V when using the 200-Ω resistor is much less than 0.1. The value can be checked using the formula $V = IR$. $I = \frac{5}{200} = 0.025$ A

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

If the graph of voltage against current is a straight line, the resistor behaves according to Ohm's law because the resistance is constant. This is called an *Ohmic resistor*. Some resistors do not behave this way – a variable resistor for example. This is called a *non-ohmic resistor*. This is also the case for resistors like the incandescent light globe. Recall that one of the factors that affect resistance is temperature. The hotter the resistor, the lower the current that can flow through it. An incandescent light globe heats up while switched on, the hotter it gets the higher the resistance, hence it behaves as a non-ohmic resistor.

Quick check 3.4

1 **Explain** the relationship between current and voltage as stated in Ohm's law.
2 Using the formula $V = IR$, **calculate** the following.
   a The resistance of a circuit where the voltage supplied is 6 V and the current is 2 A
   b The current in a circuit where the resistance is 50 Ω and the voltage is 25 V
   c The voltage in a circuit where the resistance is 100 Ω and the current in the circuit is 0.5 A
3 **Explain** how a variable resistor works and give an example of how it may be used in your home.

Investigation 3.1

Investigating resistance

Be careful

Electrical shocks may occur.

Ensure the voltage output does not exceed 6 V.

Power supply is to be turned off when changing the circuit.

Resistance/nichrome wire gets very hot if the voltage is too high, or if the power supply is left on for too long.

Ensure that no flammable materials are in contact with the wire.

Use a heat mat to prevent scorching your bench.

Aim

To investigate how the length of a wire affects its resistance.

Materials

- heat mat
- DC power supply (6 V)
- 6 connecting leads
- resistance wire such as constantan or nichrome
- alligator clips
- ammeter
- voltmeter
- metre ruler

Planning

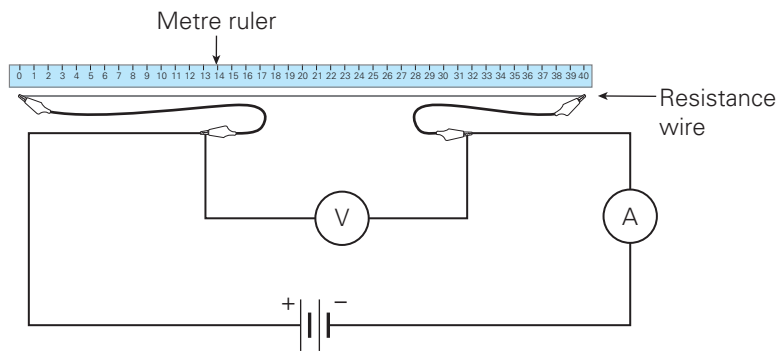
1 Write a paragraph about the factors that affect resistance.
2 Create a relevant and specific research question for this investigation.
3 Identify the independent, dependent and controlled variables for this investigation.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1 Connect the circuit shown in the diagram. For ease, follow these instructions.
   - **a** Start on the positive side of the power supply.
   - **b** Connect a lead from the positive socket to the positive side of the ammeter.
   - **c** Connect a lead from the negative side of the ammeter to the alligator clip attached to the resistance wire at the zero end of the ruler.
   - **d** Connect another lead from the other alligator clip to the negative side of the battery. This lead will be used to connect to the other side of the resistance wire and disconnect the power supply between taking readings.
   - **e** Connect a lead from the positive side of the voltmeter to the alligator clip that you connected to the ammeter.
   - **f** Connect a lead from the negative side of the voltmeter to the other alligator clip attached to the disconnection lead.



2 Draw a suitable results table. Hint: you should have four columns.
3 Record the length of the wire between the alligator clips, and the readings on the ammeter and voltmeter in your results table.
4 Move the alligator clip attached to the disconnection lead to different points on the resistance wire, recording the ammeter and voltmeter readings at each length of wire. The voltmeter readings may not change.

Results

Record your results in your results table.

Discussion

1 Calculate and record the resistance for each length of wire using the Ohm's law equation.
2 Plot a graph of length of wire (metres) against resistance (Ω), including a straight line of best fit.
3 Identify any trends, patterns or relationships in your results.
4 Explain your results using your own scientific knowledge.
5 Your line of best fit may not go through the origin. Explain where the extra resistance came from.

Conclusion

Draw a conclusion from this experiment regarding length of wire and resistance, using data to support your statement.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 3.2

Current and resistance

Be careful

Electrical shocks may occur.

Ensure the voltage output is not exceeded.

Power supply is to be turned off when changing the circuit.

Aim

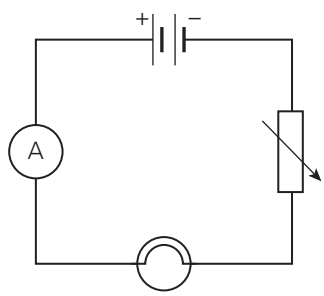
To investigate the relationship between current and resistance using a variable resistor.

Materials

- 6 V power supply
- 6 V light globe
- variable resistor
- 4 connecting wires and connectors
- ammeter

Procedure

1. Draw the results table below.
2. Set up the circuit as shown in the diagram at right and set the power supply to 6 V.
3. Adjust the variable resistor so that the light globe is at its brightest. Record the current shown.
4. Adjust the variable resistor so that the light globe gets dimmer and dimmer, recording the current at various points until it is at its dimmest.



Results

Brightness of globe	Current (A)
Brightest	
Bright	
Dim	
Dimmest	

Discussion

1. Describe what happens to the current in the circuit as the resistance of the variable resistor increases.
2. Describe what happens to the brightness of the globe as the resistance is increased.
3. Predict what is happening to the voltage across the globe as it gets dimmer.

Conclusion

Draw a conclusion from this experiment regarding current and resistance.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 3.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 3.1 questions

Remembering

1 **Draw** the symbols for the following electrical components.
   - **a** Single cell
   - **b** Three batteries in a row
   - **c** Open switch
   - **d** Resistor
   - **e** Globe

2 **Define** the following terms in your own words and give an example of each.
   - **a** Conductor
   - **b** Insulator
   - **c** Resistor
   - **d** Variable resistor

3 **Recall** the device that measures current and the units that it is measured in.

4 **Recall** the device that measures voltage and the units that it is measured in.

5 **State** Ohm's law in words and write the equation.

Understanding

6 **a** **Explain** why an ammeter needs to be connected in line with the other components of a circuit (this is called being 'in series').
   b **Explain** why a voltmeter needs to be connected across the component whose voltage you are measuring in a circuit (this is called being 'in parallel').

7 **Contrast** the terms 'voltage' and 'voltage drop'.

8 **Describe** how a variable resistor works.

Applying

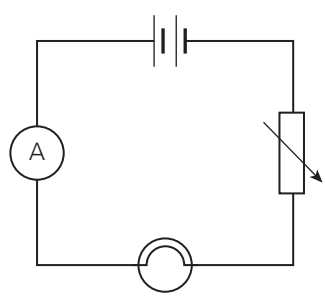
9 Both gold and copper conduct electricity. **Identify** which one of these two conducting metals would you most likely find in the following. **Propose** reasons why.
   - **a** In household wiring
   - **b** In critical electronic components

10 **a** For a certain electrical circuit, 20 coulomb (C) of charge flows past a point in 5 seconds. **Define** the term 'current' in your own words and **calculate** the current in amps.
   b For a certain electrical circuit, there is 20 J of electrical energy per coulomb of charge. **Define** the term 'voltage' in your own words and **calculate** the voltage of this circuit in volts.

11 **Use** your knowledge of thermistors and light-dependent resistors to **propose** a household appliance that uses them.

Analysing

12 The circuit below was constructed by a student using a 12 V battery and a 3 Ω light globe.
   - **a** **Identify** each of the electrical components on the diagram.
   - **b** **Label** which side of the battery is positive on the diagram.
   - **c** **Calculate** the resistance of the variable resistor if the ammeter reading is 3 A.



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

3.2 Series and parallel circuits

WORKSHEET
More circuits and their applications

Learning outcomes

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

1. understand how to measure and compare the electrical energy used over time in circuits or common appliances.
2. understand the energy star rating system and how these ratings are determined.

Series circuits

A circuit where all the components including the batteries, the switch and load(s) are all connected one after the other is called a **series circuit**. Think of the parts of the circuits all holding hands in a circle. There is only one path for the current to follow.

Figure 3.18 Series circuits can be thought of as a circle formed by joining hands.

An ammeter connected in any section of a series circuit will have the same reading because there is only one path for the current to flow. The current will be the same throughout the circuit. However, the energy, that is the voltage, provided by the battery will need to be shared across the loads in the circuit. In Figure 3.19 for example, if the light globes are identical (meaning they have the same resistance), then the voltage across each light globe is half that provided by the power source.

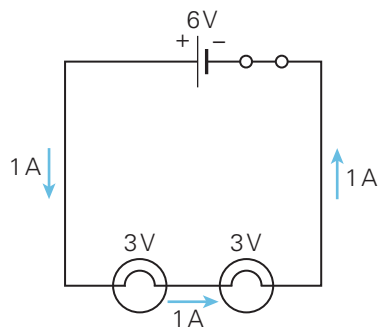


Figure 3.19 Circuit diagram with a 6 V power source and identical globes.

Another disadvantage of a series circuit is that if any one part of the circuit fails, the circuit will not work because there will be a break in the circuit, and no path for current to flow.

Try this 3.3

Series circuits

Two circuits have been set up for you by your teacher.

Circuit 1 is shown in Figure 3.20. Note the brightness of the globe.

Now look at circuit 2 in Figure 3.21 where the two globes are connected in series.

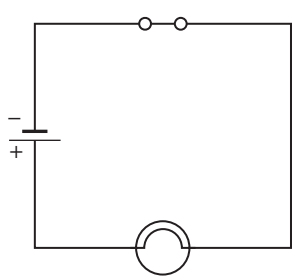


Figure 3.20 Circuit 1 – single globe

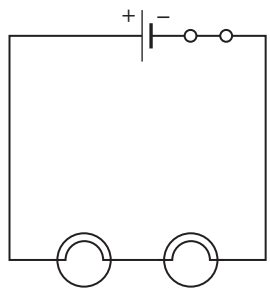


Figure 3.21 Circuit 2 – two globes in series

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Answer the following questions.

1 Do the globes in circuit 2 glow as brightly as the globe in circuit 1? Explain why or why not.
2 Predict what will happen if you disconnect the lead between the two globes in circuit 2.
3 Turn off the power. Disconnect the lead and turn the power on again. Note what happens. Explain what you observe.
4 What happens if you add another globe in series? Explain what you observe.

Parallel circuits

A circuit where all the components are connected in such a way that the current has multiple paths to follow is called a **parallel circuit**. This way each of the components can be connected directly to the battery and the current is shared. Think of the components all holding on to each other in piggyback fashion.

Figure 3.22 Parallel circuits can be thought of as 'piggybacking' on each other.

In a parallel circuit, the current has two paths it can follow at each branching point. If two identical light globes of equal resistance are connected in parallel, as shown in Figure 3.23, then the current in each branch is half that of the current from the main wire coming from the power source while the voltage across each component is the same. You can think of each light globe as being in series with the battery but in parallel with each other, so they have the same voltage, but they share the current. In a parallel circuit, each component is connected in a separate conducting path. This means that if one load component of the circuit is faulty, the other load components will still work. In Figure 3.23, if one light globe fails, the other one will still work as there is a connecting path between the battery and the other light globe.

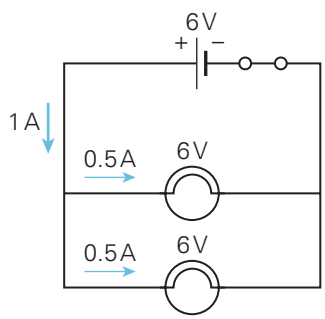


Figure 3.23 Circuit diagram with the blue arrows indicating current split

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 3.4

Parallel circuits

Two circuits have been set up for you by your teacher.

Circuit 1 is shown in Figure 3.24. Note the brightness of the globe.

Then look at circuit 2 in Figure 3.25 where the two globes are connected in parallel.

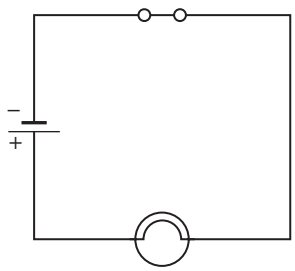


Figure 3.24 Circuit 1 – single globe

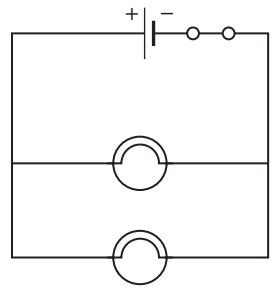


Figure 3.25 Circuit 2 – two globes in parallel

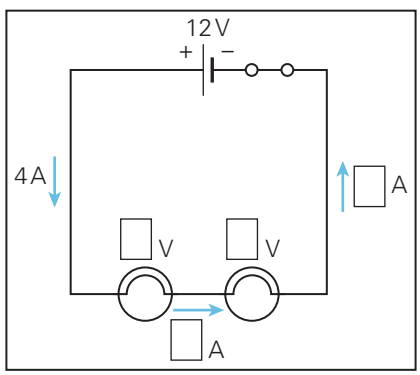
Answer the following questions.

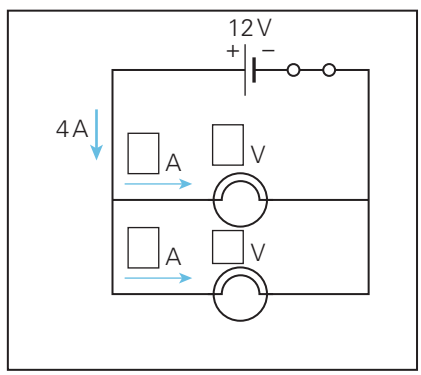
1. Are the globes in circuit 2 glowing as brightly as the globes in circuit 1? Explain what you observe.
2. Predict what will happen if you disconnect the bottom globe in circuit 2.
3. Turn the power off. Disconnect the lead and turn the power on again. What happens to the brightness of the other globe? Explain what you observe.
4. What happens if you add another globe in parallel? Explain what you observe.
5. What happens if you add another globe in series with the bottom globe? Explain what you observe.

WIDGET
Simple circuits

Quick check 3.5

1. **Describe** the differences between a series and a parallel circuit.
2. **Explain** why you would not wire your house in series configuration.
3. **Compare** the brightness of globes in series and parallel circuits.
4. Assuming that each light globe is identical, copy and **complete** the values in the following diagrams.





Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 3.3

Series and parallel circuits

Be careful

Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

Aim

To observe and compare the values of current and voltage in series and parallel circuits.

Materials

- DC power supply (6 V)
- 2 × 6 V light globes and 2 × 6 V globe holders
- connecting leads (alligator clips)
- ammeter
- voltmeter

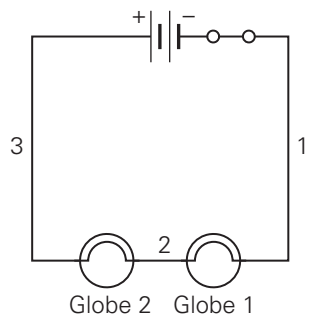


Figure 3.26 Circuit 1 – two globes in series

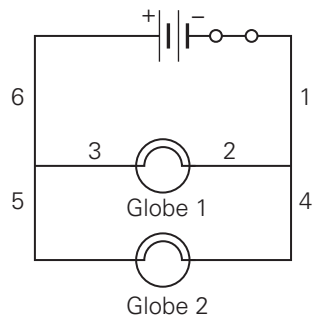


Figure 3.27 Circuit 2 – two globes in parallel

Procedure

Draw the results tables below.

Series

1 Set up circuit 1 in Figure 3.26 so that the two globes are connected in series.
2 Measure the current at the three numbered positions. Then measure the voltage across the power pack, across globe 1 and across globe 2. Record the readings in your results tables.

Parallel

1 Set up circuit 2 in Figure 3.27 so that the two globes are connected in parallel.
2 Measure and record the current at the six numbered positions. Then measure the voltage across each globe and the power source. Record the readings in your results tables.

Note: Ammeters are always connected in series. Voltmeters always in parallel across the device you want to measure.

Results

Current

Series circuit	
Position	**Current (A)**
1	
2	
3	

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Parallel circuit	
Position	**Current (A)**
1	
2	
3	
4	
5	
6	

Voltage

Series circuit	
Component	**Voltage (V)**
Power source	
Globe 1	
Globe 2	
Parallel circuit	
Component	**Voltage (V)**
Power source	
Globe 1	
Globe 2	

Discussion

1 Explain your observations regarding the current values in the parallel circuit.

3 Explain your observations regarding the voltage values in the series circuit.

4 Explain your observations regarding the voltage values in the parallel circuit.

Electrical energy transformations

An electric kettle uses electrical energy to boil water. It contains a heating element that converts electrical energy to thermal energy when electricity passes through it. The heating element then heats the water in the kettle to 100°C, at which point the water boils.

Figure 3.28 An electric kettle converts electrical energy into thermal energy.

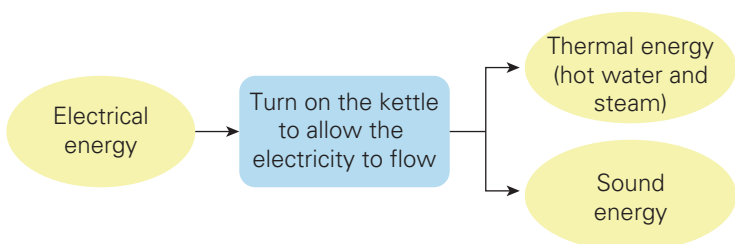


Figure 3.29 Energy flow diagram for an electric kettle

If this energy transformation was 100% efficient, then the amount of electrical energy supplied would equal the amount of energy gained by the water, however this is not the case, as can be seen in the energy flow diagram in Figure 3.29. Experiments can be conducted to test the efficiency of the energy transformation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 3.4

Energy consumption of household appliances

Aim

Measure and compare the energy consumption of different household appliances.

Materials

- plug power meter (e.g. Kill-A-Watt)
- various household appliances (e.g. lamp, fan, microwave, phone charger)
- notebook and pen for recording data

Procedure

Set-up

1 Plug the power meter into a wall outlet.
2 Plug the first appliance into the power meter.

Measurement

3 Turn on the appliance and let it run for a specific period (e.g. 5 minutes).
4 Record the power consumption displayed on the meter (in watts).

Repeat

5 Repeat the measurement for each appliance.
6 Ensure you reset the power meter before measuring a new appliance.

Results

1 Compare the power consumption of different appliances.
2 Calculate the energy used by each appliance using the formula:
energy (kWh) = 1000 × power (W) × time (hours)

Discussion

1 Discuss which appliances consume the most and least energy.
2 Explore ways to reduce energy consumption based on your findings.

INVESTIGATION

Investigation 3.5

Investigating energy transformation in a microwave

Be careful

Ensure safety equipment is worn at all times. Do not lean over or touch the beaker once it has been heated.

Aim

To investigate the thermal energy of different volumes of water.

Materials

- glass beaker
- thermometer
- beaker tongs

Planning

1
Identify the independent, dependent and controlled variables.
3 Write a hypothesis for your investigation.
4 Write a risk assessment for your investigation.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1 Put 200 mL of water in a beaker and measure the temperature. Record this in your results table.
2 Heat this water using a microwave for 1 minute.
3 Stir the water and measure the final temperature after it has been heated. Record in your results table.
4 Repeat steps **1–3** using 300 mL, 400 mL and 500 mL of water. Make sure the glass beaker is cooled between experiments, so that the initial temperature is the same. It might save time to start with four identical beakers with water at room temperature.

Results

1 Complete the following table with your results.

Volume (mL)	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)	Energy (J)
200				
300				
400				
500				

2 Calculate the thermal energy in each volume of water by using the equation:
thermal energy = mass in kg × specific heat capacity × change in temperature
The specific heat capacity of water is 4200 J/kg/°C.

Discussion

1 Describe any patterns, trends or relationships in your results.
2 Explain any trends you have identified.
3 How did the change in temperature differ between volumes of water?
4 Complete some research regarding specific heat capacity. What do you think would happen if a different liquid was used? Explain the reasoning behind your prediction.
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 to this experiment.

Conclusion

Draw a conclusion from this experiment, using data to support your statement.

Energy star rating

Understanding energy consumption in kWh helps you assess energy efficiency, compare appliances and manage your electricity usage, leading to potential cost savings and reduced environmental impact.

Any load in an electric circuit transforms electrical energy into another form of energy. But not all are efficient. For example, an incandescent light globe and an LED both transform electrical energy into light energy. However, an incandescent light globe also heats up, this means some of the electrical energy is transformed to thermal energy. Since this is not the intended purpose of the light globe, it is not useful energy output. The LED is much more efficient since less energy is lost and almost all the electrical energy is transformed to light energy. The same applies to all appliances, the more stars in the energy rating system the more energy efficient the appliance.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The kWh (kilowatt-hour) is a unit of energy. It is a measure of the amount of electrical energy used by 1 kW appliance every hour. Remember that power is the rate at which the energy is produced or consumed (in watts). 1 kilowatt is equivalent to 1 kJ per second (kJ/s). To find the amount of energy used in one hour, multiply by the number of seconds in one hour (3600 seconds). For a 1 kW appliance this results in 3600 kJ. This is a lot! In addition, electricity meters and bills used kWH – electricity is usually priced in dollars or cents per kWh. This makes it easy to calculate how much energy an appliance uses per hour and how much that costs. So, it is much more convenient to use the unit, kWh.

The appliance in Figure 3.30 uses 458 kWh per year. To relate this to daily use, you can divide 458 kWh by 365 days. This gives a usage of about 1.25 kWh per day. Note that this is based on typical usage: if the appliance is a fridge, you are using it 24 hours a day, whereas a dishwasher might only be used for one hour a day.

Figure 3.30 The more stars on an energy rating label, the more energy efficient the appliance compared to similar models. The energy consumption is given in kWh.

Explore! 5.2

The energy star rating system

1 Research the energy star rating for a range of appliance from such as fridges, washing machines and microwaves. Some of the criteria used to determine these ratings include standardised performance testing taking into consideration real-world usage patterns, durability and environmental impact. Find some specific criteria for the appliances you have researched.
2 Prepare an advertisement for your devices to persuade your audience to purchase them.
3 Present this to your class and have them vote which appliance is the best buy for energy efficiency.

WORKSHEET
How energy star ratings are determined

Worked example 3.2

Calculating energy savings of an appliance with a higher energy star rating

You're considering replacing an old refrigerator with a new energy star-rated model. Your old refrigerator uses 600 kWh per year. The new refrigerator uses 400 kWh per year. Electricity cost: $0.32 per kWh.

Working	Explanation
Old refrigerator: 600 kWh/year New refrigerator: 400 kWh/year	Data given in question
cost = energy consumption × cost per kWh = 600 kWh × 0.32 $/kWh = $192	Calculate the energy cost per year of the old refrigerator.
cost = 400kWh × 0.32 $/kWh = $128	Calculate the energy cost per year of the new refrigerator.
annual savings = cost of old refrigerator − cost of new refrigerator annual savings = $192 – $128 = $64	Calculate the difference.

By switching to a more efficient refrigerator, you save $64 per year, which adds up to $640 over 10 years. This example highlights the financial benefits of choosing energy-efficient appliances while also contributing to energy conservation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Household electricity

In your household, all your electrical appliances and lights transform the electrical energy into other forms of energy as the electrons flow through the different components. In Australia, electricity is usually supplied to homes at a voltage of 240 V and is referred to as the mains electricity. When you travel you may need a different plug to fit the socket as the socket voltage varies in different countries.

Region	Country	Voltage (V)	Region	Country	Voltage (V)
Asia	South Korea	110/220	Europe	UK	230/240
	China	110/220		France	127/230
	China (Taiwan)	110/220		Italy	125/220
	China (Hong Kong)	200/220		Spain	127/220
	Philippines	120/230/240		Greece	230
	Thailand	220		Switzerland	230
	Malaysia	240		Austria	230
	Singapore	115/230		Germany	127/230
	India	115/230/240		Holland	230
Oceania	Australia	230		Norway	230
	New Zealand	230		Sweden	230
	Fiji	120/240		Portugal	230
	Guam	120/240		Russia	127/220
	Hawaii	120	Africa	Ethiopia	220
North/ South America	USA	120		Egypt	220
	Canada	120/240		Kenya	240
	Argentina	220		Nigeria	230
	Chile	220		South Africa	220/230/250
	Brazil	127/220	Middle and Near East	Iran	230
	Peru	220		Turkey	220

Table 3.2 Voltages in use around the world

Safety

Earthing

Power points (sockets) in the home have three slots: active, neutral and earth. When you plug in an electrical device and switch the power on, current flows between slots at the top through the appliance (between the active and the neutral via the appliance). In appliances that are **earthed**, there is a third slot which is the earth slot. It is normally connected to a metal pipe in the ground; that is, directly connected locally to the earth.

earthed having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

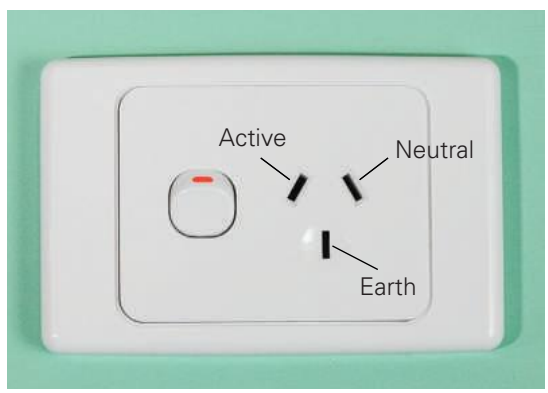


Figure 3.31 An Australian power point has three slots: active, neutral and earth.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Earthing certain appliances is essential. For example, if your toaster has a metal casing, and there is a fault in the appliance, the metal casing might accidently become 'live'. By earthing your toaster, the bottom earth pin fits into the earth socket, and thus the electric current will flow via the earth pin to the ground. This prevents the current going through the body of a person who might be touching the metal case of the toaster.

Did you know? 3.2

Electrical wiring

In Australia, the following colour code is currently used for electrical wiring. Some older electrical appliances may still have the old colour code (described in brackets):

- brown: the active wire, which is at mains voltage, 230 V (it used to be red: a colour normally associated with danger)
- blue: the neutral wire, which is nominally at 0 V (it used to be black)
- green and yellow stripes: the earth wire, which is connected to the earth (it used to be plain green).

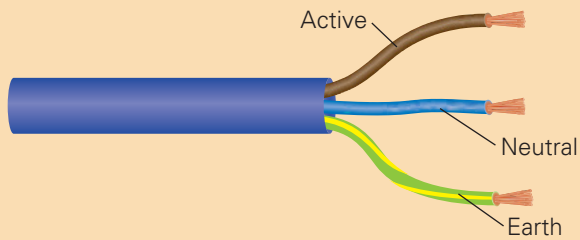


Figure 3.32 The modern colour code for electrical wires: brown for the active wire, blue for the neutral, and green and yellow for the earth.

Electrical hazards

The mains electricity supply in Australia presents a potential hazard to life. Even a relatively small current passing through the human body can be deadly. Anyone using electricity should be aware of the dangers associated with using it. All electrical work should be carried out only by qualified electricians. One of the main causes of **electrocution** in the home is the use of damaged cords and plugs. Frayed cords and plugs can expose the active, neutral and earth wires inside. As Table 3.3 shows, the human body is very sensitive to relatively small currents. You can feel one thousandth of an amp (1 mA), and a current of only 20 mA involuntarily contracts your muscles – you cannot let go of the wire! If someone grabs you to save you, they will most likely paralyse their muscles as well, placing two people at risk of electrocution.

electrocution
electric current passing through the body

Current (mA)	Effect on the human body
1	Can be felt
10	Causes pain
20	Paralysed muscles – very difficult to let go
50	Severe shock
90	Breathing is affected
150	Breathing is very difficult
200	Death is likely
500	Serious burning, breathing stops, death inevitable

Table 3.3 The size of the current determines the effect it has on the human body.

Fuses, circuit breakers and residual current devices

A short circuit can occur when frayed electrical cords or faulty electrical appliances allow the current to flow from one conductor to another (for example, from active to neutral or from active to earth) with little or no resistance. The current increases rapidly, causing the wires to get hot and possibly cause a fire.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

fuse
a device that will self-destruct if the current gets too high, breaking the circuit

circuit breaker
a device that will break the circuit if the current gets too high, without being destroyed

residual current device
a device that will break the circuit if any current leaks from a circuit, preventing electrocution

A **fuse** is device that will break the circuit if the current gets too high. The simplest type of fuse consists of a short length of conducting wire that melts when the current through it reaches a certain value, breaking the circuit.

In most modern houses, fuses have been replaced with circuit breakers. A **circuit breaker** (see Figure 3.33) carries out the same function as a fuse by breaking the circuit when the current exceeds some safety limit, such as 20 A.

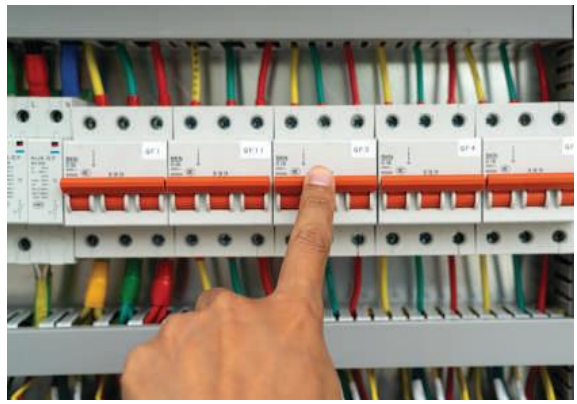


Figure 3.33 A circuit breaker protects households from potential damage caused by high currents.

VIDEO
Residual current device (RCD)

Safety switches (also known as **residual current devices**, RCDs) are different from circuit breakers. RCDs detect when current 'leaks' from circuits, possibly into a person. When 30 mA leaks from a circuit, these devices trip the power, preventing an electric shock.

Quick check 3.6

1 **Recall** the voltage of mains electricity in Australia.
2 **State** the purpose of the third socket of a power plug.

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 Using the labels switch, earth, active and neutral, redraw and then correctly **label** the electrical power point shown. Is the switch OFF or ON? **Explain** how you can tell.

2 **Describe** the differences between series and parallel circuits.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

3 **a** **Describe** the main disadvantage of a series circuit.

b **Describe** two advantages of a parallel circuit.

4 **Explain** why some electrical appliances are earthed.

5 **Describe** how electrical faults can cause house fires.

Applying

6 **Draw** a diagram to show how four 1.5 V batteries can be connected in parallel. What is the total voltage provided by this battery circuit? **Label** the positive and negative terminals of each battery.

7 **a** **Explain** what happens to your muscles when you experience a current of 20 mA from a live wire from the mains electricity.

b **Explain** reasons why you should not grab a person who is being electrocuted by a current of 20 mA.

8 **Explain** the function of circuit breaker in an electrical circuit.

9 **a** **Calculate** the energy used in kilowatt hours by a 200 W fridge in 24 hours.

b **Calculate** the energy used by a 1200 W hair straightener used for 20 minutes

Analysing

10 A student constructs circuit 1 as shown in Figure 3.34, using a 6 V battery and two identical globes, and measures the current through the circuit as 2 A.

a **Identify** whether this a series or parallel circuit. **Justify** your answer.

b **Determine** the voltage drop across each globe.

c **Calculate** the resistance of one globe.

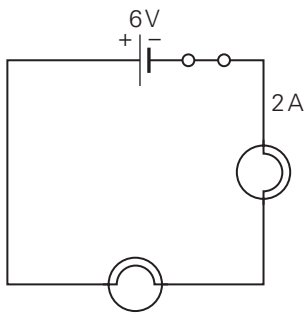


Figure 3.34 Circuit 1

11 A student constructs circuit 2 as shown in Figure 3.35. The circuit contains a 6 V battery and two identical globes of higher resistance than in Question 9.

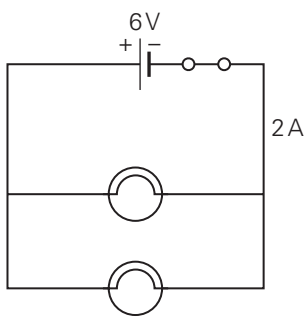


Figure 3.35 Circuit 2

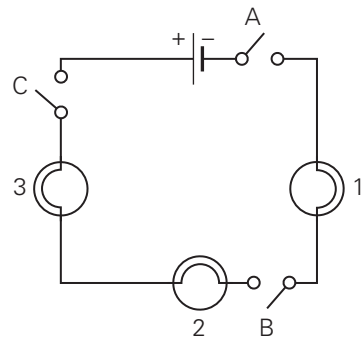
a **Identify** whether this a series or parallel circuit. **Justify** your answer.

b **Determine** the voltage drop across each globe.

c **Calculate** the resistance of one globe.

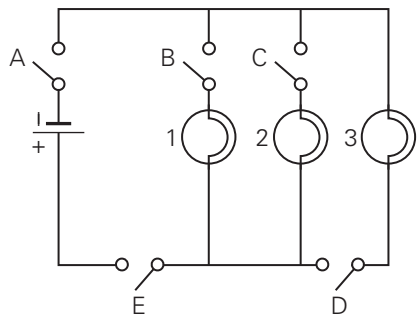
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

12 a Copy and **complete** the following table regarding the circuit shown below.



Switches turned on (or closed)	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3(on/off)
A			
B and C			
A, B and C			

b Copy and **complete** the following table regarding the circuit shown below.



Switches turned on (or closed)	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
A, B, C and D			
A, B and E			
A, C, D and E			
A, B, D and E			

Evaluating

13 **Propose** reasons why household electrical wires are coated in plastic.

14 **Evaluate** why household circuits supplying your lights, television, computers, washing machines are wired in parallel, while the fuses (and circuit breakers) to these circuits are wired in series with the circuits.

15 Imagine you are a salesperson in a home appliances store. **Determine** how to influence your customer to use the star energy rating to make an informed decision about which is the best appliance to purchase.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
3.1	draw and identify complete circuits.	
3.1	construct circuits that contain multiple components.	
3.1	measure voltage and current in series and parallel circuits.	
3.1	understand how Ohm's law (V = IR) describes the relationship between voltage (V), current (I) and resistance (R).	
3.2	understand how to measure and compare the electrical energy used over time in circuits or common appliances.	
3.2	understand the energy star rating system and how these ratings are determined.	

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Data questions

A group of students is testing the advertising claims of 10 different AA battery brands. A fresh AA battery is claimed to provide at least 1.50 V. The initial voltage for three new batteries for each brand was recorded by preparing a circuit with a multimeter, and the data is presented in Table 3.4.

Battery brand	Initial voltage of first battery (V)	Initial voltage of second battery (V)	Initial voltage of third battery (V)
1	1.63	1.60	1.61
2	1.57	1.55	1.57
3	1.24	1.29	1.45
4	1.48	1.50	1.47
5	1.52	1.50	1.51
6	1.53	1.53	1.53
7	1.50	1.55	1.50
8	1.60	1.61	1.64
9	1.65	1.65	1.65
10	1.61	1.62	1.60

Table 3.4 Recorded voltage for three new AA batteries of different brands

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1 **Identify** the battery with the highest initial voltage.
2 A 'flat' AA battery can be considered, in this case, to have a voltage of less than 1.3 V. **Determine** whether any of the newly purchased AA batteries are already flat.
3 For the first battery tested of each brand, remove any flat batteries as outliers and **calculate** the mean initial AA battery voltage.
4 With respect to the initial voltage claim of at least 1.5 V, **identify** any patterns that appear in the observed initial voltages.
5 **Classify** the battery brands as those that meet their claim of an initial voltage of 1.5 V and those that don't consistently meet their claim.
6 Now **categorise** the battery brands that do meet their claim into those with an initial voltage much higher than the claim (1.60 V+) and those consistently just above the claim (1.50–1.59 V).
7 Battery brand 9 also claims to have the 'longest lasting AA battery'. **Justify** whether the data in Table 3.4 supports this claim.
8 After complaints to battery brand 3 about the quality of their batteries, a spokesperson revealed that there was a 10% chance of a battery in their packs being sold with a voltage of less than 1.5 V. **Justify** this claim with respect to the reliability of the data presented in Table 3.4.
9 Based on the data presented in Table 3.4, **predict** whether a fourth battery of brand 3 is likely to meet the claim of an initial voltage of 1.5 V. Consider the sample size when thinking about this question.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: You are the expert!

Background information

1 How can solar powered fairy lights be designed for indoor use?
2 Why do houses need a domestic fuse box? Which device are in the same circuit? Why?
3 How can foot traffic be used to make useful electrical energy?
4 What is the future of wearable electronics?

Choose one of the questions above to investigate possible future-focussed solutions. In each case you consider the following:

- **Energy conversion:** Research how it works to convert input energy into electrical energy.
- **Series versus parallel circuits:** Compare how these two types of circuits affect performance of your system.
- **Impact of resistance:** Investigate how resistance in a circuit affects the performance.
- **Energy storage:** Explore how energy can be stored, such as in batteries, for use when needed. What are the difficulties with this?
- **Efficiency:** Consider the efficiency of your system, and compare it to traditional or other alternatives, considering energy conversion and storage.
- **Environmental factors:** Research how factors such as light intensity, weather, and geographic location affect performance and also how your system affects the environment, this could be in form of pollution, waste, materials and resources required.

Activity instructions

In teams (maximum of 4 people), you create a presentation to communicate your findings. This could be a video, or a demonstration of a prototype you constructed, or a science panel interview. It is recommended your team thinks about assigning roles and tasks for this project (for example, videographer, researcher, movie editor, scriptwriter, presenter, technical crew) so everyone has the chance to develop and use different skills.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 4

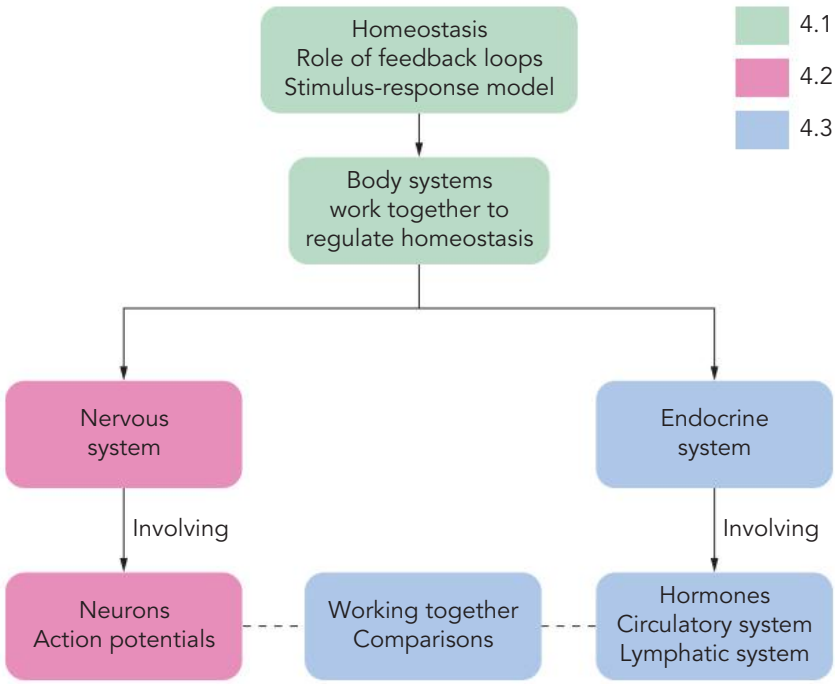
Homeostasis

Chapter introduction

The human body is a complex organism that relies on various body systems to regulate and coordinate its responses to stimuli. These stimuli can come from both external and internal sources and the regulation and coordination of responses requires the collaboration of different body systems. Negative feedback is a critical mechanism that helps maintain the body's internal environment within a narrow range of conditions, despite fluctuations in the external environment. In this chapter, you will compare the role of the nervous and endocrine systems in regulating and coordinating the body's responses to stimuli. You will also explore the operation of negative feedback mechanisms in detail, including their components, functions and examples.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

action potential
autonomic nervous system
control centre
effector
endocrine system
glucagon
homeostasis
hormone
insulin
interneuron
motor neuron
negative feedback
nervous system
neuron
neurotransmitter
osmoregulation
pathogen
positive feedback
receptor
reflex action
response
sensory neuron
somatic nervous system
stimulus
synapse
target cell

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4.1 Body systems working together

WORKSHEET
Homeostasis

Learning outcomes

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

1. explain why it is important for the body to maintain stable internal conditions.
2. identify the role of feedback loops in homeostasis.
3. describe and explain organisms' responses to stimuli using the stimulus–response model.

The importance of homeostasis–maintaining stable internal conditions

Within the human body, the 11 major organ systems interact with each other to enable humans to grow, maintain life and reproduce. Each system depends on other systems to keep the body functioning at an optimal level, and each is made up of organs with highly specific functions. Every multicellular organism depends on its body systems working together. The body does an amazing job of maintaining a stable internal environment, despite considerable changes in the external environment. This process is known as **homeostasis**.

homeostasis the process in which an organism maintains a stable internal environment despite changes in the external environment

negative feedback a regulatory process that reduces changes in a system, bringing it back to its normal state when it deviates from its set point

Maintaining homeostasis is vital because it ensures that the body's internal conditions remain within the narrow ranges required for cells and organs to function properly. If the body fails to regulate these conditions, it can lead to malfunctioning enzymes, disrupted cell processes, or even life-threatening conditions.

The role of feedback loops

Negative feedback loops

Negative feedback mechanisms play a crucial role in maintaining homeostasis. These mechanisms operate by sensing when a system deviates from a set point and then activating responses to counteract the deviation and bring the system back to its set point. If there is a change in an animal's external environment, such as a rise in temperature, the body must adapt to maintain a stable internal environment. Other physiological parameters that must be tightly regulated within the human body include blood glucose levels, blood pH and blood pressure.

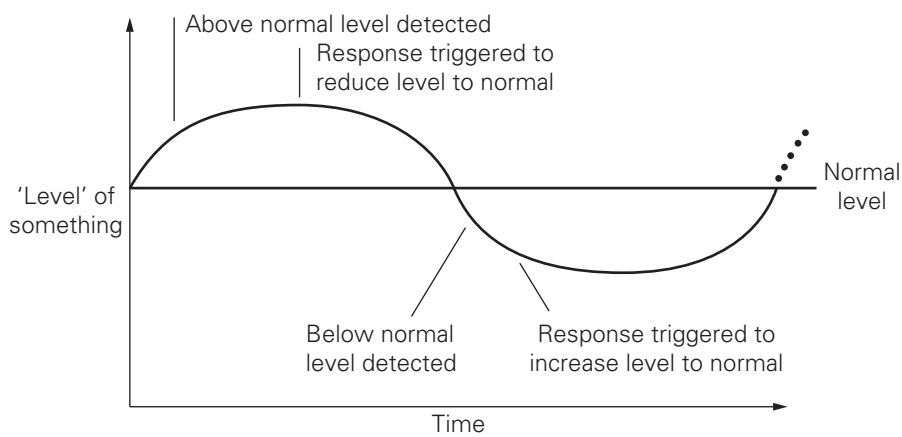


Figure 4.1 A simple negative feedback model

Stimulus–response model to explain feedback loops

VIDEO
Negative feedback

To achieve homeostasis, the body needs to respond to changes within the body's internal and external environment. A **stimulus** is any change in the environment that is detected by the human body. The change can be physical or chemical. Stimuli include changes in temperature, light, sound, pressure and chemicals in the air or food.

Changes in the environment are detected by **receptors** within the body. If a response is required, certain actions are brought about by **effectors** within the body to bring the body back to its 'normal' or optimum level.

stimulus
(plural: stimuli)
a change in the environment that is detected by the human body

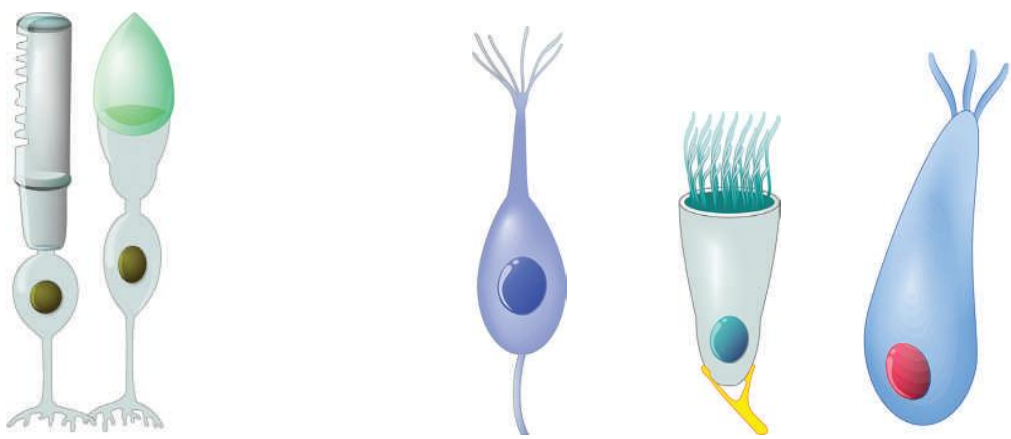
receptor
a specialised structure that allows the body to detect and respond to stimuli

effector
a muscle, a gland or an organ that carries out a response or action in response to a stimulus

Receptors are specialised structures throughout the human body that allow the body to detect and respond to various stimuli. They occur in all types of tissue, from the skin to the internal organs. There are many types of receptors, each specialised to detect a specific type of stimulus (Figure 4.2). The different receptors are described in Table 4.1

Receptor type	Location	Stimulus
Chemoreceptor	Blood vessels, brain	Changes in blood chemistry (e.g. oxygen, carbon dioxide, pH levels)
Mechanoreceptor	Skin, muscles, joints, inner ear	Physical distortion or deformation (e.g. touch, pressure, stretching, sound)
Photoreceptor	Retina of eye	Light energy
Thermoreceptor	Skin, brain	Changes in temperature (e.g. heat or cold)
Olfactory receptor	Nose	Chemicals in air (odours)
Gustatory receptor	Taste buds on tongue	Chemicals in food and drink (taste)
Nociceptor	Skin, muscles, joints, organs	Tissue damage or potentially harmful stimuli (e.g. heat, cold, pressure, chemicals)

Table 4.1 A summary of receptors in the body



Vision
Photoreceptors detect light.

Touch
Mechanoreceptors detect mechanical forces such as pressure or movement. Thermoreceptors detect temperature changes. Nociceptors detect damage to body tissues, causing pain perception.

Smell
Olfactory chemoreceptors detect chemical stimuli.

Hearing
Mechanoreceptors detect mechanical forces from the vibrations conducted from the eardrum.

Taste
Gustatory chemoreceptors detect chemical stimuli.

Figure 4.2 The different sensory receptors associated with your five senses. Their shape is closely associated with their specialised functions.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

control centre
often the brain or spinal cord, which receives signals from receptors and sends out signals to effectors to produce a response to a stimulus

response
the reaction to a stimulus

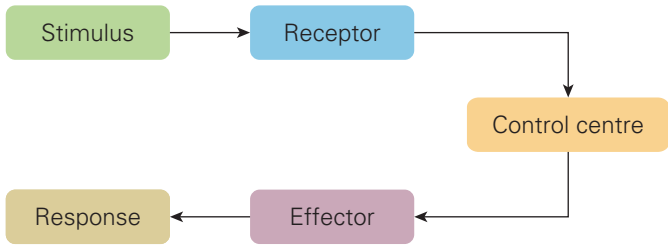
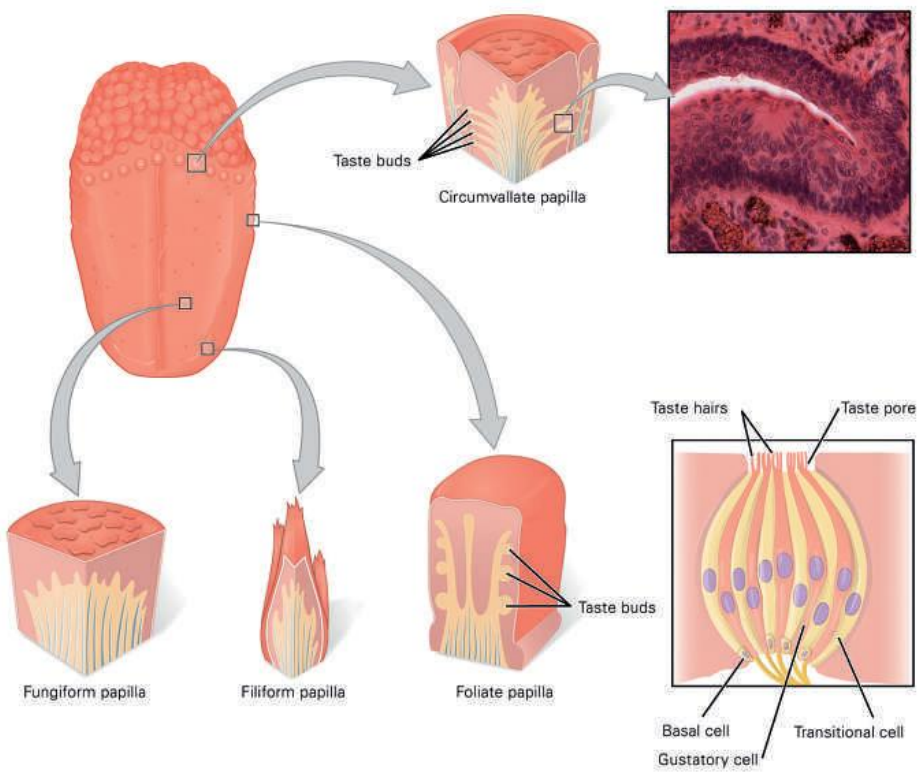


Figure 4.3 A flow chart outlining the stimulus–response model

Explore! 4.1

Taste buds

The tongue is a complex organ that contains various types of papillae, which house specialised sensory receptors known as taste buds. Papillae are small, raised structures on the surface of the tongue, and they can be different shapes and sizes. Taste buds play a crucial role in our sense of taste. The human tongue can contain thousands of taste buds, which detect different types of taste such as sweet, sour, salty, bitter and umami (savoury). Each taste bud is made up of groups of specialised cells called taste receptor cells, which are stimulated by different chemicals in the food we eat. When a taste receptor cell is activated, it sends a signal to the brain, which then translates the information into the sensation of taste. The location and number of taste buds varies from person to person, which can influence individual preferences for different types of food.



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

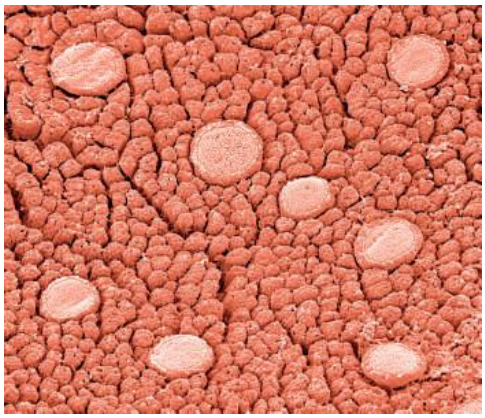


Figure 4.5 Papillae on a tongue

Figure 4.6 A cross-section of papillae. At 50× magnification, a taste bud is visible (circled) on the central papilla.

Quick check 4.1

1 **Define** 'homeostasis'.
2 **Explain** why homeostasis is so important for your survival.
3 **Describe** negative feedback.

Responses to changes in temperature

The circulatory, integumentary, respiratory, and muscular systems work together to regulate and maintain the body's core temperature within a narrow range. If the core temperature begins to rise, thermoreceptors located in both the skin and the hypothalamus detect the increase. Acting as both a receptor and an effector, the hypothalamus triggers several responses to cool the body. Sweat glands activate, releasing sweat onto the skin. As the sweat evaporates, it helps to cool the body down. Blood vessels in the skin also dilate (become larger), which allows more blood to flow to the surface of the skin, where it can release heat. These responses work together to reduce the body's temperature back to its set point. The body's observable responses to a drop in temperature are shown in Table 4.2.

Stage	Description	Example
Stimulus	A change in the internal or external environment that triggers a response	A sudden drop in external temperature
Receptor	Specialised cells that detect the change and transmit a signal to the control centre	Thermoreceptors in the skin and brain detect the drop in temperature and send a signal to the control centre.
Control centre	A structure in the brain (hypothalamus) that receives the signal and coordinates the response	The hypothalamus in the brain receives the signal and sends an electrochemical signal to the effector.
Effector	The muscles or organs that carry out the response	Muscles begin to contract and relax rapidly (shivering) to generate heat and increase the body's core temperature.
Response	The body returning to a state of balance so that the receptors are no longer active	The body's temperature returns to within a normal range, and shivering stops. As the body warms up, the thermoreceptors detect the increase in temperature and signal the hypothalamus to reduce the response.

Table 4.2 A summary of the stages of the stimulus–response model when temperature decreases

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

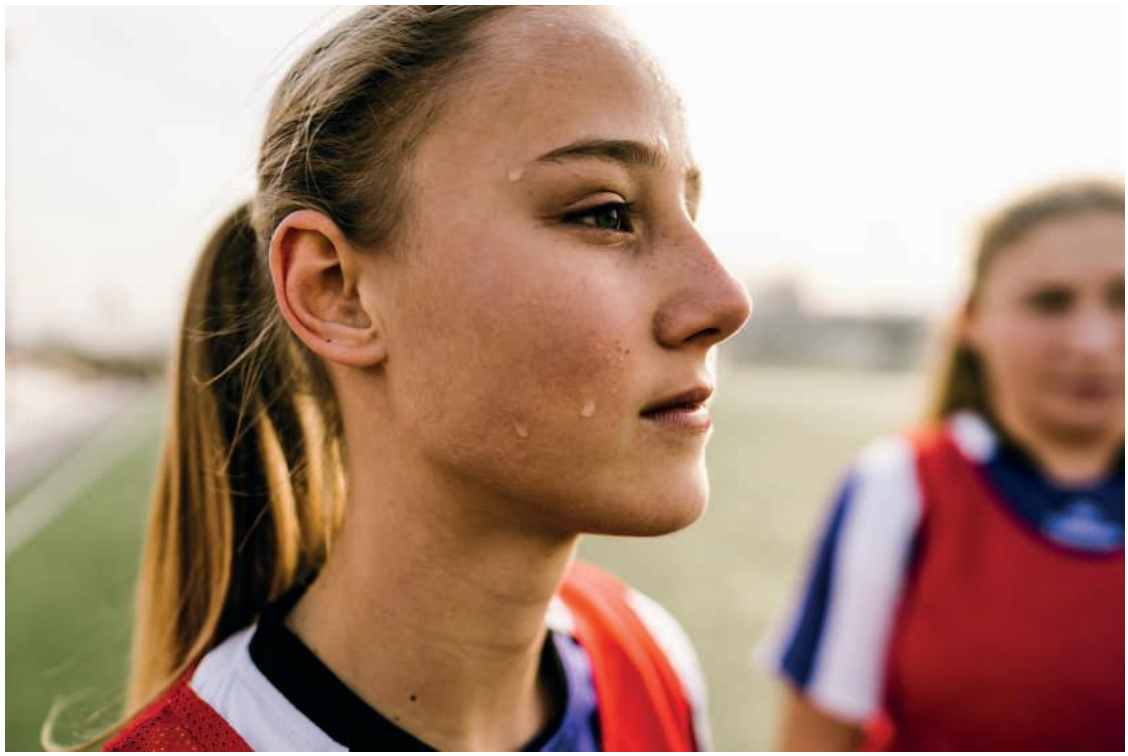


Figure 4.7 When the body's temperature increases, sweat glands are activated.

Responses to changes in extracellular pH

Extracellular pH refers to the pH level in the extracellular fluid (fluid located outside cells in the body). This fluid surrounds the cells and provides them with nutrients and removes waste products. The normal extracellular pH range in humans is between 7.35 and 7.45, which is slightly alkaline. The respiratory and renal systems maintain the pH of the extracellular fluid within this narrow range. Any deviations from this range can lead to various health problems and can even be life-threatening.

Carbon dioxide is transported in the blood in the form of bicarbonate ions and dissolved carbon dioxide. When carbon dioxide combines with water in the blood, it forms carbonic acid, which makes the blood more acidic. To maintain the pH of the blood within the normal range, the respiratory and renal systems work together to eliminate excess carbon dioxide from the body. The respiratory system increases the rate and depth of breathing, which increases the elimination of carbon dioxide through exhalation, therefore reducing the carbonic acid in the blood. The excretory system also plays a role in regulating extracellular pH by being able to excrete excess hydrogen ions or bicarbonate ions in urine.

Responses to changes in light

One of the most well-known responses to a change in light is the constriction or dilation of the pupil in the eye, which helps to control the amount of light that enters the eye. This response is also controlled by negative feedback mechanisms – the constriction or dilation of the pupil is triggered by signals from specialised cells in the retina that detect changes in light intensity and send signals to the brain, which in turn sends signals to the muscles that control the size of the pupil. When exposed to bright light, the pupil constricts to reduce the amount of light that enters the eye, whereas in low light, the pupil dilates to allow more light in (Figure 4.8).

Figure 4.8 A pupil constricts in bright light (left) and dilates in low light (right).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The body's sleep–wake cycle is also closely linked to changes in light. The hypothalamus in the brain contains a specialised group of cells called the suprachiasmatic nucleus, which acts as the body's master clock. The suprachiasmatic nucleus receives information from the eyes about changes in light and uses this information to regulate the release of various hormones such as melatonin that help to control the sleep–wake cycle (Figure 4.9).

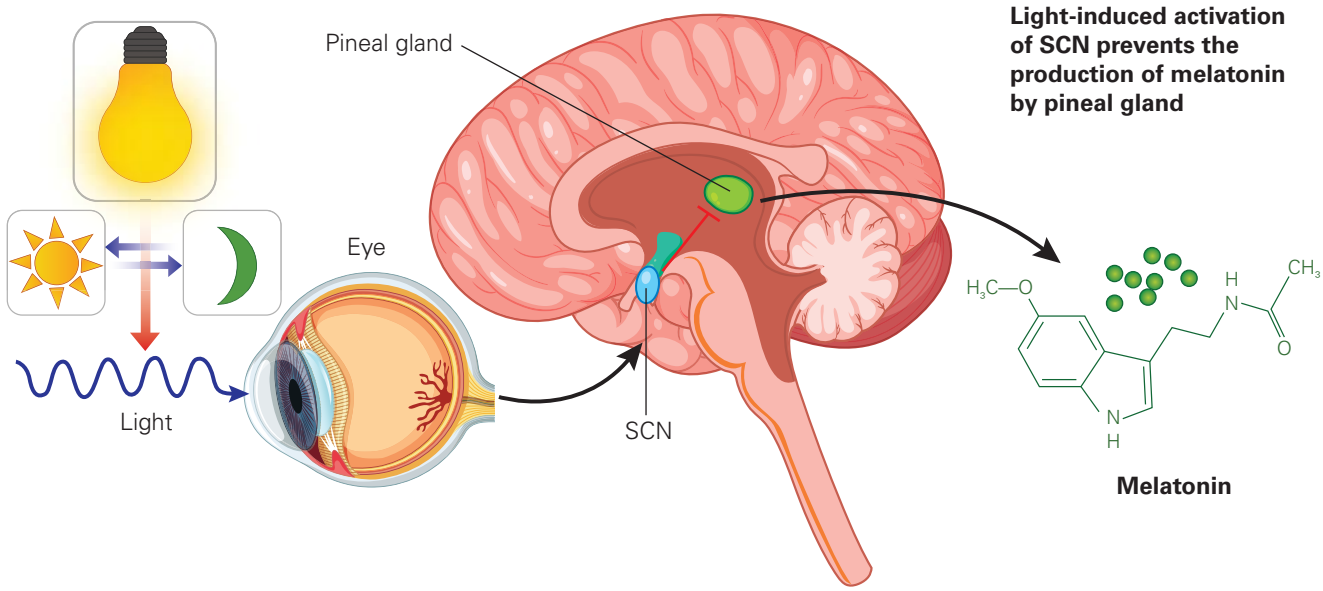


Figure 4.9 The suprachiasmatic nucleus (SCN) triggers the synthesis and release of the hormone melatonin by the pineal gland.

Changes in light can also affect mood and behaviour. Exposure to bright light can help to boost mood and increase energy levels, whereas exposure to low light can have the opposite effect, making people feel tired and lethargic.

Responses to danger

The fight-or-flight response is triggered by the release of stress hormones such as adrenaline and cortisol in response to perceived threats or stressors in the environment. These hormones increase heart rate and blood pressure, delivering more oxygen and nutrients to the body's tissues to prepare it for action. The rate and depth of breathing may also increase to ensure there is enough oxygen in the bloodstream to support the increased activity. This response is regulated by negative feedback mechanisms, as the release of hormones eventually decreases, causing heart rate and blood pressure to return to normal levels.

Figure 4.10 Many organisms have a fight-or-flight response.

Responses to pathogens

The body's observable responses to the presence of **pathogens** such as bacteria, fungi and viruses are evidence of the immune response. These responses can include inflammation, fever, pain, swelling, and changes in behaviour such as fatigue and lethargy. Inflammation is a common response, which occurs when the body sends immune cells and fluid to the site of infection to help fight off the pathogen. Fever is another common response, when the body raises its temperature to create an inhospitable environment for the pathogen. Once the pathogen is eliminated, negative feedback mechanisms cause the body's immune response to decrease, returning it to its baseline state. You will learn more about this in Chapter 5.

pathogen
any agent that can cause disease, such as bacteria, viruses or fungi

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 4.11 Fever is a physiological response to an infection caused by pathogens such as viruses, bacteria and fungi.

Quick check 4.2

1 **State** the part(s) of the body that are involved in maintaining homeostasis.
2 **Create** a stimulus–response model in your notes or on A4 paper and annotate it with information about each of the five parts, similar to Figure 4.3.
3 **Recall** the body systems that maintain the pH of extracellular fluid.
4 **Describe** how the eye responds to decreasing light levels.

Positive feedback

positive feedback a mechanism that maintains the direction of a stimulus and accelerates its effect

Unlike negative feedback, **positive feedback** mechanisms maintain the direction of a stimulus and accelerate its effect. In other words, positive feedback drives the system further from its initial state.

An example of positive feedback in organisms is the blood clotting process. When a blood vessel is damaged, platelets in the bloodstream are activated and begin to clump together at the site of injury (Figure 4.12). The platelets release chemicals that further activate more platelets, leading to the formation of a blood clot that seals the wound. This positive feedback loop ensures that the clotting process (Figure 4.13) is rapid and therefore effective in stopping bleeding.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

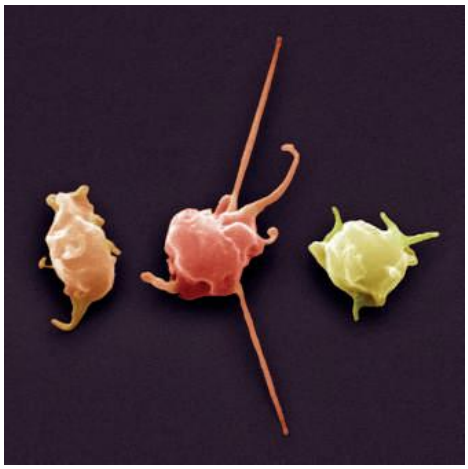


Figure 4.12 Activated platelets

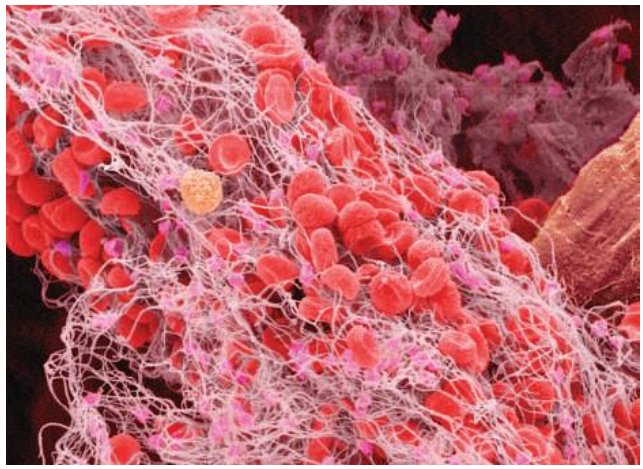


Figure 4.13 A blood clot is the result of a positive feedback mechanism.

Positive feedback is also important in childbirth (Figure 4.14). During childbirth, the hormone oxytocin is released. This stimulates contractions in the uterus, leading to the further release of oxytocin and stronger contractions. This positive feedback loop continues until the baby is born.

Oxytocin is also produced during breastfeeding. When a baby suckles on the breast, it triggers nerve endings in the nipple, which send a signal to the brain to release oxytocin. Oxytocin then stimulates the muscles surrounding the milk ducts in the breast, causing them to contract and push milk towards the nipple. This contraction further stimulates the nerve endings, which sends a signal to the brain to release even more oxytocin. This positive feedback loop ensures that more milk is produced and released in response to the baby's suckling.

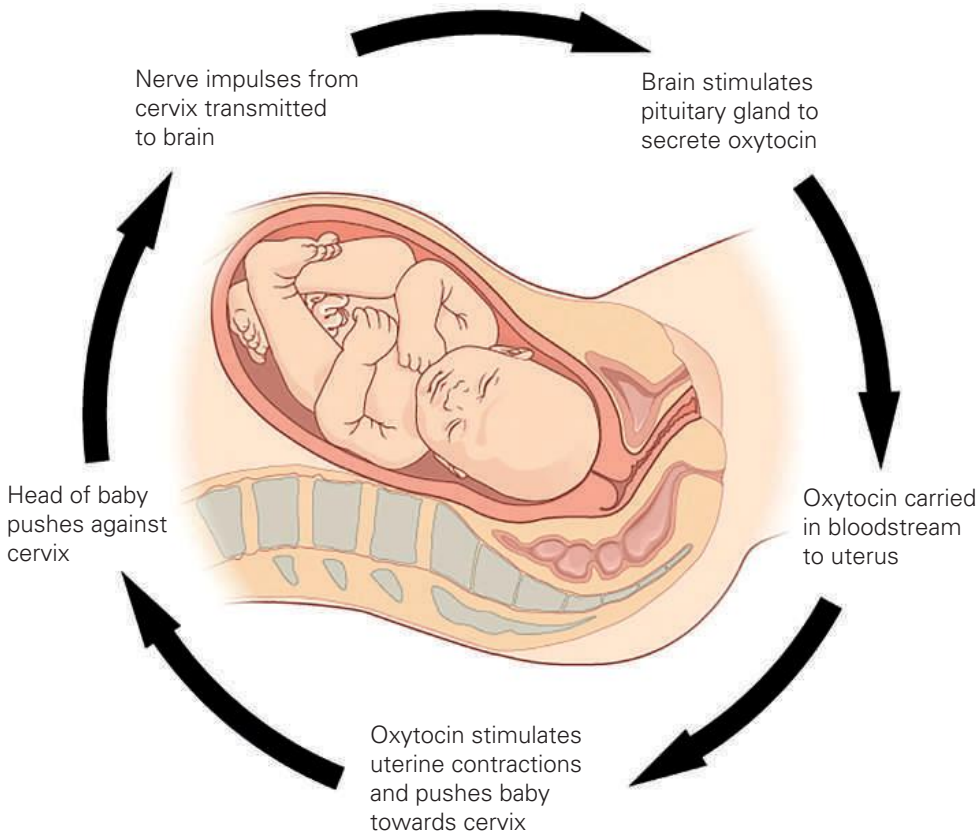


Figure 4.14 Positive feedback in childbirth involves the hormone oxytocin.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive section review and more!

Section 4.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 4.1 questions

Remembering

1 Homeostasis is the maintenance of a relatively stable internal environment. **Name** four things that are tightly regulated within the human body.
2 **Identify** the type of feedback that maintains the direction of a stimulus and accelerates its effect.
3 **State** the normal pH range of extracellular fluid in humans.

Understanding

4 **Describe** the negative feedback mechanisms that occur when the body's temperature increases.
5 **Describe** how the respiratory system can control extracellular pH.

Applying

6 **Construct** a labelled diagram showing the stages of the stimulus–response model.

Analysing

7 **Contrast** positive and negative feedback.
8 **Categorise** the following organs as receptors or effectors:
   a hypothalamus
   b baroreceptors
   c liver
   d kidney tubules
   e pancreas
   f skeletal muscles.

Evaluating

9 **Decide** if the following are examples of positive or negative feedback.
   a During childbirth, the hormone oxytocin stimulates contractions of the uterus. As the contractions intensify, more oxytocin is released, leading to stronger contractions until the baby is born.
   b When body temperature rises, the body begins to sweat, which cools the skin surface. As the skin cools, sweat production decreases until the body temperature returns to normal.
   c During blood clotting, platelets release chemicals that attract more platelets to the site of injury. As the number of platelets increases, the rate of chemical release also increases, leading to more platelets being recruited until the clot is formed.
   d In response to high levels of glucose in the bloodstream, the body produces insulin. Insulin helps cells absorb glucose, which in turn reduces the amount of glucose in the bloodstream.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4.2 The nervous system

Learning outcomes

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

1. describe the role and function of electrical impulses in the nervous system's responses to stimuli.

WORKSHEET
Neurons

The brain controls all bodily functions by communicating with different parts of the body every second of every day. It does this in two ways: by sending electrical signals and neurotransmitters via the nervous system and by communicating using chemical messengers (hormones) via the endocrine system.

The structure of the nervous system

The fundamental units of the nervous system are **neurons** (also spelled 'neurones') (Figure 4.15). A neuron is a single nerve cell responsible for transmitting signals between the brain and body. Networks of neurons enable the communication of signals throughout the body, collectively making up the **nervous system**, which consists of up to one trillion neurons.

The human nervous system is composed of two main parts:

- central nervous system (CNS), which includes the brain and spinal cord
- peripheral nervous system (PNS), which is all the neurons and nerve networks throughout the body that lie outside the CNS.

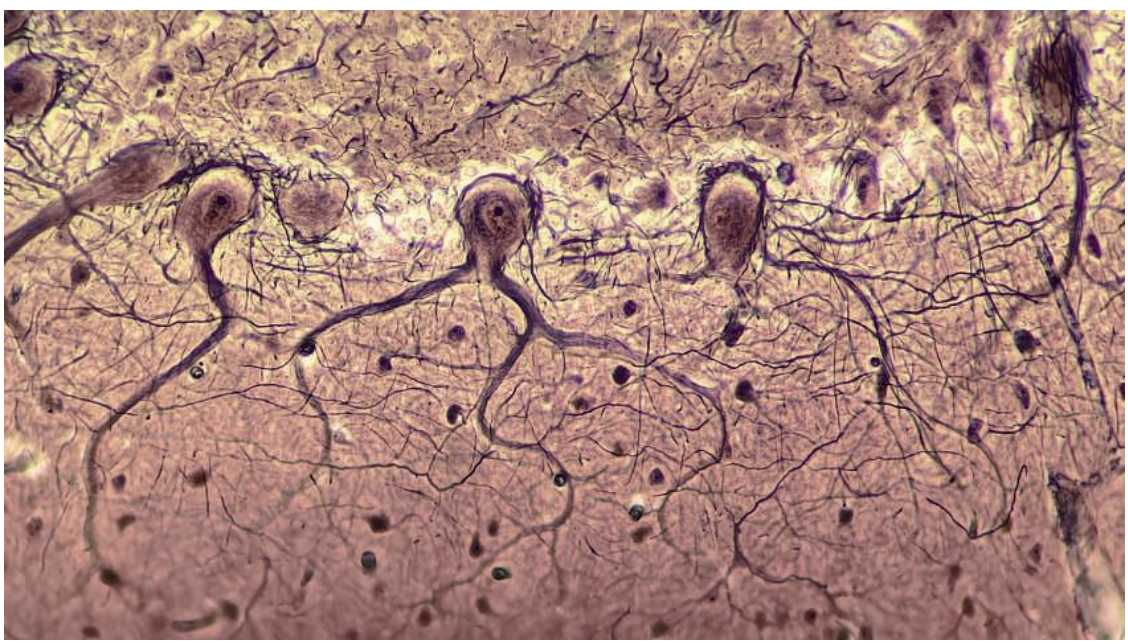
The PNS is further divided into the **somatic nervous system**, which controls the voluntary movement of muscles, and the **autonomic nervous system**, which controls involuntary body functions, such as digestion, lacrimation (making tears) and salivation. Figure 4.16 shows the key components of the human nervous system.

neuron
a nerve cell

nervous system
the body system consisting of the brain, spinal cord and peripheral nerves and receptors that communicate messages quickly within the body

somatic nervous system
the part of the peripheral nervous system involved with the voluntary control of body movements

autonomic nervous system
the part of the peripheral nervous system involved in involuntary physiological processes such as heart rate and digestion



VIDEO
The nervous system

Figure 4.15 The neuron is the basic building block of the human nervous system.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

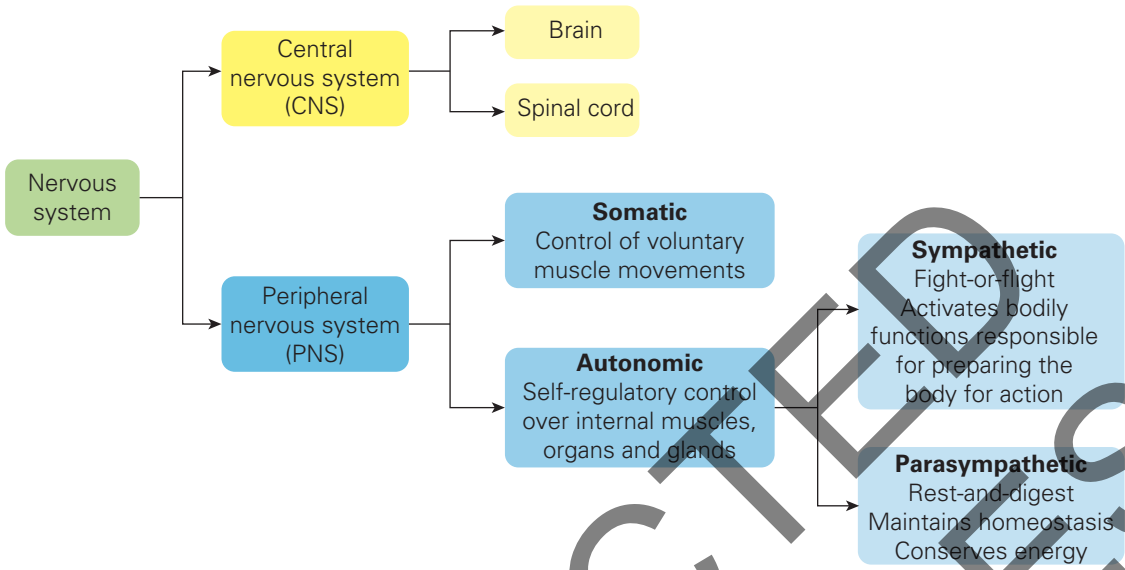


Figure 4.16 The components of the human nervous system

Quick check 4.3

1 **State** another name for an individual nerve cell.
2 **Recall** the components that make up the CNS (central nervous system) and the PNS (peripheral nervous system).
3 **Describe** the role of the somatic nervous system, giving examples that illustrate the somatic nervous system in action.

Types of neurons

Neurons transmit neural information to, from and within the central nervous system. There are three types of neurons (Figure 4.18).

sensory neuron a nerve cell that transmits messages from the sensory receptors to the central nervous system

interneuron a nerve cell that transmits information within the brain and spinal cord (central nervous system)

motor neuron a nerve cell that transmits messages from the central nervous system to effectors

- **Sensory neurons** transmit neural information from sensory receptor sites in the PNS to the CNS. The sensory information being transmitted could be from any of your five senses.
- **Interneurons** (also called relay neurons) transmit neural information within the spinal cord and brain. Interneurons connect the sensory and motor neurons and can only be found in the CNS.
- **Motor neurons** transmit neural information from the CNS to the PNS. The purpose of this information is to initiate a response in an effector, which could be a muscle or gland.

To help remember the three types of neurons, think of a SIM (Sensory, Inter, Motor) card from a mobile phone.

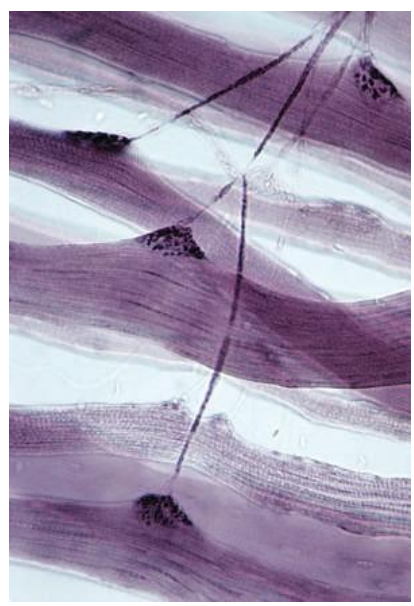


Figure 4.17 100× magnification of motor neurons attached to muscle cells

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

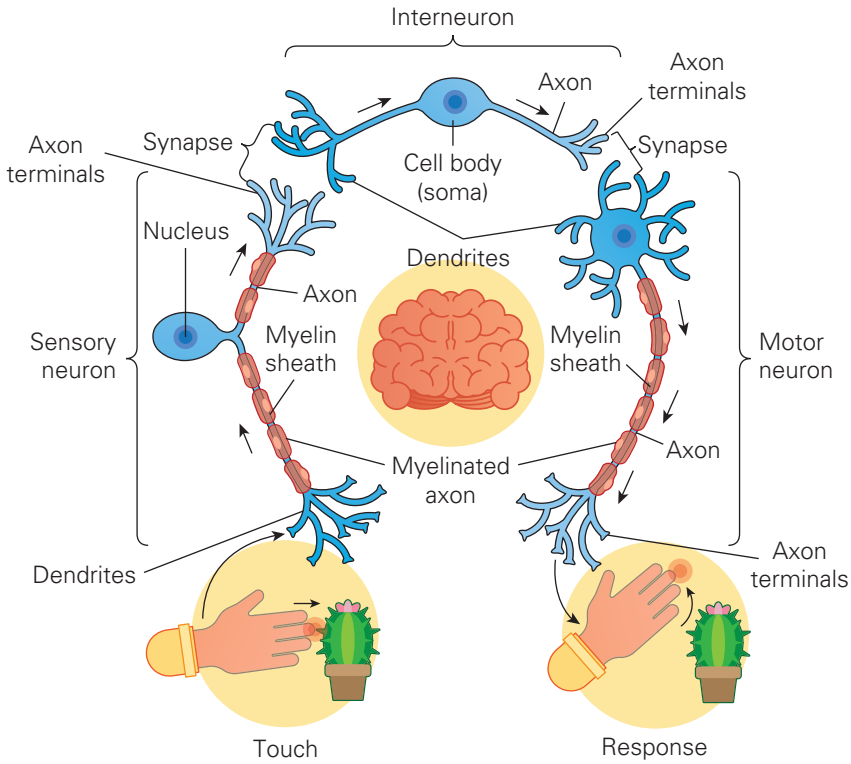


Figure 4.18 The three types of neuron (sensory, inter and motor) form an arc. Note how the sensory neuron has receptors to detect a stimulus, and the motor neuron causes your response.

Structures of a neuron

The key structures of the neuron include the dendrites, cell body (soma), axon, myelin sheath, axon terminals and **synapse**. The synapse is not a true structure – it is the junction between neurons. The synapse includes the axon terminal (of the sending neuron), the gap between the neurons (synaptic cleft) and the dendrite (of the receiving neuron). Chemicals called **neurotransmitters** are released from a neuron on one side of the synapse and travel across to bind to the neuron on the other side. Table 4.3 and Figure 4.19 show the key structures of a neuron.

synapse the junction between two neurons

neurotransmitter the chemical messenger that is released from one neuron and travels across the synapse to bind to the next neuron

Neuron structure	Function
Axon	Transfers electrical impulses from the cell body to the synapse. Axons are called 'nerves' when they are grouped together in a bundle.
Axon terminal	Found at the end of the axon and contains neurotransmitters that are held in vesicles. Neurotransmitters are released once an electrical impulse is received.
Cell body (soma)	Contains most of the cell's organelles, including the nucleus
Dendrite	Contains receptor sites that receive neurotransmitters from neighbouring neurons
Myelin sheath	A fatty, insulating layer made of Schwann cells that covers the axon. It helps keep the electrical signals inside the cell, allowing faster transmission.
Nucleus	Control centre of the cell that contains its genetic material
Schwann cells	Specialised cells that form the myelin sheath

Table 4.3 Neuron structures and their associated function

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Neuron structure	Function
Synapse	Electrical messages are passed along the neuron, but neurons do not touch one another. There is a gap between the neurons called a synapse. When an electrical impulse is received, the signal diffuses (travels) across the synapse in the form of chemical signals called neurotransmitters. The neurotransmitters then bind to the receptors on the dendrites of the neighbouring neurons.

Table 4.3 *(continued)*

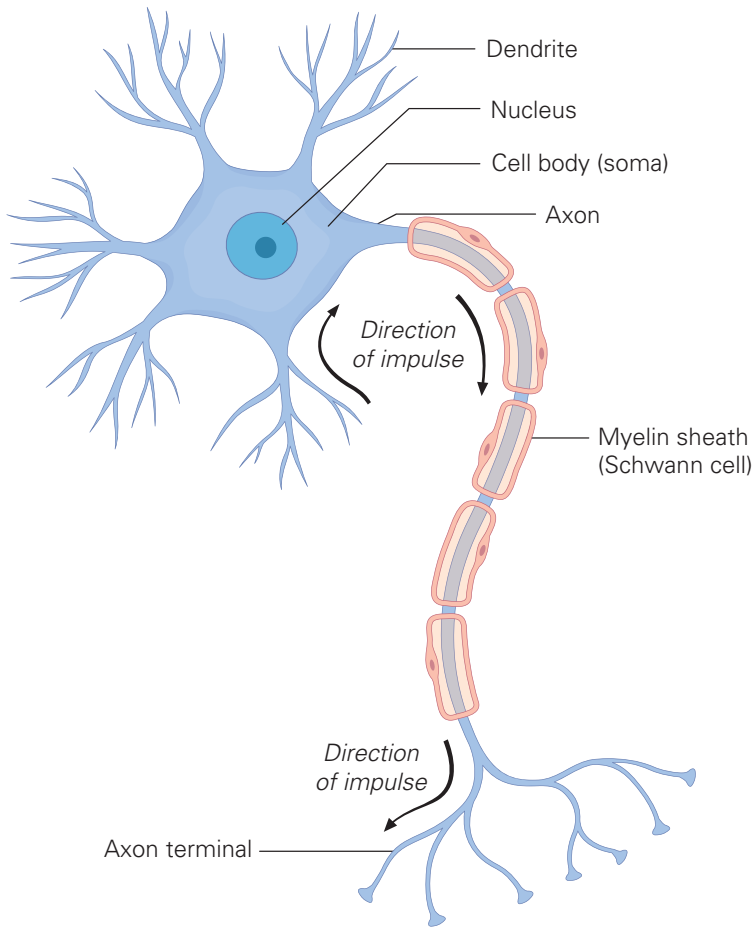


Figure 4.19 The key structures of a motor neuron. The neural impulse travels in one direction only along the neuron, from the dendrites to the axon terminals.

Quick check 4.4

1 **Name** the three different types of neurons.
2 **Recall** where interneurons are found in the body.
3 Interneurons are sometimes called relay neurons. **Explain** why you think that is an appropriate name.
4 **State** the function of the myelin sheath that covers the axon.
5 A fly lands on someone's face and they brush it off. **Name** the three types of neurons involved in the order they would be activated when the stimulus is detected.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 4.1

Making model neurons

Create a poster with models of two neurons, showing their structure and function. Make sure your poster has the following features: a title, a model of two adjacent neurons, labels for every structure on one of the neurons (along with a dot point explaining their function) and a label for the synapse.

You will need a piece of A3 paper, and your teacher will provide you with a selection of materials to make the model neurons. Suggestions include pipe cleaners, aluminium foil, pom-poms, drinking straws, modelling clay/plasticine or similar.

Suggested method

1. Cut a pipe cleaner into three pieces. Wrap the pieces of pipe cleaner around a pom-pom. The pipe cleaner pieces will be the dendrites and the pom-pom will be the soma (the cell body of a neuron).
2. Wrap the end of another pipe cleaner around the soma, so you have a long piece coming down. This represents the axon.
3. Cut pieces of drinking straw about 2.5 centimetres (cm) long and thread them onto the axon. Leave gaps between the lengths of straw. You should have a bit of pipe cleaner left at the end. The straw represents the myelin sheath.
4. Take the end of the pipe cleaner near the bottom of the last myelin sheath, twist it into a loop and cut it so it splits – or add more small pipe cleaner pieces. You are beginning to make the axon terminals.
5. Repeat steps **1–4** for the next neuron.
6. Stick the neurons onto the sheet of paper and label the parts of one neuron with a dot point explaining the function of each structure (including the synapse).
7. Put up your posters in the classroom so that the axon terminals of one person's poster connect to the dendrites on the next poster. You should have a chain of neurons forming a nerve!

Communication along and between neurons

Action potential

An **action potential** is another name for the electrical or neural impulse that moves along a neuron. Once the action potential reaches the axon terminal, neurotransmitters pass the action potential on to the next neuron.

action potential the electrical impulse (message) that is transmitted along a neuron

When a neuron is not sending a neural impulse along its axon, it is 'at rest'. Each neuron requires a minimum level of stimulation – called the neuron's threshold potential – to activate an action potential. When enough neurotransmitters arrive from other neurons, and the threshold is reached, an action potential will begin and move along the axon like a wave. If the threshold is not reached, no action potential can start. This is known as the 'all or none' principle. Once an action potential has been triggered, it is self-sustaining; that is, it will continue to the end of the axon without further stimulation.

The speed of an action potential moving along an axon varies for different neurons. The fastest travel more than 100 metres per second; the slowest travel at about 1 metre per second. The speed depends upon two factors:

- the diameter (width) of the axon – the larger the diameter, the faster the impulse
- whether the axon is insulated with a myelin sheath – an action potential travels faster down an axon with a myelin sheath.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Explore! 4.2

Multiple sclerosis

Multiple sclerosis (MS) is a chronic and often disabling autoimmune disorder that affects the CNS. It is caused by the immune system attacking the protective myelin sheath that covers nerve fibres, leading to inflammation and damage to the CNS. This damage can cause a range of symptoms, including muscle weakness, fatigue, vision problems and difficulties with coordination and balance. MS can affect people of any age, but it is typically diagnosed between the ages of 20 and 40, and it is more common in women than men.

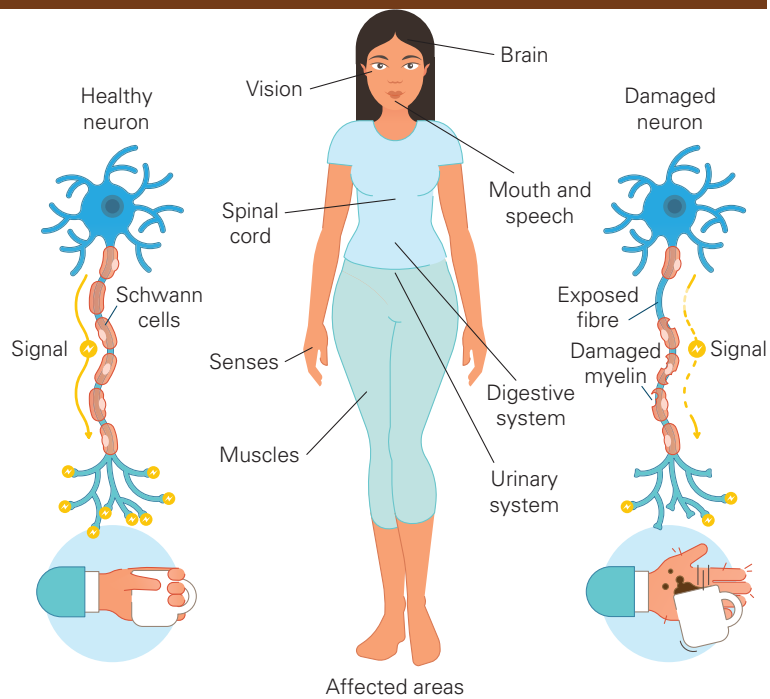


Figure 4.20 Multiple sclerosis affects many areas of the body.

Conduct some research to answer the following questions.

1 Recent research has suggested a link between glandular fever (caused by the Epstein-Barr virus) and MS. What evidence has been found to suggest this link?
2 Why is FIND-seq useful in the treatment and monitoring of MS?
3 Why is the drug cladribine effective in MS treatment?

Communication between neurons: the synapse

When neurons communicate with each other, the action potential travelling down the axon causes neurotransmitters to be released from synaptic vesicles within the axon terminal. This part of the synapse is known as the presynaptic neuron. These specialised chemical messengers then move across the gap between neurons (the synaptic cleft). Scientists have managed to identify more than 100 different neurotransmitters in the human brain alone, but evidence suggests there are significantly more than this number. Some of the more common neurotransmitters are described in Table 4.4.

Once the neurotransmitters cross the synaptic cleft, they bind to special receptor sites on the dendrite of the next neuron – called the postsynaptic neuron. The receptor sites convert the information back into electrical signals, which are then transmitted to the cell body of the postsynaptic neuron and along the axon. This process continues until the last neuron in the pathway connects to a muscle or gland, causing a response. This process is shown in Figures 4.21 and 4.22.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Neurotransmitter	Role	What can go wrong?
Dopamine	Acts within the brain on pathways associated with motor functions (movement) and emotional arousal and motivation	A lack of dopamine-producing cells in the brain can cause Parkinson's disease, a neurological condition characterised by tremors, stiffness and uncoordinated movements.
Acetylcholine	Transmits the message from the axon terminals of a motor neuron to a skeletal muscle	Curare is a plant-based toxin that was used by South American Indigenous peoples to paint the arrows of blow-darts. When shot at a victim, this toxin prevented acetylcholine from binding to the postsynaptic neuron, causing paralysis.
Serotonin	Produced in the intestine and central nervous system; regulates appetite, mood, memory and behaviour	Some scientists theorise that low levels of serotonin are linked to depression.
Glutamate	A neurotransmitter in the CNS, involved with memory and learning	High glutamate levels are involved with depression, anxiety and symptoms typical of attention deficit hyperactivity disorder (ADHD), such as the inability to concentrate. Low levels of glutamate are linked to insomnia, lack of concentration and low energy levels.

Table 4.4 Some common neurotransmitters and their roles

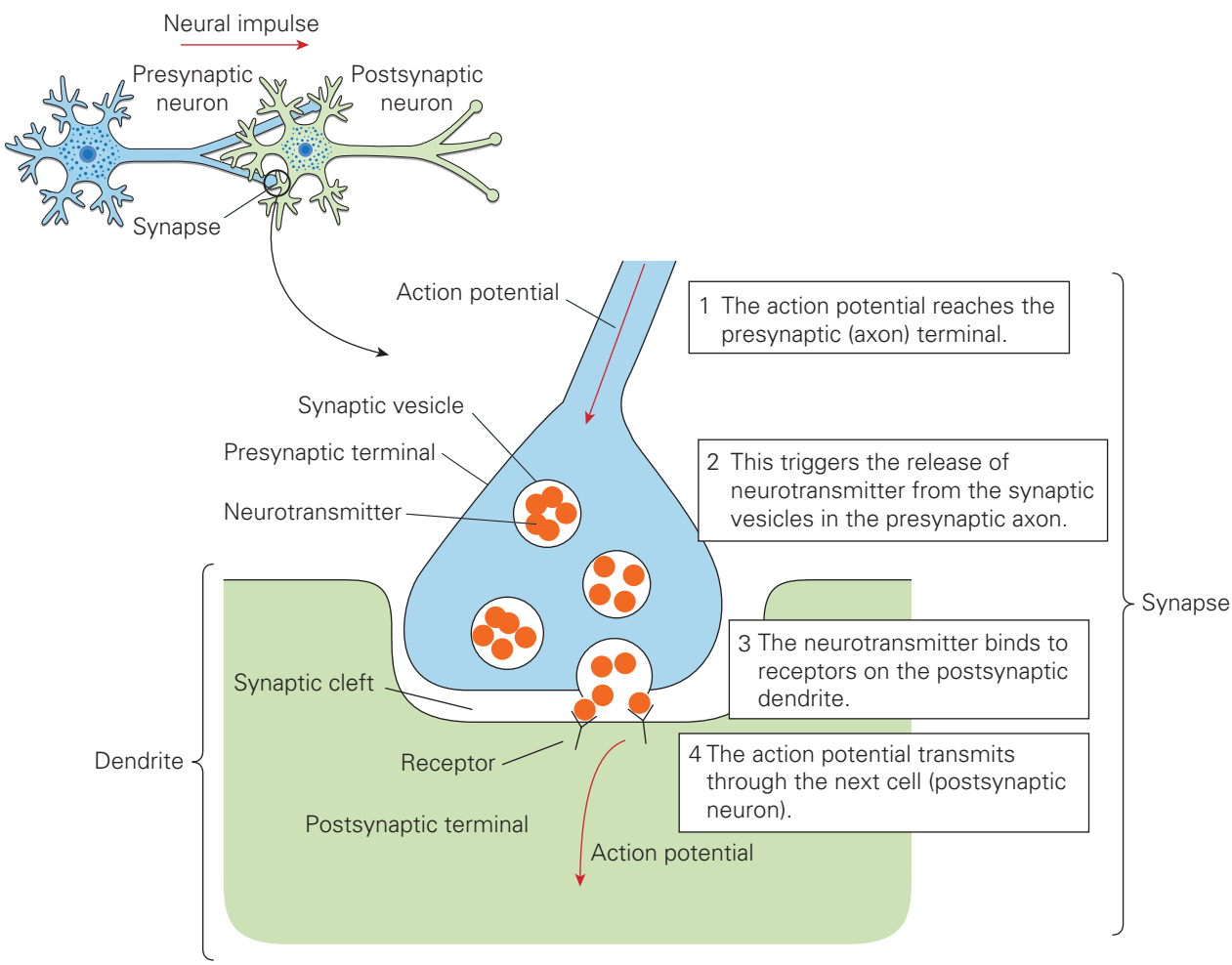


Figure 4.21 Communication between neurons. An action potential triggers the release of neurotransmitters from their synaptic vesicles in the presynaptic neuron. The neurotransmitters move across the gap and bind to receptors on the postsynaptic neuron.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

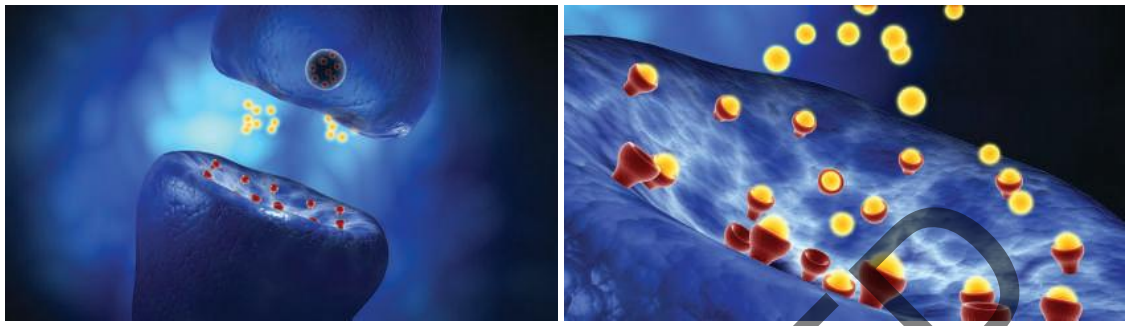


Figure 4.22 An illustration of a synapse. **(a)** A synaptic vesicle in the axon terminal storing neurotransmitters, and the neurotransmitters (yellow) crossing the synapse to be received by the receptor sites (red) on the neighbouring neuron's dendrite. **(b)** Neurotransmitters (yellow) being released across the synaptic cleft and being received by the receptor sites (red) of the dendrite if they share the same distinct size and shape.

Did you know? 4.1

The longest neuron

The sciatic nerve contains the longest neuron in the human body. It extends from the spine to the tip of the toe and can be up to 1 metre in length. It is formed by the combination of five sets of paired nerve roots in a section of the spine and has a diameter of about 2 cm, which is about as thick as your thumb!

Figure 4.23 The sciatic nerve is the longest nerve in the human body.

Quick check 4.5

1 **State** if an action potential is a signal between two neurons, along a neuron or along an axon.
2 **Recall** what the 'all or none' principle means.
3 **Define** 'neurotransmitter'.
4 **Describe** the role of the postsynaptic neuron.
5 **Recall** three common neurotransmitters, including their function.
6 **Organise** these stages of the flow chart in the correct order, showing how an action potential passes from one neuron to another.

Action potential stimulates synaptic vesicles to release neurotransmitters	Action potential initiated once threshold is reached	Neurotransmitters released into synaptic cleft	Action potential travels along the presynaptic neuron's axon	Neurotransmitters bind to receptor sites on post-synaptic neuron's dendrites

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Neurotransmitters

Recall that the human body produces many different types of neurotransmitters, and each neurotransmitter has a specific role in the functioning of the brain. Neurotransmitters do this by only binding to specific receptor sites. A neurotransmitter binds to a receptor in much the same way that a key fits into a lock, as Figure 4.24 shows.

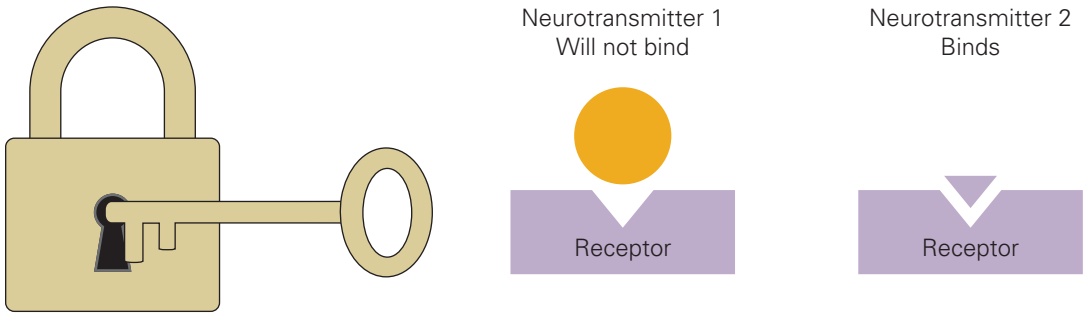


Figure 4.24 Similar to a key fitting into a lock, a specific neurotransmitter will bind only to its corresponding receptor, which ensures that it only causes the intended response.

Neurotransmitter messages can be categorised as either excitatory or inhibitory. An excitatory neurotransmitter increases the likelihood of the action potential being sent along the next neuron, whereas an inhibitory neurotransmitter decreases the likelihood of the action potential being sent along the next neuron. They are both considered important because they can initiate a response or stop something from happening at the effector site.

For example, excitatory neurotransmitters like glutamate help trigger muscle contractions when you pull your hand away from a hot surface. On the other hand, inhibitory neurotransmitters like GABA play a crucial role in calming down brain activity, such as when you're trying to relax or fall asleep.

Try this 4.2

Neurotransmission at the synapse

Use a stop motion app to create a short animation that clearly represents how neurotransmission occurs between neurons. Alternatively, you could construct a comic-book-style outline or a poster.

Label the following components.

- Presynaptic neuron (axon terminal)
- Synaptic vesicles
- Neurotransmitters
- Postsynaptic neuron (dendrites)
- Receptor sites
- Synapse
- Action potential
- Synaptic cleft

Your animation should show the movement of vesicles binding with the cell membrane and releasing neurotransmitters to the next neuron.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 4.2

Drugs

Drugs are substances that affect the brain by altering the way neurons send, receive and process information. Certain drugs, such as marijuana and heroin, imitate naturally occurring neurotransmitters to activate neurons. Alternatively, drugs such as cocaine and amphetamines stimulate neurons to produce more of the natural neurotransmitters, amplifying signals, blocking recycling of the chemicals, and disrupting communication channels.

INVESTIGATION

Explore! 4.3

Parkinson's disease

Neurodegenerative diseases refer to a variety of conditions that primarily affect neurons in the human brain. They include Parkinson's disease, Alzheimer's disease and multiple sclerosis. Parkinson's disease is a progressive and degenerative neurological condition that impairs a person's ability to control their body movements, resulting in both motor and non-motor symptoms. This is caused by the loss of cells in various areas of the brain, including the substantia nigra, where dopamine production occurs. As dopamine production decreases, the nervous system's motor functions become impaired, leading to symptoms such as tremors and rigidity.

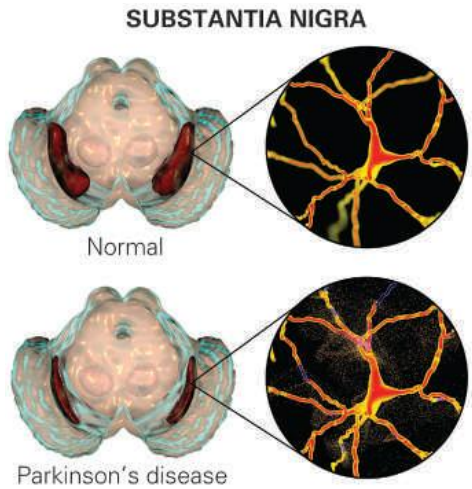


Figure 4.25 A computer-generated illustration of the human brain showing a healthy substantia nigra (top) and a degenerated substantia nigra (bottom)

Although there is currently no cure for Parkinson's disease, medication can help manage its motor symptoms by increasing dopamine levels or mimicking the neurotransmitter's effects. The development of diagnostic and treatment technologies for neurodegenerative diseases relies on advances in brain imaging and diagnostic tools. For example, a NeuroMotor Pen developed by a British company can diagnose nerve disorders such as Parkinson's disease by assessing a patient's handwriting and drawing tasks. Abnormalities are identified and used as 'digital biomarkers' to monitor patient progress. Additionally, low-cost wearable sensors and mobile phone applications can continuously detect and quantify a patient's symptoms, generating daily reports that alert doctors of any unusual data.

Conduct some research on one of the following topics.

- An imaging technique that allows us to identify and learn about Parkinson's disease (e.g. PET scans or DaT/SPECT imaging)
- A technology developed to aid people with Parkinson's disease (e.g. wearable sensor networks; MagnaReady's line of men's and women's shirts with magnetic buttons; SteadyMouse; the NexStride mobility aid; GlideTrak)

Summarise your findings by explaining how technologies have improved knowledge and understanding of Parkinson's disease or have helped people with Parkinson's live better lives.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Reflex actions

A **reflex action** is a fast, automatic response that protects the body from harm. At times, the body must react quickly without waiting for instructions from the brain. During such instances, the spinal cord is mainly responsible for detecting the stimulus and initiating a response. While a message is passed to the brain, it is done so only after a brief delay, and the brain registers both the stimulus and the response after the reflex action has already taken place.

reflex action
a fast, involuntary motor action that protects the body from harm

A reflex action, also known as a reflex arc, involves a maximum of three neurons. The signal travels to the spinal cord and then returns to the muscle, prompting a rapid contraction that does not involve the brain. Figure 4.26 shows an example of a reflex arc. When the brain is responsible for detecting and responding to a stimulus, the process is referred to as the stimulus–response model.

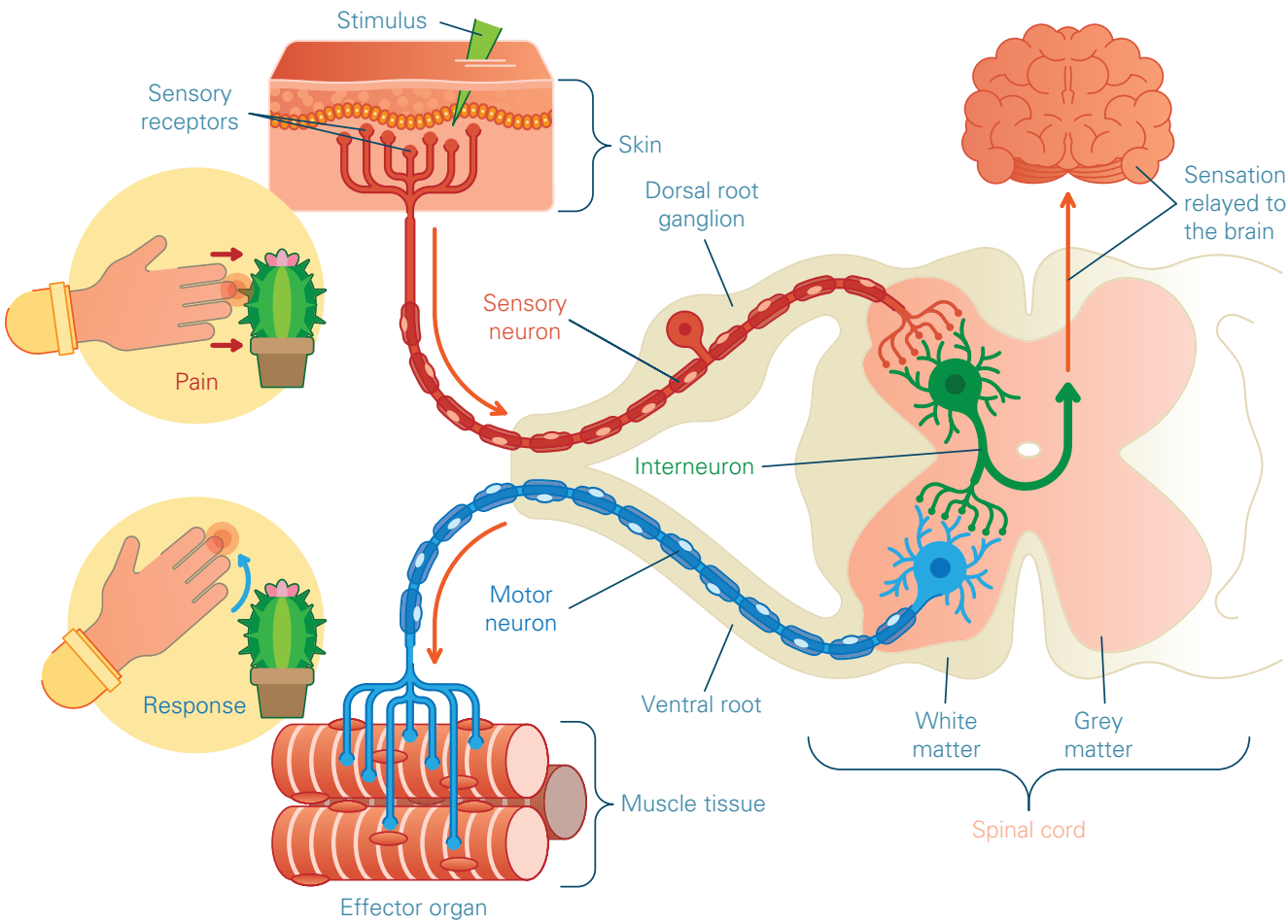


Figure 4.26 An example of a reflex arc. When you touch a prickly cactus with your finger, a receptor in a sensory neuron detects the pain and initiates an action potential. The impulse is carried to the spinal cord where the sensory neuron connects to an interneuron. The interneuron then connects to a motor neuron that sends an action potential through to the muscle tissue. Your muscles contract and you move your hand away from the sharp cactus.

WORKSHEET
Response time data analysis

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 4.3

How the nervous system drives response

A person sees a can of soft drink sitting on the bench. They feel quite thirsty, so they reach out and pick up the can to have a drink.

Referring to the components defined in the table below, describe how the person's actions fit the stimulus–response model.

Part of the stimulus–response model	Definition of this part
Stimulus	Change in the environment
Receptors	Detect the stimulus and stimulate the sensory neuron
Sensory neurons	Transmit an action potential (nerve impulse) to the integration area (the CNS)
CNS	Brain coordinates an appropriate response by sending nerve impulse along interneurons which connect to motor neurons
Motor neurons	Transmits an action potential (nerve impulse) to the effector organ (muscle or gland)
Effectors	Act to cause the response
Response	Body's reaction to the stimulus

The knee-jerk reflex

The 'knee-jerk' reflex is a common type of reflex action. During a knee-jerk reflex test, a healthcare professional taps the quadriceps tendon beneath the kneecap with a reflex hammer (Figure 4.27). The quadriceps tendon is connected to the quadriceps muscle located on top of the thigh. The tap of the hammer induces a slight stretch within the quadriceps muscle. Receptors in the muscle detect this stretch and send a message to the muscle. The knee-jerk reflex is unique because it is monosynaptic, meaning that no interneurons are involved. Instead, the sensory neuron transmits the message directly across a synapse to a motor neuron in the spinal cord. The motor neurons then conduct the impulse back to the quadriceps, causing a muscle contraction that triggers a kick. This kick confirms to the healthcare professional that a specific section of the spinal cord and the associated nerves are functioning correctly. Various reflex tests are required to obtain a more precise health assessment of the entire nervous system.

The knee-jerk reflex is in use whenever a person stands up. When standing upright, the muscles are continuously contracting and stretching to maintain balance. If a person leans back while standing, their quadriceps are stretched, and the reflex is activated. Since the person is standing, the muscle contraction that would usually cause a kick upwards instead brings them back to a stable central position. This reflex, in combination with the Achilles reflex, helps people maintain balance while walking.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

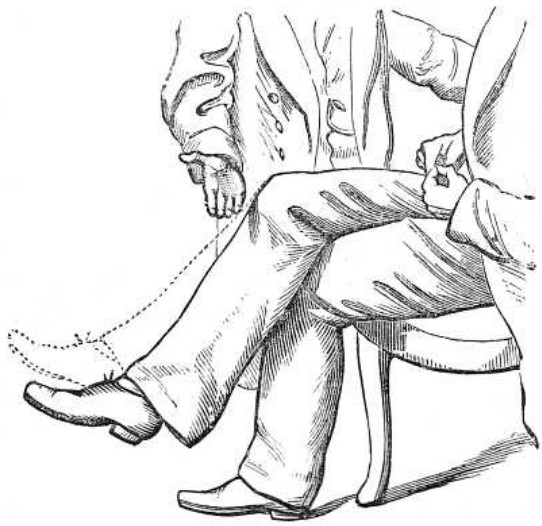


FIG. 1.—THE KNEE-JERK.
The dotted line indicates the movement which follows the blow on the patellar tendon.

FIG. 2.—THE KNEE-JERK.
Method of obtaining it when it is not readily produced in the ordinary way.

Figure 4.27 This illustration of the 'The Knee-Jerk' was drawn by William Richard Gowers, a pre-eminent clinical neurologist, for his *Manual of Diseases of the Nervous System* published in 1886.

INVESTIGATION

Investigation 4.1

Testing your reflexes and response times

Background information

Reaction time is a measure of how quickly a person responds to a stimulus. Many factors can affect reaction time, including age, gender, practice, blood sugar, alcohol, caffeine and general fitness. You will design your own investigation to explore the effect of practice time on reaction time.

Aim

To plan and investigate the effect of practice time on automatic reflexes and response times

Planning

1 Write a rationale on reaction times and the factors that affect this.
2 Create a relevant and specific research question for this investigation.
3 Write a risk assessment for this investigation.

Materials

- stopwatch
- ruler
- well-lit room

Procedure

Do not practise the experiment before starting to collect the results. You should start measuring immediately to ensure that you can determine the effect of practice time.

1 Have your partner lean their forearm on a bench with their weakest hand extending over the edge. If they are left-handed, they should use their right hand and vice versa. Ask them to make a pincer grip with their thumb and index finger with a gap of 2 cm between them.
2 Dangle the ruler above their hand so that the end marked 0 cm is hanging between their thumb and index finger.
3 Instruct them to catch the ruler with their thumb and index finger when they notice you have released it.
4 Release the ruler without warning.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

5 Take note of the measurement on the ruler where they have caught it. This is the number of centimetres that the ruler fell before the person responded. Use the conversion table (Table 4.5) to determine the reaction time.
6 Each person should complete the drop test 15 times. Record the ruler reading and reaction time for each test.

Results

1 Create a results table for this experiment.
2 Draw a graph of drop test number against reaction time.

Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)
1	0.05	21	0.21	41	0.29	61	0.35	81	0.41
2	0.06	22	0.22	42	0.29	62	0.36	82	0.41
3	0.08	23	0.22	43	0.30	63	0.36	83	0.41
4	0.09	24	0.22	44	0.30	64	0.36	84	0.41
5	0.10	25	0.23	45	0.30	65	0.36	85	0.42
6	0.11	26	0.23	46	0.31	66	0.37	86	0.42
7	0.12	27	0.23	47	0.31	67	0.37	87	0.42
8	0.13	28	0.24	48	0.31	68	0.37	88	0.42
9	0.14	29	0.24	49	0.32	69	0.38	89	0.43
10	0.14	30	0.25	50	0.32	70	0.38	90	0.43
11	0.15	31	0.25	51	0.32	71	0.38	91	0.43
12	0.16	32	0.26	52	0.33	72	0.38	92	0.43
13	0.16	33	0.26	53	0.33	73	0.39	93	0.44
14	0.17	34	0.26	54	0.33	74	0.39	94	0.44
15	0.18	35	0.27	55	0.34	75	0.39	95	0.44
16	0.18	36	0.27	56	0.34	76	0.39	96	0.44
17	0.19	37	0.28	57	0.34	77	0.40	97	0.45
18	0.19	38	0.28	58	0.34	78	0.40	98	0.45
19	0.20	39	0.28	59	0.35	79	0.40	99	0.45
20	0.21	40	0.29	60	0.35	80	0.40	100	0.45

Table 4.5 Conversion table for reaction times

Discussion

1 Identify any patterns, trends or relationships in your results.
2 The ruler drop experiment is not really testing a reflex. Draw a stimulus–response flow chart, highlighting the part that proves this is not a simple reflex. Explain why this is the case.
3 Compare your results with those of other people in your class. Do students who play particular sports or musical instruments have faster reaction times?

Evaluation

Limitations

1 Identify any potential sources of error in this experiment.

Improvements

2 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 experiment regarding practice time and reaction time. Justify your answer with data.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 4.3

Conscious and unconscious responses

A reflex action is an unconscious process because the brain is not initially involved in activating a response. This is different from a conscious process where the brain is involved in activating a response. The differences are shown in the following table.

Conscious response to stimuli	Unconscious response to stimuli
Reaction involves the brain and a level of awareness	Reaction does not involve a level of awareness by the brain
Attention must be paid to stimulus	Attention does not have to be paid to stimulus
Voluntary or intentional reaction	Involuntary or unintentional
Goal is often directed or purposeful	Reflexive or automatic, increasing chances of survival
Can be a more complex response	Most are simple responses
Tend to vary	Tend to occur in the same way each time
Can be learned	Do not require learning
Can be controlled	May not be controllable

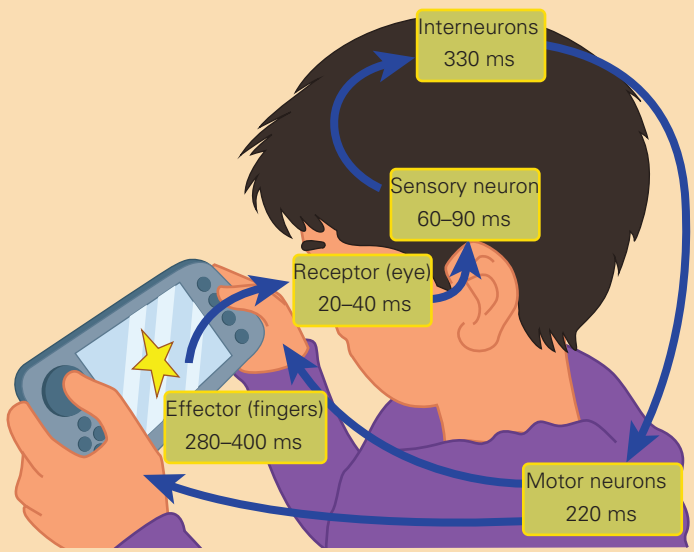


Figure 4.28 A child playing a game is an example of a conscious response. The approximate time in milliseconds (ms) is shown at each step of the process, from stimulus (light from the screen) to response (moving fingers to press buttons).

Quick check 4.6

1 'The brain is not immediately involved in a reflex arc'. **Propose** whether this statement is true or false.
2 **Illustrate** a reflex arc for a person touching a flame.
3 **Compare** the reflex arc and stimulus–response models of the nervous system.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive section review and more!

Section 4.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

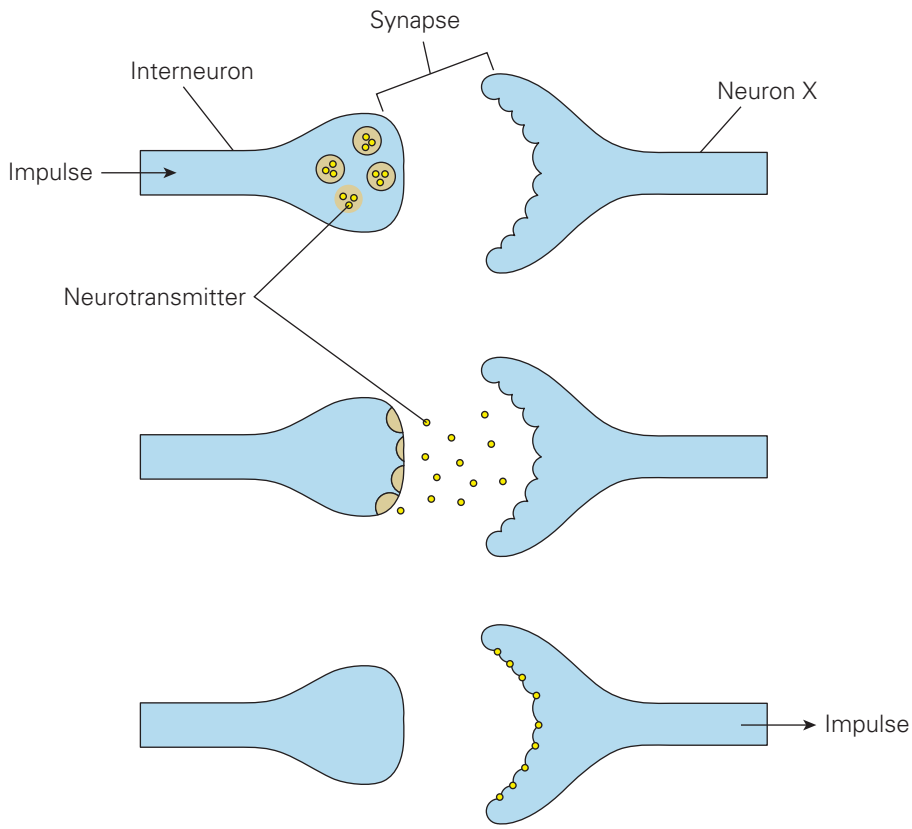
Section 4.2 questions

Remembering

1 **Name** the three different types of neurons found within the human nervous system.
2 **Define** what is meant by reflex action. Include its role in defending the body against damage.
3 **State** an example of a reflex action.
4 **State** the function of dendrites.

Understanding

5 A person picks up a very hot cup of coffee and immediately drops it, breaking the mug. **Illustrate** a flow chart, beginning at stimulus and ending in response, and highlight the section of the flow chart that demonstrates whether this is a reflex, or a response coordinated by the brain.
6 **Illustrate** a motor neuron, labelling all the key structures.
7 **Describe** how an action potential is triggered and transmitted from one neuron to the next.
8 **Describe** the synapse.
9 **Explain** how neurotransmitters cross the synapse.
10 If a drug blocks the receptor sites, **explain** the effect it could have on neurotransmission across the synapse.
11 The figure below shows how an impulse moving along an interneuron causes an impulse to be sent along another type of neuron, neuron X.



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

a **Identify** the name given to neuron X.
b **Describe** how information passes from the interneuron to neuron X. Use the diagram to help you.

Applying

12 Using the stimulus–response model, **construct** a flow chart showing the steps involved in the following scenario:
A person is standing in a crowd and hears someone call their name. They turn their head to see who called them.
Be sure to include these terms on your flow chart: stimulus, motor neuron, muscle, interneuron, sensory neuron, receptor.

Analysing

13 **Distinguish** between the stimulus and the response in the knee-jerk reflex.
14 **Contrast** conscious and unconscious responses.
15 **Contrast** the function of the motor neuron with the sensory neuron.

Evaluating

16 You sneak up behind someone and make a sudden loud noise. They respond by blinking, twitching, moving their head suddenly, screaming or throwing their hands up. Using your knowledge of reflexes, **discuss** whether their response is voluntary, and give some reasons why this reflex might be a helpful mechanism to have.
17 Caffeine is known to increase alertness levels. You usually feel tired when the neurotransmitter adenosine is released. **Discuss** how caffeine may affect adenosine receptors.
18 Dopamine is a neurotransmitter that is involved in making us feel good. Caffeine works by slowing down the rate of dopamine leaving the brain to your body, while at the same time not affecting the rate at which it is released into your brain. This leads to an increased level of dopamine in the brain for a short time. **Deduce** how this might affect your feelings and behaviour.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4.3 The endocrine system

WORKSHEET
Body communication systems

VIDEO
Parts of the endocrine system

endocrine system
the system of glands that controls hormones in the body

hormone
a chemical messenger that is secreted by endocrine glands and circulated in the bloodstream to act on a target cell

Learning outcomes

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

1. describe the role and function of hormones in the endocrine system's responses to stimuli.
2. describe how the nervous and endocrine systems work together to coordinate responses.
3. compare the nervous and endocrine systems' responses.

The nervous system does not work in isolation, it works with the body's sense organs and the **endocrine system**. The endocrine system includes glands throughout the body that secrete hormones that regulate a variety of bodily processes, such as metabolism, digestion, blood pressure and growth. Although the endocrine system is not directly linked to the nervous system, the two interact in many ways. Some of the most important endocrine glands are in the brain. These include the pineal gland, the hypothalamus and the pituitary gland.

At the base of the forebrain is a tiny collection of neurons known as the hypothalamus (Figure 4.29).

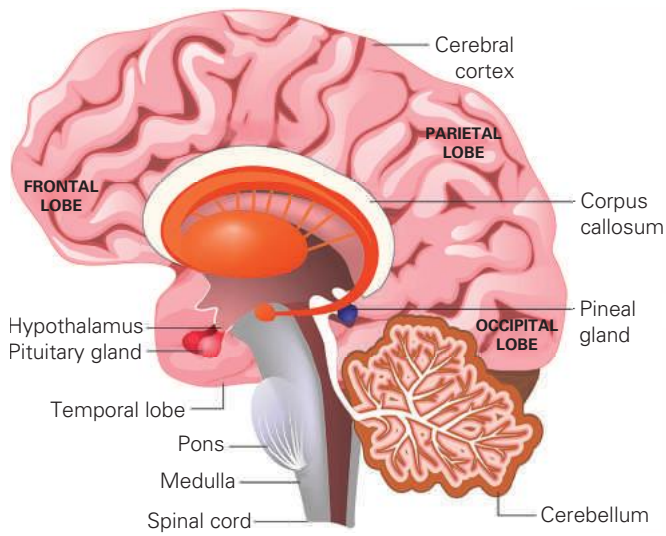


Figure 4.29 A cross-sectional view of the brain showing the location of the pineal gland, pituitary gland and the hypothalamus

The hypothalamus links the nervous and endocrine systems. It is responsible for regulating several behaviours, such as sleep, hunger, thirst, sexual behaviour, and emotional and stress responses. The hypothalamus also controls the pituitary gland and the release of several different **hormones**.

Other important glands in the body are the thyroid, thymus and adrenal glands, and the pancreas, ovaries and testes (Figure 4.30). These glands are involved in regulating metabolism, fight-or-flight responses and reproductive processes.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

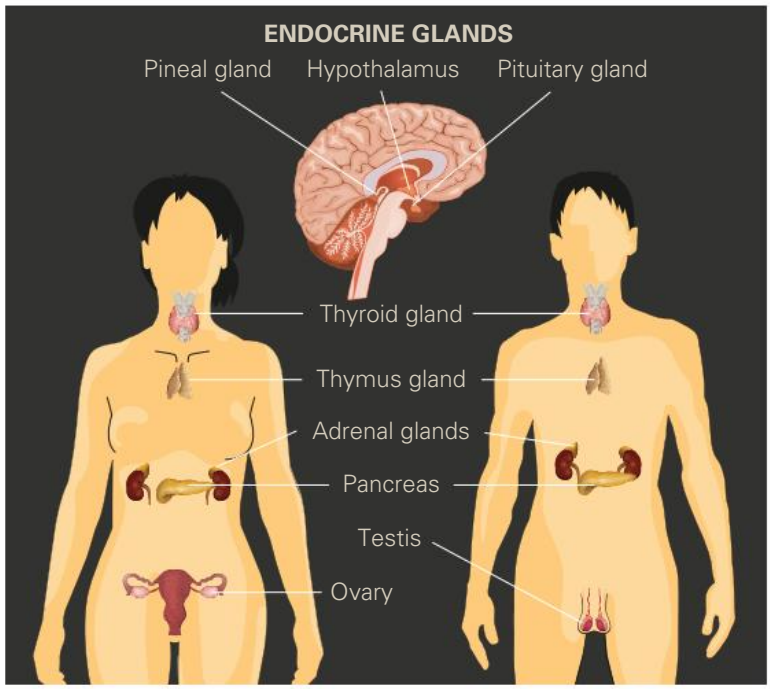


Figure 4.30 Endocrine glands in the female (left) and male (right) body

VIDEO
Hormones

target cell
a cell affected by a specific hormone

Hormones

Hormones are chemical messengers sent by the endocrine system to communicate with other parts of the body. They are made by endocrine glands, which secrete the hormones directly into the circulatory or lymphatic systems. The blood or lymph carries the hormones around the body, so hormones are transported to, and have an effect in, a different part of the body from where they are made. The cells they affect are called **target cells**. Organisms are coordinated by many hormones, and small amounts of these chemicals can have major effects. Table 4.6 shows where some hormones are produced and what effect they have on the human body.

Hormone	Endocrine gland where produced	Action of hormone
Insulin	Pancreas	Reduces blood glucose levels by increasing glucose uptake by cells and promoting the conversion of excess glucose to glycogen in liver and muscle cells.
Glucagon	Pancreas	Increases blood glucose levels by stimulating the conversion of stored glycogen into glucose and releasing it into the bloodstream.
Adrenaline	Adrenal gland	Secreted during times of fear, stress or excitement, it increases heart rate, constricts blood vessels near the skin, dilates blood vessels to some muscles, raises blood pressure, and elevates blood sugar, preparing the body for physical action during the fight-or-flight response.
Erythropoietin	Kidneys	Promotes the production of red blood cells by the bone marrow.
Growth hormone (GH), antidiuretic hormone (ADH) and others	Pituitary gland	GH promotes cell division, growth and repair in the body; ADH regulates the levels of water in the blood.
Melatonin	Pineal gland	Regulates sleep patterns by inducing sleep. It is released in darkness and ceases to be produced in light.
Testosterone	Testes	Promotes bone growth, muscle development, facial hair growth, and deepening of the voice in males during puberty.

Table 4.6 Endocrine glands and their hormones and actions

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Hormone	Endocrine gland where produced	Action of hormone
Oestrogen	Ovaries	Promotes breast and hair development and changes the shape of the hip bones in females during puberty.
Various thyroid hormones, including thyroxine	Thyroid	Controls the body's rate of energy production and metabolism and regulates the body's sensitivity to other hormones.
Parathyroid hormone	Parathyroid gland	Controls the amount of calcium in the blood and bones.
Thymosin	Thymus	Stimulates the development of T cells, which are important in maintaining a healthy immune system.

Table 4.6 *(continued)*

Endocrine-disrupting chemicals in plastics

What might be causing the increasing rates of cancer and metabolic conditions such as diabetes? What is the potential explanation for declining fertility rates? One hypothesis is that exposure to endocrine-disrupting chemicals is affecting our bodily functions. Although the scientific research supporting this hypothesis is mostly based on studies conducted on rats and mice, some researchers believe that it is applicable to humans as well. These chemicals are present in many household products including plastics. As a result, understanding safe levels of exposure is a topic of ongoing research.

1 Where might you find endocrine-disrupting chemicals in your house?
2 What everyday products might you find that contain BPA (bisphenol A)?
3 Discuss the stages of your life during which exposure to endocrine-disrupting hormones might be more harmful.
4 List some ways you could limit your exposure to endocrine-disrupting hormones.

Did you know? 4.4

Melatonin and sleep

Adolescents typically need 9.25 hours of sleep a night, but their body clock is shifted 1–3 hours later than other age groups. This means that melatonin, a hormone that regulates sleep, is released later in adolescents, causing them to feel drowsy later than others. Factors such as digital technologies, social media, and academic or athletic commitments can further disrupt sleep patterns. As a result, many adolescents experience sleep deprivation and struggle to wake up in the morning.

Figure 4.31 The pineal gland (highlighted) secretes the hormone melatonin, which controls the body's biological clock.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 4.4

Calculating your sleep debt

1 Every morning for 7 days, record the amount of sleep you had the previous night. Calculate your total sleep over the 7 days in hours.

2 The recommended number of hours of sleep for an adolescent in 7 days is:
9.25 × 7 days = 64.75 hours
Express the amount of sleep you got as a percentage by following this formula:

$$\text{percentage of required sleep} = \frac{\text{your hours}}{64.75} \times 100$$

If the percentage is greater than 100, you are getting sufficient sleep. If it is below, you are suffering from sleep debt. The lower the percentage, the greater the sleep debt. For example, if you get 8 hours of sleep each night for 7 days, then 8 × 7 = 56 so, $\frac{56}{64.75} \times 100 = 86.49\%$. This means you are only getting 86% of required sleep for a week and are suffering a 14% sleep debt.

3 Collect the results of the whole class and find the average sleep debt of your class.

INVESTIGATION

Explore! 4.5

Hypothermia

Hypothermia is a medical condition that occurs when the body's core temperature drops below normal levels, typically below 35°C. It can occur if the body's feedback systems fail to work properly.

For example, if the hypothalamus is damaged or not functioning correctly, it may not be able to detect changes in body temperature and adjust the body's response accordingly. This can result in the body losing heat faster than it can produce it, leading to hypothermia.

Another way that disorders in feedback systems can lead to hypothermia is by disrupting the body's ability to produce heat. For example, if the thyroid gland is not functioning correctly and not producing enough thyroid hormone, it can slow down the body's metabolism, leading to a decrease in heat production. This can also result in hypothermia.

Hypothermia can also lead to some unusual behaviours. Conduct some research on paradoxical undressing and terminal burrowing.

Quick check 4.7

1 **Recall** the part of the brain that is located at the base of the forebrain that controls many bodily functions such as sleep, hunger and thirst.
2 **Describe** how hormones are transported around the body.
3 **Name** the hormone that is responsible for regulating sleep patterns and inducing sleep.
4 **Define** 'target cells'.
5 **Discuss** the effects of oestrogen and testosterone.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Regulating blood glucose levels

Body cells function best when conditions are stable within narrow physical and chemical ranges, and one of the substances that needs to be highly regulated is the concentration of glucose in blood. Your brain requires a constant glucose supply and is highly sensitive to changes in blood glucose levels, as both high and low blood glucose levels can have serious consequences on the body.

insulin
a hormone secreted by the pancreas that triggers cells to take up glucose from the bloodstream and store it as glycogen in the liver and muscle cells, lowering blood glucose levels

glucagon
a hormone secreted by the pancreas that triggers the liver and muscle cells to convert glycogen into glucose, raising blood glucose levels

Negative feedback mechanisms play a crucial role in maintaining blood sugar levels and this is controlled by two hormones. **Insulin** is released by the pancreas when blood glucose levels are high. Insulin signals the liver, muscle and adipose (fat) tissue to take up glucose and store it as glycogen or fat, decreasing the concentration of glucose in the blood. Glucagon is secreted by the pancreas when blood glucose levels are low. **Glucagon** signals the liver to break down glycogen and release glucose back into the bloodstream, increasing the concentration of glucose in the blood (Figures 4.33 and 4.34). Once blood sugar levels return to normal, negative feedback mechanisms signal the pancreas to reduce glucagon secretion, preventing blood sugar levels from rising too high. This balance of insulin and glucagon secretion is critical for maintaining stable blood glucose levels and preventing the harmful effects of hyperglycaemia (high blood sugar) and hypoglycaemia (low blood sugar).

In cases of hyperglycaemia, there is an excess of glucose in the bloodstream. Over time, this can cause damage to blood vessels, nerves and organs, leading to complications such as cardiovascular disease, kidney disease and vision problems. Hypoglycaemia occurs when glucose levels drop too low, which can result in symptoms such as confusion, dizziness and fainting. If left untreated, severe hypoglycaemia can lead to seizures, coma and even death.

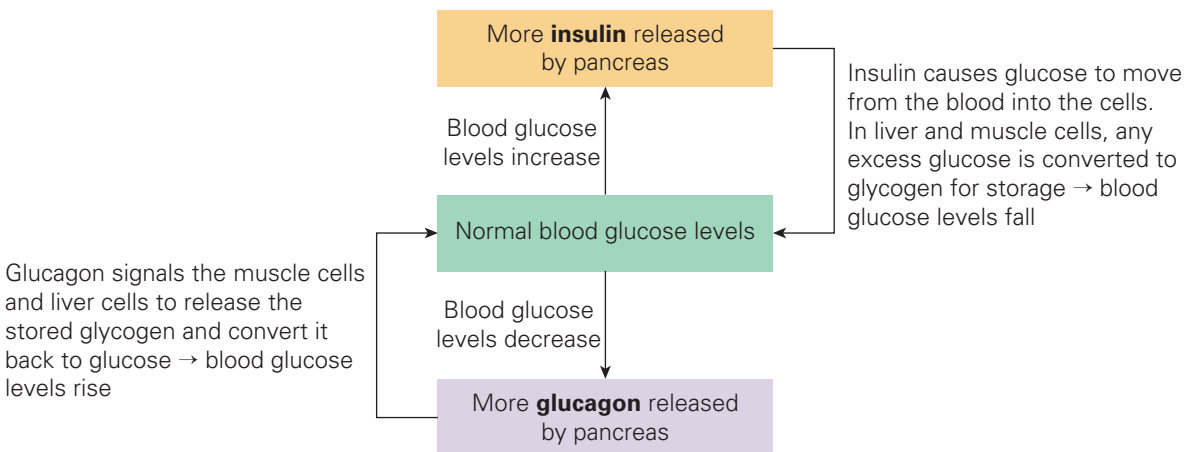


Figure 4.33 A flow chart showing insulin and glucagon maintain stable blood glucose levels

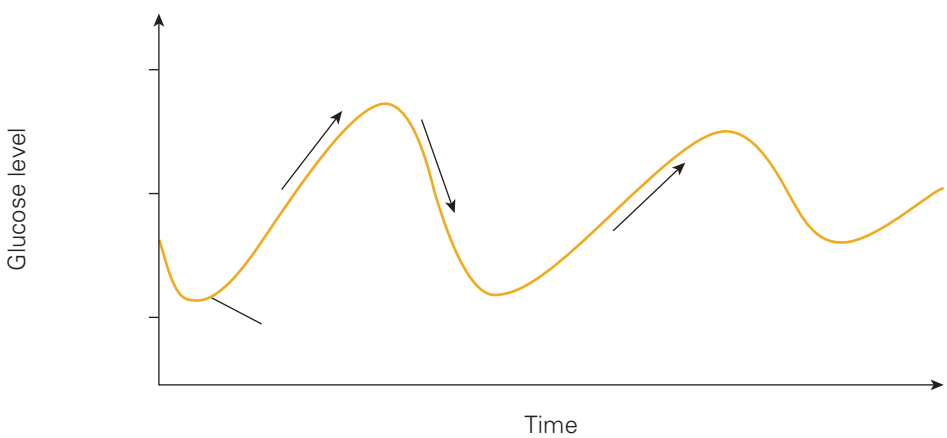


Figure 4.34 After a carbohydrate-rich meal, insulin levels in the bloodstream increase as the body needs to decrease the blood glucose levels.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

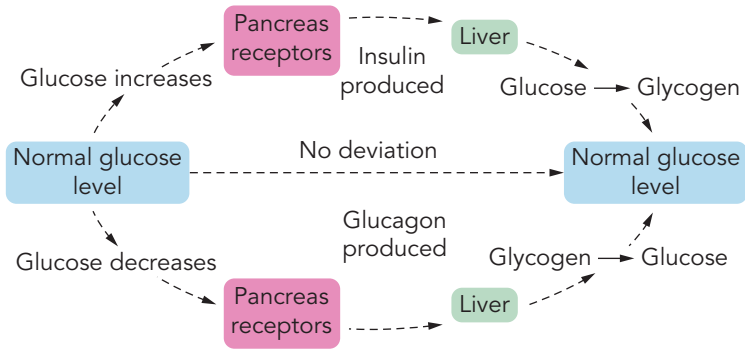


Figure 4.35 Glucose regulation

Try this 4.5

Stimulus–response model and blood glucose levels

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for control of blood glucose levels. You may choose either scenario: blood sugar levels are too high or blood sugar levels are too low. Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector and response.

Extension: Try to draw a double loop that shows both scenarios.

INVESTIGATION

Explore! 4.6

Diabetes

Diabetes is a medical condition where the body does not produce enough insulin or the body cells become resistant to insulin over time. It has become increasingly common in the Australian population, due in part to some lifestyle factors. Conduct some research to answer the following questions.

Figure 4.36 Adhesive patches can be used to continuously monitor blood sugar levels.

1. Contrast type 1 and type 2 diabetes.
2. Who is normally affected by each type of diabetes and at what age is it typically diagnosed?
3. How is each type of diabetes treated?
4. What are some of the factors that predispose people to developing diabetes?
5. Conduct some research on some of the new technologies that are being developed to support people with diabetes. You may want to consider new insulin pumps, infusion devices, continuous glucose monitors and smartphone apps.

Quick check 4.8

1. **After** a meal rich in simple carbohydrates, your blood glucose levels rise sharply. Recall the hormone that is released by the pancreas to decrease the levels.
2. **Define** hypoglycaemia.
3. **State** the role does glucagon play in the body.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 4.7

Diabetes-induced blindness

Disorders in feedback systems can lead to diabetes-induced blindness through a process called diabetic retinopathy. In diabetes, the high levels of glucose in the blood can damage the blood vessels throughout the body, including those in the retina of the eye.

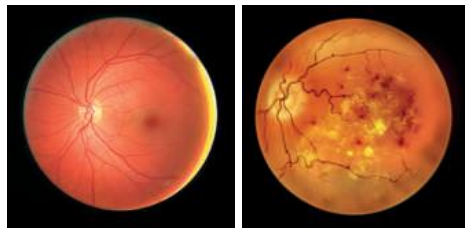


Figure 4.37 A normal retina (left) and a retina damaged from diabetes (right)

The retina is a layer of tissue in the back of the eye that is responsible for transmitting visual signals to the brain. The blood vessels in the retina can become damaged due to high blood sugar levels. The small blood vessels in the retina become weakened and leak fluid, leading to swelling and eventually scarring. As the condition progresses, new blood vessels may grow to compensate for the damage, but these vessels are often weak and prone to bleeding, which can further damage the retina and lead to vision loss.

Disorders in feedback systems, such as those that regulate blood sugar levels, can exacerbate the development of diabetic retinopathy. Poorly controlled blood sugar levels can accelerate the progression of the condition, making it more likely that a person with diabetes will develop blindness.

Complete some research to find out why people with diabetes also have to be careful about their foot care.

Regulating water levels

Regulation of the amount of water in the blood is a very important example of homeostasis. It is often referred to as **osmoregulation**. The amount of water in the blood is measured continuously by a group of osmoreceptors in the hypothalamus of the brain. They can detect if there are low levels of water in the blood (the blood is very concentrated) or high levels of water in the blood (the blood is very dilute). The flow chart in Figure 4.38 shows the steps of osmoregulation.

osmoregulation the regulation of water levels in the blood/body

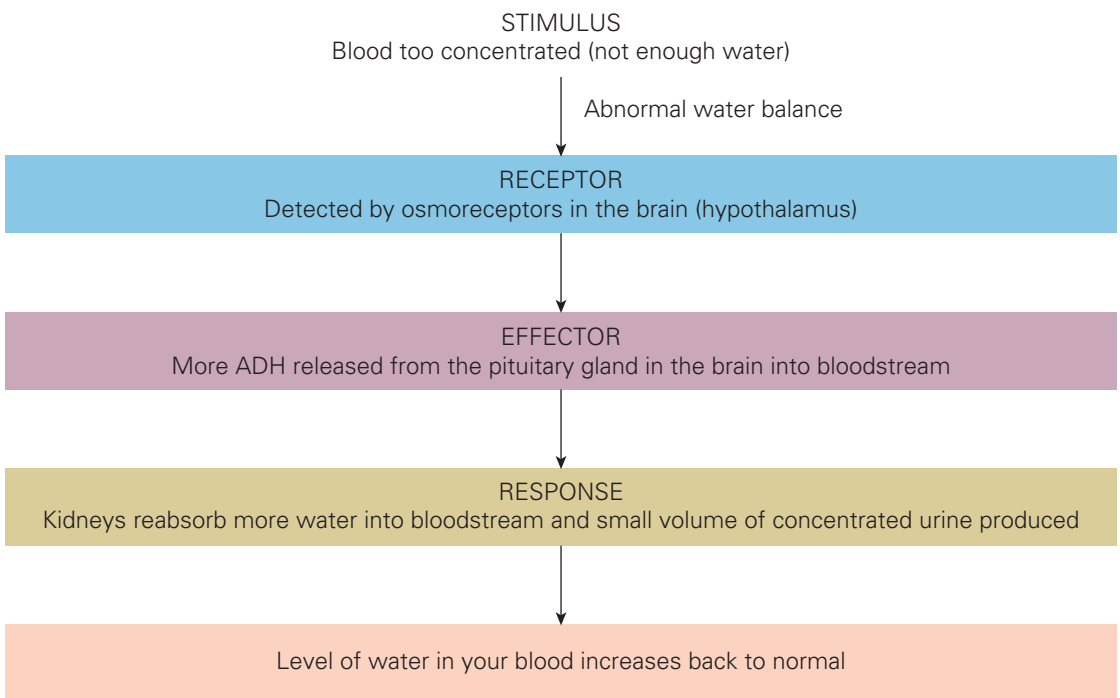


Figure 4.38 The stimulus–response flow chart for when water levels are low

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 4.6

Stimulus–response model and blood water levels

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for when water levels are too high (blood becomes too dilute). Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector and response.

Osmoregulation in response to dehydration is controlled by antidiuretic hormone (ADH), which is formed in the hypothalamus but stored in the pituitary gland. Many body systems are involved in the process.

1 Osmoreceptors in the hypothalamus (CNS) detect low blood water levels.
2 The hypothalamus triggers the pituitary gland (CNS) to release ADH.
3 ADH is carried by the blood (circulatory system) to the kidneys.
4 ADH increases the ability of the kidney tubules (excretory system) to reabsorb water and return it to the blood.
5 Water levels in the blood increase to their normal level.

Figure 4.39 The dehydration colour chart. The colour of urine indicates how concentrated it is, and therefore how dehydrated a person is.

Figure 4.39 shows a dehydration colour chart. By matching the colour of urine to the chart, you can tell whether you are dehydrated.

Quick check 4.9

1 **Recall** the organs that are involved in excretion of wastes.
2 **Recall** what ADH stands for and its role in osmoregulation.
4 **State** the part of the brain that monitors blood water concentration.

Regulating hunger

The two key hormones involved in regulating hunger are ghrelin and leptin. Ghrelin is produced by the stomach and stimulates hunger by increasing appetite and food intake. When the stomach is empty, ghrelin levels rise, signalling to the brain that the body needs food. Ghrelin then activates certain brain regions involved in appetite regulation, including the hypothalamus, which triggers the release of chemicals that increase appetite and food intake.

Ghrelin levels fluctuate throughout the day, with the highest levels typically occurring before meals and the lowest levels occurring after meals. Leptin is produced by fat cells and signals to the brain that the body has enough energy stores, suppressing appetite and promoting energy expenditure (Figure 4.40).

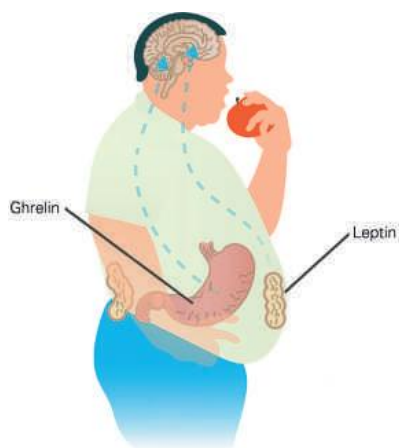


Figure 4.40 Ghrelin is produced by the stomach, and leptin is produced by fat cells.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 4.8

Improving body performance

The understanding of feedback mechanisms has enabled pharmaceuticals and other products to be developed that address various health issues and enhance performance. For example, scientists have developed synthetic insulin that mimics the natural hormone's actions to help people with type 1 diabetes maintain healthy blood glucose levels.

Figure 4.41 Insulin is injected into the body by a person with type 1 diabetes.

Similarly, sports drinks often contain electrolytes such as sodium, potassium and magnesium, which are essential for maintaining proper hydration and electrolyte balance during exercise. The feedback mechanism involving the kidneys and hormones such as aldosterone helps regulate electrolyte levels in the body. Understanding these mechanisms has enabled the development of sports drinks that help enhance athletic performance by promoting proper hydration and electrolyte balance.

Figure 4.42 An electrolyte drink may help keep you hydrated when out hiking.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 4.9

Controlling iron levels

Figure 4.43 Extreme fatigue and weakness are common symptoms of iron deficiency.

Iron is a vital nutrient that is necessary for many biological processes, including oxygen transport and DNA synthesis. However, excess iron can be toxic to the body, so it is essential to maintain iron levels within a narrow range.

The body's negative feedback mechanisms regulate iron levels through the hormone hepcidin, which is produced in the liver. Hepcidin binds to ferroportin, a protein on the surface of cells that moves iron from the cell into the bloodstream. The binding of hepcidin causes ferroportin to degrade, which reduces the amount of iron that is released into the bloodstream.

When iron levels in the blood are low, the body produces less hepcidin, which allows ferroportin to move more iron into the bloodstream, increasing iron levels. Conversely, when iron levels are high, the body produces more hepcidin, lowering iron levels.

This negative feedback loop helps to maintain balance in internal iron levels by regulating the amount of iron that is absorbed from food and the amount that is released from iron stores in the body, such as the liver and the spleen.

In addition to hepcidin regulation, the body has other mechanisms to control iron levels, such as iron-binding proteins, which bind to excess iron and prevent it from causing damage to tissues and organs.

Complete some research to determine why adolescent girls are at a higher risk of having an iron deficiency.

The nervous and endocrine systems working together

Homeostasis is maintained by the endocrine and nervous systems working together. The nervous system plays the primary role in controlling and coordinating most actions of the human body. It works in partnership with the endocrine system, which produces particular hormones that are released into the bloodstream in response to external or internal changes.

The two systems work as a team by using chemical messengers and electrical impulses to communicate with cells and glands. The speed of message transmission and the length of the effects differ between the two systems: the nervous system provides fast-acting, short-lasting effects and the endocrine system triggers slow-acting, long-lasting effects.

The endocrine and nervous systems work in a coordinated way with all the other body systems to maintain a relatively stable internal environment and protect the body from harm.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

WORKSHEET
The nervous and endocrine systems compared

Comparing the nervous and endocrine systems

The key differences between the features of the endocrine and nervous systems are summarised in Table 4.7.

Feature	Nervous system	Endocrine system
Signals	Electrochemical messengers (via electrical impulses and neurotransmitters)	Chemical messengers (hormones)
Pathway	Transmission by neurons in the nervous system	Transported in the bloodstream (circulatory system) and lymph (lymphatic system)
Speed of information transfer	Fast	Slow
Duration of effect	Short lived	Typically longer lasting
Type of action and response	Voluntary or involuntary	Involuntary
Target cells	Localised cells	Systemic (many cells may be affected)
Example of action	A friend throws a ball towards you. Your sensory receptors capture the visual stimulus, and through a network of neurons, the information is relayed to your brain. Subsequently, additional messages are conveyed through your spinal cord, and using motor neurons, your skeletal muscles receive stimulation, causing them to contract. As a result, you reach out and catch the ball.	When a male reaches puberty, the pituitary gland secretes a hormone called luteinising hormone. This acts on the testes and stimulates them to release testosterone. As the amount of testosterone builds up in his system, it triggers sperm production, muscle development, hair growth and changes to his voice.

Table 4.7 A comparison of the nervous and endocrine systems

Go online to access the interactive section review and more!

Section 4.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 4.3 questions

Remembering

1 **Name** two endocrine glands found within the brain.
2 **Recall** how hormones reach their target cells.
3 **Recall** the hormones secreted by the pancreas and what effect they have.

Understanding

4 **Explain** the difference in the speed of transmission within the nervous and endocrine systems.

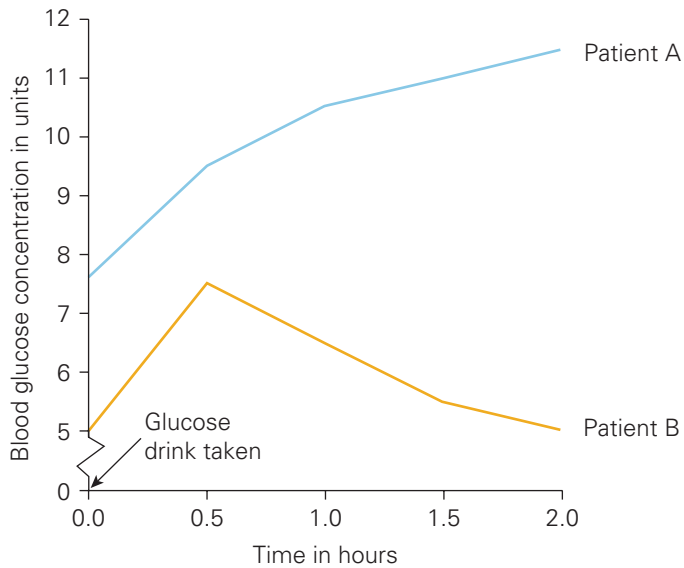
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applying

5 **Construct** a Venn diagram that shows the similarities and differences between the nervous and endocrine systems.

Analysing

6 The graph below shows the results of a glucose tolerance test for two patients, A and B. **Identify** which patient has diabetes using data from the graph.



Evaluating

7 The contraceptive pill contains a chemical which acts like the hormone oestrogen, and it must be taken daily by women. It attempts to stop sperm reaching an egg in several ways, including:

- suppressing ovulation so an egg is not released from the ovaries
- making the cervical mucus thicker so that it becomes more difficult for sperm to reach an egg
- decreasing the thickness of the lining of the womb so it is not thick enough for an egg to attach to it.

Deduce some reasons why the pill is *not* guaranteed to work 100% of the time.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

SCORCHER

Chapter checklist

Success criteria I am now able to…		Linked questions
4.1	explain why it is important for the body to maintain stable internal conditions.	
4.1	identify the role of feedback loops in homeostasis.	
4.1	describe and explain organisms' responses to stimuli using the stimulus–response model.	
4.2	describe the role and function of electrical impulses in the nervous system's responses to stimuli.	
4.3	describe the role and function of hormones in the endocrine system's responses to stimuli.	
4.3	describe how the nervous and endocrine systems work together to coordinate responses.	
4.3	compare the nervous and endocrine systems' responses.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Data questions

A student with diabetes measures their blood sugar level hourly and the data is plotted in blue in Figure 4.44. Another student, who does not have diabetes, also measures their blood sugar as a comparison, and this is plotted in orange. The students are careful to eat the same three meals on this day – breakfast, lunch and dinner at the same time – and the student with diabetes injects insulin straight after each meal.

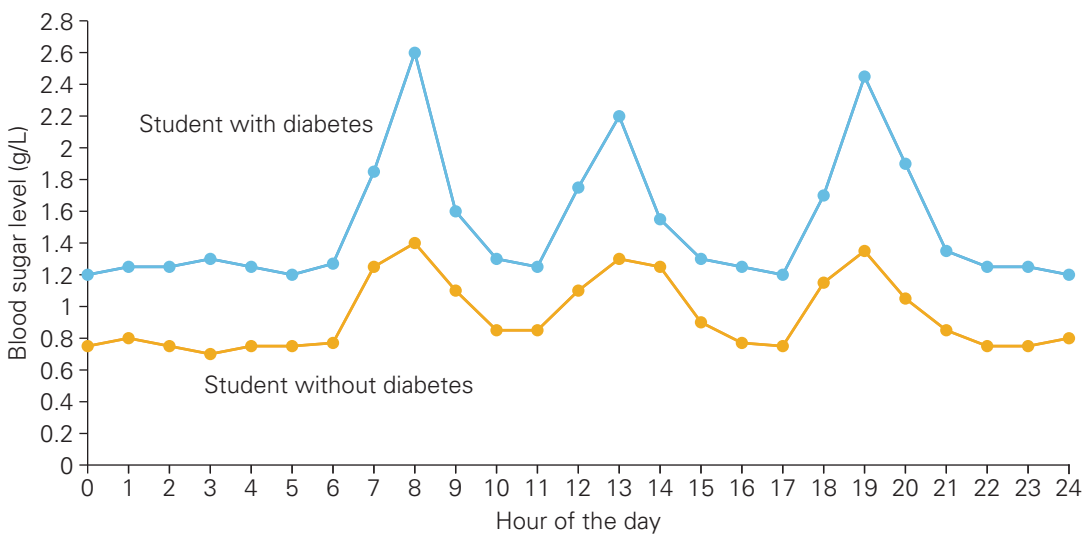


Figure 4.44 Relative blood sugar level over a 24-hour period. Orange line – student without diabetes, blue line – student with diabetes.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1 **Identify** the homeostatic (steady state) blood sugar level for each student.
2 **Determine** the times that the students ate breakfast, lunch and dinner.
3 **Identify** the peak blood sugar level for both students on this day.
4 **Identify** any patterns or trends that appear in the data.
5 **Contrast** the change in blood sugar level after each meal and provide a reason for the difference between the two students.
6 **Infer** a reason for the lower peak in blood sugar for the student with diabetes after eating lunch than after the other meals.
7 **Justify** whether the comparison of data would be valid if the students ate different meals on this day.
8 After the student with diabetes ate dinner, **deduce** the time that insulin was injected into the bloodstream. Assume that insulin starts to act immediately upon injection.
9 **Predict** what would happen to the plotted data if the student with diabetes did not use insulin directly after the breakfast meal.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Texting and reaction times

Figure 4.45 In NSW there are penalties for using a mobile device while driving. It will cost the driver 5 demerit points and a fine of about $400.

DESIGN BRIEF

Investigate whether texting is a distraction to people performing tasks.

A

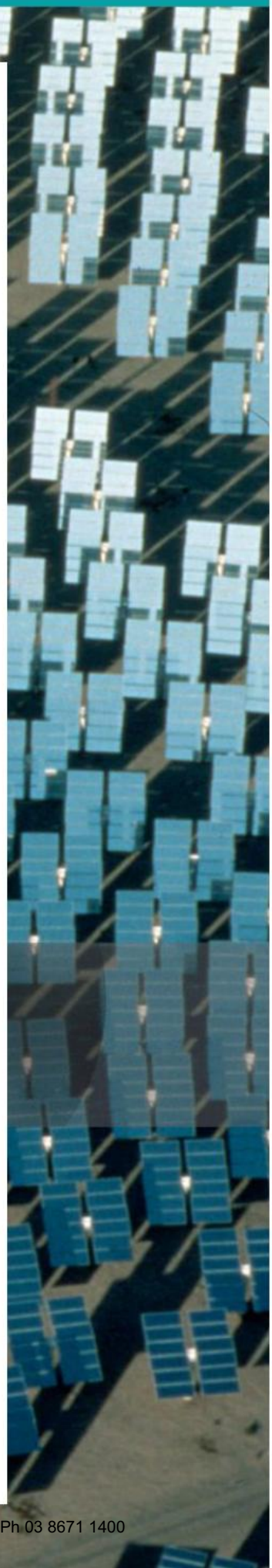
at least three sets of data
- at least three bar graphs
- a conclusion that clearly responds to the following scenario.

Transport for NSW is so worried about young people's attitudes towards texting while driving that it hired your young start-up company to conduct a sequence of experiments in the community to determine whether texting can slow down a person's reaction times.

Suggested materials

- 30 cm ruler
- scissors
- cardboard
- paper
- pen
- mobile phone to record slow-motion videos
- Microsoft PowerPoint, Google slides or Mac Keynote for presentations
- video-editing software for making short documentaries

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134



Research and feasibility

1 Research and make a list of the factors that influence a person's reaction time.

2 Create a table and make predictions of how these factors will decrease or increase a person's reaction time.

Factor	Reaction time effect	Reason
e.g. Being tired	Decrease reaction time moderately	Tiredness decreases ability to absorb information

3 Discuss in your group, then list important information you will need to record about your participants whose reaction times will be tested. Hint: make sure you have thought about all the factors that might affect a person's reaction times, such as sleep, exercise or video game playing.

Design and sustainability

4 Using the materials on the material list, design a way to test the effect of mobile phone texting on a teenager's reaction time.

5 Design a table that includes information about each participant's recorded information.

Create

6 Perform your experiment, making sure you collect multiple sets of data for each participant and their important information.

Evaluate and modify

7 Reflection is an integral and vital aspect of any project out there in the real world. How could you use ICT tools (for example, apps, video, slow-motion camera) to enhance this experiment?

8 The results may change when a different type of ruler is used, such as metal, plastic or timber. Predict how the size or length of the ruler, and whether the dominant or non-dominant hand was used, might have affected the results.

9 Consider adding other distracting sounds and sights during the activity, such as turning on a TV set or flicking a flashlight on and off. Do your responses slow with so many sensory signals?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 5

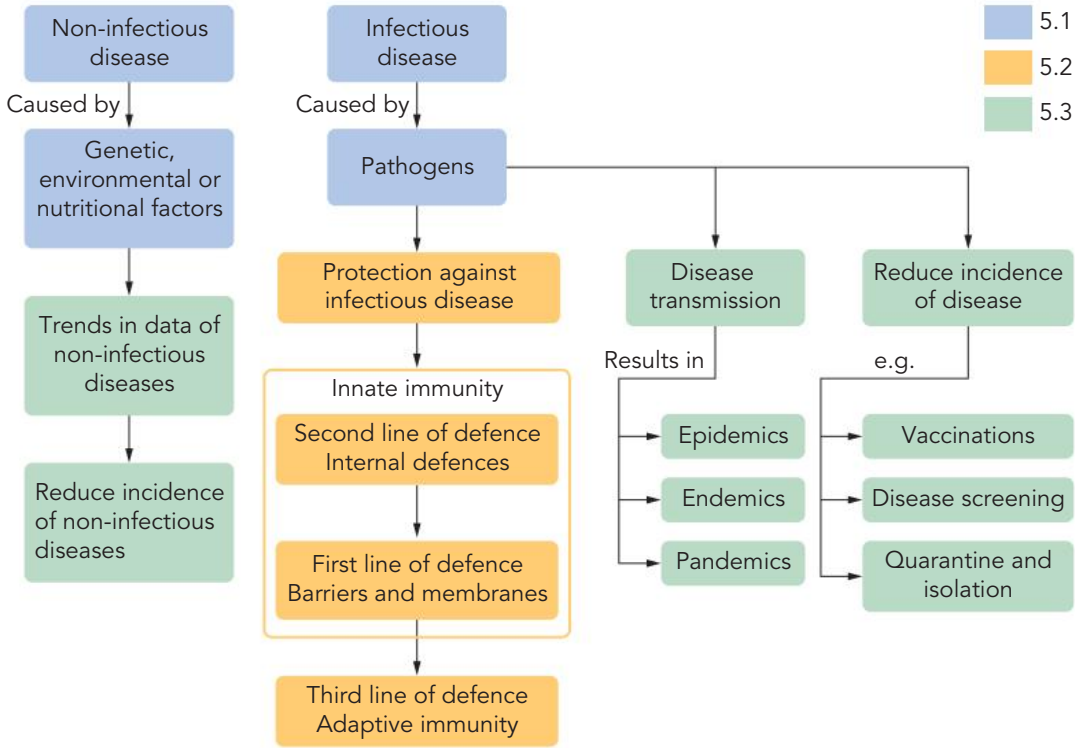
Disease

Chapter introduction

Diseases significantly impact human health. Infectious diseases are caused by pathogens like bacteria, viruses, fungi, and parasites while non-infectious diseases include conditions like diabetes and cancer. This chapter explores these diseases and the body's defence mechanisms against them. You will learn about how diseases are transmitted and explore strategies used to stop their spread, such as vaccination, hygiene practices and public health measures.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

adaptive immunity
antibiotic
antigen
antiseptic
B lymphocyte
bacteria
binary fission
budding
cellular
direct transmission
disease
ectoparasite
endemic
endoparasite
epidemic
eukaryote
fermentation
fungus
health
immune system
immunisation
indirect transmission
infectious disease
innate immunity
memory cell
non-infectious disease
non-specific immunity
pandemic
pathogen
phagocytosis
prokaryote
septic
sign
specific immunity
symptom
T lymphocyte
vaccination
vaccine
vector transmission
virus

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

5.1 Infectious and non-infectious diseases

WORKSHEET
Pathogens

Learning outcomes

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

1. distinguish between infectious and non-infectious disease.
2. identify causes of non-infectious diseases, and infectious diseases caused by pathogens.
3. investigate Australian technological advances to address disease.

Health and disease

health
is a state of complete physical and mental wellbeing

disease
is any condition that disrupts the normal functioning of the body

sign
is an observable or measurable indicator of a disease

symptom
is a subjective experience of a disease reported by the patient

infectious disease
caused by pathogens and can spread from person to person.

non-infectious disease
not caused by pathogens and cannot be transmitted between individuals.

Health is defined as a state of complete physical and mental wellbeing. A **disease** is any condition, physical or mental, that disrupts the normal functioning of the body and is characterised by a specific set of signs and symptoms. **Signs** are observable or measurable indications of disease, such as a rash, fever or weight loss. A **symptom** is any indication of a disease that can only be felt and described by a patient, such as a headache, pain, nausea or dizziness.

Diseases are broadly classified into two main categories: **infectious diseases** (transmissible) and **non-infectious diseases** (non-transmissible).

Non-infectious diseases

Non-infectious diseases cannot be transmitted from one individual to another. The various types of these diseases are outlined in Table 5.1.

Type of non-infectious disease	Description	Examples
Nutritional deficiency diseases	Caused by diets lacking essential nutrients	Marasmus Kwashiorkor Rickets

Figure 5.1 The legs of a two-year-old with rickets

Table 5.1 Non-infectious diseases

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

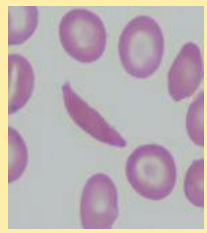
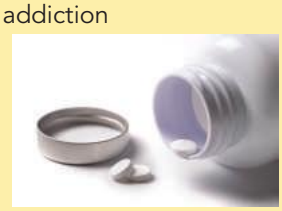
Type of non-infectious disease	Description	Examples
Genetic (inherited) diseases	Passed through genes from parents to offspring	Sickle cell anaemia Haemophilia Down's syndrome  **Figure 5.2** Normal-shaped and sickle-shaped red blood cells from a patient with sickle cell disease
Degenerative diseases	Characterised by a gradual decline in organ function due to ageing or excessive stress on the organ	Arthritis Coronary heart disease **Figure 5.3** Rheumatoid arthritis in a hand
Environmental diseases	Result from pollutants in the environment	Bronchitis Emphysema Lung cancer due to air pollution **Figure 5.4** X-ray of lungs with emphysema
Mental disorders	Disorders of the mind caused by chemical or physical factors	Schizophrenia **Figure 5.5** Different mental states
Self-inflicted and social diseases	Result from personal behaviours or societal factors	Drug addiction  **Figure 5.6** Pills

Table 5.1 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 5.1

1 **Define** health and disease.
2 **State** the difference between a sign and a symptom.

Try this 5.1

Researching technological advancements in disease treatment

Technological advances in medicine have revolutionised the way we address disease, disorders and physical trauma. Innovations from Australian researchers and institutions have made significant impacts globally, offering new treatments and improving patient outcomes.

Choose one of the following Australian technological advancements to investigate:

- Professor Fiona Stanley's research on neural tube defects and childhood diseases
- Professor Elizabeth Blackburn's work on telomeres and its implications for aging and disease
- Monash Vision Group's development of the bionic eye.

Collect detailed information about your chosen technology, including its development, purpose and impact on medical treatment. Summarise how this technology works and its benefits in treating disease, disorders, or physical trauma. You should discuss any challenges or limitations associated with the technology, before exploring how this technology has improved patient outcomes and contributed to advancements in medical science.

Figure 5.7 The da Vinci Surgical System is a state-of-the-art robotic surgical platform that enhances precision and control during minimally invasive procedures.

Infectious diseases

pathogen an infectious agent that can cause disease

cellular composed of cells

Infectious diseases are caused either directly by a **pathogen** or by toxins produced by pathogens. These pathogens can be transmitted from an infected individual to others who are not yet affected by the disease.

Some pathogens are **cellular**; they are made of cells. Examples are bacteria, fungi and parasites. Some pathogens are non-cellular, for example, viruses and prions. Table 5.2 lists common diseases caused by bacteria, fungi and viruses.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Cellular			Non-cellular	
Bacterial diseases	**Fungal diseases**	**Parasitic diseases**	**Viral diseases**	**Prion diseases**
Typhoid Gonorrhoea Syphilis Tetanus 'Strep throat' Gastroenteritis Anthrax	Ringworm Thrush Tinea	Giardiasis Malaria Scabies Hookworm	Warts Poliomyelitis Rubella Influenza Common cold COVID-19 AIDS Mumps	Creutzfeldt-Jakob disease (CJD) Kuru

VIDEO
Three main pathogens

Table 5.2 Some common diseases caused by different pathogens

Quick check 5.2

1 **Differentiate** between infectious and non-infectious diseases.
2 **Recall** the definition of a pathogen?
3 **Explain** the difference between cellular and non-cellular pathogens.

Bacteria

Bacteria are simple unicellular organisms known as **prokaryotes**, lacking membrane-bound organelles like nuclei or mitochondria (see Figure 5.8). They possess a cell wall and are too small to be visible to the naked eye individually, but clusters of bacteria form visible colonies. To study bacteria, scientists require microscopes. Most bacteria reproduce through **binary fission**, where genetic material replicates and the cell divides into two identical genetic clones. For instance, *Escherichia coli* can replicate every 20 minutes under ideal conditions, leading to rapid population growth. This exponential growth explains how bacterial infections can escalate quickly within a host's body.

bacteria (singular: bacterium) microscopic, unicellular organisms

prokaryote a unicellular organism with no membrane-bound organelles

binary fission the main asexual reproduction method in prokaryotes, where a cell divides into two identical cells.

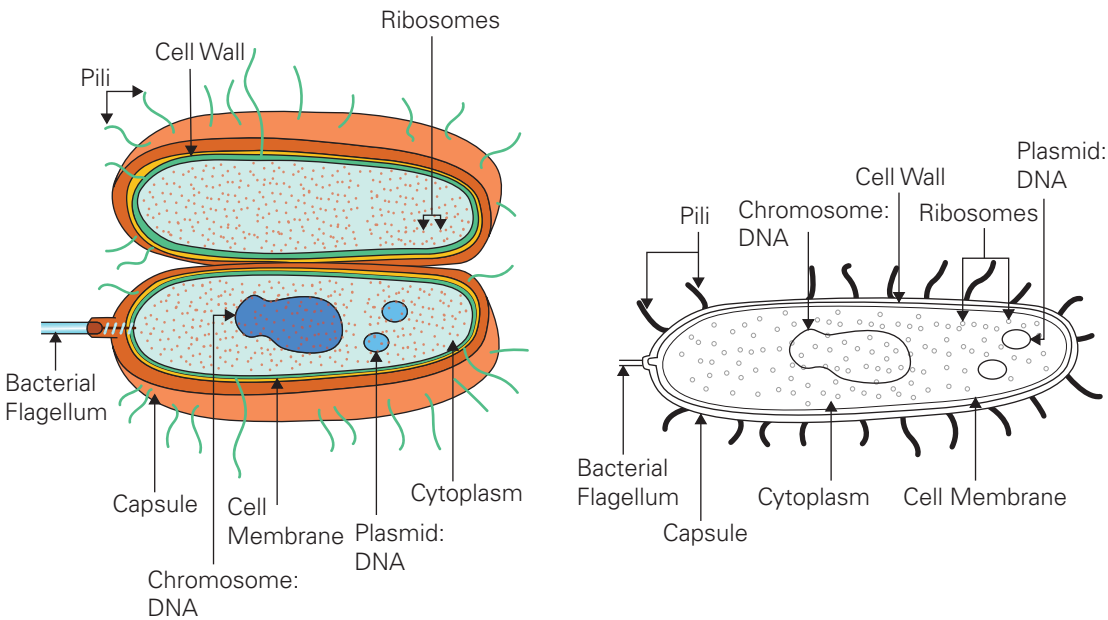


Figure 5.8 General structure of a bacterial cell

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 5.9 Coloured scanning electron micrograph (SEM) of *Escherichia coli* bacteria (pink) on a gecko's tongue. The magnification is ×8000.

Types of bacteria

One way of classifying bacteria is by the shape of their individual cells. The main shapes are rods, spheres and spirals. Examples of these can be seen in the magnified images in Table 5.3.

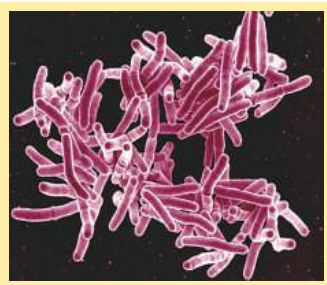
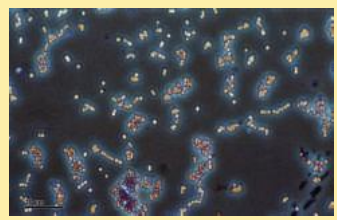
Shape	Biological name	Diseases	Magnified image
Rod	*Bacillus* (plural: *Bacilli*)	Typhoid Tuberculosis	
Spiral	*Spirillum* (plural: *Spirilli*)	Syphilis	
Spherical	*Coccus* (plural: *Cocci*)	Streptococcus (causes tonsillitis)	

Table 5.3 Common types of disease-causing bacteria

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 5.3

1 **Recall** why bacteria are considered prokaryotes.
2 **Describe** how bacteria reproduce, and why this is a problem if a pathogenic strain infects a person.
3 **State** the different names and shapes of bacteria.

Did you know? 5.1

Growing bacteria

One of the earliest methods of growing bacteria involved using jelly from an ox's eye. Today, biologists use nutrient agar plates for this purpose. Agar, a gel-like substance derived from red algae, can serve as a food source for some bacteria. When additional nutrients, such as meat extract, are added to the agar, bacteria can grow rapidly and form colonies.

Figure 5.10 Scientists used to use jelly from the eye of an ox for growing bacteria. Nowadays, a nutrient agar dish is used. This one contains bacterial colonies.

Fungi

Fungi can be single-celled or multicellular organisms with a nucleus and a cell wall made of chitin. Like plants and animals, fungi are **eukaryotic** organisms with membrane-bound organelles. Common fungi include yeasts, moulds and mushrooms. Unlike plants, fungi do not photosynthesise; instead, they are heterotrophic and produce enzymes that break down organic matter to release nutrients that they can then absorb.

Mushrooms and toadstools are examples of fungi's fruiting bodies that beak down organic matter in soil. While many fungi, particularly yeasts, coexist harmlessly on the human body, some secrete enzymes that break down keratin (a protein found in hair, skin and nails), leading to conditions such as athlete's foot, ringworm and other fungal infections.

Figure 5.11 Ringworm is a fungal infection characterised by a red, circular rash with a raised border, creating a ring-like appearance on the skin.

fungus
(plural: fungi) eukaryotic organisms which have a cell wall made of chitin and feed by secreting enzymes and then absorbing the digested nutrients.

eukaryote
an organism made of cells that contain a nucleus and membrane-bound organelles

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 5.12 A oral candidiasis (thrush) infection in a child who had taken antibiotics. Thrush is a yeast infection typically caused by *Candida* species. Antibiotics can disrupt the balance of microorganisms in the body, including beneficial bacteria that normally keep yeast growth in check. This imbalance creates an environment where yeast grows out of control, leading to symptoms like white patches on the tongue, inner cheeks and throat. Thrush is common in infants and young children, as their immune systems are still developing.

Practical skills 5.1

Fermentation

Yeast is a type of fungus, one that is very useful in the production of many foods. You might have some baker's yeast in the cupboard at home – it is used when baking bread. Yeast exists as single cells and reproduces by a process called **budding**, where a yeast cell develops a small 'bud', which grows and eventually separates to form a new yeast cell.

budding an asexual reproduction process where a new organism develops from an outgrowth or bud on the parent.

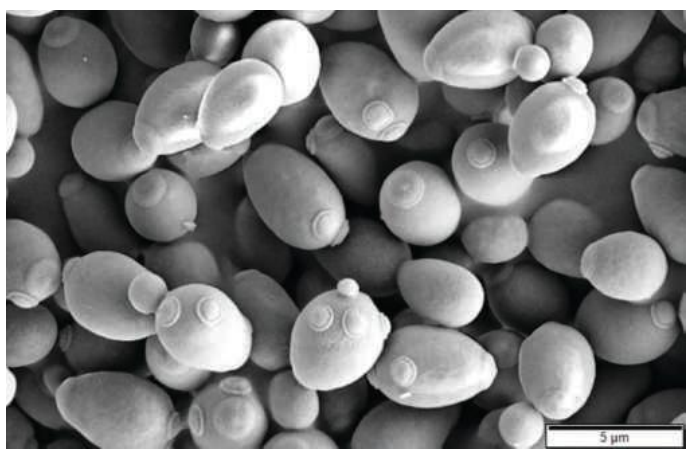


Figure 5.13 A scanning microscope image of budding yeast

In the absence of oxygen, yeast undergo **fermentation**, a process where they can produce energy by converting sugar into alcohol and carbon dioxide.

fermentation a chemical process by which energy is produced in the absence of oxygen

sugar ⟶ alcohol + carbon dioxide

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Some alcoholic beverages, such as champagne, are fizzy because the carbon dioxide produced during fermentation is trapped, creating bubbles. Similarly, in baking, the carbon dioxide generated by yeast or baking powder causes dough to rise, resulting in light and fluffy breads and cakes.

Aim

To investigate the process of fermentation using yeast.

Materials

- 5 test tubes
- test-tube rack
- balloon
- limewater
- sugar
- yeast
- delivery tube with stopper
- teaspoon
- marker pen
- measuring cylinder

Procedure

1

Fill each test tube A–D according to the table below.

A	B	C	D
2 teaspoons sugar 10 mL warm water	1 teaspoon yeast 10 mL warm water	2 teaspoons sugar 1 teaspoon yeast 10 mL warm water	2 teaspoons sugar 1 teaspoon yeast 10 mL warm water

3 Place a balloon over the end of test tube C.

4 Attach a delivery tube to test tube D and place the outlet into some limewater in a fifth test tube as shown in the diagram. Limewater will turn cloudy when carbon dioxide is bubbled through it, forming calcium carbonate.

5 Leave all test tubes for approximately 30 minutes. Observe the results after this time.

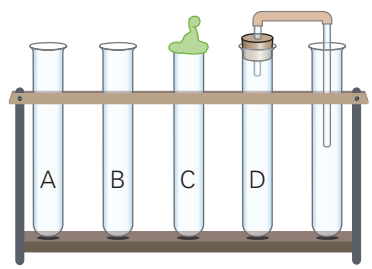


Figure 5.14 Experimental set-up

Results

Write down your observations for each test tube.

Discussion

1 Describe any trends, patterns or relationships in your results.

2 Suggest some reasons for the different results obtained in test tubes A, B and C, referring to the contents of the test tubes.

3 Explain why it is important to use warm water and not to use water that is too hot.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Viruses

virus
an extremely small, non-cellular pathogen that consists of genetic material encased in a protein coat and relies on invading living host cells to replicate

Viruses are tiny pathogens that cannot be seen with a light microscope but are visible under an electron microscope. They consist of a core of genetic material (either DNA or RNA) surrounded by a protein coat. Once they penetrate a suitable host cell, they take over its cellular machinery, turning it into a virus factory (see Figure 5.15).

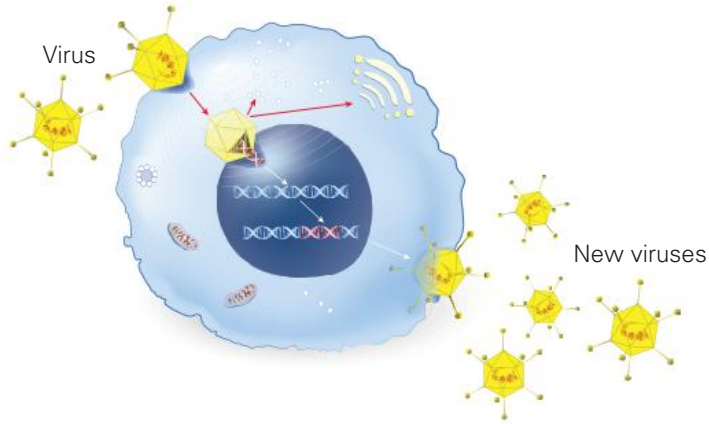


Figure 5.15 The replication of a virus via a host cell

One of the key requirements for life is the ability to reproduce. Since viruses depend on invading other cells to replicate and survive, they occupy a grey area between living and non-living. Despite this, viruses play an important role in all ecosystems, including the human body. Within your body, viruses can infect not only your cells but also other pathogens residing inside you.

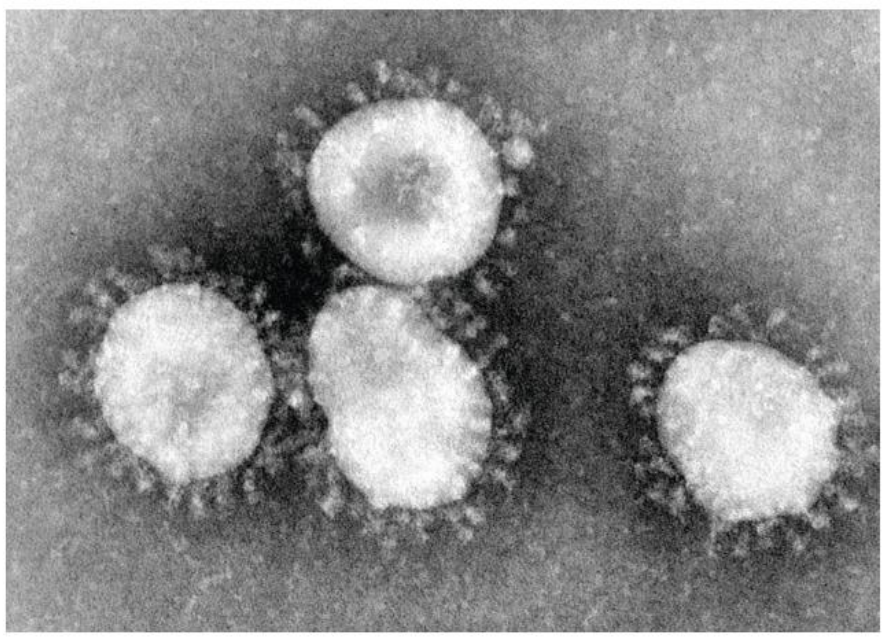


Figure 5.16 COVID-19, short for coronavirus disease, is caused by the SARS-C0V-2 virus. It is part of a group of viruses that exhibit a halo or crown-like (corona) appearance when viewed under an electron microscope.

Prions

Prions are misfolded proteins that lack a cellular structure and do not contain genetic material. Prions are not living organisms and cannot reproduce on their own. Instead, they propagate by inducing normal proteins in the brain to misfold, which disrupts brain function and leads to neurodegenerative diseases such as Creutzfeldt-Jakob disease (CJD). Prions are extremely small and not visible with standard microscopes.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 5.2

Prion diseases and organ and blood donation policies

Historically, concerns about prions have impacted organ and blood donation policies in many countries, including Australia. The United Kingdom experienced a significant outbreak of bovine spongiform encephalopathy (BSE), commonly known as 'mad cow disease' in the 1980s and 1990s, leading to cases of variant Creutzfeldt-Jakob disease (CJD) among the population. As a precautionary measure, Australian health authorities implemented strict guidelines regarding blood and organ donations from individuals with a history of residence in the UK during the time of the outbreak. Until July 2022, people who lived in the United Kingdom for over six months between 1980 and 1996 couldn't donate blood or organs in Australia due to the potential risk of transmitting prion diseases. This policy aimed to protect the Australian public from the potential risk of prion transmission through transfusions or transplantations.

Parasites

Parasites are organisms that live on or inside a host organism, relying on the host for nutrients and shelter while often causing harm. Parasites can be single-celled (protozoa) or multicellular (such as worms, arachnids and insects). They are highly specialised to their environments, evolving to exploit their hosts for survival. Parasites do not contribute any benefit to their host and may lead to a range of diseases and infections.

Parasites are generally classified into two main categories: **endoparasites** and **ectoparasites**. Endoparasites live within the host's body, often in organs or tissues. They derive nutrients from the host's internal environment, which can lead to significant health issues for the host. Examples of endoparasites include worms such as the tapeworm, or protozoan parasites such as *Plasmodium*, which causes malaria and *Giardia*, which is associated with giardiasis and can be contracted from contaminated water sources.

endoparasite
a parasite that lives inside the host's body and derives nutrients from the host's internal environment

ectoparasite
a parasite that lives on the surface of the host, feeding externally by consuming blood, skin or other bodily fluids

Ectoparasites live on the surface of the host, feeding externally by consuming blood, skin or other bodily fluids. They can cause irritation, allergic reactions and transmit diseases. The paralysis tick (*Ixodes holocyclus*) can attach to the skin of its hosts and feed on blood, causing serious health issues such as tick paralysis.

Figure 5.17 (a) A dog tick feeding on a human, **(b)** head louse, **(c)** scanning electron micrograph of the head of a pork tapeworm and **(d)** red blood cells infected with *Plasmodium*

Did you know? 5.3

Pork tapeworms

Undercooked pork can be a source of infection from the pork tapeworm, *Taenia solium*. When humans consume undercooked or raw pork containing larval cysts, the tapeworm can attach to the intestines and grow into a large adult, potentially leading to taeniasis, which may cause mild gastrointestinal symptoms. However, if humans accidentally ingest the eggs from contaminated food or water, it can result in cysticercosis, a serious condition where larvae

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

invade various tissues, including the brain. To avoid these risks, it's essential to cook pork thoroughly to an internal temperature of at least 71°C.

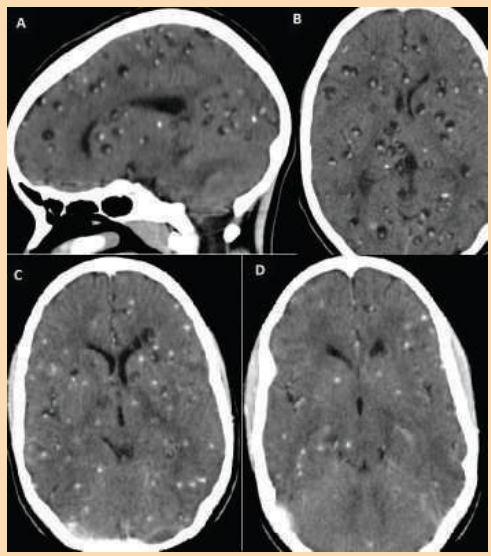


Figure 5.18 Brain CT scans of a patient with neurocysticercosis, caused by the pork tapeworm *Taenia solium*, showing multiple cysts and calcifications

Table 5.4 summarises the different types of pathogen and their characteristics, mode of transmission and treatment.

Pathogen type	Characteristics	Transmission	Treatment
Bacteria	• Unicellular • Prokaryotic • Can be beneficial or harmful	Contaminated food/water, direct contact	Antibiotics
Fungi	• Eukaryotic • Can be unicellular (yeasts) or multicellular (moulds and mushrooms) • Absorb nutrients from organic matter	Inhalation, direct contact, or through contaminated surfaces	Antifungal medications
Viruses	• Non-cellular • Require a host cell to replicate • Consist of genetic material surrounded by a protein coat	Airborne, direct contact, bodily fluids	Antiviral medications (for some), vaccines
Parasites	• Eukaryotic • Can be unicellular or multicellular • Often complex life cycles	Contaminated food/water, insect bites, direct contact	Antiparasitic medications
Prions	• Misfolded proteins • Lack cellular structure and genetic material • Cause neurodegenerative diseases	Contaminated meat, medical procedures	No effective treatment

Table 5.4 Types of pathogen and their characteristics, mode of transmission and treatment

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 5.4

1 **State** three common types of fungi.
2 **Describe** how fungi are able to obtain the nutrients they need to survive.
3 **Explain** how yeast cells reproduce.
4 **Describe** the structure of viruses and how they reproduce.
5 Scientists argue that viruses are in fact non-living. **Discuss** why this may be the case.
6 **Recall** the definition of a prion.

VIDEO
How do I become infected?

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 terms 'infectious disease' and 'non-infectious disease'.
2 **Identify** the types of pathogens that can cause infectious diseases.
3 **Determine** whether bacteria are classified as prokaryotes or eukaryotes. Why?
4 **Name** three diseases caused by viruses.

Understanding

5 **Describe** one difference between bacterial cells and eukaryotic cells (for example, plant or animal cells).
6 **Compare** bacteria and viruses.
7 **Explain** why a virus is considered to be non-living.
8 **Explain** the difference between a sign and a symptom of a disease.

Applying

9 **Identify** reasons why viruses cannot be treated with antibiotics.
10 The body's immune system may sometimes start to recognise 'self' antigens as foreign and 'non-self'. **Propose** what might happen in this case.
11 **Apply** your knowledge of bacterial reproduction to explain how a bacterial infection might spread quickly in a host.

Analysing

12 **Analyse** the differences in how signs and symptoms of diseases are detected and evaluated. Why might some diseases be more challenging to diagnose?
13 **Distinguish** between endoparasites and ectoparasites.

Evaluating

14 **Critique** the classification of diseases into infectious and non-infectious categories. Are there any overlaps or grey areas that could be reconsidered?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

5.2 Protection against infectious disease

WORKSHEET
The immune system

Learning outcomes

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

1. identify and describe how the immune system opposes the entry of pathogens.
2. describe how immunisation stimulates the body to produce antibodies to fight infection.
3. investigate Aboriginal and Torres Strait Islander Peoples' use of plants against disease.
4. write a report analysing immunisation and disease data to identify patterns and relationships.

The immune system

immune system the network of cells and tissues that enables the body to protect itself against disease

non-specific immunity the branch of the immune system that provides immunity without recognising specific pathogens. It includes the first and second lines of defence, such as physical barriers, inflammation and fever.

specific immunity the branch of the immune system that targets each particular pathogen; the third line of defence

The body's **immune system** acts as its defence against infectious diseases. To function properly, the immune system must detect, distinguish and respond to a variety of pathogens and damaged or foreign cells. The immune system has three lines of defence, which can be divided into two categories. The first and second lines of defence respond in the same way to all infections, providing **non-specific immunity**. The third line of defence offers **specific immunity** against particular pathogens (see Table 5.5).

Non-specific immune system	Specific immune system
First and second lines of defence	Third line of defence
General defence: Responds the same way to every infection	**Targeted defence:** Produces antibodies to combat specific pathogens
No 'memory' of prior infections: Responds with the same intensity each time	**Memory of prior infections:** Remembers pathogens and responds more quickly and effectively upon re-encounter (adaptive)

Table 5.5 Immune system lines of defence

First line of defence

The first line of defence aims to prevent infection as it is the initial point of contact between the human body and the pathogen. This includes surface barriers like intact skin, which protects external boundaries and mucous membranes, which protect internal boundaries such as those in the gut, mouth and nose. This line of defence is crucial because if pathogens cannot enter the host's body, they cannot disrupt normal physiological functions or cause disease. These barriers also release chemical secretions such as sweat, tears, earwax, mucus and stomach acid, which restrict pathogen growth on their surfaces and prevent their entry into the body.

Quick check 5.5

1 **Contrast** specific and non-specific immunity.

2 Copy and **complete** the following table, then **recall** what is involved in each line of defence.

Non-specific immune response	Specific immune response
First line of defence:	Third line of defence:
Second line of defence:	

3 **Explain** how skin and mucous membranes contribute to the first line of defence.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

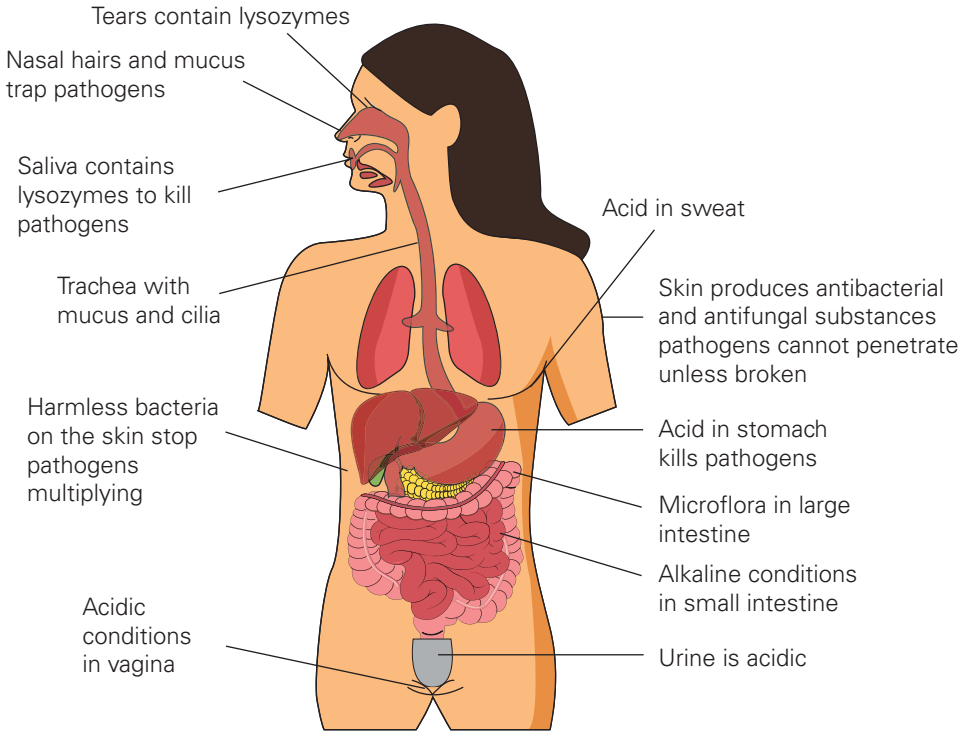


Figure 5.19 Barriers are the first line of defence

Advances in science 5.1

Spray-on skin

Patients with burn injuries are at a high risk of developing infections because they have lost their first line of defence. If patients survive the first 72 hours after a burn injury, infections become the most common cause of death. In 1993, Professor Fiona Wood and Marie Stoner developed ReCell, a revolutionary spray-on skin technology. ReCell deconstructs a small biopsy of the patient's own skin and dilutes it in a solution that can be sprayed onto the wound. This allows the patient's skin cells to populate the wound and regenerate new skin. By enabling earlier application of skin grafts, ReCell significantly reduces both the risk of infection and scarring. This technique is now used globally.

Figure 5.20 Professor Fiona Wood was the recipient of the Australian of the Year Award in 2005.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Second line of defence

phagocytosis a cellular process where a white blood cell engulfs and ingests a cell or large particle to break it down using enzymes

If pathogens manage to bypass the first line of defence, internal defences are activated. Initially, special proteins assemble to tag the pathogens, marking them for destruction. Within a few hours, white blood cells known as phagocytes begin to engulf the pathogens through a process called **phagocytosis**. This process triggers inflammation, which supports the immune response by increasing blood flow and the permeability of capillaries in the infected area, actively bringing more immune cells to the site of an infection.

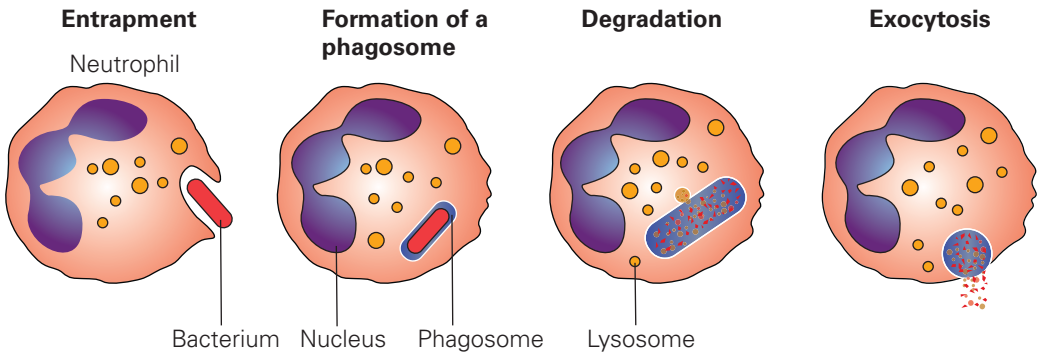


Figure 5.21 Phagocytosis by a white blood cell

innate immunity the body's immediate, non-specific defence mechanism against pathogens, involving physical barriers and immune cells that respond quickly to infections

The first and second lines of defence are known as **innate immunity**, providing immediate but non-specific protection. Innate immunity responds quickly to infections, recognising common features of pathogens, but does not adapt or improve with repeated exposure.

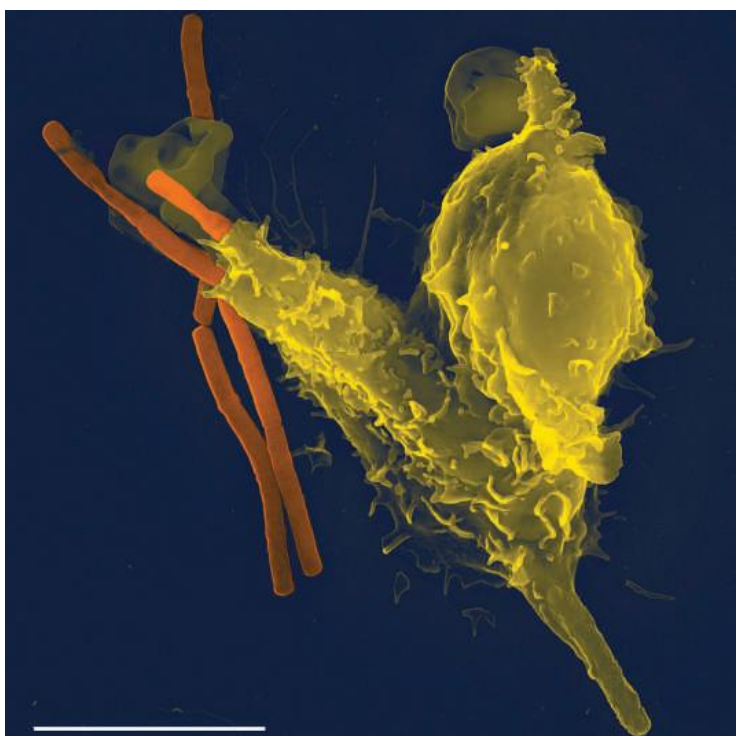


Figure 5.22 A phagocyte (yellow) targets *Bacillus anthracis* (orange), the bacterium causing anthrax, by engulfing it through phagocytosis.

Third line of defence

adaptive immunity a specific immune response that develops over time, providing a stronger response upon re-exposure

The third line of defence in the body's immune response provides specific immunity to each particular pathogen. This **adaptive immunity** can 'learn' from previous infections and respond more rapidly if the same pathogen is encountered again. This immune response typically takes a few days to become fully protective.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Immune cells must differentiate between infected or foreign ('non-self') cells and non-infected 'self' cells. They achieve this by recognising special molecules on the cell membrane called **antigens**. Healthy cells have self-antigens that do not trigger an immune response. In contrast, pathogens display foreign antigens on their surface, signalling to the immune system that these cells should be destroyed. The presence of foreign antigens activates two key types of white blood cells: **B lymphocytes** and **T lymphocytes**.

B lymphocytes (B cells) produce antibodies. These Y-shaped proteins recognise and bind to specific antigens, similar to how a lock and key must fit together. Each antibody is specific to one type of antigen (see Figure 5.23). When an antibody binds to an antigen, it signals T lymphocytes (T cells) to come and destroy the pathogen (see Figure 5.24). The T cells that perform this function are known as killer T cells. Another type of T cell, called helper T cells, acts as a team leader by providing chemical signals to other T cells and B cells, instructing them to replicate and combat the infection.

Both T cells and B cells can also form **memory cells**, which retain a record of specific pathogens or antibodies. This allows for a faster and stronger immune response if the body encounters the same pathogen again (see Figure 5.25). Sometimes, the second and subsequent responses are so effective that you might not even notice any symptoms of infection. The ability to resist a pathogen in this way is known as immunity.

antigen
a substance that triggers an immune response in the body; can be foreign (non-self) or self-antigens.

B lymphocyte
a type of white blood cell that produces antibodies to help identify and neutralise specific pathogens; also known as a B cell

T lymphocyte
a type of white blood cell that helps regulate the immune response by directly attacking infected cells or coordinating the activity of other immune cells; also known as a T cell

memory cell
a type of white blood cell formed after exposure to a pathogen that retains a record of that pathogen, allowing for a faster and more effective immune response upon future infection.

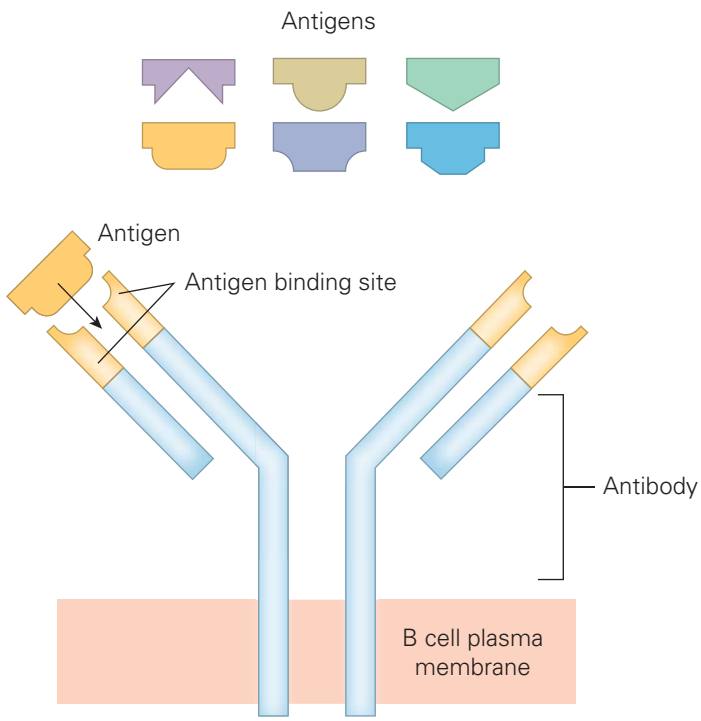


Figure 5.23 Antibodies function like a lock and key, with specific binding sites that can attach only to antigens with a matching shape and size. In this figure, only the yellow antigen fits the antibody's binding site due to its complementary shape and size. The other antigens are different shapes and cannot bind to the antibody.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

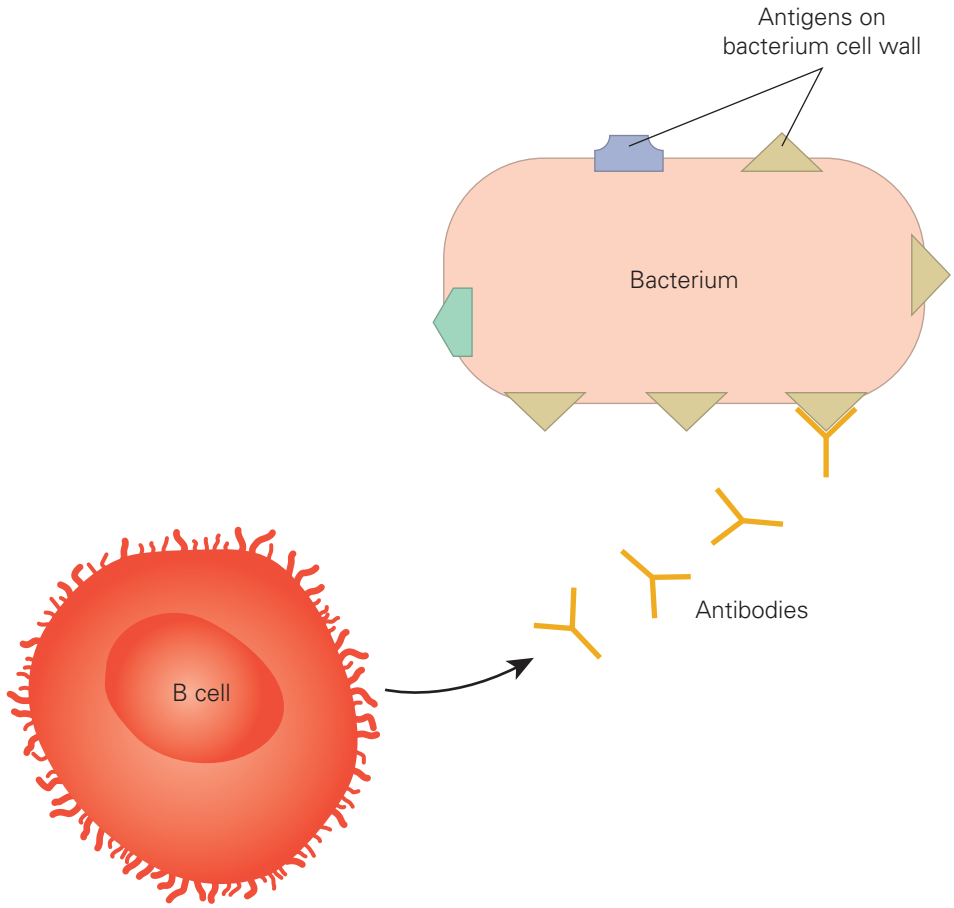


Figure 5.24 Antibodies bind to the antigens on a pathogenic bacterium, marking it for destruction and significantly shortening the bacterium's survival time.

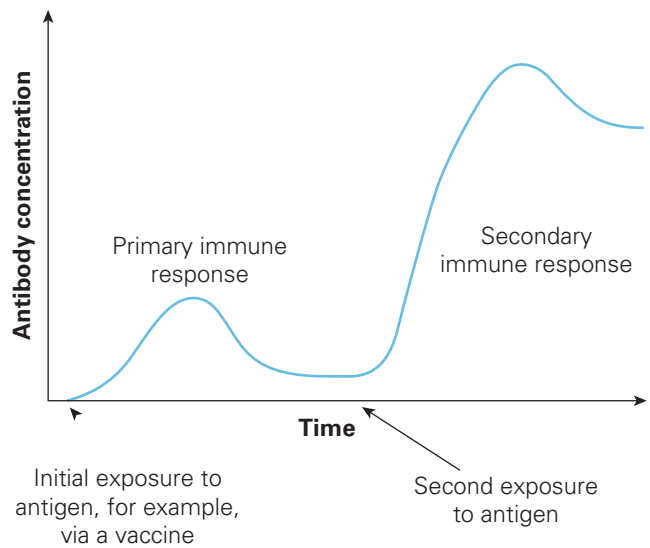


Figure 5.25 The second immune response to an antigen on the surface of a pathogen is faster and larger than the first response.

Quick check 5.6

1 **Outline** how phagocytes contribute to the second line of defence.
2 **State** the role of inflammation in the immune response.
3 **Differentiate** between B lymphocytes and T lymphocytes in the third line of defence.
4 **Describe** the function of memory cells in the immune system.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Immunisation and vaccines

Vaccines enable your body to produce antibodies against a specific pathogen without requiring a real infection. They achieve this by introducing either a dead or inactivated pathogen, or a weakened form of a living pathogen, into your body. This vaccine contains the identifying antigens but is unable to cause disease, which triggers an immune response. Your immune system recognises these antigens as a threat and produces antibodies to combat them. This process is known as **immunisation**, as it prepares you against the disease caused by that pathogen. After the immediate threat has passed, most of the antibodies will diminish, but memory cells will remain in your body, allowing for a rapid response if you encounter the pathogen again. Essentially, **vaccination** simulates the first encounter with a pathogen, offering protection without the risk of actual illness.

vaccine
a preparation made from a dead or weakened version of a pathogen, designed to stimulate immunity against that pathogen when administered through injection or ingestion

immunisation
the overall process of triggering antibody production and providing future protection against a specific pathogen, often through vaccination with a weakened or dead version of the pathogen

vaccination
the process of administering a vaccine to an individual to induce an immune response

Explore! 5.1

Albert Sabin

Albert Sabin was a renowned virologist who developed the oral polio vaccine, which has been instrumental in the global fight against poliomyelitis. There are three types of wild poliovirus (WPV): type 1, type 2 and type 3.

Unlike the earlier injectable vaccine created by Jonas Salk, Sabin's vaccine used a weakened form of the live virus, which could be administered orally. This method not only made it easier to distribute and administer but also provided longer-lasting immunity. Introduced in the early 1960s, Sabin's vaccine played a crucial role in reducing polio cases worldwide, with WPV2 and WPV3 being declared as eradicated in 2015 and 2019, respectively.

Investigate some other key scientists who have contributed to our understanding of disease, such as Louis Pasteur or Françoise Barré-Sinoussi.

Figure 5.26 The Sabin vaccine was easier to administer, often given to children on a sugar lump. The last major outbreak of polio occurred in the early 1960s, and by the late 1970s, polio had been virtually eliminated in the country. Australia was officially declared polio-free in 2000 by the World Health Organization.

Recall how a vaccine works to protect against diseases.

2 **Contrast** the roles of the antibodies and memory cells in vaccine-induced immunity.

Explore! 5.2

Human papillomavirus

Infection with certain types of human papillomavirus (HPV) can cause changes in the cells of a woman's cervix, potentially leading to cervical cancer. Cervical cancer arises from the growth of these abnormal cells in the cervix lining and is responsible for the death of one woman every two minutes worldwide. Australia is set to be the first country to eliminate cervical cancer, and this could happen as early as 2028. Since the national HPV immunisation program that was introduced in 2007, the rate of HPV infection in Australia has significantly decreased from 24 per cent among women aged 18 to 24 a decade ago to just 1 per cent. You may have received this vaccine during your school years!

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 5.27 It is hoped that over the next four decades cervical cancer will be totally eradicated.

Design an education campaign to promote the HPV vaccine for preventing cervical cancer. Start by identifying your audience, such as teenage girls, parents or school staff, before conducting research to gather information on the HPV vaccine and its benefits. Think about the medium you will use, such as social media, posters, brochures or presentations and make sure the final product is visually appealing and age appropriate.

DOC
WORKSHEET
Analysing immunisation and disease data

Developing vaccines against new and mutated pathogens

Diseases constantly evolve, with mutations creating new strains that pose ongoing challenges to public health. Viruses, such as influenza and COVID-19, frequently mutate, leading to variants that may spread more easily, evade the immune system, or resist existing treatments. These mutations necessitate continuous research and adaptation in vaccine development. Scientists monitor genetic changes in pathogens, using advanced techniques like genomic sequencing to track and analyse mutations. When new strains are identified, researchers rapidly develop and test updated vaccines to ensure they provide effective protection.

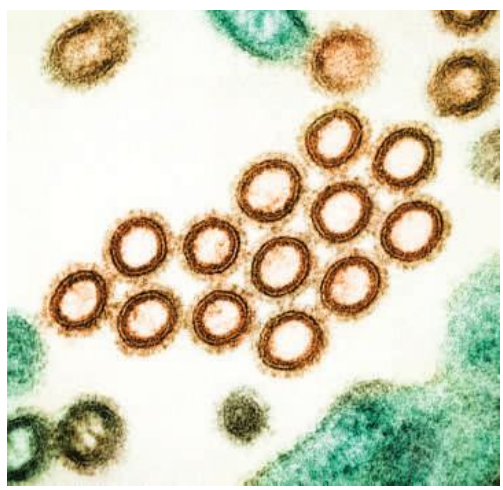


Figure 5.28 Influenza (swine strain) virus particles (coloured orange) found near the surface of an infected cell (coloured green).

Unlike traditional vaccines, which often took years to develop, the COVID-19 vaccines were created in record time. Messenger RNA (mRNA) technology, used in Pfizer and Moderna vaccines, was particularly groundbreaking. This technology allows for rapid design and production of vaccines that can be easily updated to address new variants of the virus. mRNA vaccines are being explored for vaccines against influenza, which mutates rapidly and requires frequent updates to its vaccines. Researchers are also investigating the same technology for diseases such as Zika, rabies and cytomegalovirus (CMV).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 5.2

Vaccine simulation

Use Ask a Biologist's 'Give it a Shot' vaccine simulation to explore how different factors influence disease spread. Start by choosing or designing a city and selecting a pathogen type. You can adjust settings like vaccination rates and safety measures (such as masks or social distancing). Play the simulation with various vaccination rates (10%, 30%, 50%, 70% and 90%) and record the number of healthy individuals, those who get sick but recover and those who die. Summarise your findings in a table and graph to see how vaccination rates and safety measures affect overall health and disease spread. This will help you understand how different strategies impact disease control.

Antibiotics

Antibiotics are chemical substances produced by living organisms, typically moulds, that inhibit the growth of bacteria. They are effective against specific types of bacteria but may have little to no effect on other bacterial strains.

antibiotic
a substance that inhibits the growth of bacteria inside the body

Antibiotic resistance

Antibiotics have been used in medicine since the 1930s as the primary method of fighting bacterial infections in the human body. However, the rise of drug-resistant bacteria, or 'superbugs', has become a significant concern for scientists. These superbugs cause infections that last longer, result in more severe illnesses, require more frequent doctor visits or extended hospital stays and can even lead to death.

Antibiotic resistance can occur when people do not complete their prescribed course of medication. Typically, the more sensitive and weaker bacteria are killed quickly, leading to an improvement in the patient's condition, who then might stop taking their antibiotics. However, this leaves behind bacteria that are genetically more resistant to the antibiotic. These bacteria then reproduce, creating a colony of antibiotic-resistant bacteria that can spread to others.

Figure 5.29 An agar plate covered in bacteria. Each dot represents the placement of an antibiotic disc. The size of the surrounding clear section indicates the antibiotic's effectiveness at killing that type of bacteria.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 5.4

Unnecessary antibiotics

At least 30 per cent of antibiotic courses prescribed are unnecessary, meaning no antibiotic is needed at all. For example, people often seek antibiotics for the common cold, but a cold is a viral infection, rendering antibiotics ineffective.

Antiseptics

antiseptic
a substance that prevents the growth of disease-causing microorganisms

septic
the presence of harmful pathogens in living tissue

While antibiotics can kill and inhibit the growth of bacteria, **antiseptics** prevent the growth and development of various pathogens without necessarily killing them. Antiseptics are effective against a broad range of microbes and are primarily used externally, such as in antiseptic hand washes. When harmful pathogens grow in living animal tissue, the tissue is said to be **septic**. Historically, many antiseptics used in wound care killed bacteria but also damaged or destroyed surrounding tissue. However, modern antiseptics are designed to minimise tissue injury while effectively preventing infection.

Quick check 5.8

1 **Contrast** antibiotics and antiseptics.
2 A patient in a hospital ward is isolated due to infection with a 'superbug'. **Describe** superbugs and propose why the patient needed to be isolated.
3 **Explain** why it is important to use antibiotics only as prescribed by a healthcare professional.

Investigation 5.2

Using antibacterial agents to prevent the growth of bacteria

Be careful

When handling nutrient agar plates, always wear gloves. Avoid sampling from the body or exposing the agar to pathogenic organisms. Wash your hands with soap immediately after handling the plates. Disinfect all work surfaces after collecting the plates. Once a plate is sealed, do not reopen it. After observation, sterilise the plate using an autoclave.

Aim

To determine the most effective antibacterial agent.

Planning

1 Write a paragraph about antibacterial agents and their impact on bacteria.
2 Develop a hypothesis to predict which antibacterial agents will be the most effective.
3 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
4 Complete a risk assessment for this investigation.

Materials

- Petri dish containing sterile nutrient agar
- cotton buds
- marker pen
- masking tape
- tweezers
- filter paper

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

- hole punch
- different antibacterial products (e.g. cleaning products, manuka honey, hand sanitiser)
- disposable gloves
- disinfectant
- hand wash (soap)

Procedure

1 Using a marker, split the Petri dish into quarters by drawing on the outside of the plastic base of the dish. Label three of the quarters with three of the antibacterial products you will be testing. The fourth will be your control.
2 Using a cotton bud, wipe over an object of choice, such as a phone screen, computer keyboard, computer mouse or door handle.
3 Open the Petri dish and swab the cotton bud gently over the nutrient agar.
4 Create some filter paper discs by using a hole punch.
5 Using the tweezers, dip one of the filter discs in one of the antibacterial products.
6 Place this disc in the centre of the appropriately labelled agar quarter.
7 Repeat steps **5–6** with two other antibacterial products.
8 Place a clean filter paper disc in the control quarter.

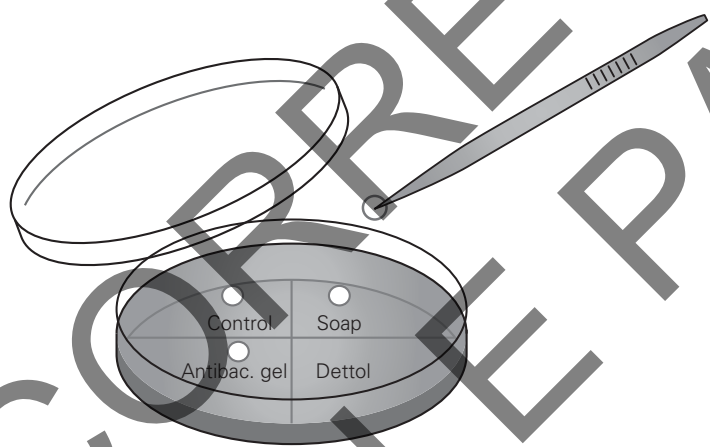


Figure 5.30 Make sure you label the outside base of the dish, not the actual agar!

9 Secure the lid with three pieces of tape.
10 Wipe down all work surfaces with disinfectant after all the nutrient agar plates have been collected.
11 The plates will be stored upside down (with the agar at the top) in an incubator at 25.0°C for 1–2 days.
12 Remove the plates from the incubator and observe the colonies of bacteria that have grown.

Warning: Microbes can produce harmful toxins, so taking careful precautions and minimising exposure can protect us from dangerous infections. It's essential to seal and destroy (by incineration or autoclaving) the plates properly. Always wash your hands after handling any plates.

Results

1 Calculate the zone of inhibition (ZOI) for each filter paper disc. The ZOI is the clear area around each disc where there is no bacterial growth. Measure the diameter of the ZOI by placing a ruler across the centre of the filter paper disc and measuring from one side of the ZOI to the other. Repeat this measurement at an angle of 90 degrees to the first to calculate the mean diameter.

continued …

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2 Sketch the colonies and ZOIs that you can see on your agar plate.

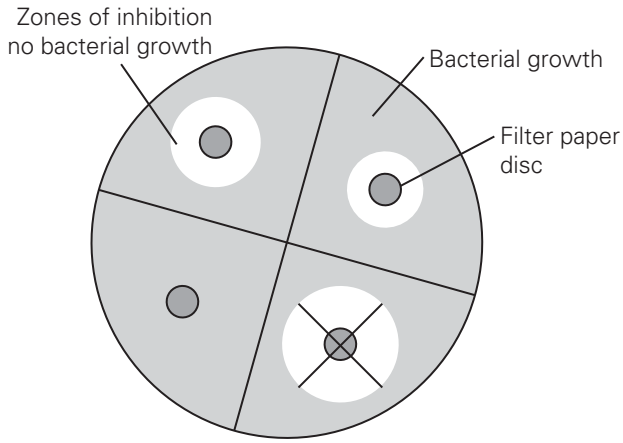


Figure 5.31 Take two measurements of each clear zone.

Discussion

1 Compare the ZOIs of each antibacterial product and the control.
2 Sequence the products in order of the most to least effective at killing bacteria.
3 Compare your results with other products that your classmates have tested. Identify the most effective product at killing bacteria.
4 Discuss why certain products may be better than others at killing bacteria.
5 Discuss the purpose of the control quarter of your agar plate.
6 Identify any potential sources of error in this experiment.
7 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 experiment regarding bacterial growth and antibacterial products. Justify your answer with data.

INVESTIGATION

Explore! 5.3

Control of disease by Aboriginal and Torres Strait Islander Peoples

Tea trees are commonly found in New South Wales, thriving in natural bush environments near streams and in wet areas such as swamps. Traditionally, the Bundjalung People would heat tea tree leaves and inhale the vapours to treat coughs and colds. They also used the leaves to create a warm, wet poultice for treating wounds and infections topically. Scientific studies have confirmed that the antiseptic properties of tea tree oil are due, in part, to its active compounds.

The swampy areas where tea trees grow are known as 'healing lakes'. When tea tree leaves fall into these waters, they slowly infuse in the water, turning it a tea colour while preserving the essential oils. Tea tree lakes were often considered sacred, particularly for women, and used in significant ceremonies, including childbirth, in Bundjalung Country.

Figure 5.32 The water is coloured by tannins from the nearby tea trees.

Use the internet to research other Aboriginal and Torres Strait Islander Peoples' use of plants to prevent or control disease.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 5.33 The Gumbaynggirr People use the sap of bloodwood trees as an antiseptic.

Section 5.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 5.2 questions

Remembering

1 A lymphocyte is a special type of white blood cell. **Identify** the two different types of lymphocyte.

2 **Define** the term 'antigen'.

3 **Identify** the primary role of the first line of defence in the immune system

Understanding

4 Antimicrobial substances A, B and C were tested for their effectiveness against a strain of bacteria growing on agar as illustrated in Figure 5.34. Interpret the results shown by answering the following questions.

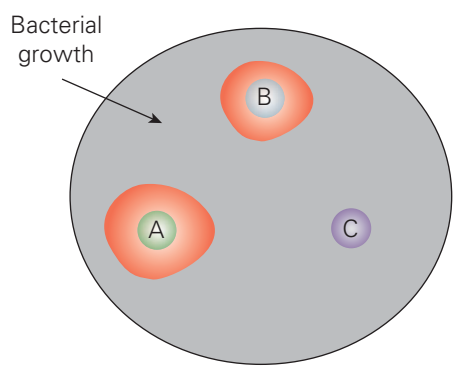


Figure 5.34 Bacterial growth

a Of the antimicrobial substances tested, which was the most effective? **Explain** your reasoning.

b Of the antimicrobial substances tested, which was the least effective? **Explain** your reasoning.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

5 **Outline** how immunisations can help fight disease.
6 **Compare** the role of antibiotics and antiseptics.
7 **Outline** the difference between non-specific immunity and specific immunity.

Applying

8 The body's immune system may sometimes start to recognise 'self' antigens as foreign and 'non-self'. **Propose** what might happen in this case.
9 Given a scenario where a patient has a burn injury, **identify** how spray-on skin technology might help prevent infection.

Analysing

10 'Superbugs' are strains of bacteria that have adapted and become resistant after coming into contact with an antibiotic. **Examine** how the development of antibiotic-resistant bacteria poses a challenge to treating infections.
11 **Analyse** why it is important for the immune system to have both non-specific and specific lines of defence.

Evaluating

12 **Contrast** the first, second and third lines of defence. You may create a Venn diagram to present the information.
13 Herd immunity describes a population's resistance to a particular disease if a high proportion of individuals within the population are immune to the disease, usually through vaccination. Based on this information and what you have learned about how vaccination works, formulate and **evaluate** positive and negative viewpoints towards compulsory vaccination of children.

14 **Discuss** the potential consequences of not completing a prescribed course of antibiotics for a bacterial infection.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

5.3 Disease transmission and management

Learning outcomes

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

1. describe infectious disease transmission and use modelling to investigate it.
2. describe and compare epidemics, endemics and pandemics.
3. describe ways to reduce the incidence of infectious and non-infectious diseases.
4. investigate data relating to a common non-infectious disease and interpret it to describe trends.

WORKSHEET infection control and data

Disease transmission

Disease transmission describes the various ways infections are spread from one person to another.

Direct transmission occurs when a pathogen is transferred directly from an infected individual to a susceptible host through physical contact. This can involve touching, kissing or sexual contact, where infectious bodily fluids, such as saliva or blood, are exchanged. Diseases commonly spread this way include colds, flu and sexually transmitted infections.

Indirect transmission happens when a pathogen is spread from an infected individual to a susceptible host via an intermediary object or environment. This can involve contact with contaminated surfaces, such as doorknobs, utensils or shared personal items. Indirect transmission also includes airborne spread through droplets or spores that linger in the air. Common examples include illnesses like tinea (athlete's foot) and respiratory infections, which can be contracted by touching contaminated surfaces or inhaling infected droplets.

Foodborne transmission occurs when pathogens are ingested through contaminated food, leading to gastrointestinal illnesses. This can happen due to improper food handling, undercooked meals, or consumption of contaminated ingredients. Common foodborne diseases include salmonella and *E. coli* infections.

Waterborne transmission happens when pathogens are ingested through contaminated water sources. This often occurs in areas with inadequate sanitation, leading to outbreaks of diseases such as cholera and giardiasis when people consume untreated or contaminated water.

Vector transmission refers to the transfer of pathogens from one host to another through a living organism known as a vector, which typically does not cause the disease itself. Vectors often include insects, such as mosquitoes and ticks, that carry the pathogen from an infected host to a new host. Examples of vector-borne diseases include malaria (transmitted by Anopheles mosquitoes) and Lyme disease (transmitted by ticks). In these cases, the vector plays a crucial role in the lifecycle and spread of the pathogen.

direct transmission the immediate transfer of pathogens from an infected individual to a susceptible host through physical contact

indirect transmission when pathogens are spread to a susceptible host via contaminated objects, surfaces or airborne droplets

vector transmission the transfer of pathogens from an infected host to a susceptible host through a living organism that carries the pathogen without causing the disease itself

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Table 5.6 outlines the main modes of transmission.

Mode of transmission	Description	Example
Direct contact	Spread through immediate contact with infected skin or bodily fluids.	A person with a cold sore kisses another individual, transmitting the herpes simplex virus.
Indirect contact	Spread through contact with contaminated objects	A student with tinea (fungal infection) showers at a camp without wearing thongs. Another student uses the same shower and contracts the infection.
Airborne	Pathogens are transmitted via droplets from coughs and sneezes, or by airborne spores.	An individual with the common cold (rhinovirus) sneezes on a train, and a nearby passenger wakes up with the infection the next day.
Waterborne	Pathogens in contaminated water can cause infection when ingested.	A person contracts typhoid after drinking untreated water in a developing country.

Table 5.6 Modes of infectious disease transmission

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Mode of transmission	Description	Example
Foodborne	Pathogens in contaminated food cause illness when ingested.	A person contracts salmonella after eating undercooked poultry.
Vectors	Disease-carrying organisms transmit pathogens.	A tourist in Papua New Guinea is bitten by a mosquito and contracts malaria.

Table 5.6 *(continued)*

Other factors in the spread of infectious diseases

Other factors may also contribute to the spread and impact of diseases. Temperature and climate play a crucial role in the proliferation of pathogens and vectors; for instance, warmer climates can facilitate the breeding of mosquitoes, leading to increased transmission of diseases like malaria and dengue fever. Conversely, cold temperatures can contribute to the spread of respiratory infections such as influenza. Socioeconomic status is another significant determinant, as individuals in lower socioeconomic brackets often face barriers to accessing healthcare, live in overcrowded conditions, and may lack resources for adequate nutrition and sanitation. These conditions can exacerbate the spread and severity of diseases.

Figure 5.35 Mosquito larvae in water

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

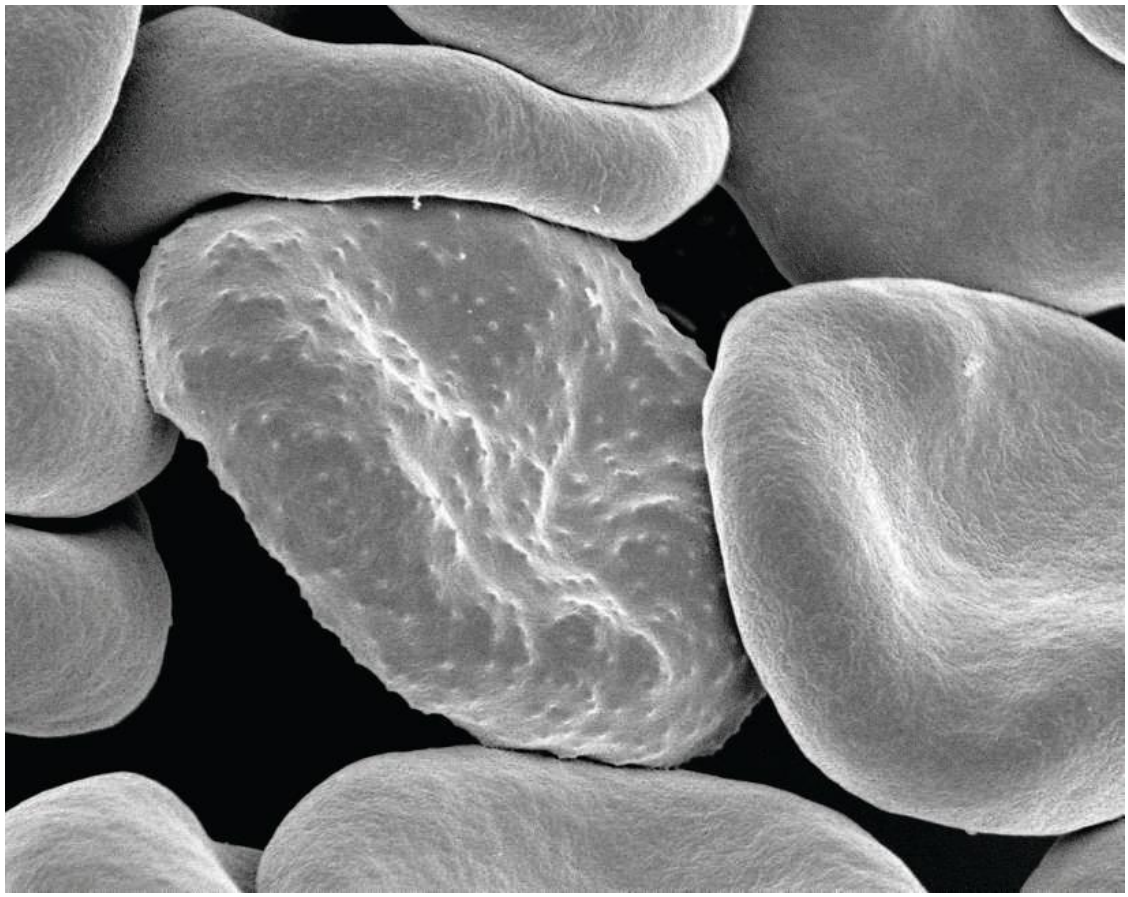


Figure 5.36 This electron micrograph shows red blood cells infected with *Plasmodium falciparum*, the parasite responsible for malaria in humans. As the parasite develops, it forms protrusions known as 'knobs' on the surface of the host red blood cells. These knobs help the parasite evade the immune system. The PlasProtecT vaccine is a promising malaria vaccine developed by Griffith University in Queensland that is designed to target *P. falciparum* by stimulating the immune system to recognise and fight the parasite.

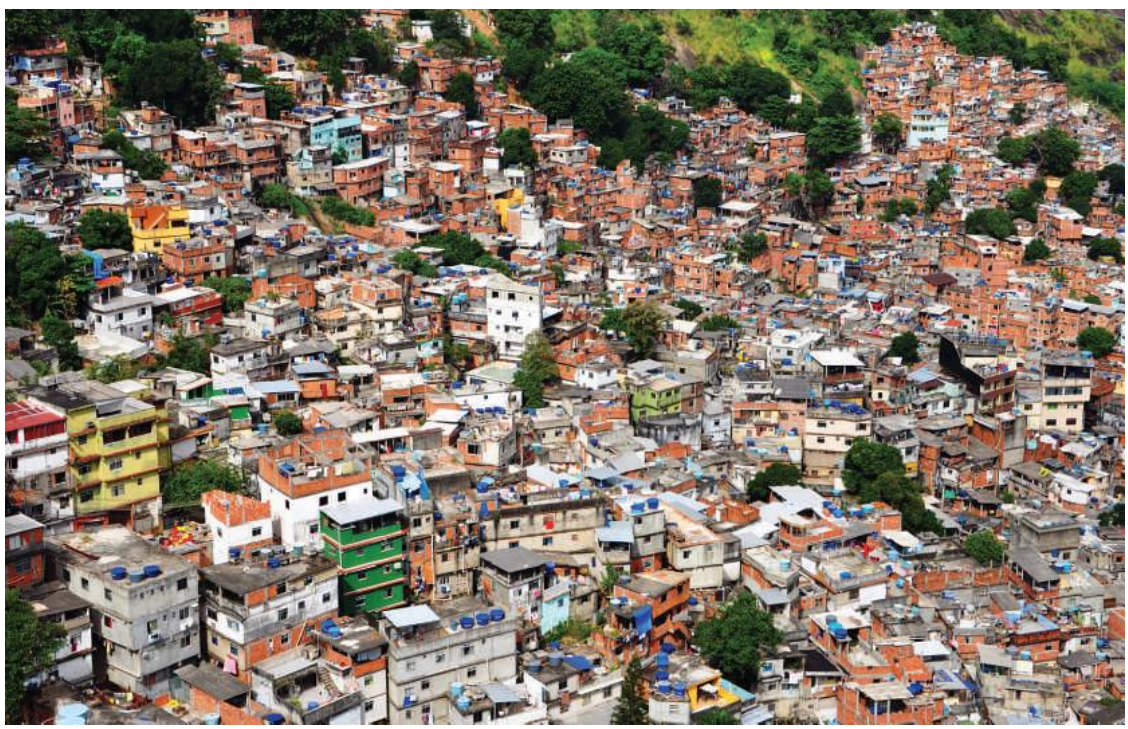


Figure 5.37 Diseases spread faster in overcrowded conditions, such as the Rocinha favela in Rio de Janeiro, Brazil.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 5.9

1 **List** the main modes of disease transmission.
2 **Explain** the role of socioeconomic status in disease spread.

Monitoring disease

The World Health Organization (WHO) oversees and analyses the spread of diseases around the world. It classifies diseases as endemic, epidemic or pandemic, providing guidance on international health responses. The WHO also allocates resources and implements strategies to effectively manage and control disease outbreaks, ensuring a coordinated global approach to public health challenges.

Epidemics occur when there is a sudden and sharp increase in the number of cases of a disease above what is normally expected in a specific area or population. This rapid rise can overwhelm local healthcare systems and lead to significant public health concerns. For example, an outbreak of influenza or a foodborne illness might reach epidemic proportions if a new strain emerges or if an existing strain becomes more virulent.

Endemics describe diseases that are consistently present within a certain geographic area or population. These diseases maintain a stable and predictable level of incidence over time. For example, malaria is endemic in many tropical regions, meaning that cases occur regularly and at expected rates within these areas. The steady presence of endemic diseases helps public health officials anticipate and manage the expected burden of illness.

Pandemics represent the most extensive pattern of disease spread, characterised by widespread outbreaks that cross international borders and affect multiple countries or continents. Pandemics involve a higher-than-expected number of cases globally, often due to new or highly transmissible pathogens. The COVID-19 pandemic is a recent example, demonstrating how a disease can spread rapidly across the world, requiring coordinated international response efforts and public health strategies.

epidemic
a sudden and widespread outbreak of a disease that exceeds the normal expected frequency within a specific area or population

endemic
a disease that is consistently present and regularly occurs within a specific geographic area or population

pandemic
a global outbreak of a disease that affects a large number of people across multiple countries or continents

Quick check 5.10

1 **Define** epidemic, endemic and pandemic.
2 **State** an example of each type of disease pattern (epidemic, endemic, pandemic).

INVESTIGATION

Explore! 5.4

Disease outbreak

Investigating disease outbreaks provides valuable insights into how epidemics and pandemics are managed and controlled. By examining specific outbreaks – such as of the Ebola virus in Sierra Leone (2014–2016), cholera in Haiti (2010) or the Hendra virus in Queensland and New South Wales (2011) – we can understand the strategies used to track and manage these diseases. Data plays an important role in this process, with graphs and tables helping to visualise the spread and impact of the outbreak.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 5.38 By the end of the 2014–2016 Ebola virus epidemic in West Africa, 28 616 people had been infected and 11 310 had died.

1. Choose one specific disease outbreak to investigate.
2. Gather information on the outbreak, including how it spread, the impact on affected communities and the response measures taken.
3. Collect and process data related to the outbreak, such as case numbers, geographic spread and response efforts. Create graphs and tables to clearly present this data.
4. Assess the effectiveness of the measures used to manage and prevent the disease during the outbreak. Consider factors such as public health interventions, vaccination efforts and treatment strategies.
5. Explore how new technologies, like DNA sequencing and nanotechnology, could improve future outbreak responses. Propose ways these technologies could be integrated into disease management and prevention strategies.
6. Prepare a presentation summarising your research, data analysis, evaluation of measures and proposed technological solutions.

Reducing the incidence of disease

Managing and reducing the incidence of diseases is crucial for enhancing public health and improving quality of life. Infectious diseases spread from person to person or through contaminated environments, so public health efforts to control their spread focus on promoting good hygiene practices, implementing quarantine measures during outbreaks and ensuring widespread access to vaccinations and medical treatments.

In contrast, non-infectious diseases are often linked to lifestyle choices, environmental factors or genetic predispositions. Addressing these conditions involves public education about risk factors such as smoking, poor diet and lack of physical activity, in addition to enforcing health policies like tobacco control measures and promoting healthier lifestyle choices. Ensuring access to healthcare services for early detection and management can also help address these public health concerns.

WORKSHEET
Investigate data for a non-infectious disease and its management

Effective strategies to achieve this include a combination of medical, educational and environmental interventions. The goal is to lower the number of new cases and (for infectious disease) prevent further spread. Table 5.7 outlines the various ways strategies that can be used to reduce the incidence of disease.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Strategy	Description	Examples
Vaccination programs	Use vaccines to stimulate the immune system and prevent specific diseases	Immunisation against measles, influenza, COVID-19
Public health education	Educate the public on healthy practices and disease prevention	Campaigns on hand hygiene, safe food practices, stopping smoking
Improving sanitation and hygiene	Ensure access to clean water, proper waste disposal and personal hygiene	Clean drinking water programs, public restrooms, sanitation facilities
Disease screening and early detection	Regular screening for early detection and management of diseases	Mammograms for breast cancer, blood tests for diabetes
Healthy lifestyle promotion	Promote diet, exercise and avoidance of harmful behaviours	Nutrition programs, exercise classes, anti-smoking campaigns

Table 5.7 Strategies to reduce the incidence of disease

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Strategy	Description	Examples
Access to healthcare	Provide affordable and accessible healthcare services for prevention and treatment	Community health clinics, subsidised healthcare programs
Vector control	Control vector populations to prevent diseases transmitted by insects	Mosquito control programs, use of insect repellent
Quarantine and isolation	Isolate affected individuals and implement quarantine to prevent disease spread	Isolation of COVID-19 patients, quarantine for Ebola outbreaks
Policy and legislation	Implement and enforce public health policies and regulations	Food safety regulations, vaccination mandates, environmental health laws

Table 5.7 *(continued)*

Quick check 5.11

1 **Explain** how vaccination contributes to disease prevention.
2 **Describe** the role of public health education in disease prevention.
3 **State** the main differences between infectious and non-infectious disease management.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Explore! 5.5

The COVID-19 pandemic

Governments and people worldwide were caught off guard when a flu-like infection emerged in Wuhan, China, in late 2019. The virus was identified and classified on 7 January, just days before the first death was reported. By 20 January cases began to appear outside China and the virus rapidly spread across the globe. By 7 March there were 100 000 confirmed cases worldwide and on 11 March the World Health Organization declared COVID-19 a global pandemic. By 3 April the number of cases had reached 1 million and by early May only a few countries had remained unaffected, with over 220 000 deaths reported.

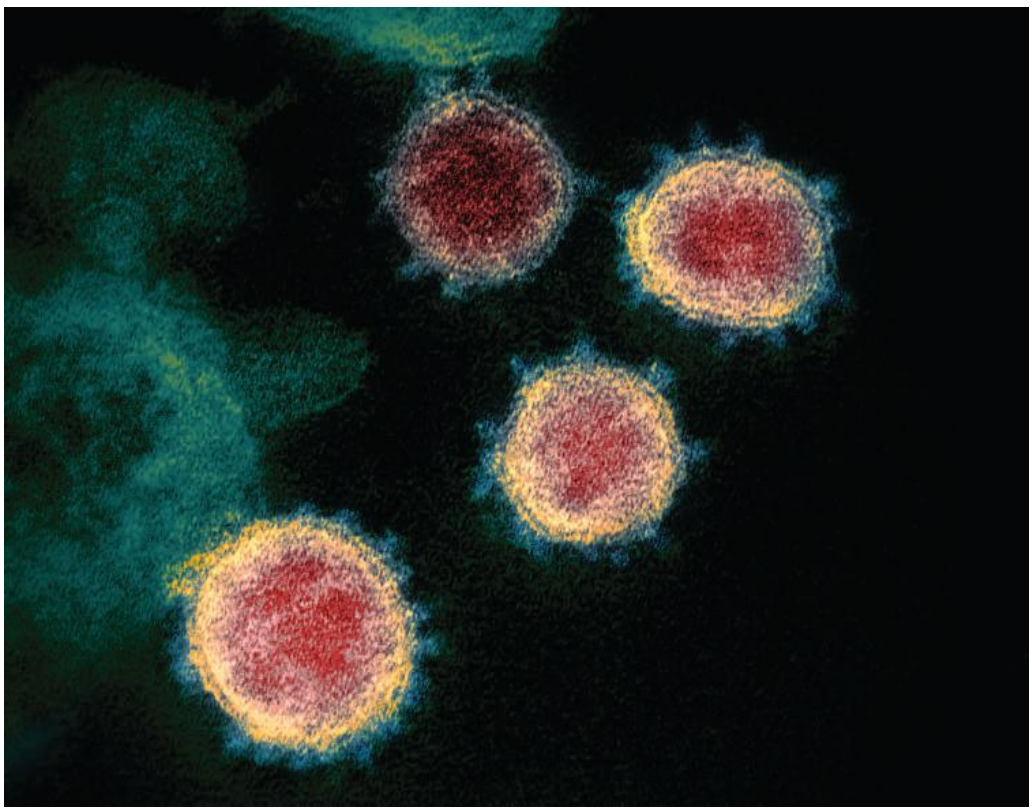


Figure 5.39 The virus that causes COVID-19

In response to the pandemic, Australia's national, state, and territory governments implemented extensive measures to curb the spread of the virus within the community. These measures included travel restrictions, business closures, bans on gatherings and directives for people to work, study and stay at home except for essential activities.

The 'lockdown' periods and physical distancing measures have marked a significant chapter in our history. As you reflect on those unprecedented times, use the internet to research the current status of COVID-19 and advancements in our understanding of the virus to answer the following questions.

1. Differentiate between the terms 'coronavirus', 'SARS-CoV-2' and 'COVID-19'.
2. How does COVID-19 compare to the seasonal flu in terms of symptoms, transmission, and impact?
3. People who become severely ill with COVID-19 often experience a decline after a week of mild symptoms. What does this suggest about their immune system's response?
4. Evaluate the effectiveness of various public health measures implemented in different countries during the pandemic.
5. Why was physical distancing an important public health measure for COVID-19?
6. How does vaccination play a crucial role in managing the SARS-CoV-2 virus?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 5.3

Investigating obesity as a public health issue

Obesity has become a significant public health issue in Australia, affecting a substantial portion of the population. Defined as having a Body Mass Index (BMI) of 30 or higher, obesity is associated with a range of serious health problems, including type 2 diabetes, heart disease, stroke, and certain cancers. In recent years, the prevalence of obesity in Australia has risen sharply, reflecting a global trend towards increasing obesity rates. Investigate the cause, effects and strategies that the Australian Government are using to prevent and manage obesity.

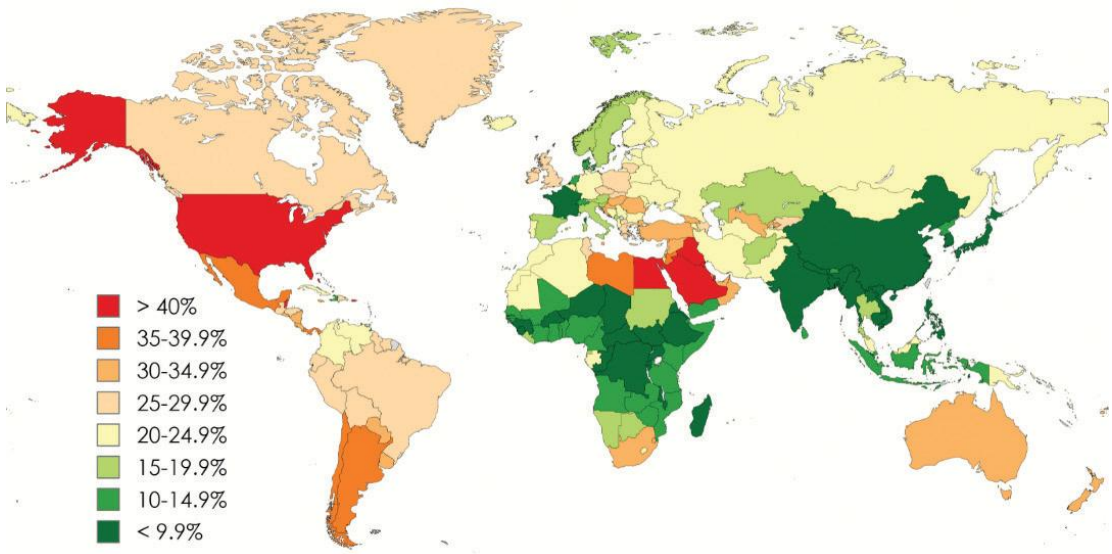


Figure 5.40 Obesity rates among adults by country in 2022, according to the World Health Organization (WHO)

Practical skills 5.3

Modelling disease transmission

To understand how infectious diseases spread, we can use models to visualise the process. In this activity, you'll use sodium hydroxide (NaOH) and phenolphthalein to simulate how a disease might spread. You'll see how the 'infection' moves through a series of containers.

Aim

Investigate how infectious diseases spread using simple models.

Materials

- sodium hydroxide (NaOH) solution
- water
- phenolphthalein solution
- pipette
- beakers or clear containers
- online simulation tool (optional)

Note: Before class, one test tube will be filled halfway with 0.1 M NaOH, and the others will be filled with distilled water.

Procedure

1 You will be given a test tube and a pipette. The distribution of these test tubes is random. Remember, one of these test tubes contains NaOH.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2 Walk around the room with your test tube. When your teacher says "stop", use your pipette to exchange a drop of fluid with the student closest to you. Repeat this process until you have completed at least three exchanges.
3 Add a drop of phenolphthalein to each test tube. If the fluid turns pink, the test tube contains NaOH and is considered 'infected'. Count how many students now have an 'infected' test tube.

Discussion

1 After the activity, how many test tubes turned pink? What does this indicate about the spread of the 'infection'?
2 How does this activity help us understand the spread of real infectious diseases? What are some similarities and differences?
3 If you had to limit the spread of the 'infection' in this activity, what changes would you make to the process? How could these changes relate to controlling the spread of actual diseases?
4 Use an online simulation tool to model the spread of infectious diseases. Adjust variables such as transmission rate and infection control measures to see how different factors affect the spread of the disease.

Section 5.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 5.3 questions

Remembering

1 **Recall** the mode of disease transmission that occurs when pathogens in contaminated food cause illness when ingested.
2 **Distinguish** between an endemic and epidemic.
3 **Name** three strategies that can be used to reduce the incidence of disease.

Understanding

4 **Explain** how direct contact transmission occurs.
5 **Describe** how temperature and climate are significant in the spread of diseases.

Applying

6 **Select** two preventive measures for a school setting to reduce the spread of airborne diseases.
7 **Identify** how improving sanitation in a developing country help reduce waterborne diseases. Provide an example.
8 If a new strain of influenza is detected, **identify** the immediate actions that public health officials should take to manage it.

Analysing

9 **Analyse** the role of socioeconomic status in the spread of diseases.
10 **Examine** how vector control measures could influence the incidence of malaria in tropical regions.

Evaluating

11 **Assess** the importance of global coordination in managing pandemics. How did international efforts influence the COVID-19 response compared to local efforts?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

	Success criteria I am now able to…	Linked questions
5.1	distinguish between infectious and non-infectious disease.	
5.1	identify causes of non-infectious disease, and infectious diseases caused by pathogens.	
5.1	investigate Australian technological advances to address disease.	
5.2	identify and describe how the immune system opposes the entry of pathogens.	
5.2	describe how immunisation stimulates the body to produce antibodies to fight infection.	
5.2	investigate Aboriginal and Torres Strait Islander Peoples' use of plants against disease.	
5.2	write a report analysing immunisation and disease data to identify patterns and relationships.	
5.3	describe infectious disease transmission and use modelling to investigate it.	
5.3	describe and compare epidemics, endemics and pandemics.	
5.3	describe ways to reduce the incidence of infectious and non-infectious diseases.	
5.3	investigate data relating to a common non-infectious disease and interpret it to describe trends.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Data questions

Type 2 diabetes is a condition that affects how the body processes blood sugar. Unlike type 1 diabetes, where the body does not produce insulin at all, type 2 diabetes occurs when the body becomes resistant to insulin or when the pancreas does not produce enough insulin. This results in elevated blood sugar levels, which can lead to serious health problems over time, including heart disease, kidney damage and nerve issues. It is often linked to lifestyle factors such as poor diet, lack of exercise and obesity. Figure 5.41 shows the number of new type 2 diabetes cases per 100 000 people in Australia, differentiated by gender.

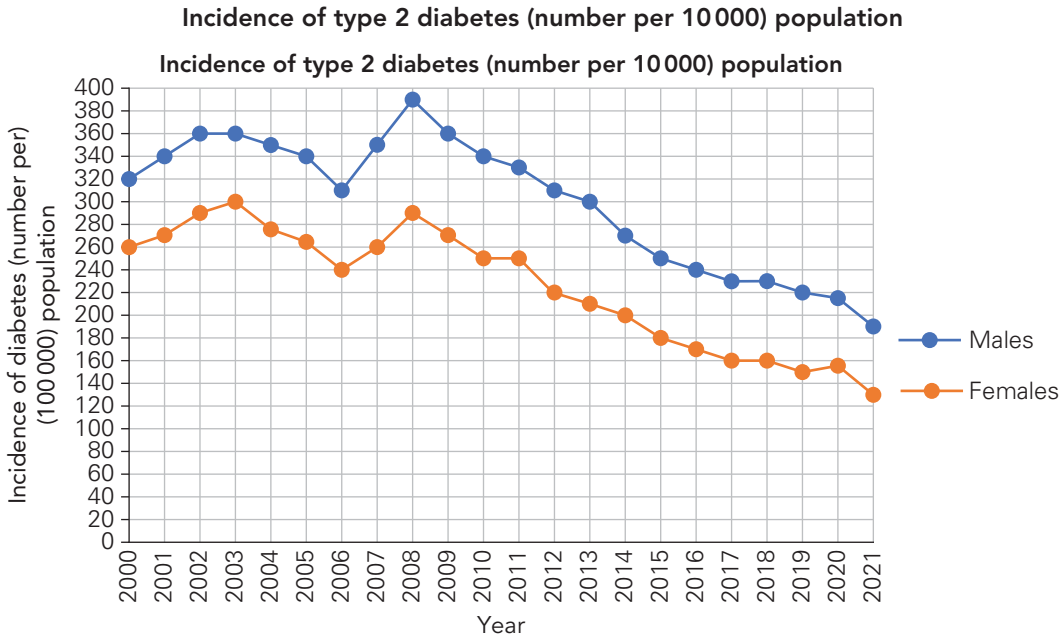
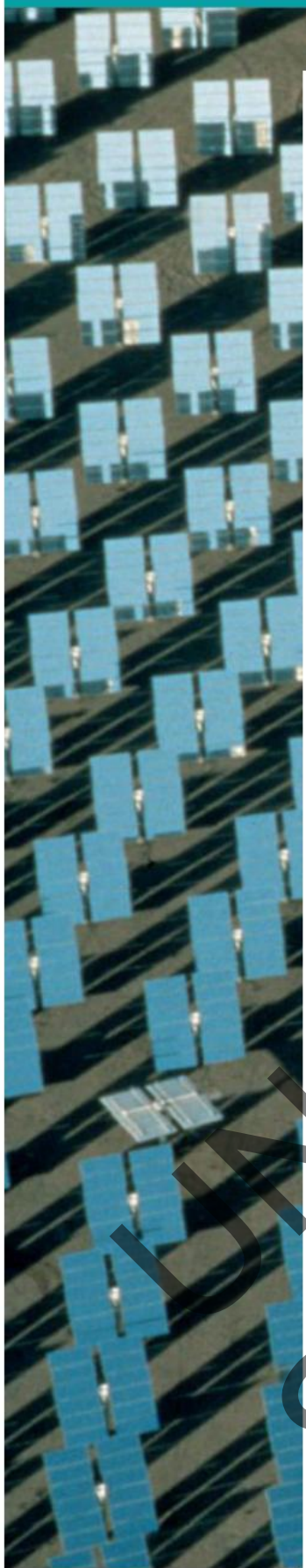


Figure 5.41 Incidence of type 2 diabetes in Australia, 2000–2021

1 **Identify** the year when the incidence of diabetes was highest for males.
2 **Identify** the year when the incidence of diabetes was highest for females.
3 **Identify** the incidence of type 2 diabetes in males in 2018.
4 **Identify** any patterns or trends that appear in the data.
5 **Contrast** the incidence of type 2 diabetes in males and females.
6 **Calculate** the percentage decrease in the incidence of type 2 diabetes between 2000 and 2021 for both males and females.
7 **Infer** a reason for the trend shown in the graph.
8 **Predict** the incidence of type 2 diabetes for females in 2030.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



STEM activity: Designing a physical distancing device

Activity instructions

You will design a device to help with physical distancing to slow the spread of a virus. Acting as biomedical engineers, you will create and test your device, analyse the data and predict its effectiveness in real-world scenarios. Then, evaluate the role of your device in promoting physical distancing and suggest improvements to this activity.

DESIGN BRIEF

Design a device that helps maintain physical distancing to slow the spread of a virus.

Suggested materials

- cardboard or foam board
- scissors
- rulers and measuring tape
- hot glue gun and glue sticks
- duct tape
- string or elastic bands
- markers
- small electronic components (optional) such as sensors, buzzers, LEDs, batteries and wires
- notebooks for sketching designs and taking notes

Be careful

Ensure all materials are used safely. Handle hot glue guns and electronic components with care. Always follow safety guidelines provided by your teacher.

Research and feasibility

1 Research how physical distancing helps prevent the spread of viruses.
2 Research existing devices and methods used to promote physical distancing.
3 List the key features of these devices and methods, and how they effectively represent real-world physical distancing.

Design and sustainability

4 Consider some design ideas, such as wearable proximity sensors, or grocery/takeaway delivery systems. Design your device. Check that your materials are safe to use and dispose of. Minimise waste wherever possible.

Create

5 Test the effectiveness of your device in promoting physical distancing. Take on the role of biomedical engineers and try to determine the device's impact on maintaining safe distances in your community.

UNCORRECTED SAMPLE PAGES

FPO

sample pages • Cambridge University Press and Assessment © Pelly, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
sample pages • Cambridge University Press and Assessment © Pelly, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Evaluate and modify

6 Evaluate the model through a group discussion and list your findings.

7 Write a short report evaluating the system you created. How could you change the design to make it more effective?

Figure 5.42 Robot waiters in Singapore

Figure 5.43 Food delivery robots

Figure 5.44 A social distancing meter using ultrasonic sensors

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

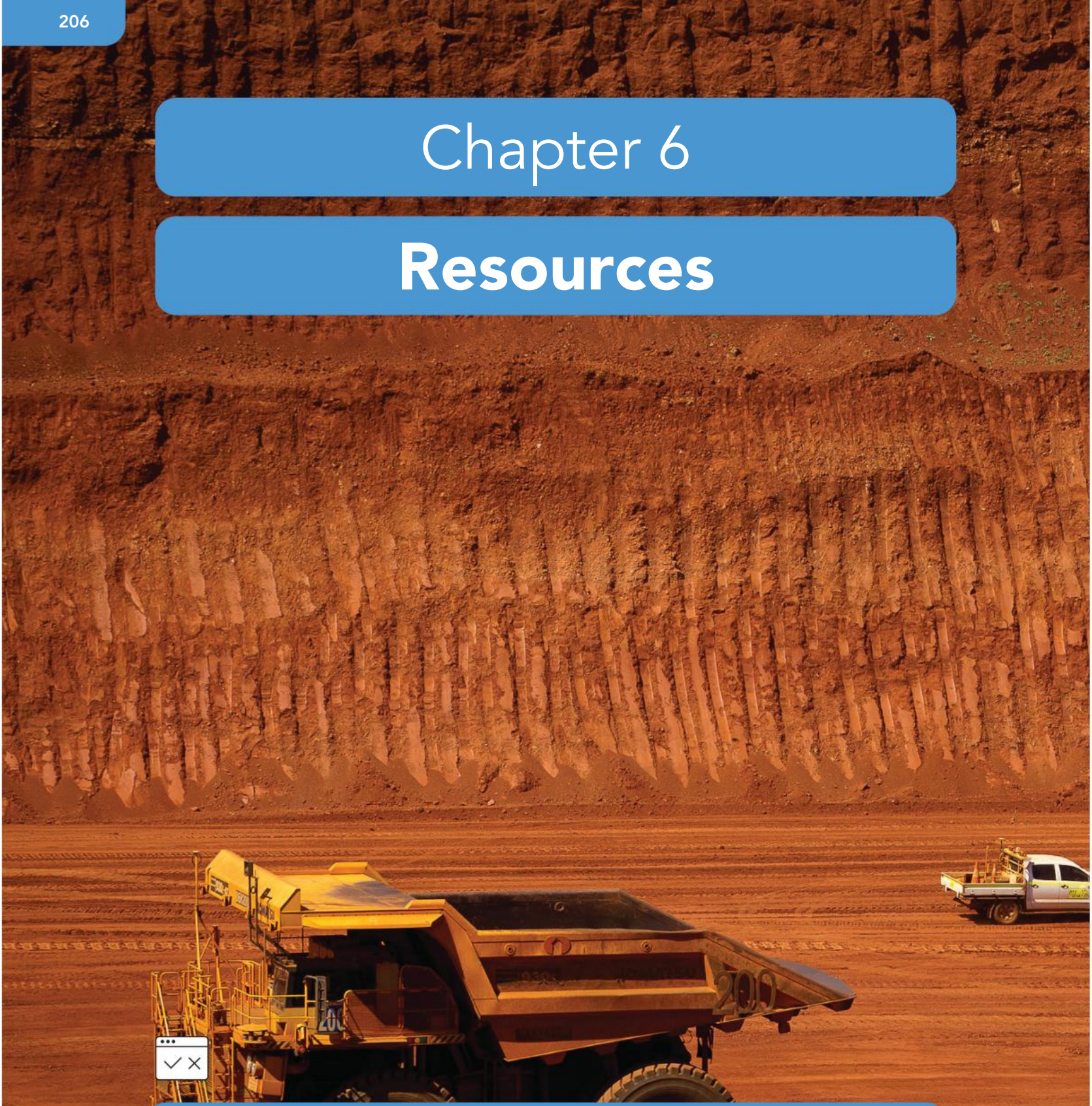
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 6

Resources

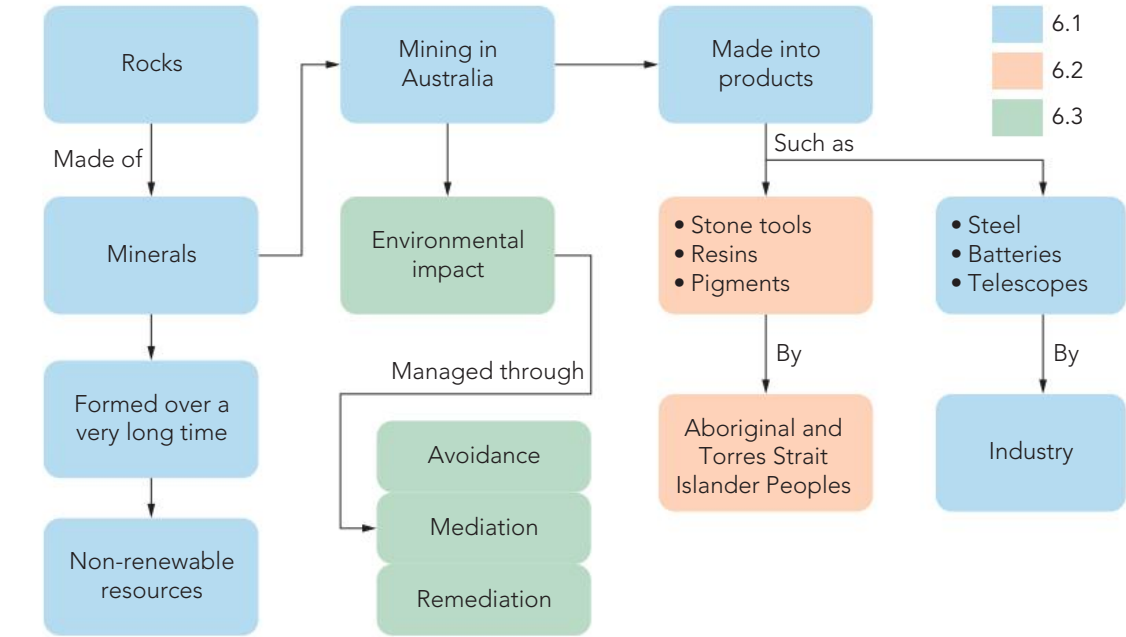


Chapter introduction

Modern society is based around the primary industries – businesses and governments that extract minerals and petrochemicals from where they formed over millions of years. These resources are then turned into products which we use every day. In this chapter, you will learn about the minerals that are minded in Australia and some of their uses. You will also learn how Aboriginal and Torres Strait Islander Peoples use natural resources, and how the environmental impact of mining can be assessed and managed.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

abiotic
biotic
ecosystem
Environment Impact Statement
exploration
leachate
mineral
phytomining
tailings dam

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6.1 Minerals and resources

WORKSHEET

VIDEO

Learning outcomes

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

1. describe the limited nature of Australia's minerals and other resources.
2. outline products made from minerals and resources extracted in Australia.

Australia is indeed a very lucky country! It is rich in natural resources that have been valuable in helping to build Australia's economy. These have provided not only for the needs of Australia but have been a source of income for the nation as they are exported to other nations who do not have the same wealth of natural resources. However, most of these resources are not renewable and will eventually run out. They are finite resources.

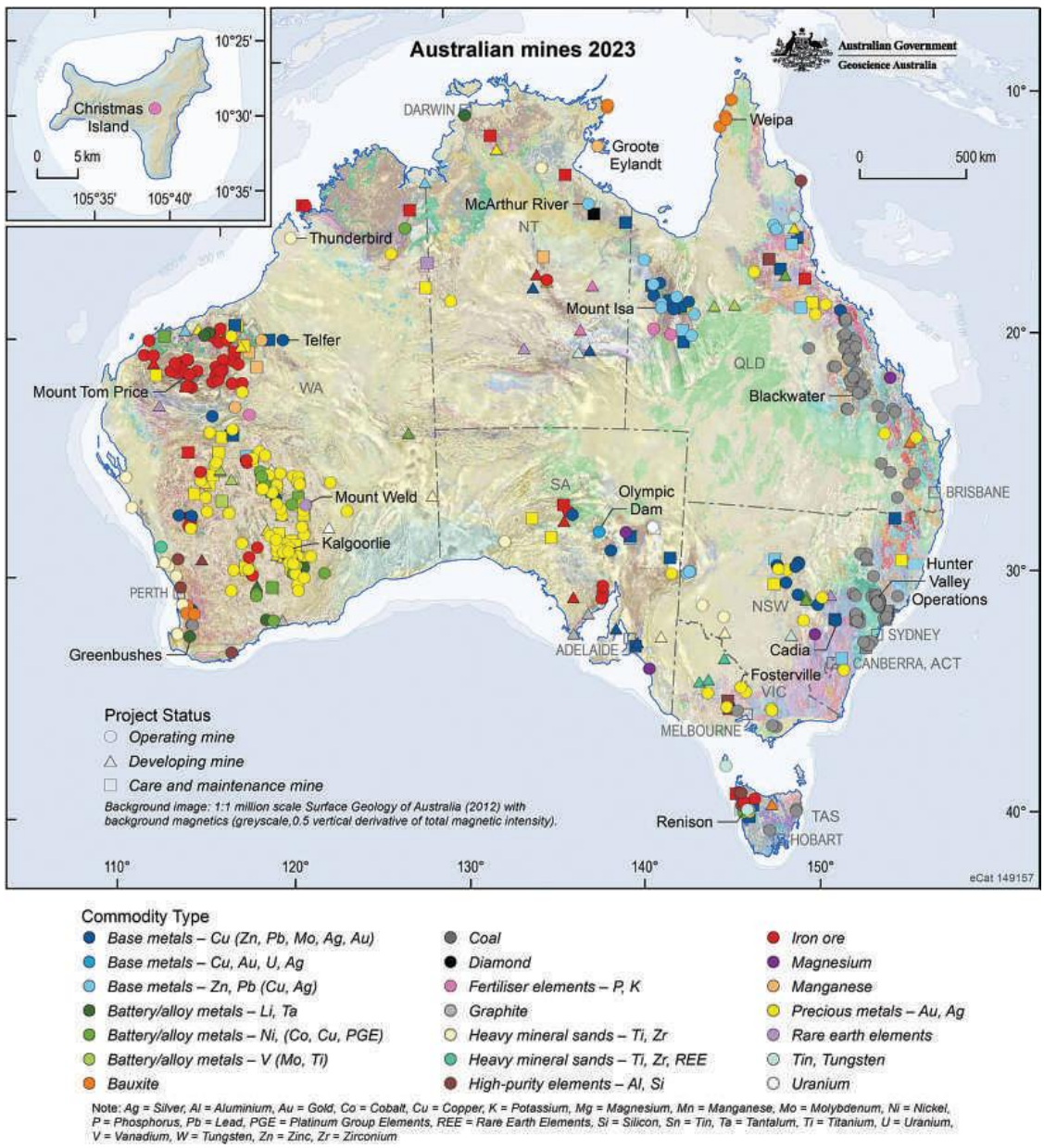


Figure 6.1 The location of significant minerals in Australia

The resources that supply Australia's energy needs are discussed in Chapter 2. These include renewable energy resources, such as solar, wind, hydroelectric and geothermal, and non-renewable energy sources, such as coal, petroleum, natural gas and uranium (although this one will last a long time). Note that in resource industries, petroleum (oil) and natural gas are usually counted as minerals, although they don't count as minerals in the scientific definition below. Apart from the energy resources, there are many other economically significant resources mined in Australia. The country is among the world's largest producers of iron ore, lithium, gold, zinc, nickel and cobalt.

Have a close look at the map in Figure 6.1. The bright red dots are the iron ore mines. Where are most of these concentrated? Notice also where most gold mines are concentrated. Now look for the coal mines. There is a pattern. If you were going to look for a place to build a mine, where do you think you might go? Looking for a resource is called **exploration**.

exploration looking for the location or extent of a resource

mineral a solid element or compound with a well-defined chemical structure

Western Australia is one of the oldest pieces of continental crust in the world and it is rich in iron. The colour of Australia's famous red earth comes from oxidised iron. In contrast, eastern Australia is relatively young in geological terms. It was once covered in forest and therefore has numerous coal deposits (made from compressed plant matter that is approximately 250 million years old). Around 66 million years ago this region of Australia experienced a period of volcanic activity: exploring these volcanic regions often results in the location of deposits of heavy metal resources.

Rocks and minerals

Minerals are the solid substances that rocks are made up of, and each mineral has a specific chemical structure that is the same throughout. Rocks, on the other hand, can be composed of several different minerals that vary throughout the structure of the rock.

Rocks form over many thousands or even millions of years. Once they have been mined and used, they are not replaced quickly. The minerals contained in rocks are used by living things, and the human body also needs different types of minerals for the elements they contain.

Some minerals are useful to humans and can be mined. Mining is the process by which minerals and other useful materials are extracted from Earth. Salt, slate, gold, marble and coal can be used as they are found. Others need to be processed to make useful products, such as metals or building materials like cement. In Australia, some of the major minerals mined are iron ore, bauxite, lithium and gold.

The extraction of metals, ores and other materials from Earth has a very long history. Archaeologists have named two periods of human history, the Bronze Age and the Iron Age, according to the metals that people were producing at that time.

Try this 6.1

The Australian mining industry

Use the internet to research some other minerals mined in Australia and what they are used for.

Iron ore

Iron is extracted from iron ores, such as the mineral hematite. However, the two most prolific iron ores found in the Pilbara region of Western Australia are called martite–goethite (M–G) and channel iron deposits (CID). Australia mines almost half the world's iron ore. Iron is used to make steel, the versatile material that is very widely used for diverse purposes from building bridges to the fork you eat your dinner with. Steel is an alloy of mostly iron with a small amount of carbon, less than 1% carbon is needed to alter the properties of iron, resulting in a much stronger material.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 6.2 Some uses of steel, an alloy of iron and carbon

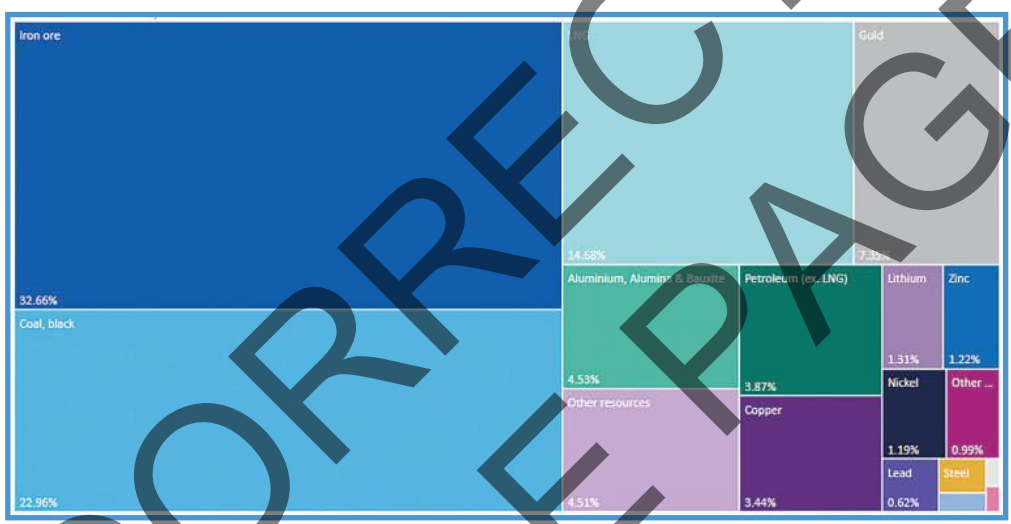


Figure 6.3 A treemap displaying the value of Australia's commodity exports in 2024. Iron ore is Australia's largest single export revenue source, bringing in A$153 billion in the 2023–24 financial year. The area of the rectangular parts in a treemap is proportional to the percentage of the whole contributed by that part.

Lithium

Australia alone produces 52% of the world's lithium. Unlike Chile, where lithium is extracted from brines (dissolved in water), Australian lithium comes from lithium rich mineral called spodumene. This is obtained from igneous rocks but also found in sedimentary rocks.

Rank	Country	2021 production (tonnes)	% of total
1	Australia	55 416	52%
2	Chile	26 000	25%
3	China	14 000	13%
4	Argentina	5967	6%
5	Brazil	1500	1%
6	Zimbabwe	1200	1%
7	Portugal	900	1%
8	United States	900	1%
	Rest of the world	102	0.1%
	Total	105 984	100%

Table 6.1 Global lithium production

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Most of the lithium mined is used for rechargeable batteries. There is a very high demand for lithium-ion batteries, but waste disposal is an environmental issue that has yet to be solved.

Figure 6.4 A lithium-ion battery of a smartphone

Figure 6.5 Coin-sized lithium batteries are used for games, small medical equipment such as blood pressure monitors, and wearable medical monitors such as for monitoring glucose levels.

Aluminium

The ore from which aluminium is extracted is called bauxite. Australia is the largest producer of bauxite in the world, producing 31% of global production in 2016. Aluminium is malleable, high strength, lightweight, resistant to corrosion and has high thermal and electrical conductivity. Among its many uses, it is used in cans and aircraft manufacture.

Figure 6.6 Aluminium is lightweight, strong and resistant to corrosion. These properties make it ideal for a variety of applications, from soft drink cans to planes.

Rank	Country	Production (tonnes)	Reserves (tonnes)
	World	327 000	30 000 000
1	Australia	110 000	3 500 000
2	Guinea	82 000	7 400 000
3	China	60 000	710 000
4	Brazil	35 000	2 700 000
5	Indonesia	23 000	1 000 000
6	India	22 000	650 000
7	Jamaica	7700	2 000 000
8	Russia	6100	480 000
9	Kazakhstan	5800	160 000
10	Vietnam	4000	5 800 000

Table 6.2 Global production of bauxite

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Gold

Gold mining has been around for thousands of years, but most of it has been extracted in the last 200 years. Gold is malleable, generally unreactive and highly conductive. It is used in jewellery, coins and many scientific instruments. Over 30% of the world's gold production comes from only three countries: China, Russia and Australia.

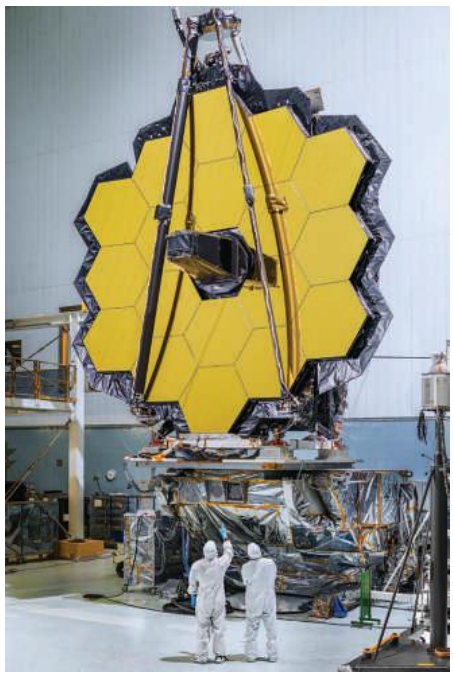


Figure 6.7 The James Webb Space Telescope is covered in a microscopically thin layer of gold to optimise the mirrors for reflecting infrared light

Figure 6.8 Olympic medals are gold plated; this means it is mostly made of silver coated with gold. Jewellery, such as the ring in this picture, is still the single largest use of all gold mined.

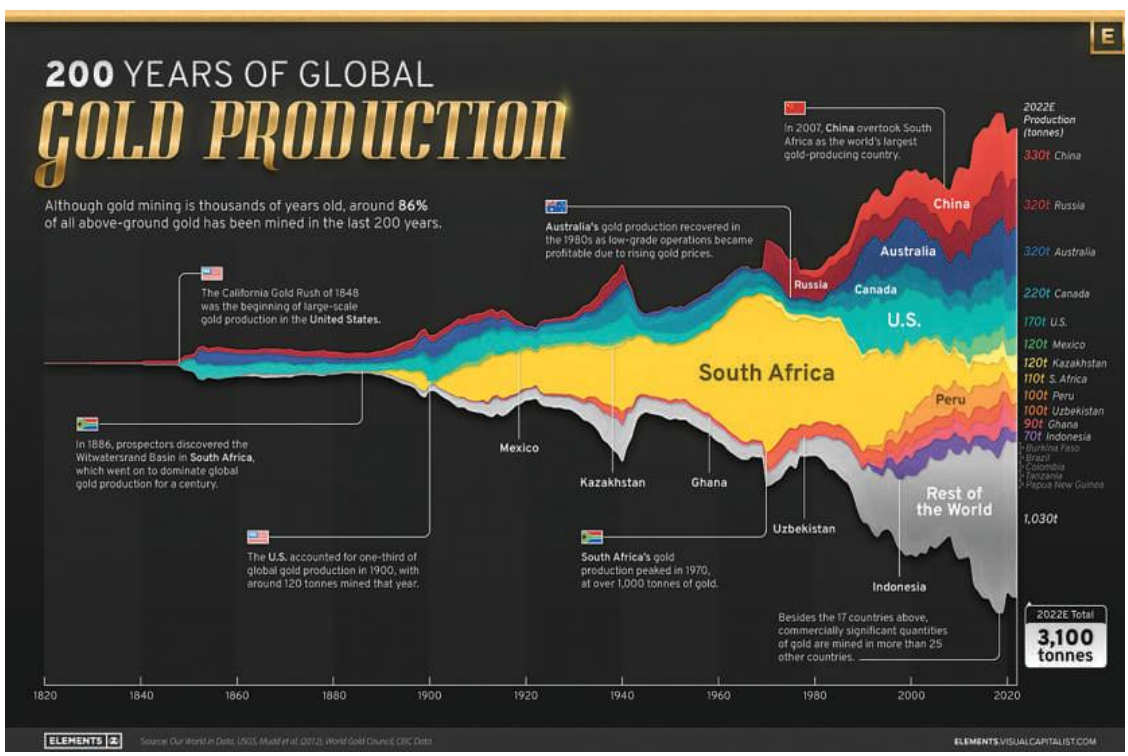


Figure 6.9 Global gold production over time

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 6.1

Opals

Opal is a silica rich gemstone. About 90% of the world's opals are from Australia, including the mining areas at Lightning Ridge and White Cliffs in New South Wales and Cooper Pedy in South Australia. The opal fields in New South Wales, Queensland and South Australia all lie within the Great Artesian Basin.

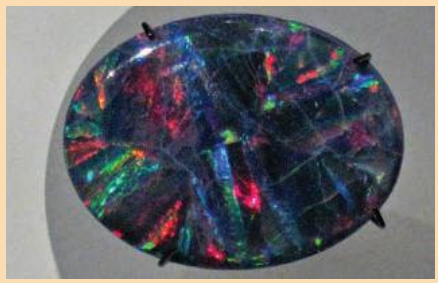


Figure 6.10 Opal from Lightning Ridge, NSW

INVESTIGATION

Explore! 6.1

Electric vehicle batteries

Electric vehicles need batteries. Conduct research on the internet and find out whether they need lithium. In your research find out why you should not dispose of lithium batteries in general rubbish and describe the environmental impact if the dependence on lithium batteries increases.

Figure 6.11 An electric vehicle charging its battery at a public charging station

Quick check 6.1

1 **Recall** which mineral is Australia's most significant export mineral.
2 **State** where the mineral from Question 1 is found.
3 **Identify** the properties of aluminium that make it so useful.
4 **Name** the ore of aluminium.
5 **Recall** the main use of lithium.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 6.2

Mining asteroids!

Is it science fiction or actually a good idea? Scientists all over the world are developing technologies to extract resources from asteroids. As many of Earth's resources are finite and extracting them has a negative impact on our environment, is it such a far-fetched idea to extract those mineral resources on asteroids where there are no damaging consequences to life or our environment? Many asteroids are rich in valuable minerals we value but the technology to achieve this and make it financially viable does not yet exist.

Figure 6.12 CSIRO's multi-resolution scanning device (MRS). The technologies used in space exploration are very applicable to mining.

Your challenge is to form an international collaboration (a group of your classmates is a good start) and design a way to mine a specific mineral of your choosing and bring it back to Earth. Your ideas can be 'science fiction' but researched to be credible. You will present your idea to the class in any way you choose (talks, interviews, videos or even a dramatisation).

Go online to access the interactive section review and more!

Section 6.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.1 questions

Remembering

1 **Recall** some metals and resources that are significant for the Australian mining industry.
2 **List** one use of:
   - **a** iron
   - **b** aluminium
   - **c** gold
   - **d** lithium.

Understanding

3 **Explain** the difference between a mineral and a rock.

Applying

4 **Propose** why electroplating with silver or gold is a very popular technique in jewellery making.

Analysing

5 **Discuss** the worldwide significance of Australia's iron ore resources. How would Australia and the world be impacted if this resource discontinued?

Evaluating

6 **Predict** whether the global demand for lithium is likely to increase or decrease. Justify your response.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6.2 Aboriginal and Torres Strait Islander Peoples' use of resources

give some examples of Aboriginal and Torres Strait Islander Peoples' use of resources.

Aboriginal and Torres Strait Islander Peoples use the minerals and natural resources found in Australia and the Torres Strait Islands for a wide range of purposes. In the past, resins and minerals were collected from the lands around them and traded between different groups. Today pigments used in artworks and ceremonies are still made from minerals found on Country.

Figure 6.13 Aboriginal performers, adorned in traditional body paint, sit on Coogee Beach as they prepare to perform in the annual Koojay Corroboree as part of National Reconciliation Week 2024.

Stone tools

In different parts of Australia and the Torres Strait, Aboriginal and Torres Strait Islander Peoples have developed varying techniques of quarrying and crafting stone tools for various purposes. Stone tools are used in day-to-day life for activities such as hunting, harvesting and preparing. Quarrying involves identifying and extracting suitable rocks from natural outcrops or from boulder fields.

Different Peoples have used a variety of rocks, such as basalt, sandstone, quartzite, chert and flint, depending on what is available on 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.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Various properties of rocks make them useful for different types of tools.

- Sandstone is often used to make tools to grind seeds.
- Basalt, a hard igneous rock is often used to make chisels, or hammer-like tools.
- Obsidian, quartzite and slate are hard but can be broken into shards with sharp edges and are used to make spear heads.

INVESTIGATION

Explore! 6.3

Making stone tools

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 Examples of the techniques and methods used in making stone tools 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 6.14 A young girl from Bow River, Western Australia, grinds stone to a powder that will be used for artworks.

Resins

Resin is a sticky flammable organic substance, insoluble in water, exuded by some trees and other plants. How often do you need glue or use items that are held together with glue? Resin is used for everything from attaching knife and woomera handles, hafting sea points to waterproofing containers and even in first aid to seal wounds.

Figure 6.15 Porcupine grass (*Triodia scariosa*) is used by Aboriginal and Torres Strait Islander Peoples to make thermoplastic resin.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

A powerful thermoplastic resin can be made from porcupine grass and grass trees. The resin is beaten out of the grass, then cleaned and heated to create a sticky black substance. As it cools, the resin hardens and can be used to fuse stone tools to wooden handles, such as spears, woomeras and axes.

Figure 6.16 An example of resin made from porcupine grass and grass trees

Pigments

Australia's red earth is abundant in an iron-rich mineral called hematite. Minerals such as hematite (red and orange) or kaolinite (a white clay mineral) are used to make pigments for painting and ceremonies by Aboriginal and Torres Strait Islander Peoples. Fixatives made from plants can also be applied to paints, enabling the pigment to bind to surfaces and increase the durability of the paintings.

Figure 6.17 Ground natural paints

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 6.18 The sandstone walls at Carnarvon Gorge, Queensland, contain stencil art paintings that are dated at approximately 4000 years old.

Go online to access the interactive section review and more!

Section 6.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.2 questions

Remembering

1 **List** three natural resources used by Aboriginal and Torres Strait Islander Peoples.

2 **Recall** the resource that grass trees and porcupine grass are used to make.

Understanding

3 **Recall** the mineral that ochre is made from and explain why it is used for creating art.

Applying

4 Aboriginal and Torres Strait Islander Peoples used stone and resins, whereas Australia's current most significant resources are metals such as iron ore and bauxite. By referring to the uses of these resources, **propose** a reason why natural resources used by Aboriginal and Torres Strait Islander Peoples in the past differ from the resources used today.

5 Imagine you wanted to make a fishing rod using the materials traditionally available to Aboriginal and Torres Strait Islander Peoples. **Write** detailed instructions, including how to obtain the materials required.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Analysing

6 The photo in Figure 6.19 below shows grooves in sandstone due to many years of Aboriginal and Torres Strait Islander Peoples using it for a particular purpose. **Deduce** why these grooves may have been formed.

Figure 6.19 Grooves in a sandstone rock

Evaluating

7 **Propose** the type of rock that would be the best for use as an axe by Aboriginal and Torres Strait Islander Peoples.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6.3 Environmental impact

Learning outcomes

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

1. evaluate the environmental impact of extracting and using a resource.

Mining of ores and minerals can have significant impacts on local environments, such as:

- soil and water contamination
- deforestation and habitat destruction
- land subsidence and sinkholes
- air pollution
- greenhouse gas emissions
- water overuse.

These impacts can be long lasting and can have significant consequences for local ecosystems, wildlife and human communities.

Look at the landscape in Figure 6.20. How could this landscape be restored to the way it was before mining began?

Figure 6.20 The United Collieries and Wambo Coal open-cut coal mine located in the Hunter Valley region, on the lands of the Wonnarua People

Environment Impact Statement document detailing the environmental (including biophysical, social and economic) costs and benefits of a development

In the past, mining enterprises were not required to repair or consider the damage to the environment at all. Companies are now required by law to submit an **Environment Impact Statement** before permission is granted to begin mining.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Before operation begins, the environment needs to be assessed accurately. The **ecosystem** and all its factors, **biotic** (living) and **abiotic** (non-living) need to be measured. If there are any endangered species, they need to be protected. Mines will disrupt the interaction between the biotic and abiotic factors, any negative effects that may affect the population must be evaluated so that the impact can be avoided or mitigated.

Mines must consider the impact of contamination of water in the area, as this may give rise to hardy weeds outcompeting the native flora and fauna. Water is an essential part of the ecosystem without which biota will be placed under significant stress. The byproducts of mining operations are known as tailings, which consist of the leftover materials after valuable minerals have been extracted from ore. A **tailings dam** is an engineered structure designed to store these byproducts. **Leachate** refers to the liquid that percolates through waste materials, often carrying dissolved substances, including heavy metals and other contaminants. In mining, leachate can arise from the interaction of rainwater with tailings or ore piles, posing risks to surrounding ecosystems and water sources if not properly managed. Together, tailings dams and leachate management are essential components of sustainable mining practices, aiming to mitigate environmental impacts.

ecosystem
the interrelationship between living and non- living components of a specific area

biotic
relating to the non-living things in an ecosystem

abiotic
relating to the non-living things in an ecosystem

tailings dam
an engineered structure designed to store the byproducts of mining operations

leachate
liquid from waste materials that carries dissolved substances including heavy metals and other contaminants

Advances in science 6.1

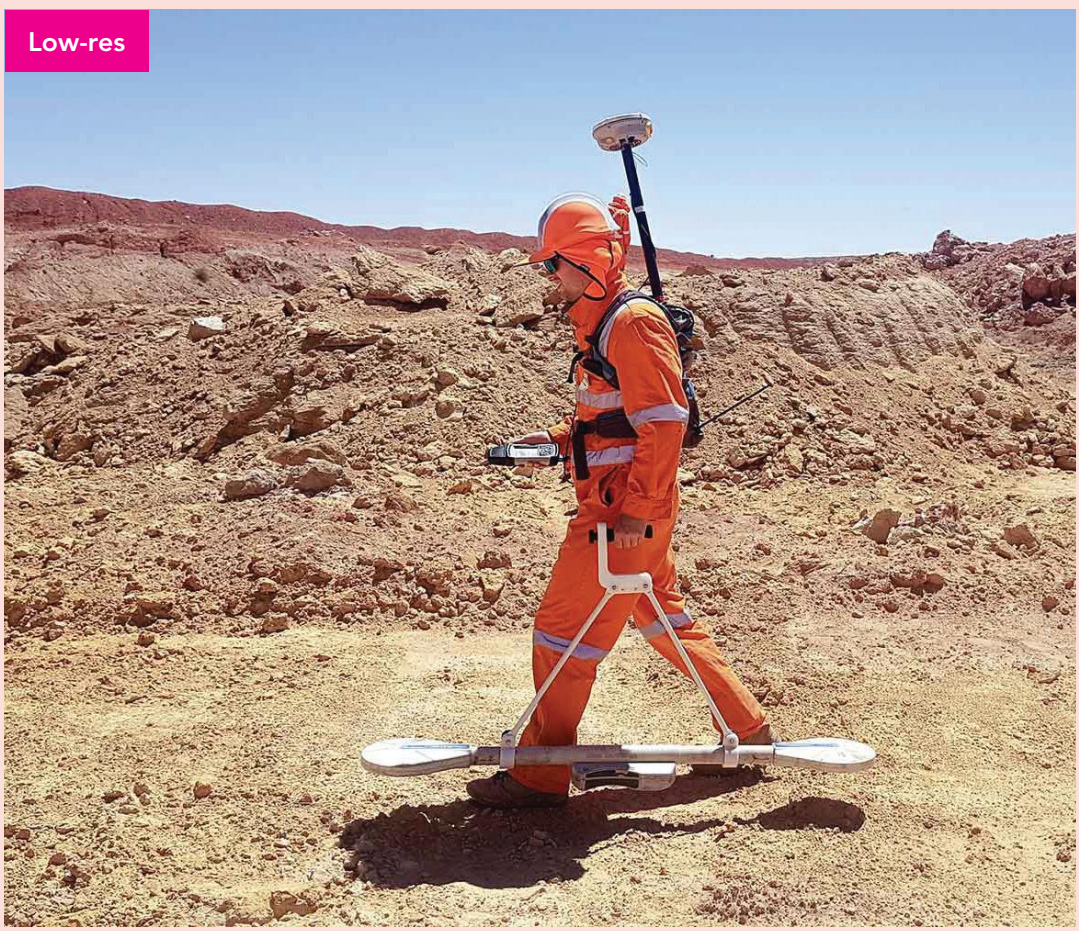


Figure 6.21 Analysis of water flow affecting a tailings dam can be monitored in detail using currently available technologies.

Specific geophysical equipment is used to conduct structural geology investigations that aim to prevent tailings dam collapses. Magnetic and seismic surveys are matched with data from boreholes and water monitoring wells to create a picture of what lies beneath the surface.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

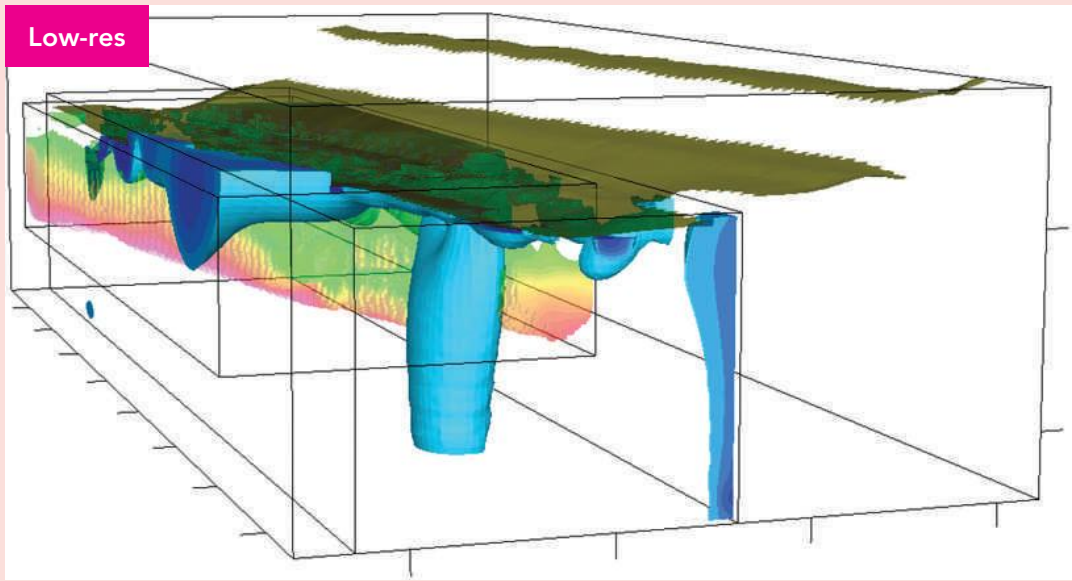


Figure 6.22 A model of the surface below a mining area created using geophysical data. This information is integral to tailing dam management to protect the environment.

Rehabilitation

When the resources in a mining site have been exhausted, the site closes, all facilities are packed up and often removed, and a rehabilitation plan is developed. The purpose of this is to return the land to the state it was in before the mine was built. For example, if it was agricultural land, then the plan would involve trying to restore the land to its original level of productivity. Rehabilitation involves scientists, government personnel, bush regenerators and local wildlife experts, among others

phytomining planting hyperaccumulator plants to absorb and accumulate the contaminants from mining

Phytomining can be used as a tool for rehabilitating areas that have been impacted by mining activities. In many cases, mining can leave behind soils that are contaminated with heavy metals and other pollutants, which can have long-term negative impacts on the environment and surrounding communities. Phytomining can be used to help remediate these contaminated soils by using hyperaccumulator plants to absorb and accumulate the contaminants. Once the plants have accumulated the pollutants, they can be harvested and removed from the site, effectively removing the contaminants from the soil. This process not only reduces the amount of pollutants in the soil, but it can also provide a potential source of revenue through the recovery of valuable metals.

Figure 6.23 The native legume *Crotalaria novae-hollandiae* is a hyperaccumulator because it retains zinc in particularly high concentrations after it is absorbed through its roots.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 6.4

Rehabilitation case study

Conduct a case study of the rehabilitation of an ecosystem after a mining activity in New South Wales. Make sure you consider:

- the mineral mined, when and by whom
- the value of the mineral, why it was mined, and what the benefits were
- the name of the ore
- how the mineral was extracted
- a description of the ecosystem before mining operations began
- whether there were any flora and fauna that needed to be relocated
- the impact on the ecosystem during the mining process
- the action taken by the mining company to minimise impact and restore it when mining activity was completed.

Compile the information and write a report aimed at the local community in which the mine is situated to justify the necessity of the mine.

Did you know? 6.2

Rehabilitation and biodiversity

Rehabilitation of the land also takes into consideration the native plants and animals that were in the site before it was mined. Disturbed areas are reshaped to reflect their original state as closely as possible, and care is taken to preserve plant species. An example of mining rehabilitation is the Woodcutters lead–zinc mine in the Northern Territory, which was closed in 1999. In 2002 it was acquired by Newmont, a mining corporation, which has rehabilitated and monitored the site as part of its commitment to sustainable business, in partnership with the Kungarakan and Warai people, who are the Traditional Owners of the land. The rehabilitation process has several stages, and the latest stage started in 2018, with the planting of wetland vegetation. The final goal is to hand back the land to the Traditional Owners.

Figure 6.24 Another example of rehabilitation is the Westside Mine (pictured), a coal mine near Lake Macquarie, NSW. The rehabilitation was completed in 2012, two months after operations stopped.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 6.1

Modelling mining and rehabilitation

Aim

To model the process of mining a resource and rehabilitating the land to return it to its original state.

Materials

- a large tray or shallow box filled with a mix of sand and soil
- mall rocks or pebbles to simulate the resource (e.g., coloured stones or small marbles)
- grass tuft on top or artificial grass.
- play dough
- plastic spoons and small containers for 'mining' tools
- small plants or grass seeds for rehabilitation
- water spray bottles
- protective gloves

Procedure

1. Work in groups of 3–5 students. Each group prepares a mine site for another team following these steps:
   - i Place the resource (coloured marbles into the sand and soil).
   - ii Cover with grass.
   - iii Make animals out of the playdough to represent the fauna present at the mine site. If they are fictional, you may need to provide an information card for the animal to give instructions on its interactions with the biotic and abiotic factors in the ecosystem.
2. Exploration phase: Each group received the prepared mine site by another team.
3. Planning: Conduct an environmental impact study. You will need to make a record of all the biotic and abiotic factors and their population sizes. If any of the species are endangered and plan need to be produced to protect it.
4. Mining: Use plastic spoons to mine the resource.
5. Rehabilitation: Restore the site to its original state, or even better than it was before!

Optional: Use tokens to represent monetary exchange. The teacher is the bank and loans them the money to purchase the mine. The groups must pay upfront for the rehabilitation. They earn money when they sell the resource and receive fines for failing to restore the land.

Discussion

Discuss the effectiveness of the model and complete a PMI table (Plus, Minus, Interesting).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 6.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 6.3 questions

Remembering

1 **State** how much of the world's iron ore is mined in Australia.
2 **Recall** two more economically important metals mined in Australia.
3 **Identify** the correct words to complete the following sentences.
   a Steel is made from about 99% _____.
   b Bauxite is the ore from which _____ is extracted.
4 **Define** the following terms in your own words.
   a Ore
   b Resin
   c Tailings dam

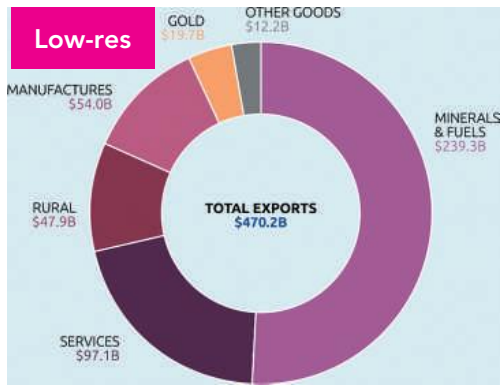
Understanding

5 **Describe** one impact mining can have on the local environment.
6 **Explain** why biotic and abiotic factors in an ecosystem need to be studied before mining operations begin.

Applying

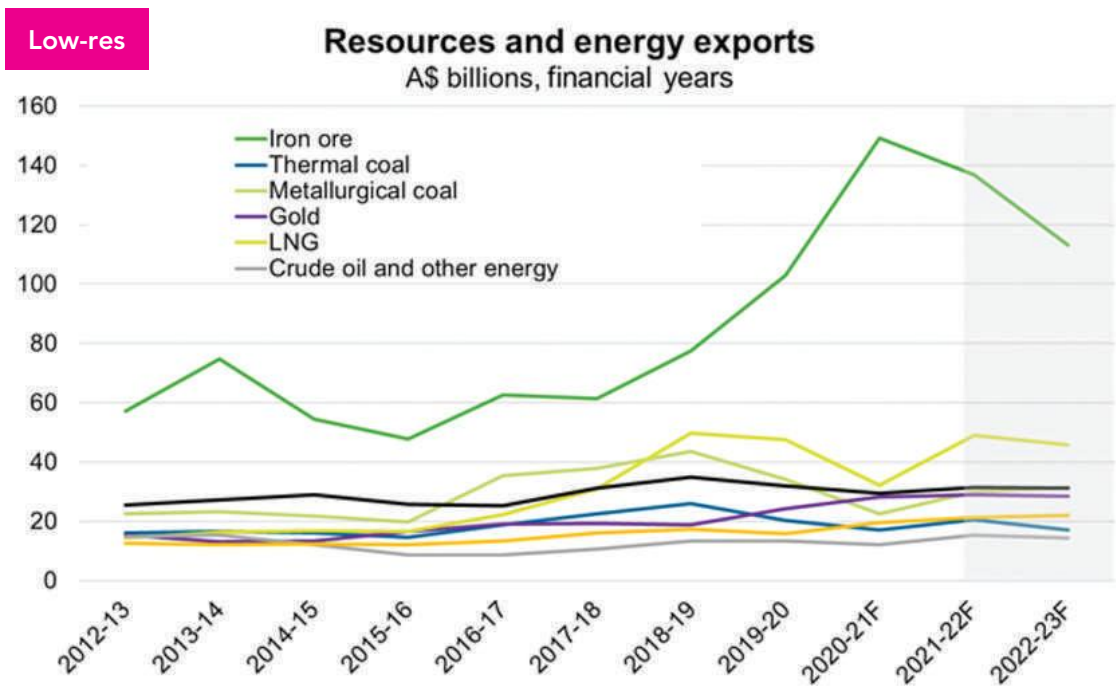
7 **Interpret** the pie chart below to assess the importance of Australia's natural resources to its economy.

Low-res



8 Using the following graph, **compare** the value of Australia's iron ore and gold to the natural recourses used to produce energy in the graph below (LNG stands for liquified natural gas).

Low-res

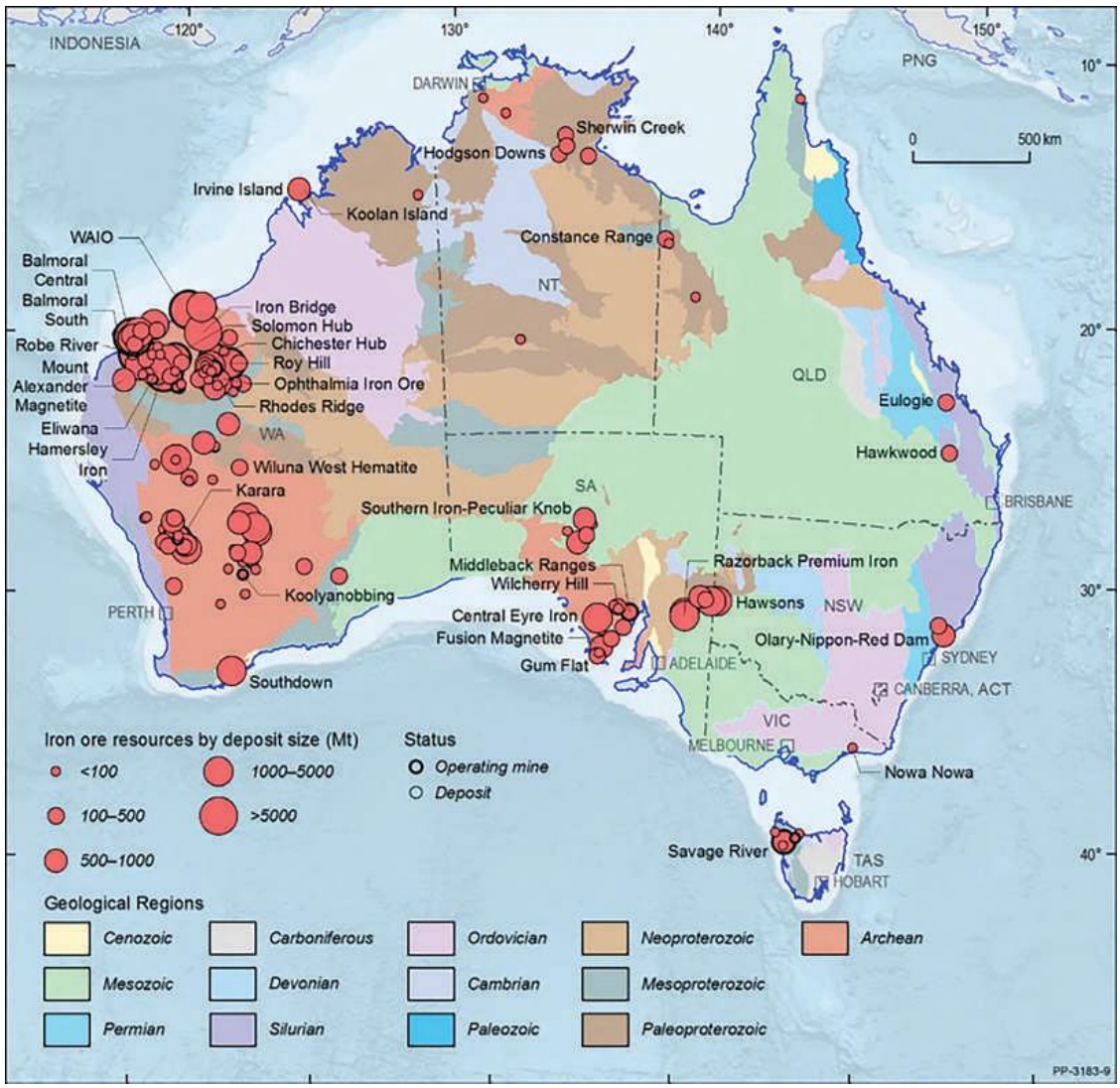


Source: Deparment of Industry, Science, Energy and Resources, June 2021 projections

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Analysing

9 **Use** the image below to **determine** environmental, transport and social considerations in the operation of iron ore mines in Australia.



Evaluating

10 **Assess** the importance of natural resources to Australia.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
6.1	describe the limited nature of Australia's minerals and other resources	
6.1	outline products made from minerals and resources extracted in Australia.	
6.2	give some examples of Aboriginal and Torres Strait Islander Peoples' use of resources.	
6.3	evaluate the environmental impact of extracting and using a resource.	

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Data questions

Iron ore is a key Australian export, and an Australian iron ore deposit commonly contains the minerals hematite, magnetite and pyrite, among others. The iron content of these minerals is presented in Table 6.3, and an example of the percentage of mineral components at different depths of an iron ore deposit drill sample is shown in Figure 6.25.

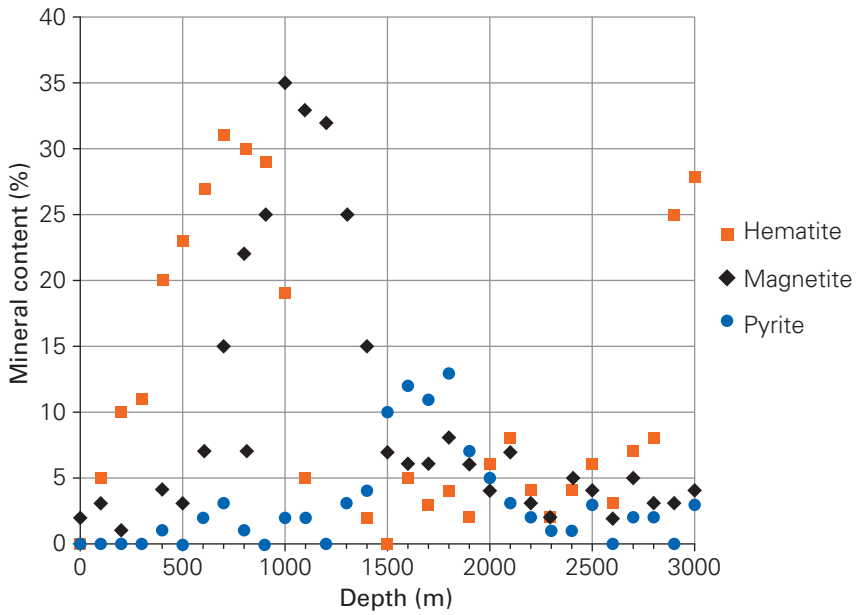


Figure 6.25 Mineral content of an iron ore exploration extract, depending on the depth of drilling

Mineral	Formula	Iron content	Colour
Hematite	Fe_2O_3	70%	Red
Magnetite	Fe_3O_4	72%	Black
Pyrite	FeS_2	47%	Yellow

Table 6.3 Examples of minerals found in Australian iron ores

1 **Identify** which mineral described in Table 6.3 presents the highest iron content.
2 **Identify** the mineral with the highest content in the ore at 400, 1100 and 1800 m.
3 **Contrast** the iron content in hematite, magnetite and pyrite and suggest which of these minerals is the least sought after.
5 **Deduce** which mineral has the lowest overall content in the ore at depths 0–3000 m.
6 Given the response to Question 5, **infer** a reason why the mining company has concerns about mining beyond 1500 m in depth.
7 Some miners had thought that they had found gold at a depth of 1800 m, but analysis revealed an iron-based mineral. **Justify** their observation with respect to the colours of iron-containing minerals.
8 At close to 3000 m depth, the content of hematite is raised again. **Predict** the percentage of hematite content at 3100 m in this drill sample.
9 **Predict** the colour of the rock sample taken at 1200 m depth.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Mining Australia's natural resources

DESIGN BRIEF

Design a game to reflect the positive and negative impacts of mining Australia's natural resources.

Activity instructions

Your game can be a board, card or interactive video game. The winner of the game must have the most positives to protect both the environment and the economy.

Here are some examples you might consider:

- The type of resource (each resource has different value)
- The uses each resource. What products rely on them?
- Political and financial ties with other countries
- The cost of mining, including the environmental impact statements or fines for failing
- The environmental consequences (remember to include transport and associated carbon dioxide emissions)
- Exploration – how will you find the resource? Lucky dip? Roll of the dice, payment with a particular card?
- You may include natural resources used to make energy (see Chapter 2). You might need to conduct research to include as many of Australis's natural resources and its value.

Evaluate and modify

When your game is complete, play test it with other classmates from different teams. Each student scores the game out of 10 (10 being the best). The scoring is based on fun and educational value to lift the awareness of the significance of Australia's natural resources and promote discussion.

Low-res

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

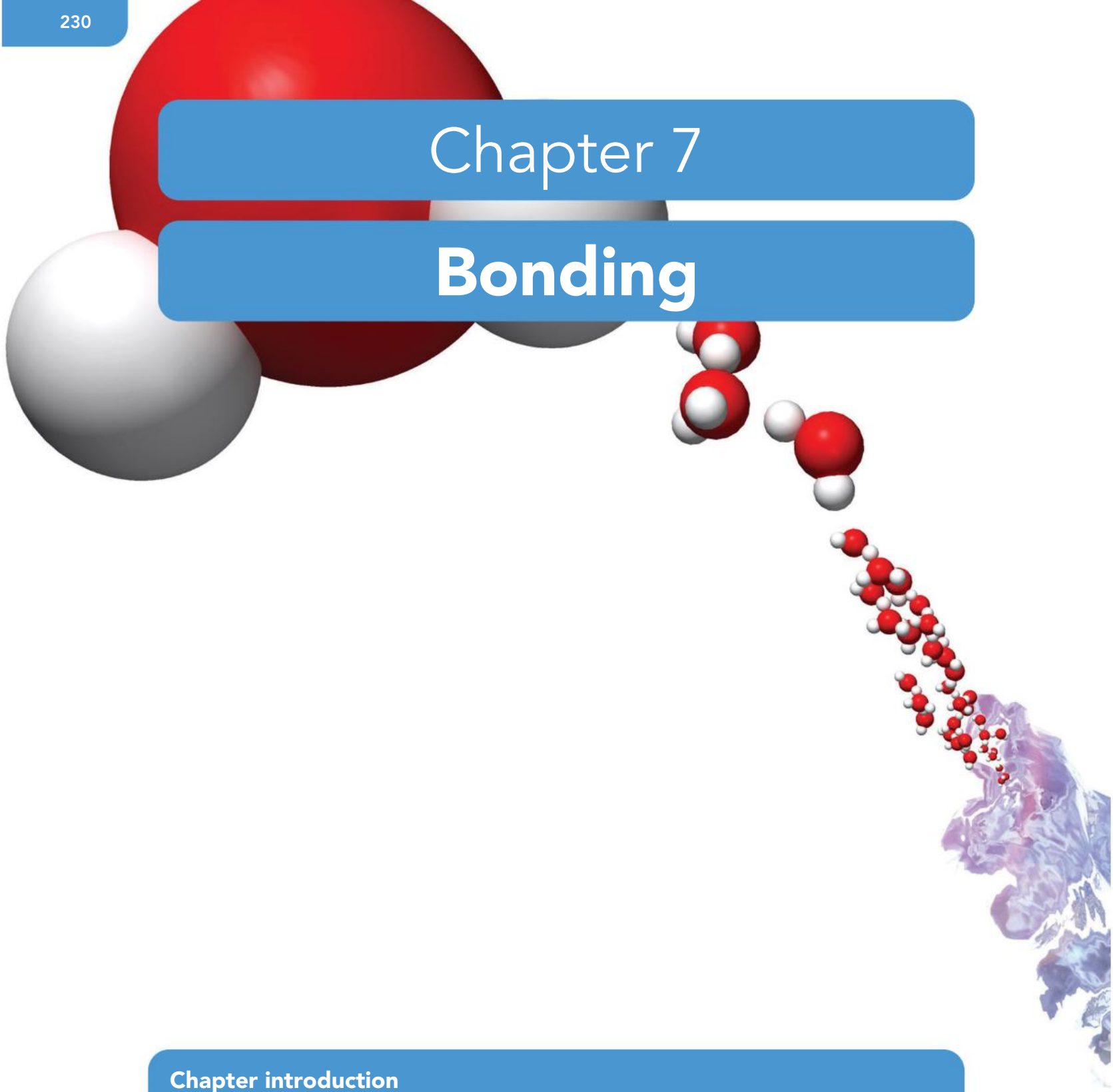
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 7

Bonding

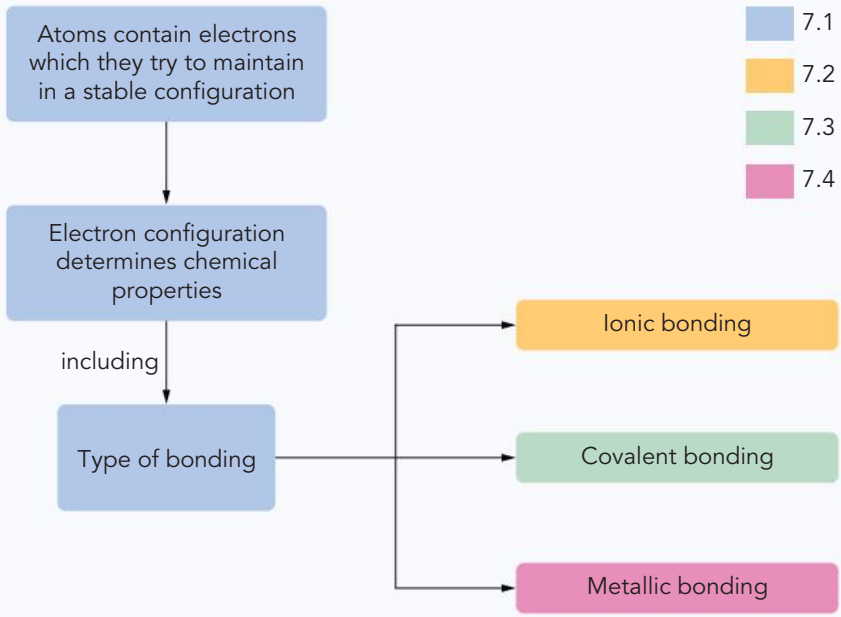


Chapter introduction

You have already learnt about the structure of an atom and what the position of an element in the periodic table tells us about its properties, including how it will react with other elements. In this chapter you will explore how atoms bond with other atoms to make bigger molecules and compounds. You will discover that the number and arrangement of electrons in an atom determine its reactivity and influence how different elements bond with one another. Chemical bonds are central to chemistry as they give matter its physical and chemical properties. Just as we can now make predictions on the behaviour of different elements based on their position in the periodic table, understanding the process of chemical bonding will help us explain the properties of chemical substances. This will give us more insight into what is going on in the world around us every day!

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

anion
cation
covalent bond
delocalised electrons
diatomic
dissociation
electrostatic force
ion
ionic bond
noble gas configuration
stable electron configuration

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

7.1 Stable electron configurations

WORKSHEET Valence electrons

Learning outcomes

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

1. recall the definition of valency and use it to explain how atoms achieve stable electron configurations.
2. determine the number of electrons an atom needs to gain, lose or share to achieve a stable electron configuration.
3. explain noble gas configuration and relate it to bonding.
4. use models to visualise cations and anions.

What is a stable electron configuration?

Previously, you have learned about the atomic model and how to use the periodic table and atomic number to determine the number of electrons an atom has and how they are arranged. Remember that the electrons in the outer shell are called valence electrons and the elements of each group on the periodic table all have the same number of electrons in each atom's outer shell. A useful way of writing the number of electrons for an element is in an electron configuration, showing how many electrons are in each shell.

Group	Atomic number	Name	Electron configuration	Valence electrons
1	3	Lithium	2,1	1
1	11	Sodium	2,8,1	1
1	19	Potassium	2,8,8,1	1
2	4	Beryllium	2,2	2
2	12	Magnesium	2,8,2	2
2	20	Calcium	2,8,8,2	2

Table 7.1 The electron configurations of the first three elements in group 1 and the first three elements in group 2. Note that each group 1 element has one valence electron, and each group 2 element has two valence electrons.

You will recall that some elements are very reactive and some are more stable. The reactivity of an element depends on its group (how many valence electrons it has) and its period (how many shells it has and so how far the valence electrons are away from the nucleus). However, every atom of an element shares a similar ability to gain, lose or share electrons to create a full outer electron shell and become stable. This takes place through reactions with other atoms and these reactions give the atoms what is known as a **stable electron configuration**.

stable electron configuration an electron configuration where the outer shell of the atom is full

noble gas configuration an electron configuration where the outer shell is full, similar to the electron configurations of the noble gases

Later in this chapter you will learn about the different ways atoms can achieve stable electron configurations, but first you will explore the noble gases (group 18) and find out why they are so unreactive.

Noble gas configuration

The noble gases are a very unreactive group of elements due to their electron configurations. As they all have full outer shells, there is no need to react with other atoms or elements to achieve stable electron configurations. Therefore, stable electron configuration can also be called **noble gas configuration**.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 7.1 The noble gas argon is used as a shield in welding as it is so unreactive due to its full outer shell of electrons.

Group	Atomic number	Name	Electron configuration	Valence electrons
18	2	Helium	2	2
18	10	Neon	2,8	8
18	18	Argon	2,8,8	8

Table 7.2 The noble gases all have full outer shells. As the first shell can only hold two electrons, helium has a full outer shell of two, while the remainder have full outer shells containing eight electrons.

Quick check 7.1

1 **Recall** what determines the reactivity of a chemical element.
2 **Recall** how many valence electrons magnesium would have if it had a stable electron configuration.
3 **Identify** the characteristic of noble gas atoms that gives them their property of being very unreactive.

Valency and bonding

The number of valence (outer shell) electrons an atom possesses determines how it will bond with other atoms. Atoms of metallic elements, located on the left side of the periodic table, have fewer than four electrons in their outer shell. Metals tend to want to lose electrons and obtain a full, outer shell, making them stable. When they lose electrons, they form positively charged **ions** (known as **cations**).

ion
a charged version of an atom, formed from the loss or gain of electrons

cation
a positively charged ion formed from the loss of electrons

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

To represent ions, we use positive (+) and minus (–) signs. A single + sign indicates the atom has lost one electron, while a number before the + sign indicates how many electrons were lost. Remember that even though an electron has been lost, the + sign is used because the number of positively charged protons in the nucleus remains the same. Therefore, if the atom loses one electron, it will now have one more proton that electrons, so the overall charge is +1.

$Na+$ or Mg^{2+}

Non-metals, located on the right-hand side of the periodic table, have atoms with outer shells that are almost full. To achieve stability, they tend to gain electrons – forming negatively charged ions (known as **anions**) represented like this:

anion
a negatively charged ion formed from the gain of electrons

S^{2-} and F^-

A single – sign indicates the atom has gained one electron, while a number before the minus sign indicates how many electrons were gained.

Cations and anions are collectively known as ions; that is, a charged version of an atom.

An atom's willingness to lose or gain electrons is an indicator of its chemical reactivity.

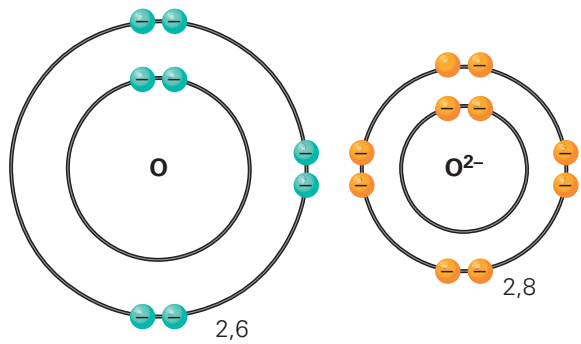


Figure 7.2 An oxygen atom has an electron configuration of 2,6. It tends to gain two electrons to achieve a stable outer shell, giving it an electron configuration of 2,8. This gives it a net negative charge and it is represented as O^{2-}.

Try this 7.1

Modelling ions

For this activity, you will need to draw or print a blank Bohr model like the one shown in Figure 7.3. You will also need two different colours of coloured lollies like jellybeans

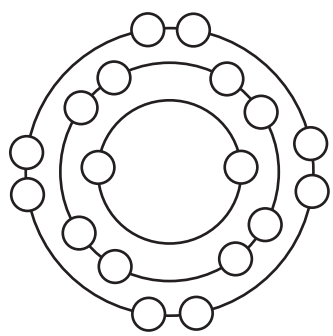


Figure 7.3 Blank Bohr model

Use your jellybeans to create models of some different atoms. Note the number of protons of the element in the centre of the model each time and then either take away or add (using the other colour of jellybeans) electrons to achieve a stable outer shell. In your book, record the model of the ion for each element, noting if it is a cation (positive) or an anion (negative) and how many electrons have been gained or lost.

Try this for the following elements: sodium, calcium, oxygen, chlorine, phosphorous.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 7.1

The Large Hadron Collider

The Large Hadron Collider (LHC) is used for international scientific research and is based at CERN on the border of Switzerland and France. The LHC is a particle accelerator that can make particles, like protons and ions, collide at close to the speed of light!

Use your preferred search engine to find the Large Hadron Collider page on the CERN website. Explore the facts and figures for answers to the following questions.

Figure 7.4 An inside view of the Large Hadron Collider at CERN

1 How long is the ring in which particles are accelerated at the LHC?
2 What is a hadron?
3 What is one of the main goals of the LHC?

Section 7.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 7.1 questions

Remembering

1 **Recall** why atoms react to achieve full outer shells.
2 **Recall** the names for a positively charged ion and a negatively charged ion.
3 **Identify** which of the following are stable electron configurations.
   a 2,8,1
   b 2,2
   c 2,8
   d 2,8,8
   e 2

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4 **Determine** the electronic configurations for the following elements.
   - **a** Helium (He)
   - **b** Beryllium (Be)
   - **c** Phosphorous (P)
   - **d** Potassium (K)

Understanding

5 For each of the following elements, **determine** their electron configurations, their stable electron configurations and their symbol as an ion.
   - **a** Magnesium
   - **b** Oxygen
   - **c** Sodium
   - **d** Fluorine

6 **Compare** the number of protons and electrons in an uncharged atom with those in an ion.

7 **Determine** which group of the periodic table an element that forms an ion with a charge of +2 is in. **Explain** your answer.

Applying

8 **Apply** your knowledge of electron configurations to explain what is significant about the electronic configurations of group 18 elements.

9 **Apply** your knowledge of atoms and ions to determine the identity of an element that forms ions with a –1 charge and 18 electrons.

10 Sulfur has the electronic configuration 2,8,6. **Construct** a diagram showing the arrangement of the electrons within a sulfur atom.

Analysing

11 **Compare** the formation of an ion from a metal atom (magnesium) and a non-metal atom (chlorine).

12 **Explain** why a cation is usually smaller than the atom it is formed from.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

7.2 Ionic bonding

Learning outcomes

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

1. recall how ionic bonds are formed.
2. construct chemical formulas for ionic compounds.
3. recall physical and chemical properties of ionic compounds.

WORKSHEET
Ionic bonds

When an electron is transferred from one atom to another, positive and negative ions are formed (Figure 7.5). Positively charged cations are attracted to negatively charged anions, and this attraction is known as an **ionic bond**. Strong **electrostatic forces** bond the ions together into an ionic compound, which tend to take on a lattice structure. The structure of a sodium chloride lattice is shown in Figure 7.6. Because the bonds are strong, ionic compounds tend to have high melting temperatures. For example, table salt (NaCl) has a melting point of 801°C.

ionic bond
a strong bond between an anion and a cation, formed via electron donation

electrostatic force
an attractive or repulsive force between particles caused by their electric charges

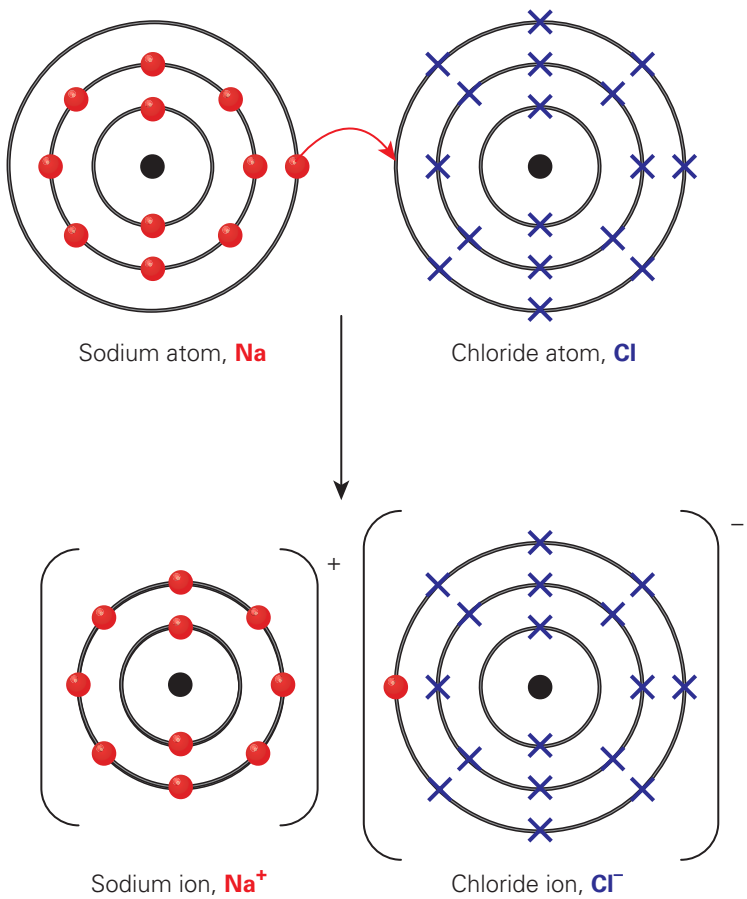


Figure 7.5 Ionic bonding in sodium chloride

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

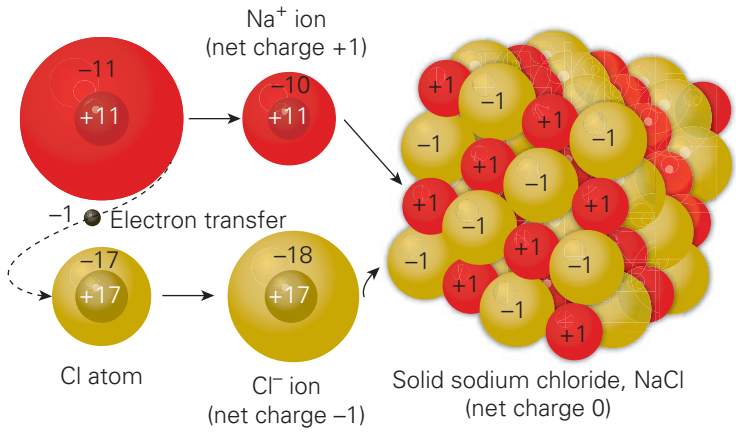


Figure 7.6 A sodium atom donates an electron to a chlorine atom (left). The sodium atom now forms a positively charged cation, and the chlorine atom forms a negatively charged anion. These ions are attracted to each other and bond to form an ionic compound (right). Ionic compounds form crystal lattices with high melting points.

Quick check 7.2

1 **Recall** what valence electrons are.
2 **Define** these terms in your own words:
   a ion
   b cation
   c anion.
3 **Explain** why some elements form cations while others tend to form anions.

In the example in Figure 7.6, sodium has one valence electron (2,8,1) and chlorine has seven (2,8,7). This means that one atom of sodium can donate one electron to one atom of chlorine, and they react in a 1:1 ratio to form sodium chloride (NaCl). If you consider magnesium (2,8,2) reacting with oxygen (2,6), they will also react in a 1:1 ratio as the magnesium atom has two valence electrons to donate to an oxygen atom to achieve full outer shells for each atom in magnesium oxide (MgO).

However, elements are not always able to react together in a 1:1 ratio as elements from different groups have atoms with different number of valence electrons. Consider a reaction between sodium and sulfur to form sodium sulfide. An atom of sodium has a single valence electron while sulfur needs two to fill its outer shell. Therefore, two sodium atoms react with one sulfur atom, as shown below and in Figure 7.7.

$$Na^+ + S^{2-} \rightarrow Na_2S$$

The number 2 in subscript following the chemical formula for sodium means that there are 2 sodium atoms in the molecule.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

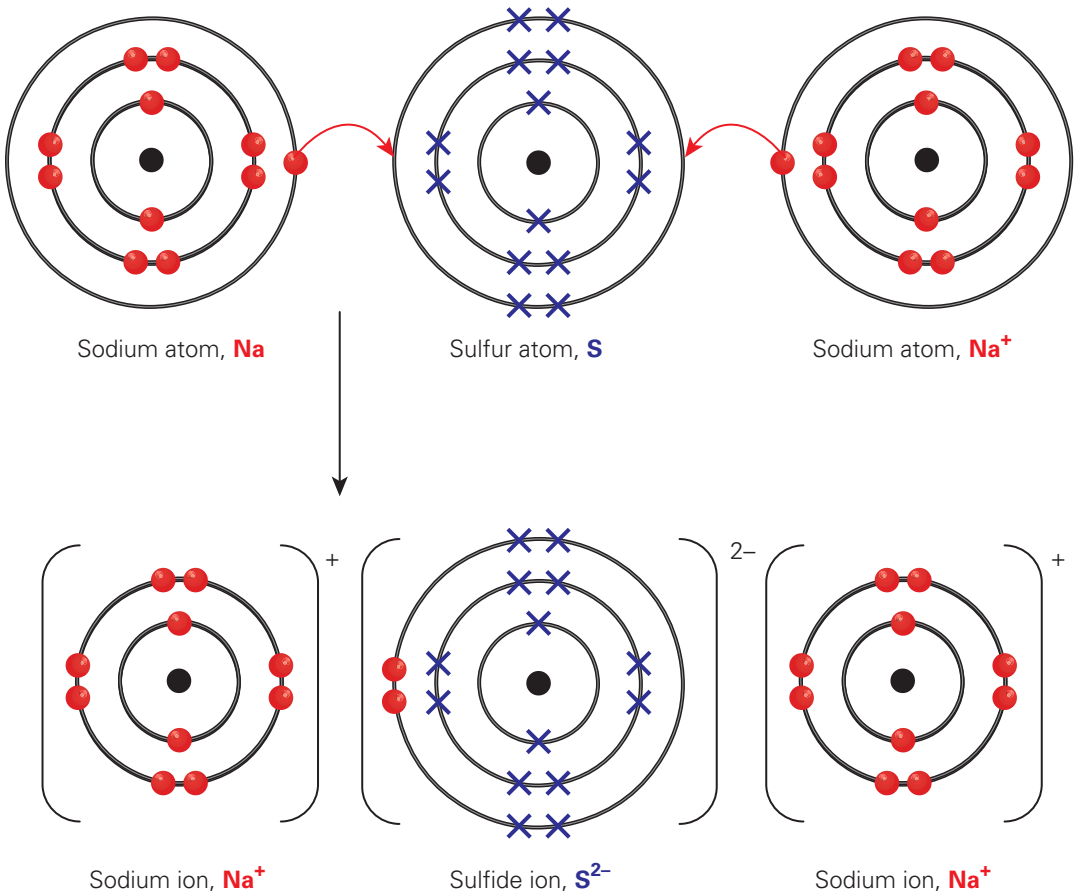


Figure 7.7 Ionic bonding in sodium sulfide (Na_2S)

Quick check 7.3

1 **Determine** the chemical formula for the following ionic compounds.
- **a** Lithium fluoride
- **b** Beryllium chloride
- **c** Sodium fluoride
- **d** Potassium sulfide
- **e** Sodium nitride

Naming ionic compounds

You may already have noticed that when ionic compounds are named, the metal cation is named first, followed by the non-metal anion. This is quite straightforward as it is the same order used when writing the chemical formula. However, rather than simply listing the cation followed by the anion, the ending (suffix) is changed to -ide. Therefore, instead of naming NaCl 'sodium chlorine', it is named 'sodium chloride'.

Quick check 7.4

1 **Name** the following ionic compounds.
- **a** MgO
- **b** $CaCl_2$
- **c** AlF_3
- **d** KCl

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Properties of ionic compounds

Ionic compounds have a unique set of properties due to the nature of ionic bonds. You already know that they have high melting and boiling points. This is due to the strength of the electrostatic attraction between ions in ionic compounds, meaning that a great deal of heat energy is required to overcome the attraction and melt or boil the compound. This means that ionic compounds are usually solid at room temperature.

Solid ionic compounds are hard and brittle. The strong ionic bonds between the cations and anions lead to a highly ordered arrangement of ions in a three-dimensional crystal lattice.

A summary of the chemical properties of ionic compounds:

- usually dissolve in water to form ions
- react with acids or bases
- decompose when heated
- tend to form crystalline salts after reactions.

Advances in science 7.1

Ionic liquids

It is a well-known property of ionic compounds that they have very high melting points, usually well above 600 °C . However, research has been ongoing for several years into substances known as ionic liquids. Simply put, they are ionic compounds with melting points below 100 °C. This is achieved because their cations are much bulkier than those we are familiar with and so they don't pack nicely into a neat and tightly packed lattice. This means that it takes less energy to disrupt the bonds, and their melting points are surprisingly low.

They have a lot of potential uses, but recently scientists have been particularly interested in their ability to capture and fix carbon dioxide from the environment where it is contributing to negative environmental impacts.

Figure 7.8 Carbon dioxide emissions contribute significantly to climate change. Could the use of ionic liquids be part of the solution?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 7.1

Copper sulfate crystals

Aim

To view the structure of copper sulfate crystals.

Be careful

Gloves should be worn to prevent any harmful skin contact with copper sulfate. Appropriate disposal methods should also be used for any leftover solutions.

Materials

- 500 mL beaker
- water
- copper sulfate
- funnel
- conical flask
- filter paper
- spatula
- stirring rod
- heating pad
- hot plate
- microscope

Procedure

1. Heat a beaker of water to around 80°C.
2. Add copper sulfate a spatula at a time, stirring to dissolve. Continue to do this until you have created a saturated solution, where a few grains remain undissolved.
3. Allow the solution to cool slowly and leave it in a covered beaker for 24 hours.
4. Carefully decant the solution to discover the crystals formed at the bottom.
5. Use tweezers to carefully remove one of the crystals and examine it under the microscope.
6. **Optional:** Suspend a small crystal in a saturated copper sulfate solution using thread. Cover the beaker with foil and watch the crystal grow over the coming days and weeks.

Discussion

1. Describe the structure of the crystal you saw under the microscope.
2. How do the ionic bonds between copper ions and sulfate ions give rise to this structure?
3. Why was hot water used to make the copper sulfate solution?

Most ionic compounds are soluble in water. Water is a polar molecule, meaning that one side of it is partially negatively charged and one side of it is partially positively charged. When ionic compounds are placed in water, they dissolve or **dissociate** into cations and anions as these are attracted to the polar (charged) water molecules. The anion is attracted to the positive end of the water molecule (hydrogen) and the cation is attracted to the negative end of the water molecule (oxygen).

dissociation the break-up of ions that occurs when an ionic compound dissolves

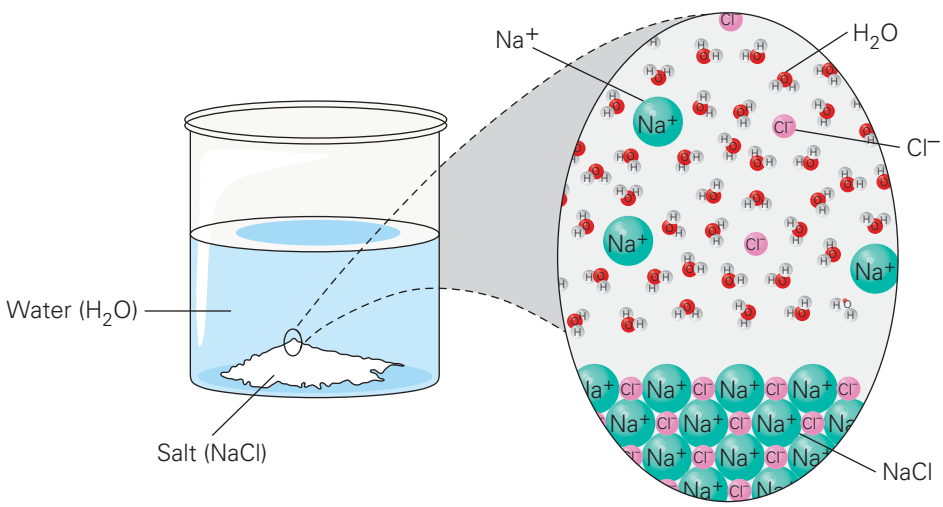


Figure 7.9 Salt dissolves in water as it dissociates into its ions, which are attracted to opposite ends of the polar water molecules.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Ionic compounds do not conduct electricity when they are solids as the ions are held in fixed positions. However, if they are molten or in solution, their ions are free to move around and can conduct electricity. This is another important property of ionic compounds.

Practical skills 7.2

Investigating the conductivity of ionic compounds

Aim

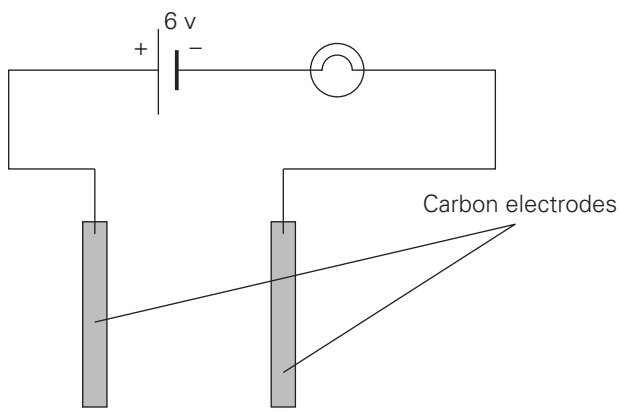
To determine the conductivity of the ionic compound sodium chloride.

Materials

- salt (granules are preferable to larger crystals)
- water
- stirring rod
- beaker
- power pack
- light globe
- carbon electrodes
- connecting wires

Procedure

1 Set up an electrical circuit as shown below
2 Place electrodes into solid salt granules and switch the power pack on. Observe whether the globe lights.
3 Add 2–3 spatulas of salt to half a beaker of water and stir to dissolve.
4 Place electrodes in the beaker of salty water and observe whether the globe lights.



Discussion

1 What did you observe on each occasion and what conclusions can you draw from these observations?
2 Is it appropriate to draw a conclusion on the conduction of electricity by all ionic compounds from this investigation? If not, what further investigation(s) could you do?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 7.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 7.2 questions

Remembering

1 **Recall** the definition of a cation.

2 **Complete** the following:

When a _____ reacts with a _____ an ionic bond is formed.

Example: _____

The metal atom _____ electrons and becomes a _____ charged ion or _____.
The electrons are transferred to _____ and it becomes a _____ charged ion _____.

The positive and negative ions are held together strongly by _____ forces.

3 **Recall** four properties of ionic compounds.

Understanding

4 For the following elements, **state** the chemical formula of their ion.

a Magnesium **c** Lithium **e** Rubidium
b Krypton **d** Sulfur

5 **Explain** why sodium ions and chlorine ions are stable.

6 **Write** the name of the following ionic compounds:

a LiCl **b** NaBr **c** MgF_2

7 **State** the formula of the following ionic compounds.

a Potassium chloride
b Calcium fluoride
c Sodium oxide
d Magnesium oxide

Applying

8 **Apply** your knowledge of ionic bonding to explain why sodium fluoride has a melting point of 992°C.

9 **Apply** your knowledge of ionic bonding to explain why neon is a non-metal, but it is not found in ionic compounds.

10 **Construct** a diagram to show the transfer of electron(s) between magnesium and chlorine to form magnesium chloride.

11 The melting point of strontium chloride ($SrCl_2$) is 874°C. **Predict** whether $SrCl_2$ would conduct electricity at 630°C and explain your answer.

Analysing

12 A diagram of part of the crystal of calcium chloride shows 15 calcium ions and 30 chloride ions. Use this information to **determine** the formula of calcium chloride.

13 Magnesium reacts with Element X to form a compound with the general formula MgX. **Determine** the most likely formula be for the compound formed between lithium and element X.

Evaluating

14 Adam insists that sodium chloride does not conduct electricity while his friend Clare is certain that it does. **Determine** who is right and **explain** why.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

7.3 Covalent bonding

WORKSHEET Covalent bonds

Learning outcomes

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

1. recall how covalent bonds are formed.
2. construct chemical formulas for covalent compounds.
3. identify elements that form diatomic molecules.
4. recall physical and chemical properties of covalent compounds.

When atoms of non-metals bond together, they both require some electrons to complete their outer shell, but neither is prepared to lose theirs! Instead, these two atoms can share electrons, forming a molecule which is held together by a strong **covalent bond**.

covalent bond a strong bond, almost always between two non-metals which share electrons to form a molecule

An oxygen (O) atom has an electron configuration of 2,6. As we have seen previously, it requires two electrons to complete its outer shell. Instead of receiving electrons from a metal atom and forming an ionic bond, it can instead share electrons with another non-metal, such as hydrogen, and form a covalent bond. As hydrogen only has one valence electron, while oxygen needs two electrons to have a stable outer shell, it will need to form covalent bonds with two hydrogen atoms. Refer to the molecule in Figure 7.10: each hydrogen atom has a full outer shell (two electrons), and the oxygen atom has a full outer shell (eight electrons). Each bond in a covalent molecule is a shared pair of electrons.

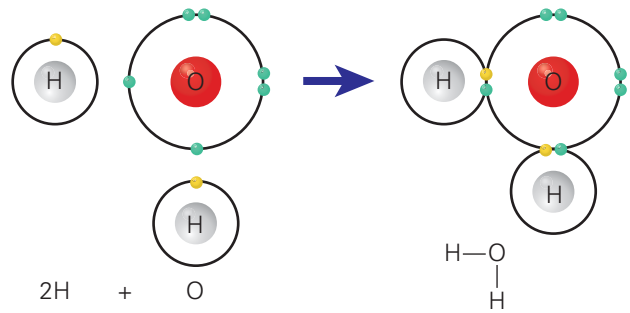


Figure 7.10 Two hydrogen atoms and an oxygen atom covalently bond to form a water molecule. Diagrams like this are useful to show how electrons are shared. The lines between the atoms in the bottom right of the figure represent covalent bonds.

Quick check 7.5

1 **Identify** whether covalent bonding involve donation or sharing of electrons.
2 Water is a covalent compound with the formula H_2O. **Explain** why oxygen covalently bonds with 2 hydrogen atoms, not one.
3 Use a diagram to **show** covalent bonding in hydrogen chloride.

When atoms in a covalent molecule share just one electron pair (one electron from each atom), this creates a single bond, as with the previous example of water. However, atoms can share more than one electron with each other to form double and even triple bonds! Let's consider another common covalent compound, carbon dioxide (CO_2). A single carbon atom covalently bonds with two oxygen atoms. Each oxygen atom needs two additional electrons to complete its outer shell and carbon has four electrons available to share, so it shares two with each oxygen atom. This means each oxygen atom shares two electron pairs with carbon, making a double bond. We can also write this as O=C=O.

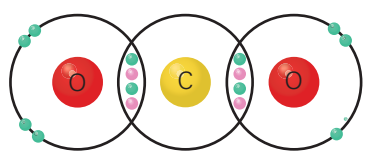


Figure 7.11 Two oxygen atoms and a carbon atom covalently bond to form a carbon dioxide molecule. Each oxygen shares two electron pairs with the carbon molecule, creating double bonds.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

There is one other type of covalent bond: a triple bond, where three electron pairs are shared between atoms. This is much less common in covalent molecules but is shown by a triple line.

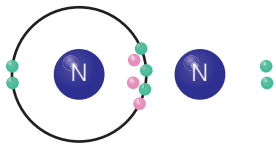


Figure 7.12 Two nitrogen atoms covalently bond to form a diatomic nitrogen gas molecule. Each nitrogen atom shares three electron pairs with the other, creating a triple bond.

Quick check 7.6

1 Carbon dioxide is a covalent compound with the formula CO_2. **Identify** the kind of covalent bonds that carbon forms with oxygen and **explain** why.

2 Use a diagram to **show** how electrons are shared in the covalent bonds of CO_2.

Properties of covalent molecules

Compared with ionic compounds, covalent molecules tend to have low melting and boiling points. They have variable solubility in water, depending on their shape and structure. Unlike ionic compounds, when covalent molecules melt, boil, or dissolve in water, they remain as whole molecules; the covalent bonds are not broken.

Covalent molecules are poor conductors of electricity as they are neutral, they do not consist of charged ions.

A summary of the chemical properties of covalent compounds:

- often do not dissolve in water to form ions
- react with acids or bases
- decompose when heated strongly
- some like hydrocarbons undergo combustion reactions.

Explore! 7.2

Giant covalent structures

Giant covalent structures contain many, many atoms joined together by covalent bonds. They are usually arranged into giant lattices, which are incredibly strong due to the number of bonds involved.

Carbon is a particularly versatile element due to its four valence electrons which give it the ability to form a range of different covalent bonds (single, double or triple). This allows it to be the basis of an entire subsection of chemistry (organic chemistry) that you will learn about in Chapter 8. It also means it is found in a range of different forms as an element, known as allotropes.

Diamond, graphite and fullerenes are three allotropes of carbon. Research these allotropes, their structures and how they all have very different properties, despite each being a solid carbon structure.

Figure 7.13 Diamond, graphite and bucky balls (fullerenes) are all solid forms of carbon with very different structures and properties.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Elemental gases

diatomic
consisting of two atoms

You may have noticed by now that some elements, oxygen for example, are always found in pairs. They are what are known as **diatomic** elements, and their formulas are written with a subscript 2 after their symbol to indicate there are two atoms in each molecule, like O_2 (oxygen) and H_2 (hydrogen).

You may also realise that most of these are gases. In fact, except for the noble gases, all elements found as gases at room temperature are diatomic. These elemental gases are oxygen, hydrogen, nitrogen, chlorine and fluorine. As they are all non-metals, they bond together covalently.

Two other halogens (group 17 elements), bromine and iodine, are also diatomic but are not gases at room temperature.

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 **Recall** what happens to electrons in a covalent bond.
2 **Recall** how many electrons are shared in a single covalent bond.
3 **Recall** three properties of covalent molecules.

Understanding

4 **Draw** a diagram showing the covalent molecule NH_3.
5 **Detail** the greatest number of covalent bonds a carbon atom can form?
6 **Determine** the number of covalent bonds that atoms of the following elements want to form with other atoms and the total number of valence electrons, based on their position in the periodic table.
   a Hydrogen
   b Oxygen
   c Chlorine
   d Carbon
   e Nitrogen
7 **Determine** which of the following are covalent molecules.
   a NH_3
   b H_2O
   c MgO
   d PCl_3
   e CO
   f Cl_2
   g He
   h NaCl
8 **Explain** why covalent molecules cannot conduct electricity.

Applying

9 Astatine is a synthetic element, made one atom at a time in huge 'atom-smasher' machines. It is in the halogen group on the periodic table. **Determine** how many covalent bonds would an atom of this element form.

Analysing

10 **Distinguish** between electrons involved in an ionic bond compared with a covalent bond.
11 **Compare** how an oxygen atom would participate in an ionic bond versus a covalent bond.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

7.4 Metallic bonding

Learning outcomes

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

1. recall how metallic bonding occurs.
2. compare and contrast the physical and chemical properties of metals, ionic compounds and covalent molecules and relate these to their uses.

WORKSHEET Metallic bonds

You will recall that metals have some characteristic properties. They are malleable, ductile, lustrous and have high melting and boiling points, although not as high as those of ionic compounds! You also already know that atoms of metals have a tendency to lose or give up their valence electrons in order to achieve a full or stable outer shell. This means that they become positively charged cations. In metallic bonding, the metal atoms do not donate their electrons to non-metal atoms but are held together by electrostatic forces in a lattice structure among a 'sea' of **delocalised electrons**. These electrons are free to move, and this form of bonding creates a strong but flexible lattice which gives metals many of their properties.

delocalised electrons freely moving electrons that are shared between more than two atoms in a substance

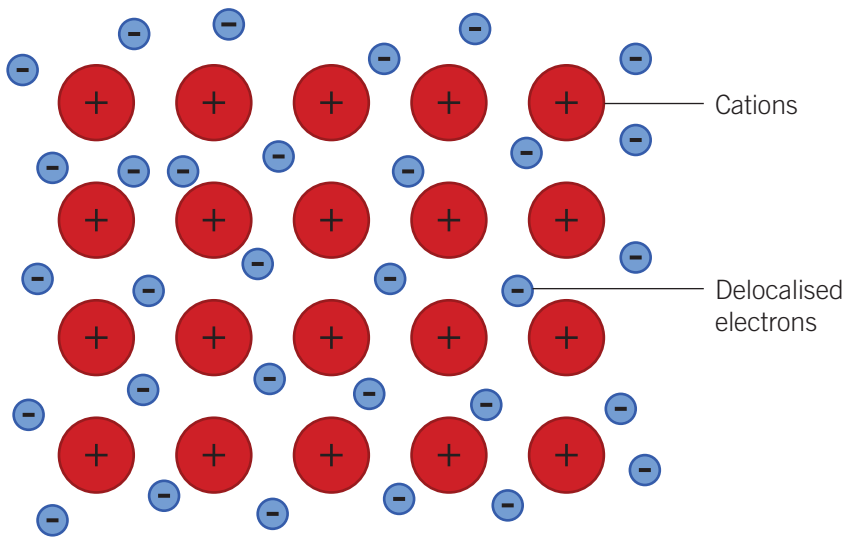


Figure 7.14 Metallic bonding occurs by having a sea of delocalised electrons moving among positively charged metal ions (cations).

These free moving electrons make metals excellent conductors of electricity. Remember that electricity is the movement of charged particles through a substance. Negatively charged electrons can carry charge and move throughout metals, conducting electricity.

Similarly, the movement of electrons allows for the transfer of heat through metals. Electrons absorb heat and transform it into kinetic (movement) energy, moving faster and transferring the heat throughout the metal.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

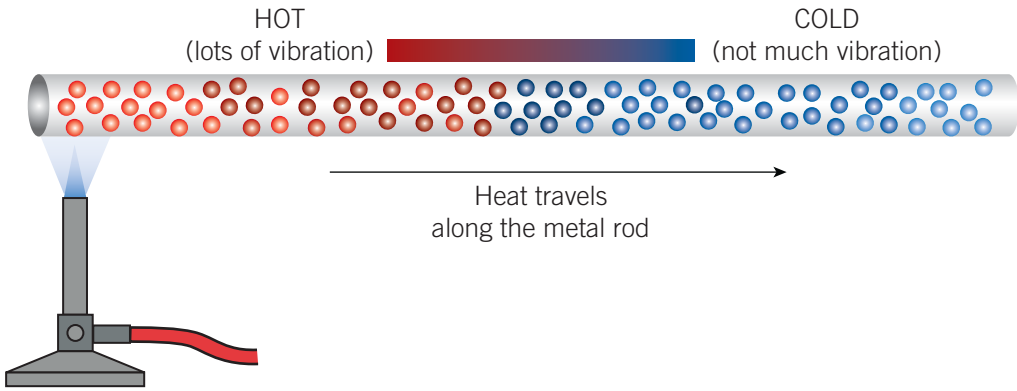


Figure 7.15 The conduction of heat by electrons free to move in a metal rod

Quick check 7.7

1 **Recall** the basic features of metallic bonding.
2 **Identify** the feature of metallic bonding that makes metals good conductors of electricity.

INVESTIGATION

Explore! 7.3

Superconductors

Conduction of electricity by the flow of electrons is a particularly useful property of metals. However, all electrical circuits have some level of electrical resistance and lose some energy through transformation into heat. Superconductors are a group of materials, including some familiar metals, that can conduct electricity without any energy loss when they are cooled under a certain temperature.

1 Find some examples of superconductors and the temperatures they need to be cooled to to avoid energy loss.
2 Resistance in electrical circuits is caused by collisions between electrons. How does this change in superconductors?
3 Discuss the possible uses of superconductors.
4 Quantum levitation is a cool phenomenon that can be achieved with some superconductors. See if you can you find out the basics of how it works.

Figure 7.16 Levitation of a magnetised cube above a liquid nitrogen cooled superconductor

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 7.3

Observe and compare properties of ionic, covalent and metallic substances

Aim

To compare the properties of ionic, covalent and metallic substances and relate them to their uses.

Materials

- salt granules
- sugar granules
- wax
- copper wire
- distilled water
- Bunsen burner
- tripod
- gauze
- 4 crucibles
- 4 small beakers
- stirring rod
- spatula
- simple electrical circuit with carbon electrodes (See *Practical skills 7.2*)

Procedure

1. Copy the results table below into your lab journal and complete the second and third rows.
2. For each substance, place a small amount in a crucible and heat over the Bunsen burner. Record your observations.
3. For each substance, test its conductivity of electricity by placing it between the carbon electrodes of the circuit and observing the globe. Record your observations.
4. For each substance, place a piece or a spatula full in a small beaker and add water to determine if it is soluble. Record your observations.
5. For those substances that were soluble, determine the conductivity of the solution using the electrical circuit. Record your observations.

Results

Substance	Salt (NaCl)	Sugar ($C_{12}H_{22}O_{11}$)	Wax ($C_{31}H_{64}$ or similar)	Copper (Cu)
Bonding				
Appearance				
Melting point				
Conductivity as solid				
Conductivity in solution				
Solubility				

Discussion

1. Write a discussion on how your observations related to the bonding of the substances tested.
2. Were there any unexpected or conflicting results? If so, can you think of an explanation?
3. How do the properties demonstrated in this investigation relate to the uses of ionic, covalent and metallic substances? Use specific examples in your response if you find that helpful.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 7.4

Uses of ionic, covalent and metallic substances

Use your results from *Practical skills 7.3* and further research to create a table of four uses each of ionic, covalent and metallic substances or your choice. Include a column that relates each use to a property of the substance.

Go online to access the interactive section review and more!

Section 6.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.4 questions

Remembering

1 **Identify** the missing word:
Metals are good conductors of electricity because they contain electrons that are _____.

2 **Describe** the metallic bonding model.

Understanding

3 **Explain** why metal atoms form cations not anions.

4 **Explain** why oxygen would not be able to form a metallic bond.

Applying

5 The table shows the ability of different substances to conduct electricity. **Explain** these results using your knowledge of the structures of the substances.

Substance	Conducts electricity
Solid calcium chloride	No
Molten calcium chloride	Yes
Iodine	No
Zinc	Yes

Analysing

6 **Suggest** why the melting point of sodium chloride is higher than the melting point of carbon tetrachloride (CCl_4).

7 **Compare** metallic, ionic and covalent bonding using a Venn diagram.

Evaluating

8 Umraj is given an unknown compound to identify as ionic, covalent or metallic in his school laboratory. Suggest three different tests he could carry out to start this process and **explain** how they would allow him to determine what type of molecule he has been given.

9 Calcium is an essential mineral, required for muscle movement and nerve function. Applying your knowledge of the properties of different elements, **explain** why calcium supplements are found in the form of calcium carbonate ($CaCO_3$) or other compounds, not pure calcium.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
7.1	recall the definition of valency and use it to explain how atoms achieve stable electron configurations.	
7.1	determine the number of electrons an atom needs to gain, lose or share to achieve a stable electron configuration.	
7.1	explain noble gas configuration and relate it to bonding.	
7.1	use models to visualise cations and anions.	
7.2	recall how ionic bonds are formed.	
7.2	construct chemical formulas for ionic compounds.	
7.2	recall physical and chemical properties of ionic compounds.	
7.3	recall how covalent bonds are formed.	
7.3	construct chemical formulas for covalent compounds.	
7.3	identify elements that form diatomic molecules.	
7.3	recall physical and chemical properties of covalent compounds.	
7.4	recall how metallic bonding occurs.	
7.4	compare and contrast the physical and chemical properties of metals, ionic compounds and covalent molecules and relate these to their uses.	

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Text to come Review questions coming at 2pp

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Data questions

Magnesium and calcium are group 2 alkaline earth metals and can be taken as general health supplements to aid regulation of bodily functions including muscle function and bone development. A scientist is testing the claim from eight different supplement brands that their magnesium and calcium tablets contain 200 mg of each element. Each supplement was analysed and the amount of magnesium or calcium present in each tablet is presented in Figure 7.17.

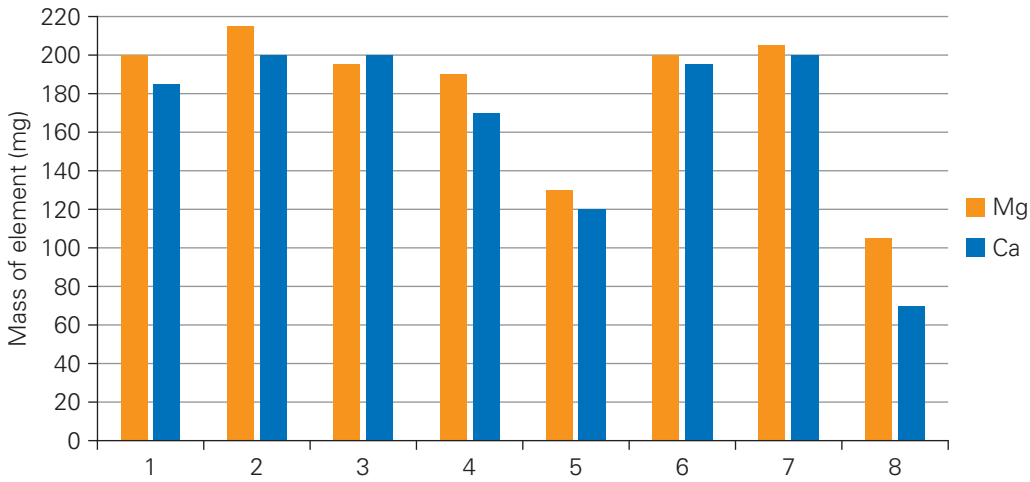


Figure 7.17 Mass of magnesium or calcium found in eight commercial supplement samples

1 **Identify** all samples that had less than the advertised 200 mg of magnesium.
2 Brand 3 advertised that the magnesium content was 200 mg ±10%. **Calculate** the minimum amount of magnesium that could be present in this advertised sample.
3 Use your answer to Question 2 to **determine** whether the analysed brand 3 has a magnesium content within the advertised range.
4 Brand 5 is being investigated for false advertising with its claim that 'we have a more accurate calcium content than (brand 1)'. Explore this statement and **draw conclusions** about its accuracy.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

5 A spokesperson for Brand 6 has stated that 'the calcium content is more difficult to maintain as it is a more reactive metal than magnesium'. **Contrast** the magnesium and calcium content in brand 6. Does this explanation match the data presented in Figure 7.17?

6 **Identify** the general trend between the mass of magnesium and the mass of calcium in a brand's supplements.

7 The 200 mg magnesium supplements are deemed to be falsely advertised if the content is found to be below 180 mg. **Compare** the data for the eight samples. Which of the brands have been falsely advertised?

8 A magnesium content of over 220 mg would also be considered misleading advertising. Use the data to **justify** that no brand is providing misleading information in this regard.

9 Brand 7 has released a new series of magnesium and calcium supplements containing 250 mg of magnesium or calcium. Use your response to Question 5 to **predict** whether the samples of these products would contain more magnesium or calcium.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Researching the uses of graphene

Background information

Graphene is a single atom-thick layer of carbon atoms arranged in a hexagonal lattice. It is a remarkable material with impressive electrical, thermal and mechanical properties. It has been described as a 'wonder material' because it has the potential to revolutionise industries ranging from electronics to healthcare, energy storage and beyond.

Its key properties include:

- High electrical conductivity: Ideal for use in electronics and energy devices.
- Strength: It is stronger than steel, yet lightweight and flexible.
- Thermal conductivity: Efficient heat transfer, which makes it useful in electronics and energy systems.
- Transparency: Graphene is transparent, making it ideal for touchscreens and other optical devices.

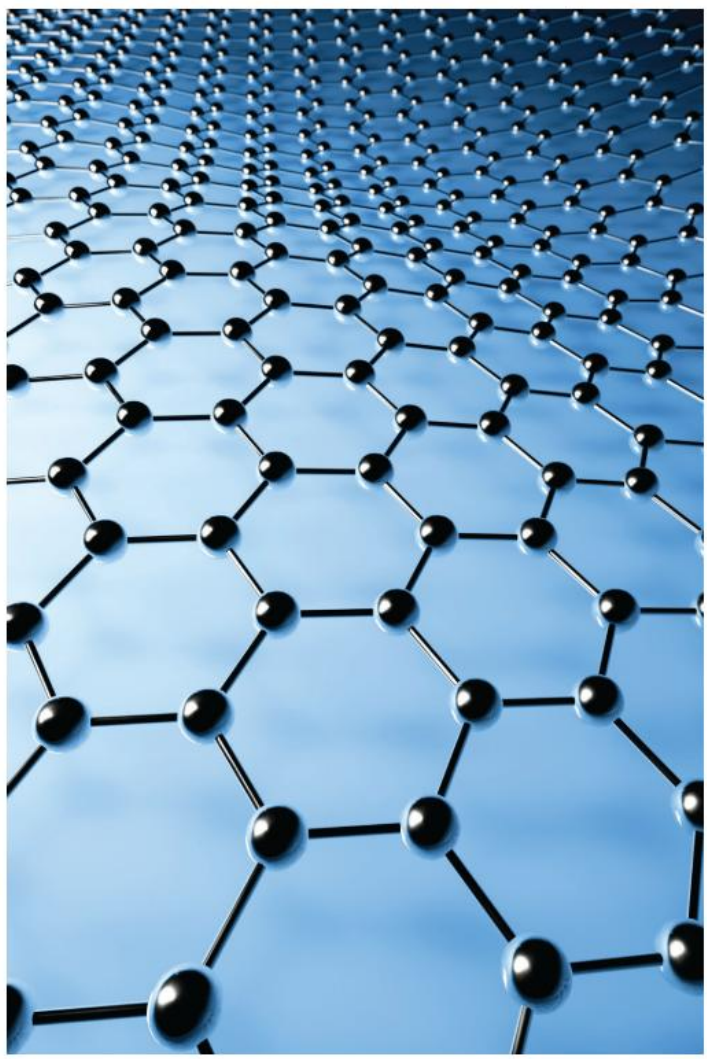


Figure 7.18 Graphene is an allotrope of carbon, arranged in a honeycomb lattice with remarkable properties.

Low-res

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

521755134

Activity instructions

Working in small groups, research graphene and its uses. Prepare a presentation in a mode of your choice to present to the class on graphene and one area where it is being used of could be used.

Areas to consider researching:

- electronics and computing (e.g. faster transistors, flexible electronics)
- energy storage and batteries (e.g. graphene-based supercapacitors, better batteries)
- materials science (e.g. graphene in composites, coatings and construction materials)
- environmental applications (e.g. water filtration, pollution control)
- other innovative uses (e.g. graphene in clothing, solar panels or space technology).

Ensure you include the following in your research and presentation:

- Introduction to graphene. Consider:
  - What makes graphene so special compared to other materials?
  - Where was graphene first discovered and by whom?
  - Why do scientists and engineers believe graphene could change the world?
- Describe the application of graphene in your field.
- Explain how its properties make it suitable for that use.
- Present any challenges or limitations related to the use of graphene in this area.
- Include real-world examples or case studies if possible.
- Be prepared to answer questions after your class presentation.

Note: ensure you use credible sources such as academic journals, educational websites or articles by research organisations in your research.

Reflection

Write a short reflection (1–2 paragraphs) on how you think graphene could change the future of technology or society.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

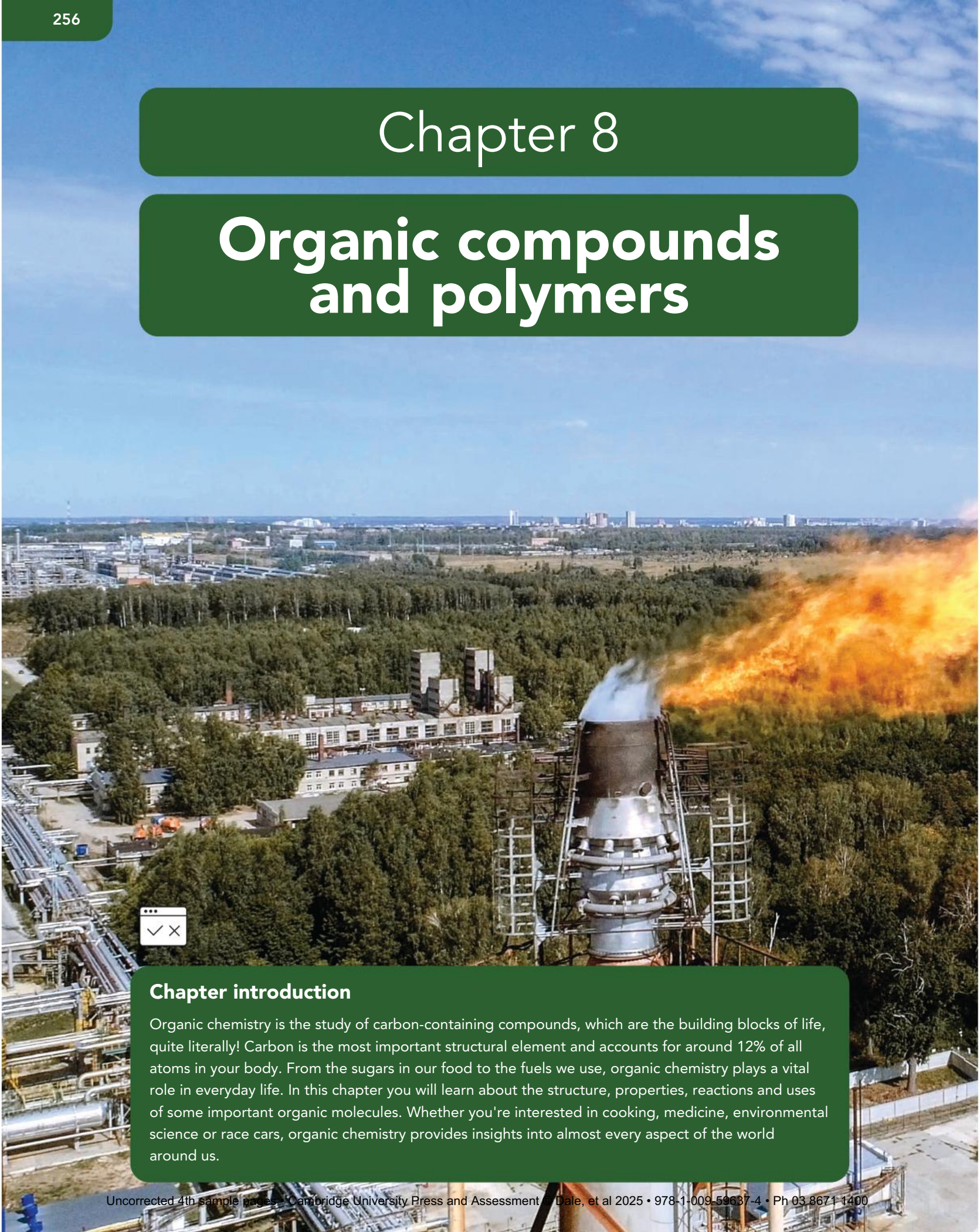
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 8

Organic compounds and polymers

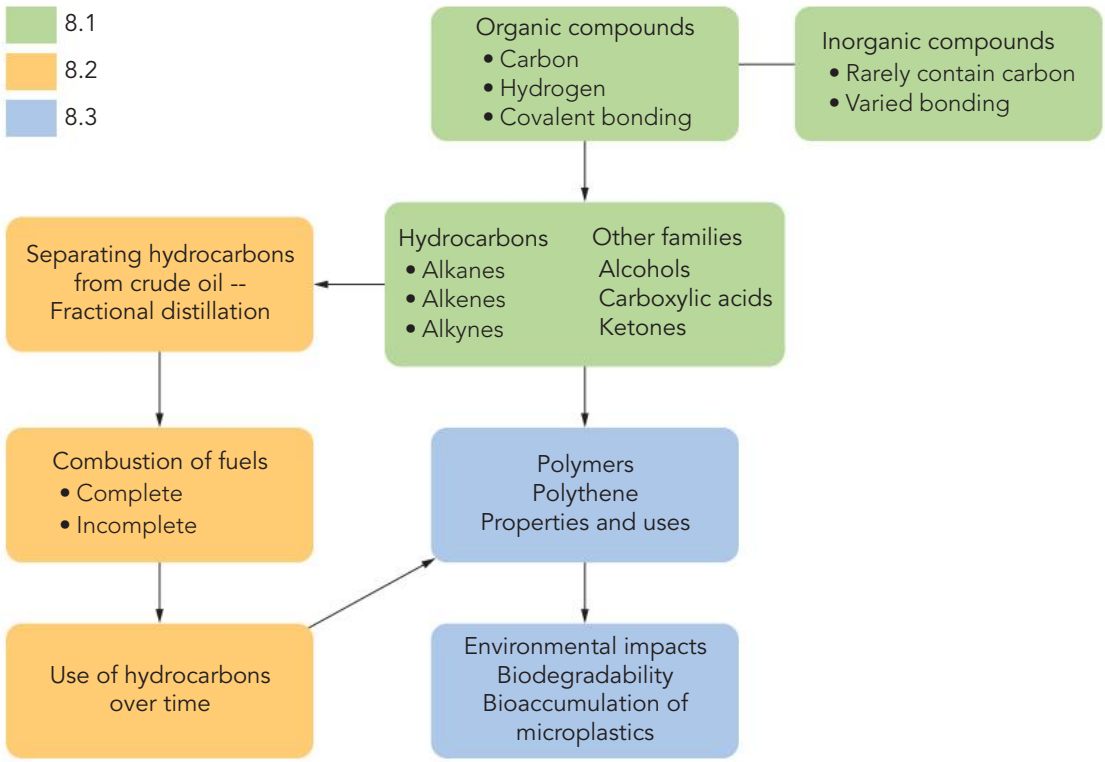


Chapter introduction

Organic chemistry is the study of carbon-containing compounds, which are the building blocks of life, quite literally! Carbon is the most important structural element and accounts for around 12% of all atoms in your body. From the sugars in our food to the fuels we use, organic chemistry plays a vital role in everyday life. In this chapter you will learn about the structure, properties, reactions and uses of some important organic molecules. Whether you're interested in cooking, medicine, environmental science or race cars, organic chemistry provides insights into almost every aspect of the world around us.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

alcohol
alkane
alkene
alkyne
bioaccumulation
carboxylic acid
combustion
exothermic
fractions
functional group
homologous series
hydrocarbon
inorganic
microplastics
monomer
organic
parent chain
polymer
saturated
synthesise
unsaturated

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

8.1 Introduction to organic compounds

WORKSHEET Naming organic compounds

Learning outcomes

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

1. distinguish between organic and inorganic compounds.
2. recognise and draw the structure of simple alkanes.
3. name simple organic compounds using IUPAC nomenclature.

These days if we hear that something is 'organic' we are often talking about food that is farmed without chemical additives such as fertilisers and pesticides and containing no genetically modified organisms.

Figure 8.1 When we think of the word 'organic', fresh vegetables often come to mind.

When scientists talk about 'organic' chemistry, they are talking about the chemistry of carbon compounds. This might sound like a very narrow field of interest, but there are estimated to be around 20 million different known **organic** compounds. This is many more than the total number of **inorganic**, or non-carbon-based, compounds. This incredible number is also constantly growing as scientists are regularly discovering or **synthesising** new carbon compounds.

organic class of compounds containing carbon covalently linked to other elements, usually also containing hydrogen

inorganic compounds that generally do not contain carbon

synthesise to make a chemical compound

So where do you find organic molecules? A diverse range of substances including detergent, fuel, rubber, cosmetics, food, fabrics, medicines and plastics contain organic molecules. They are all around us, and understanding their chemistry is very important.

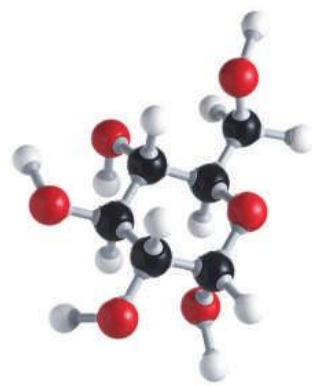


Figure 8.2 Molecular model of glucose, an example of an organic molecule. The chemical formula for glucose is $C_6H_{12}O_6$. Black spheres represent the carbon atoms, red spheres the oxygen atoms and white spheres the hydrogen atoms.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 8.1

How organic chemistry got its name

The name 'organic chemistry' was applied to the chemistry of carbon compounds at a time when scientists thought that these compounds could only be produced by living things such as plants and animals. They believed that this was due to the 'vital force' that was only present in living beings. Although we now know that we can produce carbon compounds from inorganic substances, the name has remained.

Figure 8.3 Many organic compounds are animal and plant products, so scientists believed that they could only be produced by living things and so called the study of them 'organic chemistry'.

While inorganic compounds usually do not contain any carbon, there are a few exceptions to this: carbon dioxide, carbon monoxide, graphite, carbides, some carbonates and some cyanides. These compounds contain carbon, but it is not bonded to hydrogen, and they are still considered to be inorganic. So, it is accurate to say that all organic compounds contain carbon, but not all carbon compounds are organic.

Organic molecules		
Common name	**Formula**	
Sugar	$C_{12}H_{22}O_{11}$	
Caffeine	$C_8H_{10}N_4O_2$	

Table 8.1 Some examples of organic and inorganic substances

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

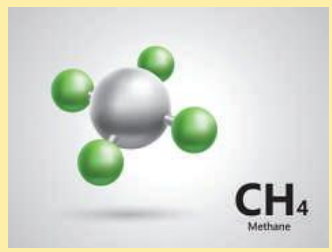
Common name	Formula	
DNA molecules	$C_{10}H_{16}N_5O_{13}P_3$	
Methane	CH_4	
Inorganic substances		
Salt	NaCl	
Iron	Fe	
Diamond	C	
Carbon dioxide	CO_2	

Table 8.1 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

So why are there so many organic compounds? This is due to the unique chemical properties of carbon. Carbon has four valence electrons, allowing it to form four covalent bonds. These covalent bonds can be single (one shared pair of electrons), double (two shared pairs of electrons) or triple (three shared pairs of electrons). This ability makes it amazingly versatile.

Did you know? 8.2

Silicon-based life in science fiction

Silicon is the element below carbon in the periodic table, meaning it has similar properties and can also form four covalent bonds. For this reason, science fiction writers and some scientists have long imagined that perhaps there could be silicon-based life in our universe!

The reality is that silicon bonds are much stronger than carbon bonds, which makes it unlikely to be a part of organisms that grow and replicate and therefore break and reform bonds frequently. Although perhaps on another planet, at much higher temperatures, silicon-based alien life could be found!

Figure 8.4 The science fiction writer Isaac Asimov wrote over 500 books during his life and considered the possibility of silicon-based rather than carbon-based life.

Carbon is also unusual among the elements as it can combine with other carbons to form rings or long chains. The variation in the bonds carbon can form results in many different, stable compounds formed from carbon.

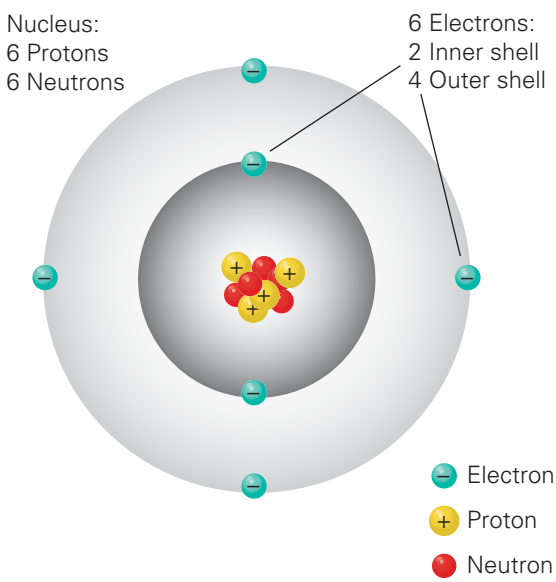


Figure 8.5 Each carbon atom has four valence electrons and so it can make four single bonds or combinations of double, triple and single bonds.

Quick check 8.1

1 **Recall** the difference between organic and inorganic compounds.
2 **Recall** the different types of covalent bonds carbon can make.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Naming organic compounds

Before you learn more about different organic compounds, it is important to understand how they are named. In the early days of organic chemistry, new compounds were named by the person who discovered them in any way they chose. This led to names like 'morphine' for the compound discovered in opium that relieves pain, after Morpheus, the Greek god of dreams, due to the compound's tendency to make people sleepy. Urea got its name because it was originally isolated from urine.

However, when naming anything in science, there needs to be a universal system so that everyone can understand what is being referred to with absolute certainty; moving just one atom to a different place on a molecule can completely change its physical and chemical properties! With organic chemistry, accurate naming is particularly critical because organic molecules can get extremely complex.

In organic chemistry, we use a naming system that was developed by the International Union of Pure and Applied Chemistry (IUPAC). The starting point of their set of rules is to identify the **parent chain** and count the number of carbon atoms it contains. IUPAC has developed some prefixes for numbers of carbon atoms that you will need to learn in Table 8.2.

parent chain the longest continuous chain of carbon atoms in an organic molecule

Number of carbons	Prefix
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-
9	Non-
10	Dec-

Table 8.2 IUPAC prefixes for the number of carbon atoms in the parent chain

The alkanes

The simplest group of organic molecules are the **alkanes**. They consist of a chain of carbon atoms with single bonds to each other. The remaining valence electrons form single bonds to hydrogen atoms. This means they have the maximum amount of hydrogen atoms possible and can be described as **saturated**. The simplest alkane is methane, CH_4. The prefix meth- indicates it has one carbon and the suffix -ane, indicates it is an alkane. Alkanes are also part of a subset of organic compounds known as the **hydrocarbons**.

Ethane, C_2H_6 is the next largest alkane. Every time a carbon is added to the chain, two extra hydrogens are also added. This regular increase and the similar structures and chemical properties of the alkanes make them what is called a **homologous series**. The word homologous is often used in science and comes from Greek, 'homo-' meaning 'the same'.

alkane simple organic compounds consisting of single bonded carbon chains single bonded to hydrogen atoms

saturated an organic molecule that contains only single bonds between carbon atoms and is bonded to the maximum amount of hydrogen atoms

hydrocarbon organic compound composed entirely of carbon and hydrogen atoms

homologous series a family of compounds with similar properties that share the same general formula

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

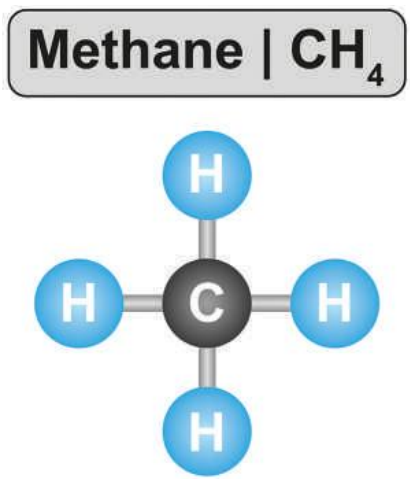


Figure 8.6 Methane is the simplest alkane, consisting of a single carbon atom with single bonds to four hydrogen atoms.

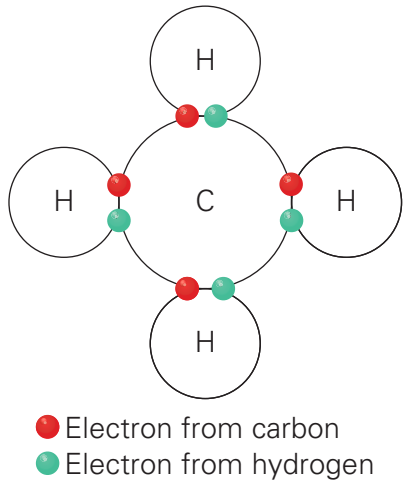


Figure 8.7 Each single covalent bond consists of a valence electron from hydrogen and a valence electron from carbon, shared between the atoms.

As the same number of carbon and hydrogen atoms are added each time the chain size increases, the alkanes have a general formula of:

$$C_nH_{2n+2}$$

where n is the number of carbon atoms. Using the general formula, you can determine the molecular formula for any alkane if you know how many carbon atoms it contains. For example, if there were 12 carbons in an alkane chain, following the general formula, the molecular formula would be $C_{12}H_{24+2}$, which gives $C_{12}H_{26}$.

Quick check 8.2

1 **Recall** the prefixes for hydrocarbon chains with one, two, three, four and five carbons.
2 **Recall** the general formula for the alkanes.
3 Using correct IUPAC nomenclature, **name** the straight chained alkane with seven carbons.

A common way of representing organic compounds is to use a structural formula. Rather than drawing in all the electrons, they are depicted with each covalent bond represented by a line. Table 8.3 shows the first eight alkanes, their molecular formulas and their structural formulas.

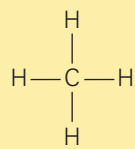
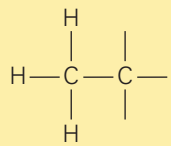
Name	Molecular formula	Structural formula
Methane	CH_4	
Ethane	C_2H_6	

Table 8.3 The first eight hydrocarbons in the alkane homologous series

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

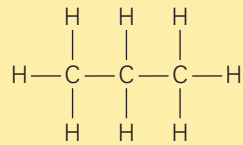
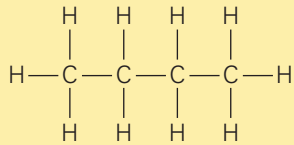
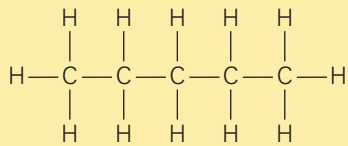
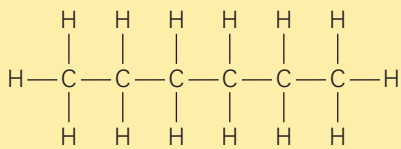
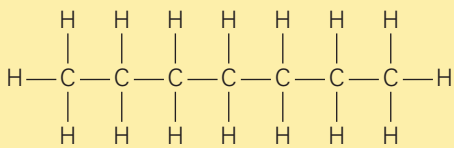
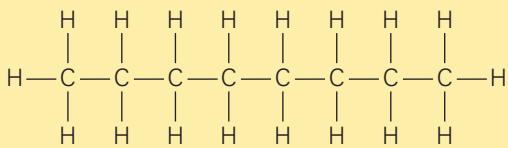
Name	Molecular formula	Structural formula
Propane	C_3H_8	
Butane	C_4H_{10}	
Pentane	C_5H_{12}	
Hexane	C_6H_{14}	
Heptane	C_7H_{16}	
Octane	C_8H_{18}	

Table 8.3 *(continued)*

Quick check 8.3

1 **Draw** the structural formula for nonane.
2 **State** the molecular formula for octane.
3 **Describe** the atoms and bonds found in an ethane molecule.

Unsaturated hydrocarbons

alkene hydrocarbon containing at least one double bond

alkyne hydrocarbon containing at least one triple bond

While alkanes are the simplest organic molecules. **Alkenes** and **alkynes** are also hydrocarbons. Alkenes have at least one carbon–carbon double bond, and alkynes have at least one carbon–carbon triple bond.

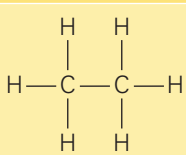
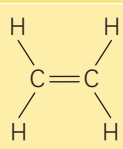
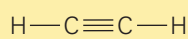
Ethane	Ethene	Ethyne
		

Table 8.4 Note that these three compounds all have two carbons, so have the prefix eth- in their name. Ethene has a double bond, indicated by the two lines joining the carbons and the -ene in its name. Ethyne has a triple bond between the carbons, indicated by the three lines and the -yne in its name.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Alkenes and alkynes are named in a similar way to alkanes with the prefix at the start of the name indicating the length of the carbon chain (Table 8.4). Alkenes will then end with -ene, indicating the double bond and alkynes will end with -yne indicating the triple bond.

unsaturated
a compound that contains at least one double or triple bond and does not therefore have the maximum amount of hydrogen bonds

The general formula for alkenes is:

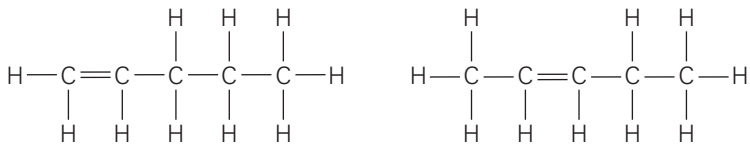
$$C_nH_{2n}$$

and the general formula for alkynes is

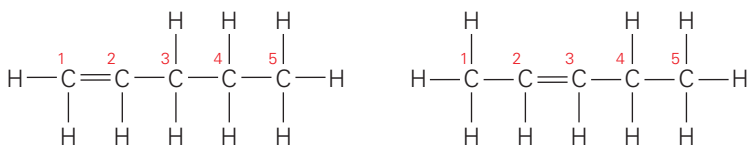
$$C_nH_{2n-2}$$

As alkenes and alkynes are not fully single bonded, they do not have the maximum amount of hydrogen bonds and are therefore **unsaturated** hydrocarbons. When naming, it is also important to know where in the hydrocarbon chain the double or triple bond occurs.

Consider the following two compounds:

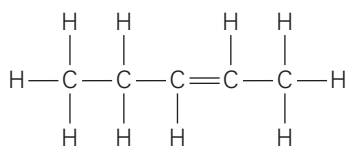


Both compounds have a five-carbon chain, pent-, with a double bond, -ene. However, they are clearly structurally different and so need a different name to ensure that there is no confusion between them. According to IUPAC conventions, a number is inserted in the name to show which carbon the double (or triple) bond begins at. To do this, the carbons in the chain need to be numbered from one through to five with the numbers starting at whichever end of the molecule gives the lowest number for the double or triple bond. So, for both molecules, numbering starts on the left-hand side and the top hydrocarbon is named pent-1-ene, and the lower is named pent-2-ene.



Note that the number is inserted into the name with dashes either side of it. Where the number is one in naming, it can often be left out, so pent-1-ene can be simplified and just called pentene.

Now consider the molecule shown below. Can you deduce its name?



This time the numbering starts from the right and the molecule is also pent-2-ene. When we compare it to our earlier pent-2-ene, we see that it is structurally the same. It has just been drawn in a different direction, and we are looking at it from the other side.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

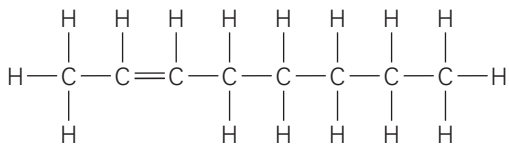
It is like we are looking at a car from different sides. From one side we see the boot on the left, from the other side the boot is on the right. It just depends on where you are standing, but it is still the same car.

Figure 8.8 These cars are shown in different directions, but they are still the same car. It is important to ignore the direction organic molecules are drawn in when naming them, and to follow the rules.

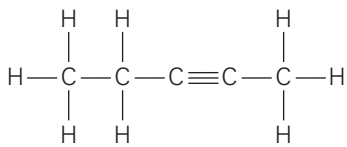
Quick check 8.4

1 Using correct IUPAC nomenclature, **name** the following compounds.

a



b



Draw the structural formulas and name two different alkenes that can be formed with a seven-carbon chain.

Other organic families

So far, we have looked at the hydrocarbons, but there are many other families of organic compounds. Each family has a distinctive **functional group**, that is a group of atoms that will give compounds containing this group similar chemical properties. Two important families are the **alcohols** and **carboxylic acids**.

functional group a group of atoms responsible for the chemical properties of a group of compounds

alcohol an organic compound with a hydroxyl functional group

carboxylic acid an organic compound with a carboxyl functional group

Alcohols

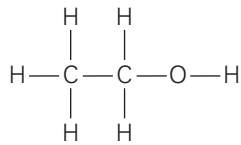
Alcohols have a hydroxyl functional group. That is, they have an –OH attached to a carbon atom.

Alcohols are one of the most common organic compounds. They are used for sterilising in hand sanitisers, as fuels and as solvents such as in perfumes and cosmetics. Ethanol can also be used in alcoholic drinks and many alcohols make up the building blocks needed for synthesising other more complex organic compounds.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 8.9 Alcohols are a family of organic compounds with many uses.

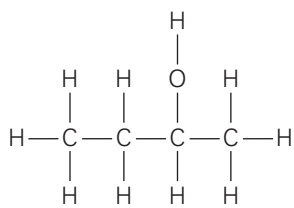
An example of an alcohol is ethanol.



You may have noticed that this compound is very similar to ethane, with a hydroxyl group replacing one hydrogen. Thus, according to IUPAC rules, the naming of simple alcohols identifies the number of carbons in the single bonded chain, using the prefix eth-, followed by -an-, as the chain is saturated (based on an alkane). The name then ends in -ol indicating the presence of the hydroxyl group.

If the hydroxyl group is not on the end of the chain (attached to the first carbon) a number must be included to identify where the hydroxyl group is attached.

For example, this compound has a four-carbon single bonded chain, so its name starts with butan-. There is a hydroxyl group, so it will end with -ol. However, it is not found on the end carbon. Remembering to number the carbons from the end closest to the functional group, this molecule is butan-2-ol.

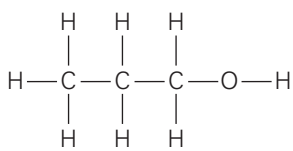


Quick check 8.5

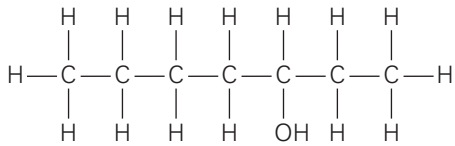
1 **Draw** the structural formula for hexan-3-ol.

2 Using correct IUPAC nomenclature, **name** the following organic compounds.

a



b



3 **Write** the molecular formula for an alcohol with a six-carbon chain.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Carboxylic acids

The carboxylic acids have a carboxyl (COOH) functional group. That is, they have a carbon that is double bonded to an oxygen atom and to a hydroxyl group.

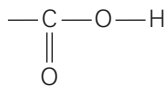
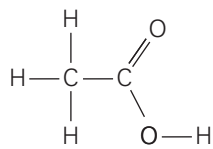


Figure 8.10 Carboxyl functional group of carboxylic acids

You will notice that the carbon in the carboxyl functional group has only one free valence electron, so can only form one more single covalent bond with either a hydrogen or another carbon. This means that the carboxyl group will always be found on the end of a carbon chain.

An example is ethanoic acid.



Naming carboxylic acids requires identifying the number of carbons in the chain to give the start of the name, in this case there are two carbons and they are single bonded, so we use ethan-. The functional group present is the carboxyl group, so the name ends in -oic acid. The complete name is ethanoic acid.

Carboxylic acids are found widely in nature. Ethanoic acid is found in vinegar, citric acids are found in citrus fruits such as lemons and oranges, long chain fatty acids make up components of fats and oils, and proteins are made up of amino acids that contain carboxyl groups.

Figure 8.11 Citrus fruits contain the carboxylic acid known commonly as citric acid.

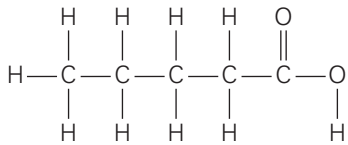
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 8.6

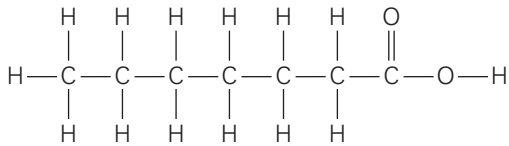
1 **Recall** the structure of a carboxyl functional group.

2 Using correct IUPAC nomenclature, **name** the following carboxylic acids.

a



b



3 **Write** the name, structural formula and molecular formula for a carboxylic acid with a carbon chain length of three.

We have looked at a few functional groups, but there are many more in organic chemistry.

Table 8.5 below shows a selection of these families and their functional groups. The 'R' in the functional group designates a carbon chain that can be of any length.

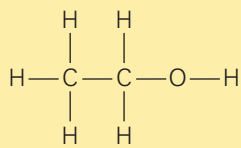
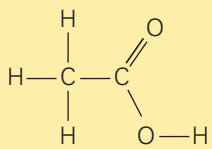
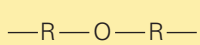
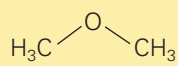
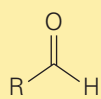
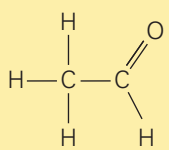
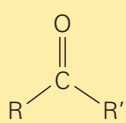
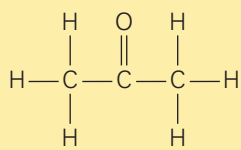
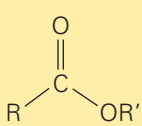
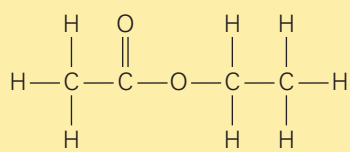
Family name	Functional group	Example
Alcohols		
Carboxylic acids		
Ethers		
Aldehydes		
Ketones		
Esters		

Table 8.5 A selection of organic functional groups

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

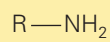
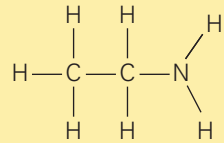
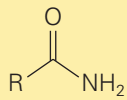
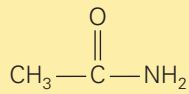
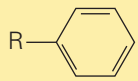
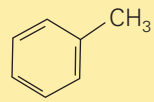
Family name	Functional group	Example
Amines		
Amides		
Aromatics		

Table 8.5 *(continued)*

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

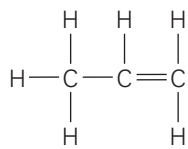
Section 8.1 questions

Remembering

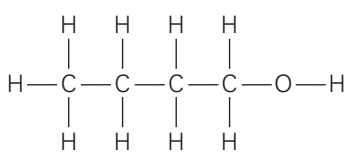
1 **Recall** the difference between organic and inorganic molecules.
2 **Recall** the name for the hydrocarbon family of molecules containing at least one triple bond.
3 **Define** the term 'homologous series' and give an example.

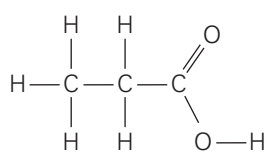
Understanding

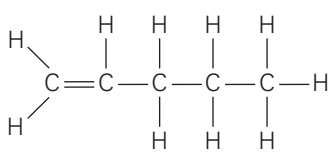
4 **Determine** which hydrocarbon family C_3H_6 belongs to and draw its structural formula.
5 **Draw** the structural formula for heptane.
6 **Explain** why the molecule below is named prop-1-ene or propene, not prop-2-ene.



7 Using the general formula for alkanes, **determine** how many hydrogen atoms would be present in a twenty-four-carbon chain alkane.
8 **Name** the following molecules.

a 

b 

c 

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applying

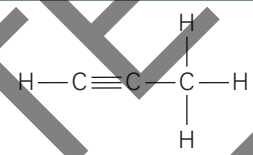
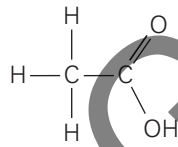
9 **Explain** why carbon is present in so many compounds in our universe.

10 **Explain** why the molecule pentan-4-ol is incorrectly named and state its correct name.

11 Sodium bicarbonate ($NaHCO_3$) contains both carbon and hydrogen. **Explain** why it is not considered an organic molecule.

Analysing

12 Copy and **complete** the data in the following data table.

Number of main chain carbons	Name	Identifying feature(s) or functional group	Molecular formula	Molecular structure
	Heptane	Saturated hydrocarbon		
1		Alcohol		
			C_3H_4	
	But-2-ene		C_4H_8	
2				

FPO

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

8.2 Reactions and uses of organic compounds

WORKSHEET Writing combustion reactions

Learning outcomes

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

1. describe the differences between complete and incomplete combustion of hydrocarbons, and compare combustion products and the amount of energy released.
2. describe how hydrocarbons can be separated from crude oil.
3. identify the uses of hydrocarbon compounds and how this has changed over time.

Combustion reactions

combustion the reaction of a fuel with oxygen, usually producing heat and light

exothermic a reaction that releases heat

One of the most common uses of hydrocarbons is as fuels as they are highly flammable (burn easily) and release large amounts of energy in the form of heat. **Combustion** is the scientific term for burning. Combustion of hydrocarbons is an **exothermic** reaction, meaning the reaction releases heat. For combustion to take place, oxygen is required. In general terms, a combustion reaction is the burning of a hydrocarbon (fuel) in the presence of oxygen, to produce carbon dioxide, water, heat and light.

hydrocarbon + oxygen → carbon dioxide + water + heat + light

When methane undergoes combustion, one molecule of methane reacts with two molecules of oxygen to produce one molecule of carbon dioxide and two molecules of water.

methane + oxygen → carbon dioxide + water

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

This is an example of complete combustion because enough oxygen is present to combine with all the hydrogen and carbon in the fuel to form water and carbon dioxide. However, if only a limited supply of oxygen is available, methane will undergo a process called incomplete combustion, which will lead to the formation of carbon monoxide and carbon (soot).

$CH_4 + O_2 \rightarrow C + 2H_2O$ OR $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$

In reality, incomplete combustion produces a mixture of carbon, carbon monoxide and carbon dioxide, depending on the amount of oxygen available.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 8.1

Observing combustion

Set up a Bunsen burner in the lab and get out a boiling tube and holder. Be careful as the Bunsen burner flame and anything it heats will be hot.

Light the Bunsen burner with the air hole open and observe the flame, then close the air hole and observe. How did the flames differ? Why do you think that was the case?

Now take the boiling tube containing some water and hold it over each flame for a minute or two. What do you observe? Can you explain your observations?

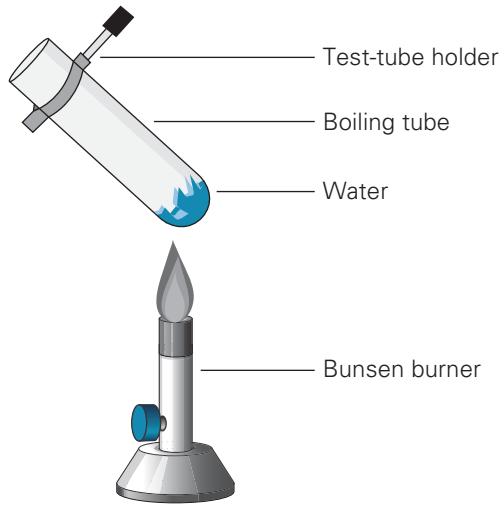


Figure 8.12 Heat water in a boiling tube over two different flames and make your observations. Note: it is important to angle the mouth of the tube away from you in case the water starts to boil.

Quick check 8.7

1 **Explain** why combustion reactions are described as exothermic reactions.
2 **Identify** the reactant gas required for all types of combustion reactions.
3 Carbon dioxide and water are released during the combustion of octane. **Write** a word equation for this reaction, assuming complete combustion takes place.

INVESTIGATION

Explore! 8.1

Controlled firestick farming

For thousands of years, Aboriginal and Torres Strait Islander Peoples have used fire to sustain Australian bushland and plant growth, in a practice known as firestick farming. Research the benefits of this practice and answer the following questions.

1 What is firestick farming?
2 At what time of year, in the *north* of Australia, is firestick farming most effective and why?
3 What are the products of combusting plant material in excess oxygen?
4 What are the effects of these products in the environment? Consider whether firestick farming enhances or reduces the magnitude of these effects.

Figure 8.13 A firestick is used to burn off dry grass in Arnhem Land, Northern Territory.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Alkanes used as fuels

Different hydrocarbons have different physical properties including, their melting and boiling points, which makes them useful as fuels in different situations. Table 8.6 shows some of the alkanes used as fuels in everyday applications.

Alkane	Methane Ethane	Propane	Butane	Octane	Hentriacontane ($C_{31}H_{64}$)
Uses or occurrence					
Comments	Methane is the major component of natural gas used in gas stoves. Ethane is the second most abundant component of natural gas.	Propane is commonly stored in cylinders and used as fuel for barbeques in the form of liquified petroleum gas (LPG).	Butane is used as the fuel for portable stoves. It is also the fuel found in many lighters.	Petrol is primarily a misture of alkanes ranging from 5–12 carbons.	Hentriacontane is a typical component of paraffin wax candles.

Table 8.6 Everyday uses of alkanes as fuels

INVESTIGATION

Investigation 8.1

Energy release by combustion of organic compounds

Background information

Some fuels are better than others at releasing energy from combustion reactions. The energy released by combustion is usually recorded as the amount of energy in joules (J), released by combustion of a specific mass of fuel. For example, joules per gram (J/g).

Many of the everyday alkanes used for fuels have low boiling points and exist as gases at room temperature, so in a school lab environment it is easier to investigate energy release using alcohols.

Often the fuels we use in everyday life are not pure substances, but in this investigation you will be using pure alcohols and comparing the amount of energy they release in J/g.

This can be done by heating water through the combustion of organic compounds and using the following calculation:

$$E \text{ (energy released)} = mc\Delta T$$

Where:

m = mass of water in grams (g)

c = specific heat capacity of water (4.18 J/g/°C)

ΔT = change in temperature of the water in °C

In this investigation you will use different alcohols to increase the temperature of 200 mL water by 10°C, making ΔT = 10°C and m = 200 g (1 mL of water has a mass of 1 g). Therefore, for this investigation, E will remain the same:

$E = mc\Delta T = 200 \times 4.18 \times 10 = 8.36 = 8360$ J or 8.36 kJ

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Using *E* and the mass of hydrocarbon combusted, the amount of energy released for every gram (g) of fuel can be calculated.

For example, if 4 g of fuel is used:

$$\text{energy of combustion} = \frac{\text{energy released (J)}}{\text{mass of fuel (g)}}$$
$$= \frac{8360}{4}$$
$$= 2090 \text{ J/g or } 2.09 \text{ kJ/g}$$

Aim

To compare the energy released by the combustion of different alcohols.

Be careful

Alcohols are very combustible so take care when handling flames and do not leave lit spirit burners unattended.

Materials

- conical flask
- thermometer
- stand and clamp
- methanol-filled spirit burner
- ethanol-filled spirit burner
- propanol-filled spirit burner
- butanol-filled spirit burner
- balance
- measuring cylinder

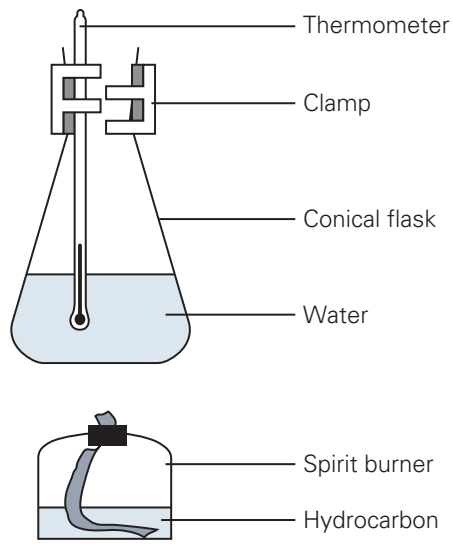


Figure 8.14 Experimental set-up to measure the energy released by combustion of hydrocarbons

Procedure

1. Copy the results table shown below into your journal and complete the number of carbons column.
2. Set up the apparatus as shown in Figure 8.14.
3. Weigh the first burner (including the alcohol it contains) and record the initial mass.
4. Add 200 mL of cold water to the conical flask using a measuring cylinder and use the thermometer to record its initial temperature.
5. Light the wick on the burner, adjust the height of the flask if needed so the tip of the flame just reaches the bottom of the flask.
6. When the temperature has risen 10°C, replace the cap to extinguish the flame.
7. Once it has cooled down slightly, weigh the burner and record the final mass.
8. Clean the flask and replace the water before repeating steps **3–7** with the remaining alcohols.

Results

1. Copy and complete the table below.

Alcohol	Number of carbons	Initial mass (g)	Final mass (g)	Mass of alcohol combusted (g)	Energy of combustion (kJ/g)
Methanol					
Ethanol					
Propanol					
Butanol					

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2 Using the data recorded in your investigation, calculate the mass of alcohol combusted to raise the temperature of the water 10°C and record this in the table.
3 Using *E* calculated in the background information section and the method shown there, calculate the energy of combustion for each alcohol.
4 Draw a graph of your data with the number of carbons on the horizontal axis and energy of combustion on the vertical axis.

Discussion

1 Which alcohol released the most energy per gram?
2 Do your results show a trend? Can you describe it?
3 Use your findings to predict a trend in the energies of combustion of the alkane homologous series.
4 Research the published values for the energy of combustion for the alcohols used and compare them with your data. Are there any differences? How can you account for these differences?
5 What changes could you implement to improve this investigation? Explain how these changes would improve the investigation.

Conclusion

Write a short conclusion relating the energy of combustion of alcohols to the number of carbon atoms in their carbon chain.

Refining crude oil

Crude oil is a natural resource formed from the fossilised remains of marine organisms such as algae and plants that have undergone intense heat and pressure within the earth's crust over millions of years. This liquid carbon rich deposit can be found underground in reservoirs at the sites of ancient oceans.

Crude oil is extracted today from both beneath land and the ocean floor. It is a mixture of hydrocarbons in liquid form, but its colour and consistency vary based on its composition. Depending on the amount of heat and pressure that was applied when it formed, different hydrocarbons were created, resulting in variations in the mix of hydrocarbons in the crude oil, or in the formation of coal or natural gas.

Figure 8.15 Crude oil is extracted from underground reservoirs by oil rigs through both onshore (above land) and offshore (ocean) drilling.

Crude oil is a valuable resource as the different hydrocarbons within it are used for a wide range of purposes.

fractions groups of hydrocarbons with similar chain lengths

In order to use them, the different hydrocarbons must be separated into **fractions** through a refining process. Fractional distillation is an important separating technique enabling the fractions to be separated on the basis of differences in boiling point.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Fractional distillation takes place in industrial plants known as oil or petroleum refineries. Crude oil is heated by a furnace at the bottom of a fractionating column (Figure 8.17). The mixture boils and components rise through the tower. As they move further up and away from the furnace, the temperature gets cooler and when each component reaches the appropriate temperature, it condenses and is removed. Smaller chain organic molecules tend to have lower boiling points and will therefore condense further up the tower in cooler areas while large molecules have higher boiling points and condense lower down in the tower.

Figure 8.16 Fractional distillation of crude oil takes place in industrial refineries.

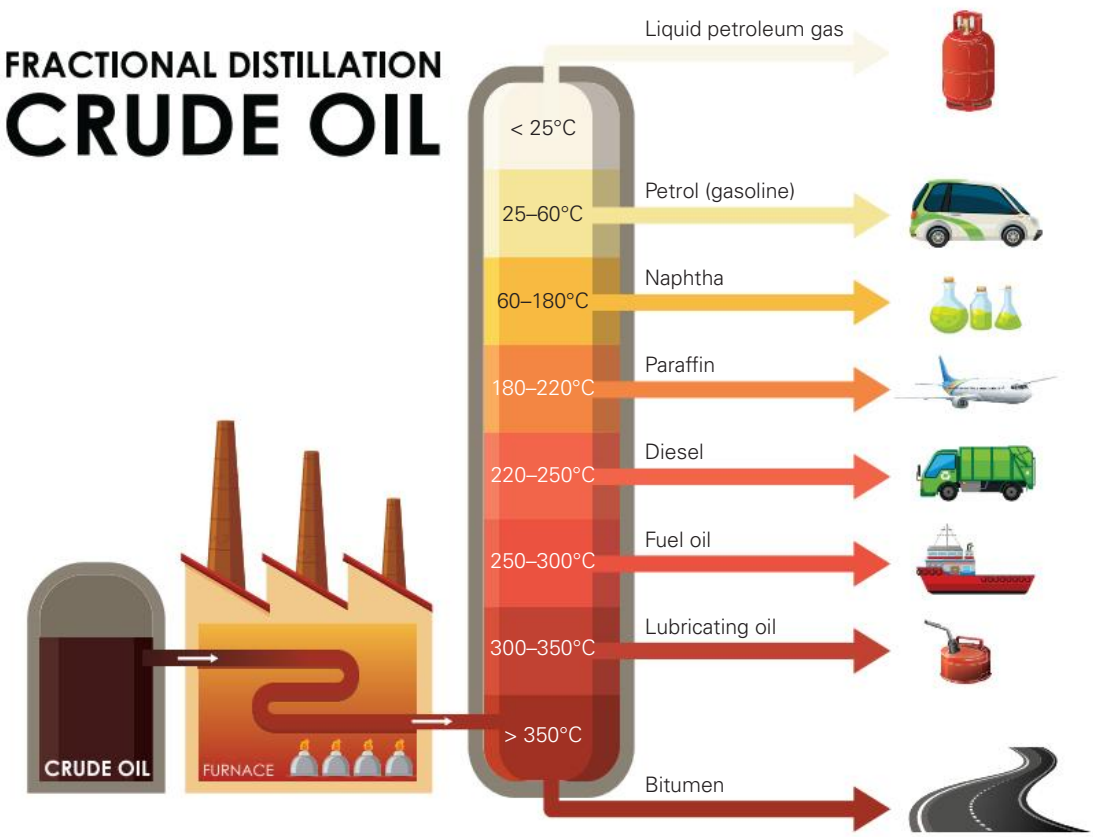


Figure 8.17 Diagram of a fractionating tower for distillation of crude oil

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Each fraction collected therefore has a mixture of molecules with a certain range of boiling points. The fraction with the smallest hydrocarbons contains petroleum gas or natural gas that we use for cooking and heating our homes. Most of us travel in petrol-fuelled cars daily. Petrol is found in a heavier fraction, consisting of larger molecules with higher boiling points (25–60°C). Diesel, often used in heavier vehicles and agricultural machinery, is an even heavier fraction, with a boiling point range of 220–250°C. The components that do not boil at all are referred to as bitumen, which is used in mixtures to make asphalt for the building of roads and car parks.

Quick check 8.8

1 **Explain** the purpose of fractional distillation.
2 **Recall** whether smaller molecules condense towards the bottom or the top of the fractionating tower.

Did you know? 8.3

Clothes from crude oil

You may know that some of your clothes are made from or contain polyester, but did you know that polyester is made from resources that come from crude oil? Polyester is a polymer (more on these in the next section) consisting of repeating molecules produced from fractions containing products like ethane, propane and butane following fractional distillation of crude oil.

Polyester has become less popular due to consideration of the environment and a move towards more sustainable practices. However, it is commonly used in fast fashion and nearly two thirds of all clothing discarded annually is made of or contains non-biodegradable polyester.

Figure 8.18 Polyester jackets made of a synthetic polymer derived from crude oil

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 8.2

Fractional distillation of crude oil

Aim

To separate crude oil (substitute) into its component parts or fractions.

Be careful

Crude oil substitute is highly flammable so must be kept away from flames.

Lab coats, safety glasses and gloves should be worn.

Materials

- crude oil substitute
- Bunsen burner
- heatproof mat
- round bottom distilling flask with side arm
- thermometer (0–360°C)
- retort stands and clamps
- condensing tube with hoses
- 4 conical flasks with stoppers
- bent delivery tube
- boiling chips
- dropper pipette
- 4 watch glasses
- 4 wooden splints

Procedure

1 Set up the apparatus as shown in Figure 8.19. The bulb of the thermometer should be level with or just below the side arm to the condenser.

2 Heat the bottom of the distilling flask gently with the lowest burner flame. Watch the thermometer and when the temperature reaches 100°C, remove the conical flask. Put a stopper in the mouth of the flask, this is the first fraction.

3 Promptly move a clean flask under the delivery arm.

4 Collect three more fractions:
- 100–150°C
- 150–200°C
- 200–250°C

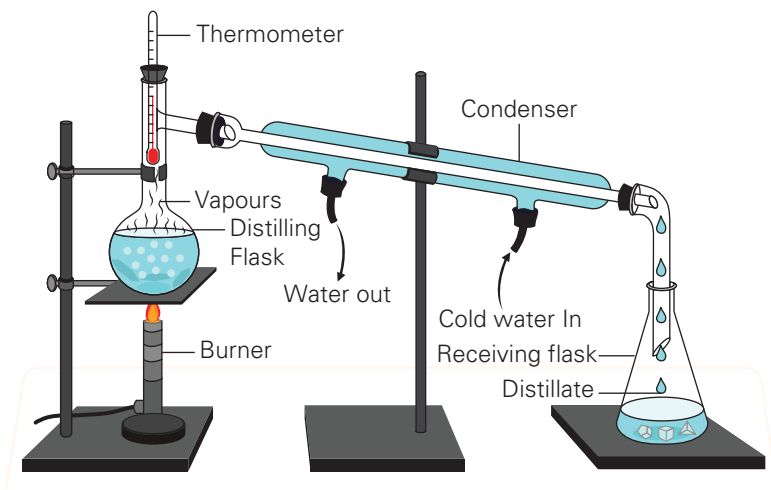


Figure 8.19 Distillation apparatus

Results

Complete and record the results of each of the following tests on the four fractions:
- colour
- viscosity (how thick is the fraction, or how easily does it pour?)
- smell (gently waft the smell towards you with your hand)
- flammability. Pour a very small sample onto a watch glass and light it using a burning splint. Note how easily it ignites, the speed of burning and how much smoke is produced.

Discussion

1 Compare the characteristics of the fractions with higher boiling points to the fractions with lower boiling points.

2 Which fractions contain the molecules with longer carbon chains? What can you deduce from this about the relationship between molecule size and boiling point?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The changing use of hydrocarbon products over time

While hydrocarbon compounds have been essential to modern life for over a century, humans have used them for much longer. Long before we developed a scientific understanding of their properties, humans used hydrocarbons for lighting and as adhesives or waterproofing agents. Early civilisations like the Mesopotamians and Egyptians discovered natural bitumen, which they used for waterproofing boats, sealing structures, and even in the mummification process. Ancient people also used bitumen and other natural oils for medicinal purposes.

Did you know? 8.4

Greek fire!

Greek fire was an ancient incendiary (flammable) weapon used by the Byzantine Empire (Eastern Roman Empire in 330 CE), known for its ability to burn even on water. It was probably made from a mixture of hydrocarbons, such as petroleum, combined with other chemicals like sulfur and quicklime, creating a highly flammable substance. The exact composition of Greek fire remains a mystery, but its use of hydrocarbons allowed it to be an incredibly effective weapon in naval warfare and sieging tactics.

Figure 8.20 Image from an ancient manuscript showing the use of Greek fire against the enemy fleet in battle.

The use of hydrocarbons has increased dramatically since the start of the 20th century. Initially, hydrocarbons were primarily used as fuels, with petroleum-based products powering early engines, cars and factories. Petrol and diesel, derived from crude oil, became the primary fuels for cars, revolutionising transportation and shaping modern society.

The range of hydrocarbon applications has now expanded well beyond using them for fuels. Hydrocarbons are key components in a wide array of products, including engine lubricants, which reduce friction and wear in car engines, and various synthetic polymers used in manufacturing plastics,

Figure 8.21 The ford model T from the 1920s. The use of hydrocarbons in the form of oil and petrol went hand in hand with the beginning of the automotive industry.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

synthetic fibres and rubber. For example, common materials like polyethylene and polyester, found in everyday items such as packaging, clothing and household goods, are made from hydrocarbon-based chemicals. You will learn about polymers and their uses in the next section.

As technology advances, hydrocarbons continue to play a crucial role in industrial processes. However, there is a need to find sustainable alternatives to these hydrocarbons as they are derived from a non-renewable resource. Their use, particularly as fuels, also contributes to the build-up of greenhouse gases and other environmentally harmful products. Finally, the accumulation of plastics in the environment, due to their lack of biodegradability and increased use, is a serious issue causing pollution and harm to many ecosystems.

Section 8.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 8.2 questions

Remembering

1 **Recall** the difference between complete and incomplete combustion.
2 **Recall** the products of a complete combustion reaction.
3 **Describe** what crude oil is and how it is formed.

Understanding

4 **Write** a word equation for the complete combustion of ethanol.
5 The word equation for a reaction is shown below. **Deduce** what type of reaction it is.

pentane + oxygen → carbon + carbon monoxide + water

6 Maya forgets to open the air hole on her Bunsen burner when she is heating a beaker of water and a black substance forms on the bottom of it. **Explain** what this is and why it forms.
7 **Explain** why fractional distillation produces fractions of molecules of similar sizes but cannot separate out specific molecules.
8 **Recall** two important products of fractional distillation and describe what they are used for.
9 **Describe** briefly how the use of hydrocarbons has changed over time.

Applying

10 One of the fractions produced during fractional distillation produces diesel, a fuel source consisting mainly of hydrocarbons. **Explain** what hydrocarbons are and why they are a good fuel.
11 Bitumen is a very viscous (thick) product of fractional distillation with a boiling point of around 400°C and a high carbon content. **Suggest** reasons why it is not usually used as a fuel source.

Analysing

12 The following table shows the boiling points of some of the alkanes. Using your understanding of fractional distillation, **explain** why decane condenses at a lower point in the column than hexane.

Alkane	Boiling point in °C
Hexane	69
Heptane	99
Octane	126
Nonane	151
Decane	174

Evaluating

13 Some residential heaters use wood as a fuel source rather than natural gas. **Explain** why wood is a more sustainable resource than natural gas.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

8.3 Polymers

WORKSHEET
Biodegradable polymers

Learning outcomes

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

1. identify the raw materials used in polymers.
2. describe the properties of a range of polymers.
3. conduct a physical survey of polymers in your local environment.
4. investigate the biodegradability of packaging materials.
5. research the bioaccumulation of microplastics in an Australian ecosystem.
6. assess the environmental impacts of materials that are used as alternatives to those derived from crude oil.

polymer
natural or synthetic substances composed of very large molecules made up of multiples of simpler molecules

monomer
a molecule that can be bonded to other identical molecules to repeat and form a polymer

Polymers are large molecules made up of smaller repeating units called **monomers**, linked together in long chains. A chain made out of paperclips is a polymer, made of single paperclip monomers.

Figure 8.22 A polymer could be likened to a chain of paperclips.

They are found in a wide variety of materials, from everyday items like plastic bottles and rubber bands to natural substances like silk and cellulose (a component of plant cell walls). Their structures make them useful in many different applications, being strong like polycarbonates which are used in engineering, flexible like polyethylene which is used in food packaging, or waterproof like polyurea which is used in wall plaster.

WORKSHEET
Investigate the biodegradability of different packaging materials

While some polymers like proteins, cellulose and DNA are naturally occurring, many are synthetic. Nearly all synthetic polymers are derived from crude oil. Many synthetic polymers are what we call plastic. In fact, all plastics are synthetic polymers. Plastics are very useful materials, but they do not readily biodegrade due to their general lack of chemical reactivity and complex bonds that are not easily digestible by microorganisms. This means they tend to accumulate and are harmful to the environment.

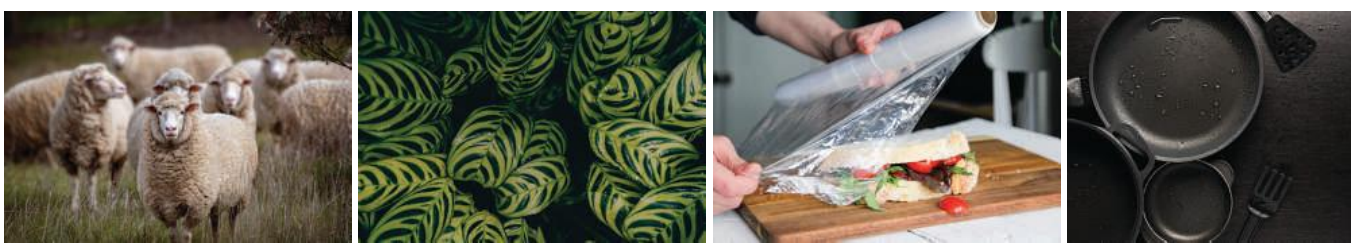


Figure 8.23 Natural polymers include wool and cellulose in plant walls, while polyethylene in food wrap and Teflon used to coat non-stick cookware are examples of synthetic polymers.

Quick check 8.9

1 **Recall** what a polymer is.
2 **State** two examples of natural polymers and two examples of synthetic polymers.
3 **Name** the substance most synthetic polymers are derived from.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 8.5

Polymer bank notes

In 1988, Australian scientists at the CSIRO developed the polymer bank note, making Australia the first country in the world to convert from paper-based notes. Now polymer bank notes are also used in thirty other countries. Australian bank notes start out as plastic pellets, which are melted and blown into a bubble three storeys high! The walls of the bubble are pressed together and cooled to form a laminated polymer film.

Figure 8.24 Australian polymer bank notes

Polyethene

Polyethylene or polyethene (PE) is a common simple polymer that is used to make plastic bags, cling wrap and a variety of other everyday items. It is made from multiple ethene monomers joined together by what is called a polymerisation reaction. The two-carbon alkane, ethene, is derived from crude oil and is reacted under high temperatures and pressures, in the presence of a catalyst, to form PE (Figure 8.25).

As you have learned, alkenes are unsaturated, as shown by the double bond in ethene. When the monomers join to form PE, this double bond is broken, and the carbon atoms make an additional single bond with the ethene monomers to either side.

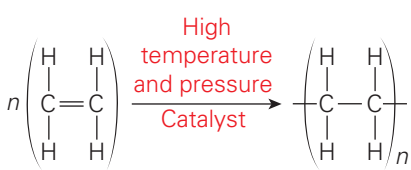


Figure 8.25 Multiple ethene monomers are joined to form long polyethene polymers. The '*n*' refers to the number of ethene monomers that can be joined to form any length of polyethene.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Different variations of PE have been synthesised to give different properties. High density PE (HDPE) consists of long, unbranched chains of PE that fit together closely and are therefore dense, strong, opaque and rigid. It is used to make plastic bottles. Low density PE (LDPE) consists of chains of PE with additional branches off the main hydrocarbon chain. This means they do not pack together as closely and are less dense, transparent and flexible. LDPE is used commonly in food packaging.

Quick check 8.10

1 **State** the name of the monomer used to make polyethene.
2 **Explain** why all plastics are called polymers.

Properties of polymers

Polymer	Properties	Common uses
Polyethene (PE)	Flexible, low cost, durable, forms thin films	Shopping bags, plastic bottles, packaging film, waste bags
Polystyrene	Lightweight, easy to process, insulator, can be expanded into an insulating foam	Insulation and food packaging
Polyvinyl chloride (PVC)	Durable, resistant to chemicals, good insulator, can be rigid or flexible	Pipes, medical devices, wiring insulation, vinyl records, clothing and footwear
Polypropylene	Tough, durable, resists shattering, resistant to heat	Buckets, cups, pallets, food containers
Polyamide (nylon)	Flexible, elastic, strong and lightweight	Textiles, carpets, kitchen utensils
Polytetrafluoroethylene (Teflon)	Chemically unreactive, low friction/slippery, high working temperatures	Non-stick cookware, coating medical devices

Table 8.7 Properties and uses of some common polymers

Practical skills 8.3

Polymers from milk

Aim

To create polymers from the protein casein in milk.

Background information

Casein is the major protein in milk, accounting for around 80% of the protein found in cow's milk. It is a complex organic molecule (Figure 8.26) which unfolds when the pH of milk is lowered by adding acid. This is the process that happens when milk curdles as the casein molecules unfold into long chains (monomers) that join to form polymers that can be moulded into a material that looks and feels similar to plastic.

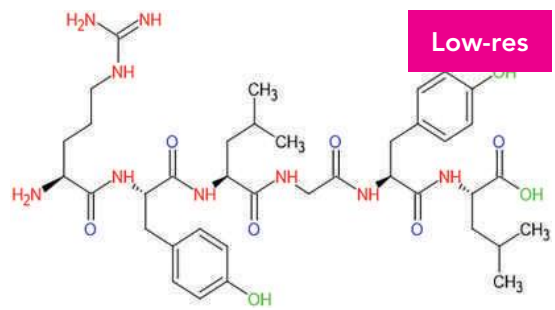


Figure 8.26 The molecular structure of casein, the major protein found in milk

Materials

- milk
- white vinegar
- measuring cup
- pasteur pipette
- spatula
- 2 × 500 mL beaker
- hot plate
- paper towels or muslin
- spoon
- optional: equipment to cut, mould or colour the plastic

continued ...

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1. Heat approximately 250 mL milk in the beaker on the hot plate until the milk is steaming.
2. Add approximately 20 mL of white vinegar to a fresh beaker and pour in the hot milk. You should see the milk start to curdle, forming white clumps.
3. Mix the milk slowly for a few seconds with a spatula.
4. Stack four layers of paper towels/sheet of muslin on the bench.
5. When the milk and vinegar mixture has cooled slightly, scoop the curds onto the paper towel/muslin.
6. If you are using paper towel, fold the edges over the curds and press down to absorb the excess liquid, using extra towels if needed. If you are using muslin, wrap the curd in it and squeeze the excess liquid from the ball of curds.
7. Knead the curd ball well and notice the change in the feel of it. This is the plastic-like casein.
8. If you have time, you can use the plastic to make and colour different shapes. It will then harden over 1–2 days.

INVESTIGATION

Explore! 8.2

Polymers in your local environment

1. Choose a local environment to explore. This could be the school grounds, your classroom, the fridge at home, your bedroom, or any location you choose.
2. Conduct a physical survey of the environment to determine how many different polymers there are. These should be natural and synthetic polymers. Use online research to help you identify the polymers if needed.
3. Choose one synthetic and one natural polymer to investigate further. Research how they are formed, what properties the possess and how those properties relate to their function in the environment you found them in.

INVESTIGATION

Explore! 8.3

Bioaccumulation of microplastics

Bioaccumulation refers to a process where harmful substances like microplastics build up in the tissues of living organisms over time. **Microplastics** are tiny plastic particles, less than five millimetres in size, resulting from the breakdown of larger plastic items or from microbeads (tiny plastic particles) in cosmetics and cleaning products.

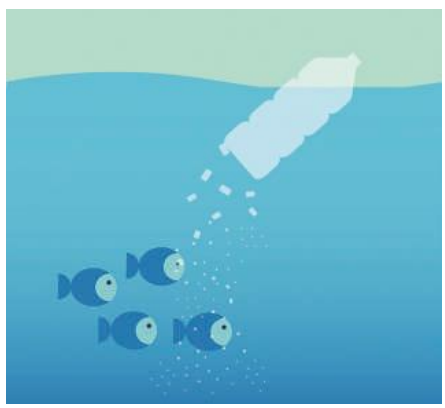


Figure 8.27 The breakdown of a plastic bottle into smaller, eventually micro and nano, particles that are ingested by marine organisms.

bioaccumulation the gradual accumulation of substances, such as plastics of chemicals, in an organism

microplastics extremely small pieces of plastic resulting from the breakdown of human and industrial waste

When microplastics enter the environment, they can be ingested by marine animals, plants, or other organisms. As these organisms are eaten by predators higher up the food chain, the microplastics accumulate in the tissues of each successive consumer. This process leads to harmful effects, ultimately disrupting the health and functioning of ecosystems. Bioaccumulation of microplastics is particularly concerning in aquatic ecosystems and it can also affect human health through the consumption of seafood.

Choose one of the five Australian ecosystems below as a case study to research the bioaccumulation of microplastics and write a short report. Consider the source of the plastics, the impact on the ecosystem, any broader impacts and what is or can be done to prevent further damage.

- The Great Barrier Reef – Marine life and the coral ecosystem
- Sydney Harbour – Fish and aquatic organisms
- Tasmanian Marine Ecosystems – Marine fish and invertebrates e.g. oysters
- Kangaroo Island – Seabirds and marine mammals
- Swan River (Western Australia) – Freshwater ecosystems and fish

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 8.4

Environmental impacts of alternative materials

In response to the harmful environment impacts of many materials such as plastics derived from oil, a number of alternative materials have been proposed to replace them. For example, paper straws are now used instead of plastic straws. However, these alternative materials have their own environmental impacts.

Research the environmental impacts of three materials that are used as alternatives to those derived from crude oil. Write a report comparing their impacts with the oil-derived material. Conclude with an assessment of how much of an improvement the alternative material is over the oil-based material.

Go online to access the interactive section review and more!

Section 8.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

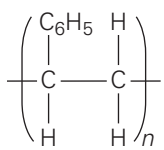
Section 8.3 questions

Remembering

1 **Recall** the definition of a polymer.
2 **Recall** the name used for a manufactured polymer.
3 **Name** three synthetic polymers that might be found in a household kitchen and their use.
4 **Recall** four common properties of plastic that make it useful.

Understanding

5 **Summarise** what happens when monomers of ethene are reacted under high pressure and temperature in the presence of a catalyst.
6 **Explain** what property of synthetic polymers means they are not usually biodegradable.
7 Polystyrene is a synthetic polymer with the structure shown below. Using your understanding of polymerisation, **draw** the structural formula of the monomer polystyrene is formed from.



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
8.1	distinguish between organic and inorganic compounds.	
8.1	recognise and draw the structure of simple alkanes.	
8.1	name simple organic compounds using IUPAC nomenclature.	
8.2	describe the differences between complete and incomplete combustion of hydrocarbons, and compare combustion products and the amount of energy released.	
8.2	describe how hydrocarbons can be separated from crude oil.	
8.2	identify the uses of hydrocarbon compounds and how this has changed over time.	
8.3	identify the raw materials used to make polymers.	
8.3	describe the properties of a range of polymers.	
8.3	conduct a physical survey of polymers in your local environment.	
8.3	investigate the biodegradability of packaging materials.	
8.3	research the bioaccumulation of microplastics in an Australian ecosystem.	
8.3	assess the environmental impacts of materials that are used as alternatives to those derived from crude oil.	

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Data questions

Table 8.8 shows the melting and boiling points of the alkane homologous series.

1 Using graph paper, plot a suitable graph and **draw** a line of best fit to show the relationship between number of carbons and boiling point.

Alkane	Molecular formula	Boiling point (°C)
Methane	CH_4	–164
Ethane	C_2H_6	–89
Propane	C_3H_8	–42
Butane	C_4H_{10}	–1
Pentane	C_5H_{12}	Data not given
Hexane	C_6H_{14}	69
Heptane	C_7H_{16}	98
Octane	C_8H_{18}	125

Table 8.8 Melting and boiling points of the alkane homologous series

2 **Describe** the trend shown in your graph.

3 Using your graph, **predict** the boiling point of pentane.

4 Using extrapolation, **predict** the boiling point of nonane.

5 **Determine** the state of butane at 20°C.

6 Considering the data, **compare** the storage methods for propane and heptane.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Investigating food packaging

Background information

Plastics are synthetic polymers derived from the products of the fractional distillation of crude oil. They have very useful properties including being strong, flexible and often cheap to make and use, but cause an environmental concern due to their lack of biodegradability.

Plastic waste takes between 20 and 500 years to degrade and while some polymers can be recycled, according to the World Wildlife Fund in 2021, only around 12% of the nearly 3 million tonnes of plastic produced in Australia annually is recycled. The production of plastics also contributes detrimentally to the environment through the production of greenhouse gas emissions.

DESIGN BRIEF

Design and conduct an investigation to determine the physical properties and biodegradability of different food packaging materials.

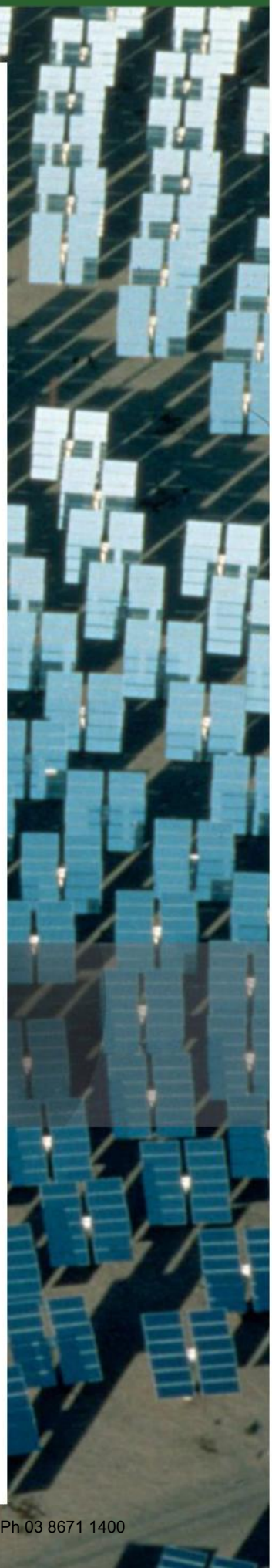
Figure 8.28 Plastic products accumulate in the environment due to their common use and lack of biodegradability.

Over the past few years, Australia has started to act by banning single use plastics, including those previously used for takeaway food products.

Low-res

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

521755134



Activity instructions

In groups of two or three, your task is to design and conduct an investigation to determine the physical properties and biodegradability of different food packaging materials.

Research and design

1 Discuss different takeaway food packaging options available, choose and collect samples of four to five different options, including some polymer-based options.

2 Design an investigation that can be carried out in the school laboratory with the equipment available to test the properties of the packaging materials you have collected. Ensure you consider properties that are relevant to their use as food packaging like cost of production, structural integrity when filled with food etc.

3

Conduct your investigations and record results.

5 Supplement your results where required with research.

Analyse, discuss and evaluate

6 Present the findings of your investigation in a mode of your choice, e.g. a poster or a scientific report.

7 Include a discussion on the positives and negatives of each packaging option in relation to cost, function and environmental impact and determine which represents the best option for packaging of takeaway food in Australia.

8 Evaluate the effectiveness of your investigation including any limitations or errors that arose.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 9

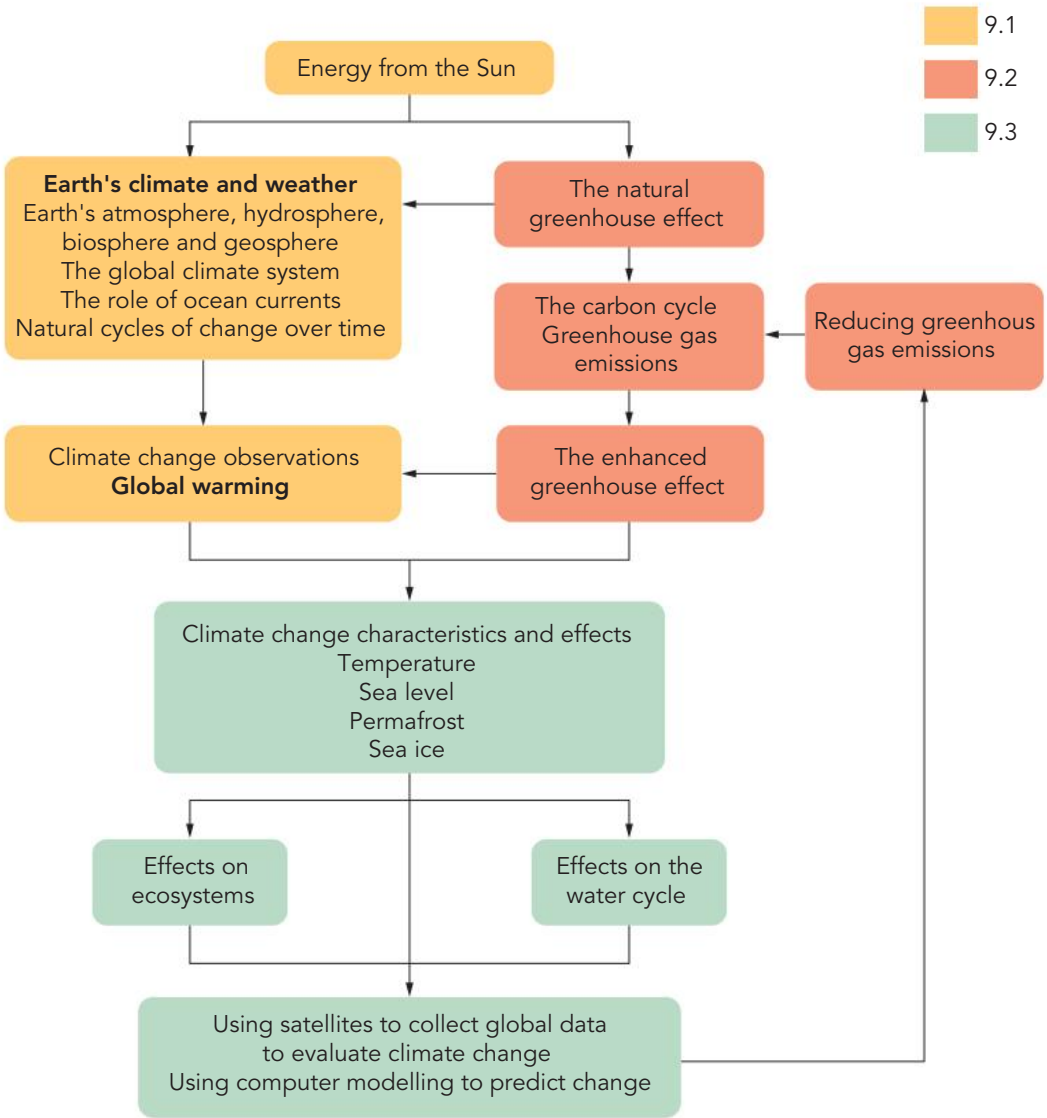
Climate science

Chapter introduction

Earth is a complex system consisting of the atmosphere, hydrosphere, geosphere and biosphere and the cycles that link them together. Many climatic processes are the result of interactions between the spheres, which create a dynamic global climate. Changing interactions have caused climate to change in the past, to be changing in the present and to be predicted to change in the future. In this chapter, you will learn about how the natural cycles of climate change are being affected by humans. You will understand the factors that regulate, and the evidence for, global climate change and learn how scientists predict changes to Earth's climate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al. 2023 • 978-1-009-51637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

anthropogenic
atmosphere
biosphere
carbon sink
carbon source
climate
climate change
enhanced greenhouse effect
geosphere
glacial period
global warming
greenhouse effect
greenhouse gas
hydrosphere
interglacial period
sphere
weather

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1009-59637 • • Ph 03 8671 1400

Earth's climate and weather

Learning outcomes

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

1. distinguish climate and weather.
2. identify what mainly determines climate on Earth.
3. describe trends in the Earth's climate using evidence.

atmosphere
the mixture of gases above the surface of Earth

geosphere
includes Earth's magma, lava, rocks and minerals

biosphere
all the areas on Earth and in its atmosphere that contain life

The Earth's climate and weather are driven by energy from the Sun. They are features mainly of the **atmosphere**, influenced by the **hydrosphere** (bodies of water, groundwater, and water vapour in the atmosphere) and, to a lesser extent, the top layers of the land, the **geosphere**. The **biosphere** (all living things) can also influence the climate, especially plants and algae. These four 'spheres' interact and should always be considered in discussions of global climate.

Figure 9.1 Climate and weather on Earth are determined by the energy from the Sun and interactions in the atmosphere, hydrosphere, geosphere and biosphere, all represented in this image.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The atmosphere

The atmosphere is the layer of gases that surrounds Earth. It is composed of various gases, including nitrogen (78%), oxygen (21%), argon (1%) and trace amounts of other gases such as carbon dioxide and neon. The atmosphere is responsible for regulating Earth's temperature and protecting it from harmful radiation, and it plays a critical role in the water cycle. It is divided into several layers, including the troposphere, stratosphere, mesosphere, thermosphere and exosphere, each with distinct characteristics and properties.

The troposphere

The troposphere is the lowest layer of Earth's atmosphere, extending from Earth's surface up to an altitude of approximately 6 to 20 kilometres. It is where most weather occurs and is where the majority of the water cycle occurs. Water evaporates from the Earth's surface into the atmosphere, forming clouds through condensation, and eventually precipitates as rain, snow or other forms of precipitation. The troposphere is composed mainly of nitrogen and oxygen, along with trace amounts of other gases, such as water vapour, carbon dioxide and methane.

The temperature in the troposphere decreases with altitude, which is why the highest temperatures are near Earth's surface and the lowest temperatures are at the top of the layer. This temperature gradient leads to convection currents, which drive weather patterns and atmospheric circulation. The troposphere is critical for supporting life on Earth, as it provides the oxygen we breathe, regulates Earth's temperature and plays a vital role in the carbon and water cycles.

The stratosphere

The stratosphere is the layer of Earth's atmosphere above the troposphere, extending from approximately 20 to 50 kilometres in altitude. It is characterised by a relatively high concentration of ozone, which absorbs ultraviolet radiation from the Sun. The temperature in the stratosphere increases with altitude because the ozone layer absorbs solar radiation, which creates a stable layer that inhibits mixing with the troposphere below.

The boundary between the troposphere and stratosphere is home to the jet stream, a high-altitude, fast-moving wind that influences weather patterns. The stratosphere plays a crucial role in regulating Earth's temperature.

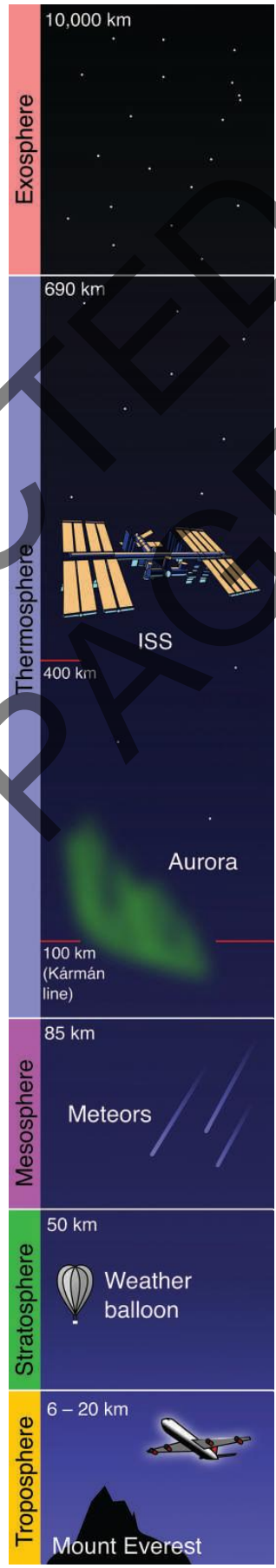


Figure 9.2 The five layers of Earth's atmosphere

Quick check 9.1

1. **Name** where the most of Earth's weather and the water cycle occurs.
2. **Recall** the source of energy that drives Earth's climate and weather.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Explore! 9.1

The Antarctic hole in the ozone layer

In 1985 scientists found that parts of the ozone layer above the continent of Antarctica had broken down. They also noticed that similar thinning of the ozone layer was happening over parts of Australia, and that this correlated with an increase in cases of skin cancer. They needed to find out why this had happened and if it could be reversed. Do some research and answer the following.

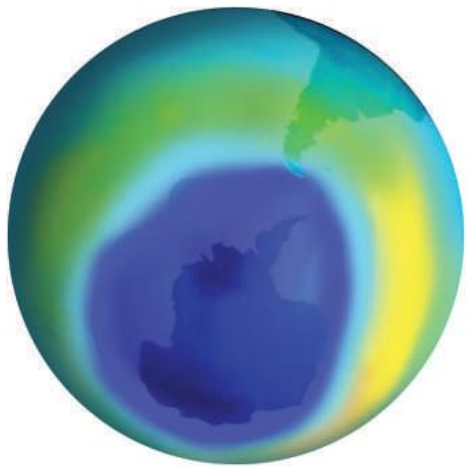


Figure 9.3 The hole in the ozone layer above Antarctica. The bluish-purple areas show the least amount of ozone.

1. Compare the atomic structures of oxygen gas (O_2) and ozone gas (O_3).
2. Identify the main function of the ozone layer in more detail to explain the impact of ozone thinning.
3. Research the causes of ozone thinning. Is it related to climate change, or a separate issue?
4. Describe the purpose of the Montreal Protocol.
5. In October 2022, a UN-backed scientific panel released a report saying the ozone layer is on track for a full recovery. When do they predict this will happen by?

The biosphere

The biosphere is the thin layer of Earth where life can exist. It is made up of all the living organisms on the planet, including plants, animals and microorganisms, as well as the physical environments in which they live.

Figure 9.4 Human activities, such as pollution and deforestation, can have significant impacts on the biosphere and interactions with climate change.

The biosphere extends from the deepest parts of the ocean to the highest peaks of the lower atmosphere, and from the polar ice caps to the Equator. It is a complex and interconnected system, with organisms relying on each other for survival and functioning together to maintain the delicate balance of the planet's ecosystems. It interacts with the atmosphere, hydrosphere and geosphere, being affected by them and also having influence upon them.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 9.2

1. **Recall** the definition of 'biosphere'.
2. Flying birds are part of the atmosphere, true or false? **Justify** your choice.

The hydrosphere

hydrosphere all of the water found on Earth (e.g. lakes and rivers)

The hydrosphere refers to all the water on Earth, including oceans, rivers, lakes, groundwater and even water in the atmosphere. It plays a critical role in supporting life on Earth, as all living organisms require water to survive.

The hydrosphere also plays a key role in regulating Earth's climate, as it absorbs and distributes heat throughout the planet. Additionally, the movement of water in the hydrosphere, such as through the water cycle, helps to shape Earth's surface and create important habitats for various organisms.

Figure 9.5 The water cycle in action in the hydrosphere. This weather event would be described by the amount of rain that fell and the date, whereas the climate in respect of rainfall at this location would be described by its monthly distribution, the area where it fell, and its total annual amount.

Quick check 9.3

1. **Recall** the definition of 'hydrosphere'.
2. **Give** an example of something that is part of the hydrosphere.

The geosphere

The geosphere refers to the solid and fluid rock and mineral parts of Earth, including the crust, mantle and core. It is the largest of Earth's spheres, and it plays a crucial role in supporting life on the planet. The geosphere is responsible for providing the foundation for Earth's surface features, including mountains, valleys and plateaus. It is also home to valuable natural resources, such as minerals and fossil fuels, which are essential to human societies. As we will see in this chapter, fossil fuels have a great impact on climate change. Lastly, the geosphere – due to its spherical shape, rotation, tilt and orbit, as covered in Stage 4 – determines the seasons and climatic differences between latitudes on Earth.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 9.6 The geosphere is constantly undergoing changes due to natural processes like plate tectonics, erosion and volcanic activity, which can influence climate and weather.

The global climate system

The Sun's radiation forms the foundation of Earth's climate system. Radiation that reaches Earth's surface interacts with the different spheres and drives various atmospheric, oceanic and land processes that collectively determine the global climate. The Sun's radiation heats air and water, evaporates water into the air, and drives wind and ocean currents. These interactions create weather patterns and climate zones, which can be seen in Figure 9.7. The absorption and reflection of the Sun's radiation by Earth's atmosphere and surface also regulate Earth's temperature, influencing global climate. Understanding the flow of energy in the 'spheres' is essential to understanding climate and weather.

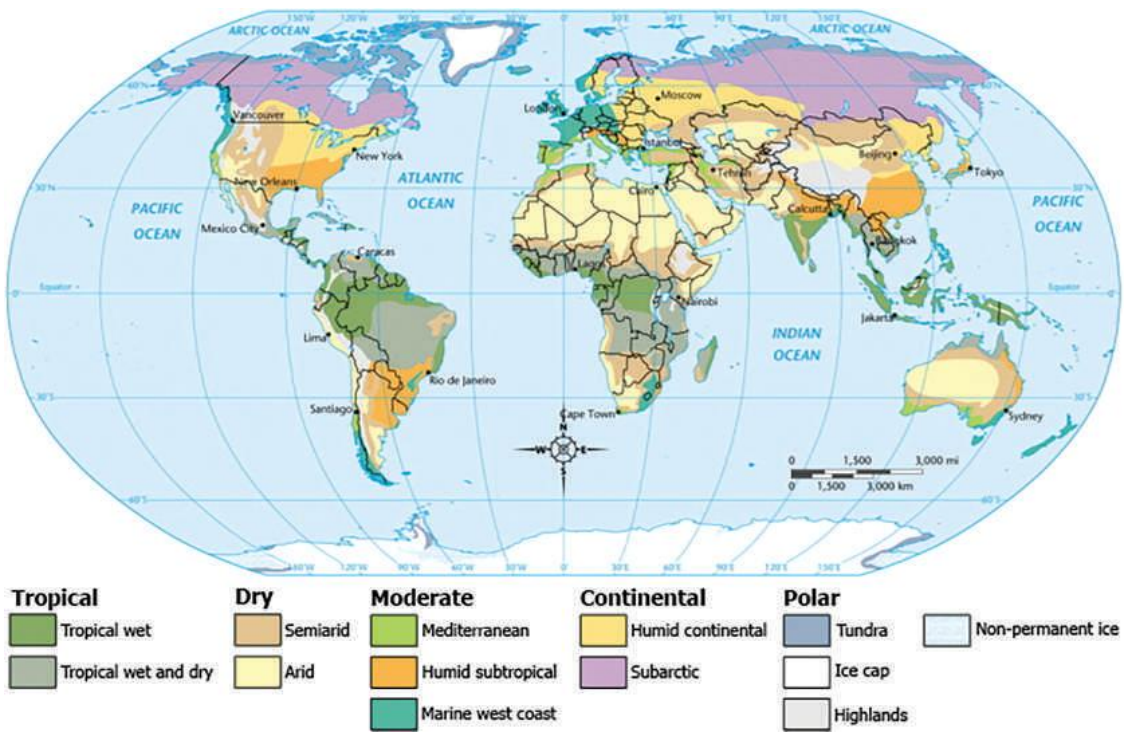


Figure 9.7 Global climate zones

Describe how the Sun is the primary source of energy for Earth's climate system.

2. **Identify** the major climate zone of Australia.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Climate versus weather

The difference between **weather** and **climate** is merely the time frame. Weather describes the conditions of the atmosphere in terms of temperature, cloud, rain and wind over a short period of time (minutes to months). The climate of an area is how the area behaves over a much longer period of time, usually 30 or more years. Different areas can have different climates; for example, the climate in New South Wales is very different from the climate in the Northern Territory.

weather
the atmospheric conditions (such as temperature, cloud, rain or wind) at a particular time over a particular area

climate
the average or prevailing weather conditions of an area over long periods of time

Different areas of the world have differing climates due to the:

- uneven distribution of the Sun's rays because of the curvature of the Earth
- proximity to the sea; land takes less energy to heat than water, so land temperatures rise quickly during the day and fall quickly during the night. The sea tends to remain cool during the day but retains its warmth at night
- tilt of Earth's axis, which causes seasons
- features on the land such as mountains. Air cools when it expands so when air passes over a mountain its temperature drops. This is why mountain tops are often covered in snow or cloud
- type of soil or plant life.

Did you know? 9.1

The East Coast Low

Eastern Australia experiences more storms in summer because of the presence of a weather pattern called the East Coast Low (ECL). An ECL is a low-pressure system that forms along the eastern coast of Australia, particularly in summer, bringing heavy rainfall and strong winds. ECLs are a result of warm ocean temperatures, high-pressure systems and the coastal topography of eastern Australia. These conditions provide the energy and moisture needed to generate intense storms, making the region particularly vulnerable to severe weather events during the summer months.

Figure 9.8 Lightning above the Three Sisters, Blue Mountains National Park

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The role of deep ocean currents

The Sun's radiation is absorbed by the ocean, particularly in tropical waters. The ocean plays a critical role in Earth's climate system as it doesn't just store heat, it also distributes it around the globe through the water cycle.

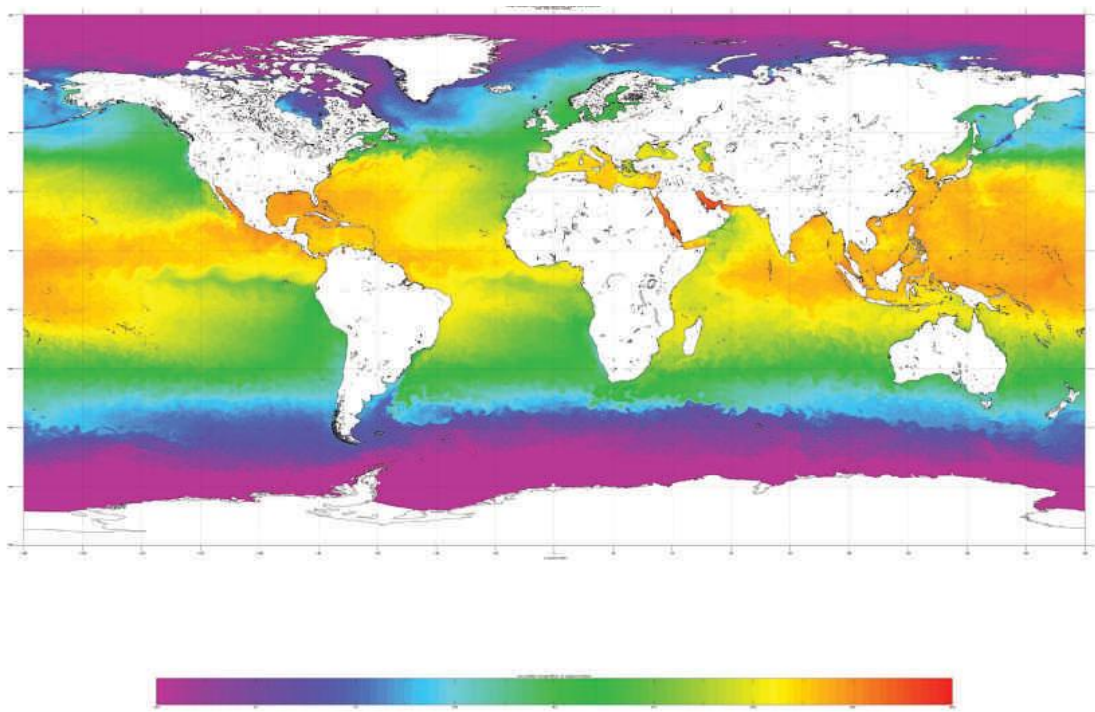


Figure 9.9 Global sea-surface temperatures taken from the National Oceanic and Atmospheric Administration (NOAA) Office of Satellite and Product Operations. The colourmap ranges from −2.0°C (purple) to 34.6°C (red).

Evaporation is a key component of this heat exchange. When ocean water absorbs the Sun's radiation, it heats up and evaporates into the atmosphere, leading to an increase in temperature and humidity. This increased humidity then condenses into clouds, which can lead to stormy weather. Storms are carried by trade winds and travel long distances, distributing heat and moisture around Earth. This exchange of heat and moisture between the ocean and the atmosphere helps to regulate the global climate.

Deep ocean currents play a significant role in driving weather patterns, especially in areas away from the Equator. Ocean currents are influenced by a complex interplay of factors, including wind, temperature gradients, salinity, Earth's rotation and tides. They help regulate global temperature by transporting heat from the Equator to the poles. This transfer of heat helps distribute the warm Equatorial waters to the colder polar regions, balancing the temperature difference between the two regions and mitigating extreme temperature differences between the two areas.

The major ocean currents typically form circular patterns, flowing clockwise in the Northern Hemisphere and anticlockwise in the Southern Hemisphere, mainly following coastlines. By distributing heat, ocean currents can affect local and regional climates, and they play a major role in the global climate system. In addition, deep ocean currents also mix water and nutrients from the ocean's surface to its depths. This process supports the overall health and productivity of oceanic ecosystems by ensuring the availability of essential nutrients for marine life. The movement of these nutrients plays a critical role in nutrient cycling, connecting the hydrosphere and biosphere and contributing to the balance of life in ocean ecosystems.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 9.5

1. **Define** the term 'weather'.
2. **Give** one reason why climates on Earth differ.
3. **Describe** how deep ocean currents regulate global temperatures.

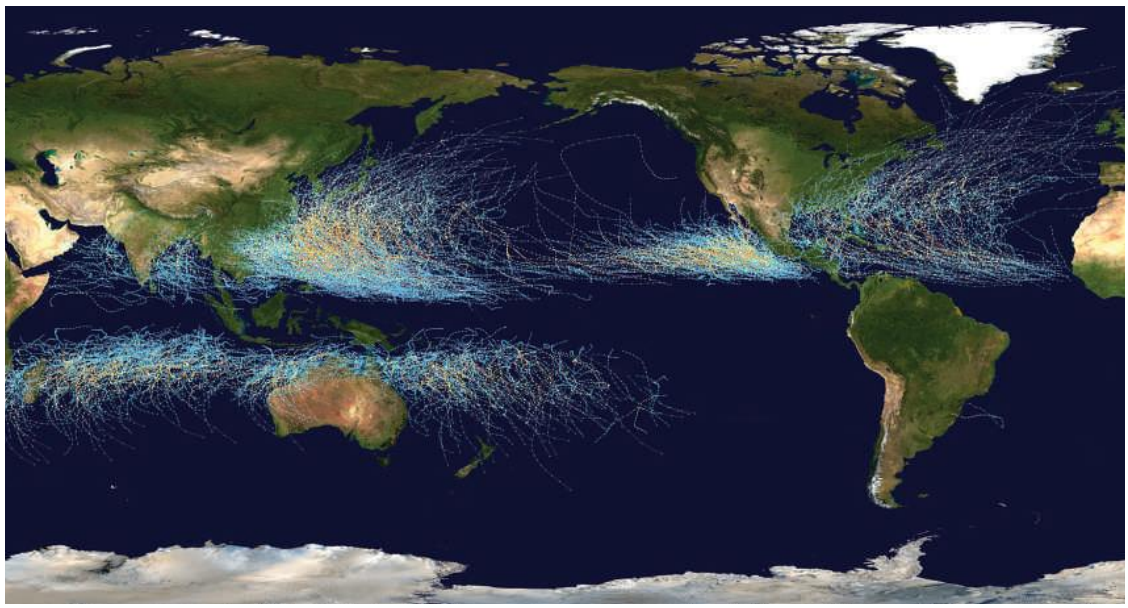


Figure 9.10 A map of tropical cyclone tracks. The higher evaporation rates in the tropics contribute to the higher rainfall and more active weather patterns in that region.

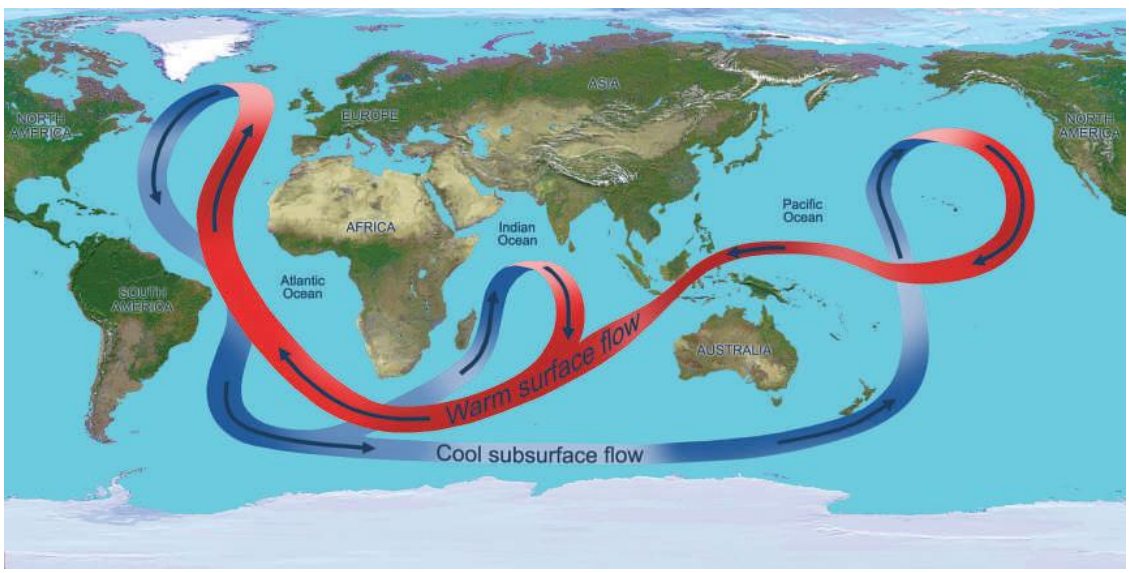


Figure 9.11 The most well-known deep ocean current is the thermohaline circulation, also known as the 'global conveyor belt'. This current is driven by differences in water temperature and salinity (haline), which affect water density. Warm water from the tropical regions flows towards the colder North Atlantic, releasing heat into the atmosphere, and then returns as cold, dense, salty water to the equatorial regions to begin the cycle again. This heat and salt-driven exchange significantly impacts the climate of regions far from the Equator, helping to distribute heat across Earth's surface and contributing to a more stable global climate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Observations of climate change

climate change statistically significant change to a measurement of climate, such as mean global temperature, that has been sustained for an extended period, typically decades or longer

glacial period a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

interglacial period a period in Earth's history when an increase in global temperatures is sustained for a long period of time

Climate change occurs when a significant change in the state of the climate has been sustained for an extended period, typically decades or longer. The change must be identified by statistical tests, such as to the mean of a significant climate measure. An example is global mean temperature for a year, calculated by averaging thousands to millions of temperature observations over the course of a year. Climate change can occur due to natural causes, such as changes in the Sun's intensity, natural variations in Earth's orbit, volcanic eruptions and variations in ocean currents. Natural climate change however takes thousands of years – sometimes millions.

Earth's climate is dynamic and has undergone significant changes throughout history. In the past, Earth has experienced many ice ages, where the planet was far colder than it is today, as well as warmer periods, when temperatures were higher than they are today.

A **glacial period** is when a reduction in global temperatures is sustained for a long period of time. The last glacial period started around 115 000 years ago and ended around 11 700 years ago. During this period, sea levels were much lower than now due to the presence of vast ice sheets. As a result, it was possible to walk from Tasmania to mainland Australia across a land bridge. However, as sea levels rose, the land bridge was submerged, creating the Bass Strait. The Torres Strait was once a land bridge that connected the Australian continent with Papua New Guinea. Rising sea levels eventually submerged this land bridge, creating the strait that now links the Arafura and Coral seas.

For approximately the last 11 700 years, we have been in an **interglacial period**, and Earth's climate has remained relatively stable throughout this period, with only small fluctuations. Figure 9.13 shows that after the last glacial period, a peak was reached relatively recently. The trend over the past 2000 years has been cooling. However, that has reversed in recent decades.

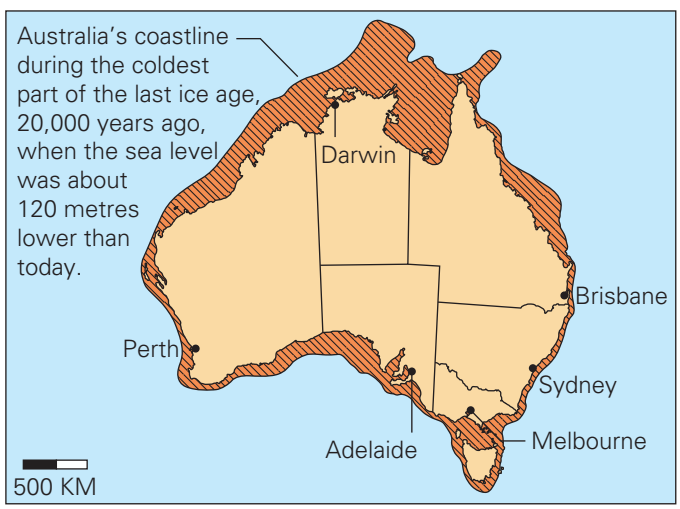


Figure 9.12 In the last ice age, ice sheets locked up much of Earth's water, lowering sea levels and making the coastline of every continent lower and further out to sea than it is today.

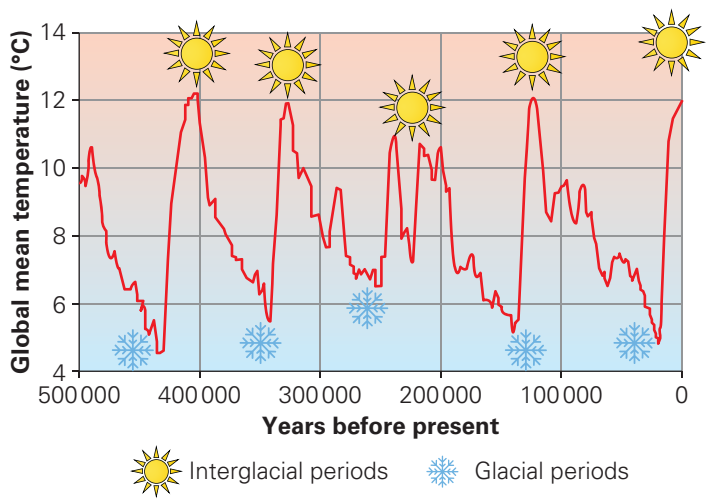


Figure 9.13 Earth has undergone natural cycles of warming and cooling.

Global warming and the evidence for it

A rise in mean global temperature was first reported in 1938 but wasn't widely accepted until the late 20th century. The data has been graphed in Figure 9.14, showing the difference or *anomaly* from the 1951–1980 mean global temperature.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

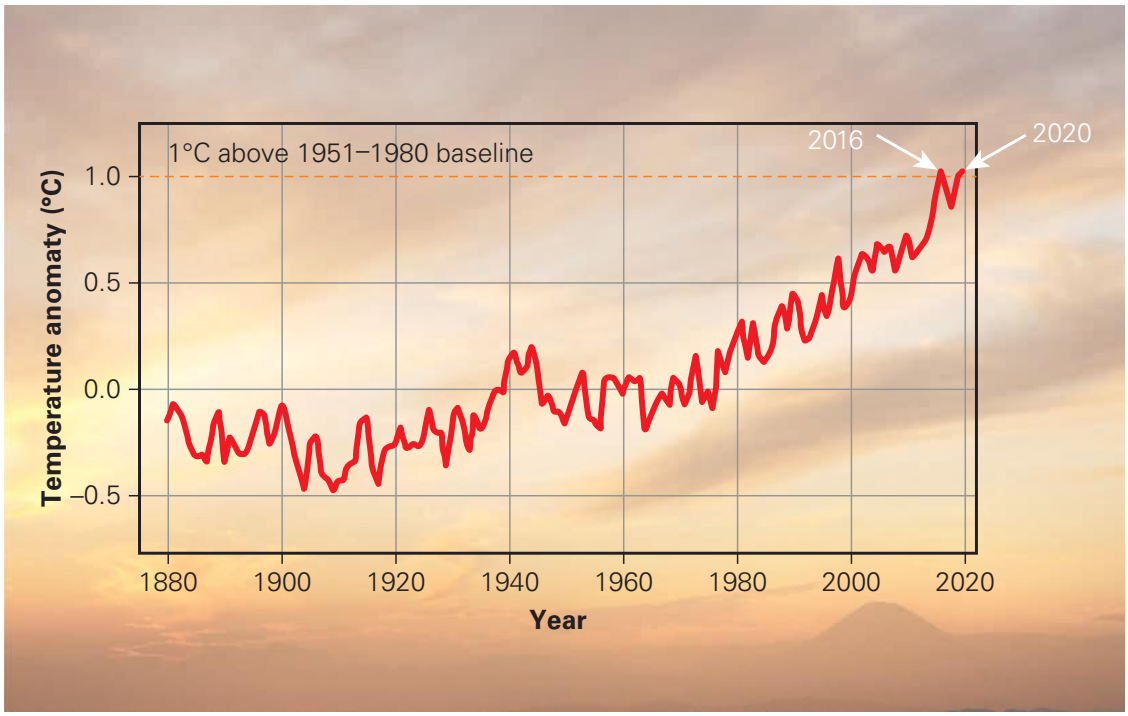


Figure 9.14 Mean global temperature anomaly from 1880 to 2020. The anomaly (deviation from what is considered normal) is measured as the difference in mean global temperature for each year compared to the calculated 1951–1980 mean global temperature, which is selected as the baseline, labelled 0.0 on the graph. Up to1940 global temperatures were fractionally below the baseline, and from about 1970 they have been rising and in 2016 and 2020 were 1°C higher than the baseline.

The rise shown from about 1978 to 2020 is about 1°C and, although not high, the amount of heat energy added to the atmosphere and hydrosphere to cause such a rise is considerable. There is not yet a clear consensus on what this means for the weather and climate phenomena and events that we experience (rain, storms, drought, seasonal changes). There is some evidence of an increase in extreme weather events (floods and drought for example). Data for several decades are needed to ensure that apparent changes in weather are not due to chance.

Because weather is so naturally variable, single weather events cannot be taken as evidence of global warming or cooling. Even a month by itself is not long enough to give reliable data. Only the mean global temperature over a year is considered to be a reliable observation, and that is just a single data point.

Similarly, warming or cooling in a particular location or region is not a reliable observation for a global change. Severe winters in Europe from the 17th to early 19th centuries, such as when fairs were held on the frozen Thames in London, were once considered global. Now, they are believed to have affected only the Northern Hemisphere.

The most reliable observation of the temperature of the Earth is the global mean temperature for each year over decades. Therefore, individual weather events like heat waves, cold snaps, storms, cyclones, droughts or floods are not considered as support or refutation for global warming. Only as part of a long-term pattern can such a conclusion be made. The definition of climate change given above reflects this principle.

The consensus in the scientific community by the end of the 20th century was that global warming is real. This is the current major trend in global climate. The present rate of change in temperature – about 1°C over 50 years – is about 10–20 times faster than the fastest natural warming at the end of the last glacial period. Section 9.2 will discuss the cause.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

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. Define:
   - **a.** Atmosphere
   - **b.** Biosphere
   - **c.** Lithosphere
   - **d.** Hydrosphere
2. **Recall** the layer of the atmosphere where most of the weather occurs.
3. **Recall** the energy source for Earth's climate.

Understanding

4. **Explain** the difference between weather and climate and give an example of each.
5. **Explain** the impact that deep ocean currents have on global climate.
6. **Describe** the current major trend in global climate and whether it fits the definition of climate change.

Applying

7. Using global warming as an example of the evidence required for climate change, **identify** what evidence would be required to support or refute a claim that Earth is getting drier (experiencing less rainfall).
8. Use the natural cycle shown in Figure 9.13 to **predict** the trend in the Earth's climate over the next 100 000 years.
9. Using Figure 9.14, **describe** in your own words the overall trend for that period, and the separate trends from 1880 to 1970, and 1970 to 2020.

Analysing

10. A claim is made in an online forum that global warming is not real since last winter in the town where the writer lives was the coldest for 50 years. **Justify** whether this observation is reliable and can be used as evidence to refute global warming, using at least three reasons.
11. Using Figure 9.14, **predict** by extrapolation the global mean temperature anomaly (difference from the baseline of 0°C) in the year 2070.

Evaluating

12. Earth's climate fluctuates over scales of thousands of years.
    - **a.** **List** three possible natural causes of these fluctuations.
    - **b.** **Explain** the main difference between natural climate change and the current global climate trend.
    - **c.** **Identify** a difference in Earth's biosphere between what it was 10 000 years ago and today, that might be a factor in explaining the answer to part **b**.
13. Consider a future space station designed to be permanently inhabited by 1000 people and the systems it would require to support them. **Compare** the space station's systems with those of the Earth that support life.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

9.2 The greenhouse effect

Learning outcomes

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

1. explain how the natural greenhouse effect influences global climate.
2. analyse data on the relationship between industrialisation and global warming.
3. analyse data on atmospheric carbon dioxide concentration and global mean temperature.
4. explain the enhanced greenhouse effect as the cause of global warming.
5. identify actions to reduce greenhouse gas emissions and their advantages and limitations.

WORKSHEET
The enhanced greenhouse effect

How a greenhouse warms plants

In cold seasons and regions, it is not possible to grow some fruits and vegetables. In these places, growers may use greenhouses to cultivate weather-sensitive or temperature-sensitive plants or plants that are out of season. Greenhouses provide a protective shield against harsh weather conditions, ensuring optimal growth conditions for the plants. The advantage of using a greenhouse is that it offers more control over the growth conditions, allowing growers to tailor the environment to the specific needs of the plants.

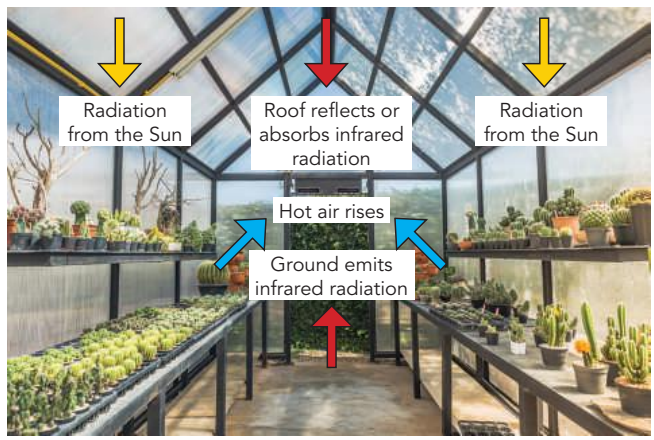


Figure 9.15 Greenhouses protect plants from cold and adverse weather conditions by keeping in the thermal energy.

Greenhouses are typically constructed from glass or plastic materials that let light through. When the Sun's radiation passes through the greenhouse's walls and roof, it heats the ground and air inside the greenhouse. The heated ground emits infrared radiation, which is reflected back into the greenhouse by the glass. The hot air rises but cannot leave the greenhouse (Figure 9.15). As a result, the temperature inside rises. This helps to keep the plants at an optimum temperature, promoting healthy growth.

Quick check 9.6

1. **Name** a type of radiation emitted from the hot ground.
2. **Explain** why greenhouses are made of glass or plastic.

Natural greenhouse effect

Earth naturally retains heat through a process similar to a greenhouse, but on a much larger scale. Most of the Sun's radiation enters Earth's atmosphere and warms the ground and oceans. Some of the radiation is reflected back into space by ice, clouds and water.

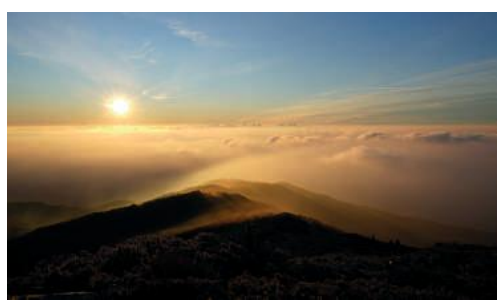


Figure 9.16 The Sun emits radiation, which passes through the atmosphere.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

greenhouse gas a gas that contributes to the greenhouse effect

However, the ground and oceans continue to emit radiant energy back towards the atmosphere in the form of infrared radiation. This infrared radiation is absorbed and reflected back towards the surface by a layer of gases known as **greenhouse gases**. Water vapour (H_2O) is the most abundant greenhouse gas, making up 95% of the total. Methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) are three of the other most common greenhouse gases.

Table 9.1 compares the effectiveness in retaining heat of the three most common greenhouse gases after water vapour. Methane is more effective than carbon dioxide at trapping heat, therefore it has a higher global warming potential, meaning it can absorb more heat per unit of mass than CO_2. However, CO_2 is much more abundant in the atmosphere and has a longer lifespan, so overall it has a greater impact on global climate.

WIDGET Greenhouse effect

Greenhouse gas	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)
Proportion of total greenhouse gases (%)	84	9	5
Persistence in the atmosphere	100 years	10 years	100 years
Effectiveness of trapping heat compared to carbon dioxide		30 times more effective	300 times more effective

Table 9.1 A summary of the three most common greenhouse gases, excluding water vapour

Explanation of the greenhouse effect

greenhouse effect the process by which gases in the lower atmosphere absorb and re-emit infrared radiation, trapping heat from the Sun

The process by which the Sun's solar energy is trapped in Earth's atmosphere is known as the **greenhouse effect**. The Sun's radiation, primarily in the visible light wavelength, can directly pass through the atmosphere because it is short wave. However, long-wave radiation emitted from the ground and oceans in the form of infrared radiation is absorbed by greenhouse gases, which then re-emit the radiation in all directions, including back towards the Earth's surface, raising atmospheric temperatures and keeping the Earth warm. This process is crucial for the survival of organisms, as it helps regulate Earth's climate and ensures conditions that support life. If greenhouse gases were absent, infrared radiation from the Earth's surface would escape more freely, and Earth would be on average about 33°C colder – a frozen planet.

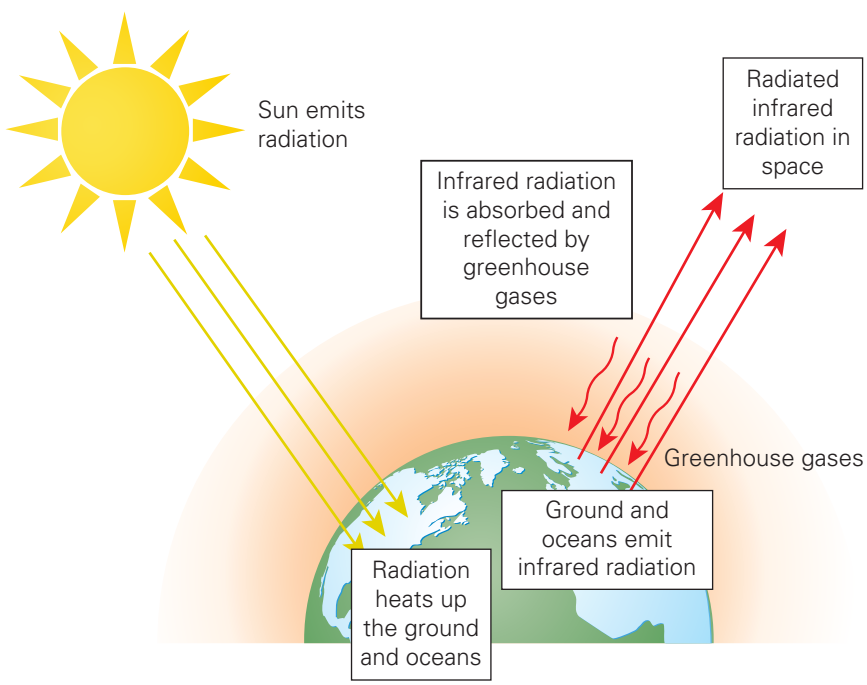


Figure 9.17 A summary of the greenhouse effect

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 9.7

1. **Give** the name and formula of one common greenhouse gas.
2. Most of the radiation emitted from the Sun heats the ground and the oceans. **Describe** what happens to the rest of this radiation.

Enhanced greenhouse effect

The **enhanced greenhouse effect** is a phenomenon in which human activities, such as burning fossil fuels and deforestation, release large amounts of greenhouse gases, such as carbon dioxide, into the atmosphere. The increase in these gases traps more heat from the Sun, which increases the temperature of Earth's atmosphere and surface, leading to **global warming** – described in the Section 9.1. This is also called **anthropogenic** climate change. The current rate of global warming due to the enhanced greenhouse effect is much faster than the natural greenhouse effect.

enhanced greenhouse effect the intensifying of the natural greenhouse effect due to human activity

global warming the long-term rise in the average temperature on Earth, primarily caused by the increase of greenhouse gases in the atmosphere

anthropogenic caused or influenced by people

Cause: increased greenhouse gas concentration

The major cause of the enhanced greenhouse effect is increased concentrations of greenhouse gases (carbon dioxide, methane, nitrous oxide and water vapour) in the atmosphere. Figure 9.18 is a graph of global atmospheric carbon dioxide concentration from 1700 to 2020. In this period, the concentration rose from about 280 parts per million (ppm) to about 420 ppm, an increase of about 50%. The industrial revolution started in Britain in 1750 and industrialisation has continued steadily until today, as well as the mechanisation of transport, agriculture and domestic life. Table 9.2 summarises how humans have contributed to the increased levels of these greenhouse gases.

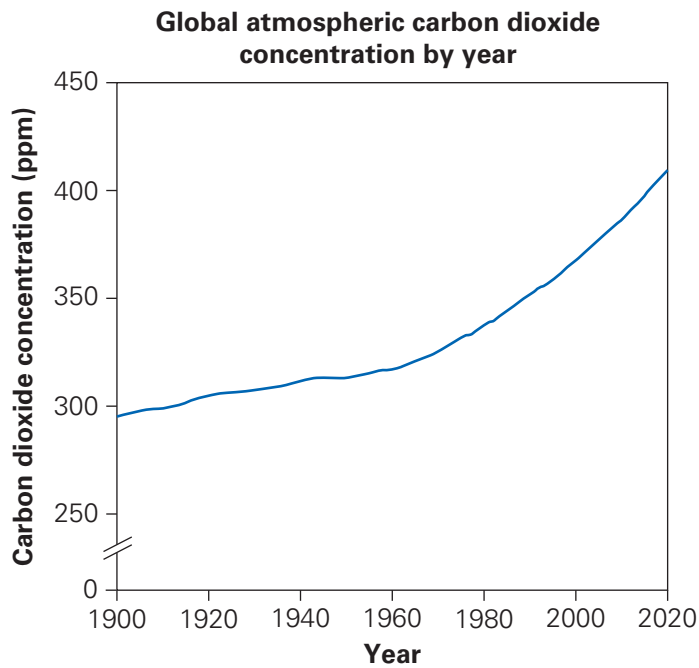


Figure 9.18 Global atmospheric carbon dioxide concentration in parts per million from 1900 to 2020, showing a rise of about 40%. Note that the vertical axis is broken.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

WORKSHEET Increasing global temperatures

Greenhouse gas	How humans have increased its concentration in the atmosphere
Carbon dioxide (from burning fossil fuel, industries, deforestation and soil disturbance)	Burning fossil fuels such as coal, oil and gas by transport, industry and the residential and domestic sector. In 2023, fossil fuels contributed 65% of total electricity generation, including coal (46%), gas (17%) and oil (2%). Other industrial processes such as cement manufacture also emit carbon dioxide. Deforestation and soil disturbance are other contributors to increased concentration. Fewer trees lead to less carbon dioxide being absorbed from the atmosphere through photosynthesis, impacting the atmosphere by increasing the concentration of greenhouse gases. If the trees are burned, this further contributes to the greenhouse effect by releasing stored carbon. Additionally, trees release significant amounts of water vapour during transpiration, affecting the hydrosphere. With fewer trees, less water vapour enters the atmosphere, leading to reduced rainfall and potentially altering weather patterns
Methane (from agriculture and permafrost melting)	Farming cattle and sheep produce methane when they digest grass, and growing rice in paddies releases methane from microbes in the flooded soil. Agriculture contributes 11% of Australia's greenhouse gas emissions, with 70% of that coming directly from livestock. Increased temperatures lead to the melting of permafrost, frozen soil that contains trapped methane produced from the decomposition of plants and animals.
Nitrous oxide	Using fertilisers increases the amount of nitrogen in the nitrogen cycle, therefore increasing the production of nitrous oxide. Adding fertilisers containing nitrates to the soil accelerates their conversion into nitrous oxide, a potent greenhouse gas.
Water vapour	The natural concentration of water vapour in the atmosphere is the most abundant greenhouse gas, but it is essential for life, part of the global climate, its concentration naturally fluctuates and we can't control it. For these reasons it is not considered alongside the other greenhouse gases in climate change solutions.

Table 9.2 How human activity increases greenhouse gas concentrations in the atmosphere

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

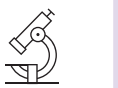
Try this 9.1

Reinstatement of traditional fire management practices

Conduct some research on how technological advances in monitoring greenhouse gas emissions and other environmental factors have contributed to the reinstatement of traditional fire management practices as a strategy to reduce atmospheric pollution.

Quick check 9.8

1. **State** one way in which we have increased the concentration of carbon dioxide in the atmosphere.
2. **Give** one way we have increased the concentration of nitrous oxide in the atmosphere.
3. **Describe** what the enhanced greenhouse effect has led to.



Investigation 9.1

Comparing the natural and enhanced greenhouse effects

Aim

To compare the impacts of the natural and enhanced greenhouse effects.

Materials

- baking soda
- vinegar
- 2 × 500 mL beakers
- 100 mL measuring cylinder
- cling wrap
- 2 elastic bands
- 2 weighing boats
- balance
- marker pen
- sticky tape
- stopwatch
- 2 thermometers
- high-intensity lamp
- heat-resistant gloves

Procedure

Part 1: Prepare the results table

1. Read the rest of the steps in the method and make a prediction about what will happen.
2. Create an appropriate results table for this experiment.

Part 2: Prepare the equipment

1. With the marker pen, label one of the 500 mL beakers 'Control'.
2. Using the sticky tape, tape one of the thermometers to the inside of this beaker. It must be about 5 cm above the bottom of the beaker.
3. With the marker pen, label the second beaker 'CO_2'.
4. Tape the thermometer to the inside of this beaker, again making sure it is 5 cm from the bottom.
5. Prepare the cling wrap and elastic bands for sealing; you will cover each beaker immediately after you have poured in the liquid.

Part 3: Collect the data

1. Using the balance, weigh 35 g of baking soda into each weighing boat and pour it into each beaker.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2. Using the 100 mL measuring cylinder, measure 65 mL of water and pour it into the control beaker. Immediately cover it with the cling wrap and elastic band.
3. Using the same 100 mL measuring cylinder, measure 65 mL of vinegar and pour into the CO_2 beaker. Immediately cover it with the cling wrap and elastic band.
4. Swirl the contents of each beaker to make sure that the baking soda has fully dissolved.
5. Place both beakers underneath the lamp.
6. Record the starting temperature of each atmosphere before the lamp is turned on.
7. Turn on the lamp and start the stopwatch.
8. Measure the temperature in each beaker every 2 minutes for 8 minutes. Record the temperatures in your results table.
9. At 8 minutes, measure the temperature and then turn off the light.
10. Record the final temperature 2 minutes later.

Results

1. Calculate the increase in temperature in each container by the difference between the temperature at 8 minutes and the starting temperature.
2. Calculate the thermal energy retention by the difference in the temperature at 8 minutes to the temperature at 10 minutes.

Discussion

1. State the container that showed the greatest increase in temperature. Did this match your prediction?
2. State the container that retained the most thermal energy in the final 2 minutes.
3. Explain these results by using your own knowledge and scientific research.

Conclusion

1. State a conclusion about the enhanced greenhouse effect based on this experiment.
2. Support the statement by using your data.

Did you know? 9.2

The carbon impact of emails

A book published in 2010 popularised the idea that reducing the number of emails sent could have a significant impact on greenhouse gas emissions. The book stated that an average person's yearly email use generates 3–40 kg of carbon dioxide and other greenhouse gases, which is comparable to driving 16–206 km.

While deleting 1000 emails would save about 5 g of CO_2, manually deleting them on a laptop for 30 minutes emits 28 g of CO_2.

This means that manually deleting emails can have a greater carbon impact than just storing them, because it consumes more energy from using the computer.

In reality, the carbon footprint of sending emails is difficult to quantify and the numbers constantly change due to improving data transmission and storage efficiency. The carbon values for emails seem small, and reducing the number of emails sent or deleting them may not significantly reduce energy consumption as digital data storage and transmission systems operate continuously. Instead, reducing the carbon footprint of email use can be achieved by using electronic devices that consume less electricity and retaining them for as long as possible.

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 9.19 Digital data storage and transmission centres, like this Google-owned one in Iowa, United States, operate continuously. They use a constant amount of energy, regardless of whether an email is sent or not.

Explore! 9.2

Global Greenhouse Gas Monitoring Infrastructure

In 2023, the United Nations announced that it had created a new Global Greenhouse Gas Monitoring Infrastructure. The infrastructure will integrate space and Earth surface-based observation systems and aims to provide real-time tracking of greenhouse gases to help inform policy choices. The platform will address uncertainties about the emission of greenhouse gases and provide faster and more accurate data on the state of the planet's atmosphere. What are the advantages to this new infrastructure?

Explore! 9.3

Your carbon footprint

A carbon footprint is the volume of greenhouse gases (including carbon dioxide) emitted into the atmosphere as a result of the actions of a specific individual, event, organisation or product.

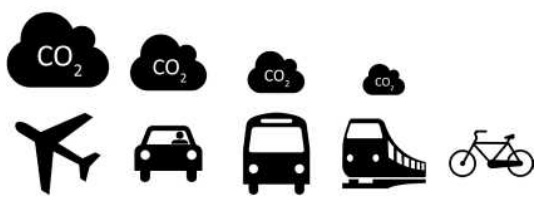


Figure 9.20 Some methods of transport have a bigger environmental impact than others.

Search online for a reliable carbon footprint calculator. Suggested websites include the United States Environmental Protection Agency or the Global Footprint Network.

Gather information on your daily habits such as transportation, energy usage, diet and waste management.

Use the carbon footprint calculator to input your daily habits and activities. The calculator will provide you with an estimate of your carbon footprint in metric tonnes.

Analyse your carbon footprint results and identify areas where you can reduce your carbon emissions. For example, you can consider walking or riding a bicycle instead of travelling to school in the car, reducing energy consumption at home, or reducing waste.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 9.2

Reducing carbon footprints

Plan a social media campaign to encourage young people to reduce their carbon footprint.

VIDEO
The greenhouse effect

The carbon cycle

Carbon dioxide emissions from human activity are our most significant contributor to the enhanced greenhouse effect. Since the Industrial Revolution in the 1800s, we have been burning large amounts of fossil fuels for energy. This means we have been moving stored carbon from the lithosphere into the atmosphere, directly affecting the balance of the carbon cycle.

The carbon cycle describes the movement of carbon between Earth's spheres. In the atmosphere, carbon exists primarily as carbon dioxide, which is exchanged with other spheres through processes like photosynthesis and respiration. In the biosphere, plants absorb carbon dioxide during photosynthesis, storing carbon in their biomass, while animals release it back through respiration. The hydrosphere absorbs carbon dioxide into oceans, where it dissolves or forms carbonates that marine organisms use to build shells, which eventually settle as sediments. In the lithosphere, carbon is stored in rocks, fossil fuels and sediments, with volcanic activity and fossil fuel combustion releasing it back into the atmosphere as carbon dioxide.

carbon source
a process or an area that releases carbon

carbon sink
an area where carbon is stored (e.g. ocean, forests or fossil fuels)

Note that respiration, decomposition and burning plant material as fuel releases carbon dioxide that was very recently removed from the atmosphere via photosynthesis, and so this does not lead to a net increase in atmospheric carbon dioxide. However, bushfires can release such large amounts of carbon dioxide, and the vegetation may never fully recover, so that may lead to a net increase.

As part of the carbon cycle, Earth has **carbon sources**, which are processes or areas that release carbon (such as the burning of fossil fuels), and **carbon sinks**, which are areas where carbon is stored (such as the oceans, plants or fossil fuels).

Burning fossils fuels and releasing their stored carbon is a problem because the carbon cycle does not have enough carbon sinks to remove the excess carbon from the atmosphere. Fossil fuels take millions of years to form, and Earth's carbon sinks cannot remove enough carbon dioxide to prevent it from building up in the atmosphere. The accumulation of carbon dioxide in the atmosphere is increasing Earth's greenhouse effect.

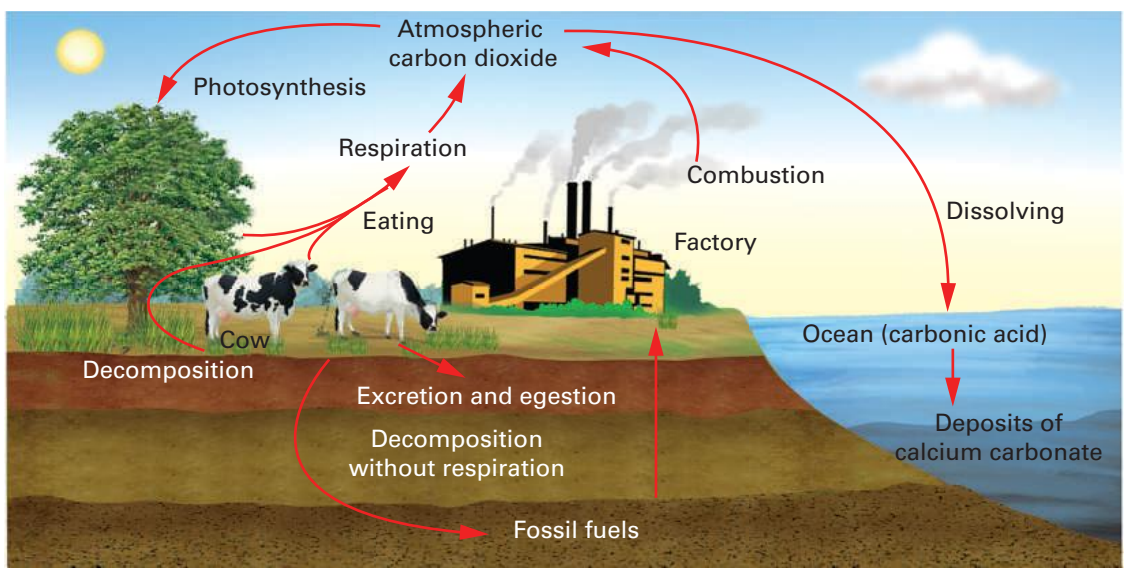


Figure 9.21 The carbon cycle. The important part for the greenhouse effect is the combustion of fossil fuels releasing carbon dioxide into the atmosphere.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 9.9

1. **Define** 'carbon source' and give an example.
2. **Define** 'carbon sink' and give an example.

Explore! 9.4

Cow burps

Beef and dairy cattle contribute significantly to climate change through the following processes:

- **Methane emissions.** Cows produce methane through their digestive process known as rumination.
- **Land use change.** Beef and dairy production often require the conversion of natural habitats, such as forests and grasslands, into agricultural land for growing feed crops and for pasture. This conversion leads to the loss of carbon-absorbing vegetation and soil, and releases carbon into the atmosphere.
- **Fertiliser use.** Growing crops to feed cattle requires the use of fertilisers, which produce nitrous oxide.
- **Transportation emissions.** Beef and dairy products are often transported long distances, contributing to emissions from transportation.

Figure 9.22 Most methane from cows is emitted through their burps, although some comes from flatulence too. In 2022, a design group called Zelp (Zero Emissions Livestock Project) won a design competition for creating a cow mask that converts methane emissions into CO_2 and water vapour.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Reducing greenhouse gas emissions

Reducing greenhouse gas emissions is essential for addressing the enhanced greenhouse effect. Several strategies have been developed to achieve this goal, each with its own set of advantages and limitations. These are listed in Table 9.3.

Method	Description	Advantages	Limitations
Renewable energy sources	Energy sources like solar, wind, hydro and geothermal that produce electricity with lowered greenhouse gas emissions.	• Directly reduces greenhouse gases • Creates jobs	• May have an unreliable supply • High initial costs • Requires significant land
Energy efficiency improvements	Using less energy to perform the same tasks, such as through improved appliances and building designs.	• Quick implementation • Encourages innovation	• High initial costs
Carbon capture and storage technology	Technology that captures CO_2 emissions from industrial processes and stores it.	• Capable of largescale CO_2 capture	• Expensive • Risk of CO_2 leakage
Reforestation and afforestation	Planting trees to absorb CO_2.	• Supports biodiversity • Prevents soil erosion	• Requires large land area • Trees take time to mature • Ongoing management required
Sustainable agriculture	Farming practices that improve soil health and reduce greenhouse gas emissions, such as crop rotation and no-till farming.	• Improves soil health • Supports biodiversity	• Lower short-term profits • Requires education and training
Policy and regulatory measures	Government policies and regulations that set standards and provide incentives for reducing greenhouse gas emissions.	• Can promote large-scale changes	• Political challenges • Increased costs for businesses and individuals • Requires international cooperation

Table 9.3 Methods of reducing greenhouse gas emissions

Figure 9.23 Advances in building design have resulted in eco houses that produce less greenhouse gas emissions. Improving energy efficiency, such as better insulation, is often the most effective measure, in both cold and warm climates.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 9.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 9.2 questions

Remembering

1. **Name** three gases in the atmosphere that are responsible for the greenhouse effect.
2. **Define** 'enhanced greenhouse effect'.
3. **State** the name of the radiations emitted from the:
   a. Sun
   b. ground and oceans.
4. **Recall** the sources of methane in the atmosphere.

Understanding

5. **Explain** the differences between the natural and enhanced greenhouse effects.
6. **Explain** why the following statement is incorrect: 'The greenhouse effect is caused by humans'.
7. **Explain** how the greenhouse effect mimics a greenhouse.

Applying

8. **Illustrate** a diagram to show how the greenhouse effect keeps Earth warm.

Analysing

9. Make a rough sketch of the axes and a line of best fit for Figure 9.18 for the years 1900 to 2020. On your same graph, on the right hand side, sketch the global CO_2 concentration axis from Figure 9.18 and add a sketch of the plotline from that graph for the same years. **Describe** the trends shown by both graphs and **discuss** whether they show a relationship between global mean temperature and CO_2 concentration and if so, of what kind.
10. **Distinguish** between greenhouse gases and other gases in the atmosphere, such as nitrogen and oxygen.
11. **Contrast** carbon sinks and carbon sources by giving examples.

Evaluating

12. **Predict** what the conditions on Earth would be like without greenhouse gases and the greenhouse effect.
13. **Decide** why our focus related to the enhanced greenhouse effect is on carbon dioxide and not on other greenhouse gases.
14. We have known about the damaging effects of carbon emissions for a long time. **Propose** why Australia still produces electricity from coal.
15. **Discuss** the reasons why the carbon cycle is altered by the release of carbon emissions from burning fossil fuels.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

9.3 Climate change characteristics and effects

WORKSHEET Analysing Antarctic ice core data

VIDEO Indicators of climate change

Learning outcome

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

1. explain climate change characteristics, effects and consequences on ecosystems.
2. explain climate change characteristics, effects and consequences on the water cycle.
3. investigate how satellites collect global data and how it is used to evaluate the impact of climate change.

To better understand the impacts of climate change and track progress in mitigating its effects, scientists use a variety of effects of climate change as indicators to monitor changes in the climate system. These indicators provide a picture of the state of the climate.

Changes in ocean and atmospheric temperatures

Ocean and atmospheric temperatures reflect the overall temperature of the planet's surface. Any long-term increase in atmospheric and ocean temperatures will affect many aspects of Earth's systems, including ocean circulation, sea level and weather patterns, leading to climate change. Rising temperatures result in increased rainfall, the melting of glaciers and ice sheets, and rising sea levels. Increased temperatures in the atmosphere result in more energy being available to create extreme weather events such as storms and cyclones. Temperature changes are monitored by a variety of instruments, including satellite measurements, ocean buoys and weather stations, providing evidence for climate change and the ongoing impact of human activities.

Sea levels

As global temperatures increase, ice caps melt and cause a rise in sea levels. Ocean water in equatorial regions expands as it warms, contributing to further sea level rises.

Increasing sea levels can cause coastal flooding and erosion and affect coastal ecosystems and communities. Sea level measurements are made using equipment such as satellite altimeters and tide gauges.

Figure 9.24 Left: Coastal infrastructure will be destroyed by sea level rises and an increase in extreme weather events. Right: The Arctic is experiencing warming at more than twice the global average rate, a phenomenon known as Arctic amplification. This rapid temperature increase is causing significant ice melt, leading to the loss of sea ice and glaciers. The reduction in ice cover diminishes the habitat available for species like polar bears, seals and walruses.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 9.3

La Niña events are getting worse

La Niña is a climatic phenomenon characterised by the cooling of the central and eastern tropical Pacific Ocean. It is the counterpart to El Niño, which is characterised by warming of the same region. La Niña events can have significant impacts on global weather patterns, causing alterations in temperature, precipitation and wind patterns.

Some of the effects of La Niña include increased rainfall in some areas, drought in others and changes in atmospheric circulation patterns that can affect tropical storms. La Niña is one of the important factors that scientists consider when making long-range weather and climate forecasts.

VIDEO
El Nino southern oscillation

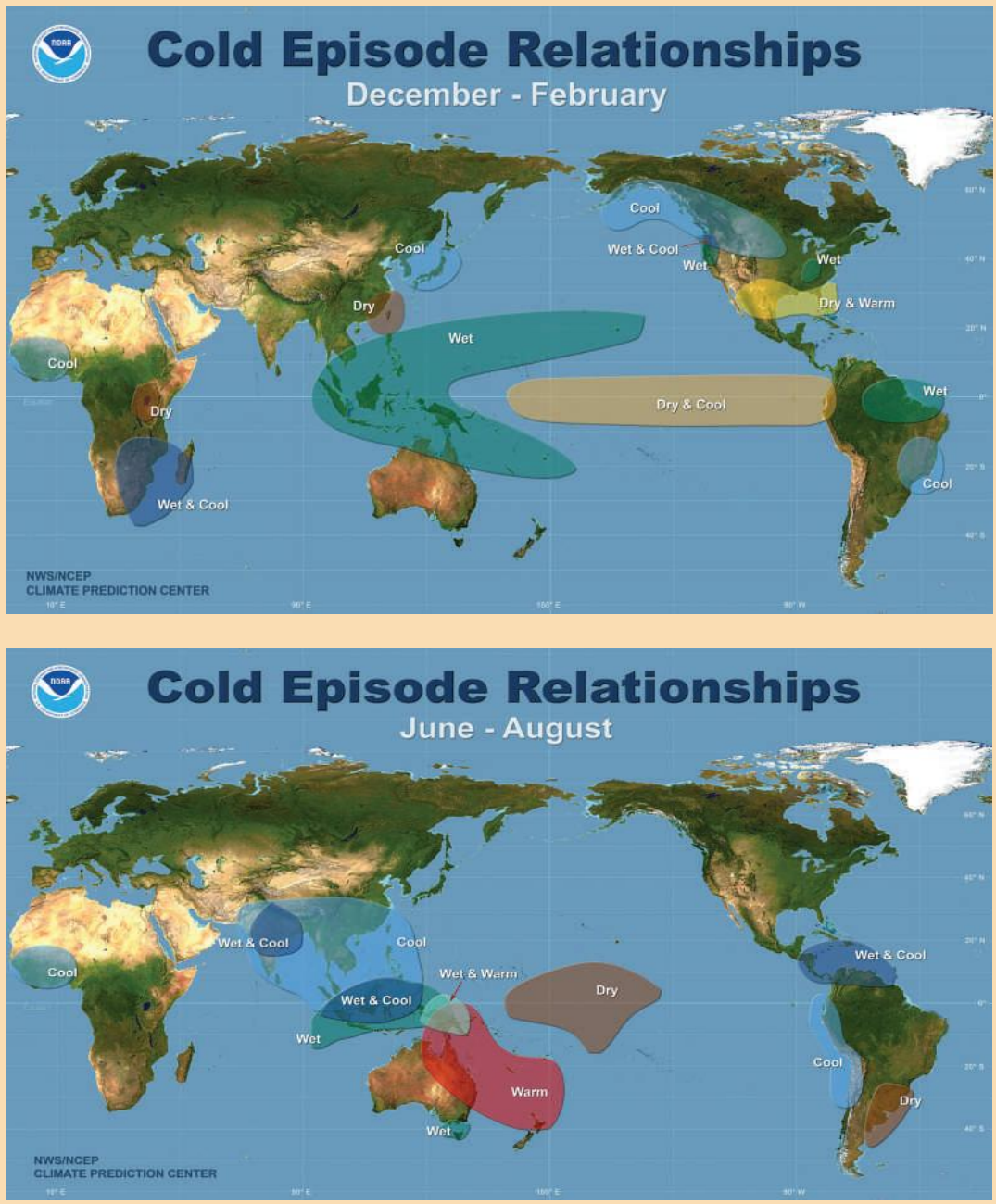


Figure 9.25 Global weather impacts of La Niña. These diagrams show areas of the globe which experience cooler or warmer, wetter or dryer weather compared to the seasonal norm during the months indicated.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

La Niña events are a natural part of Earth's climate system, but their severity and frequency may be influenced by climate change, as rising global temperatures can disrupt the balance of ocean and atmospheric conditions that drive these events.

Figure 9.26 La Niña typically increases the chance of above-average rainfall for northern and eastern Australia during summer. The impact of the 2022 La Niña on rainfall in Australia was exacerbated by the warming of the Indian Ocean, which has been attributed to human-caused climate change. This warming likely contributed to record rainfalls and devastating floods.

INVESTIGATION

Investigation 9.2

Salinity and density

Background information

When seawater freezes in winter, only the water freezes – the salt is left behind in the unfrozen seawater below. Waters with higher concentrations of salt are denser and sink to the ocean floor. Different densities are the main cause of ocean currents, circulating seawater from the sea floor to the surface and all around the globe. This water carries with it thermal energy, organic matter and nutrients.

With rising temperatures, less seawater is freezing, which is reducing the density of the oceans. If seawater circulation slows, and organic matter and nutrients also stop circulating, the impact on the survival of marine life would be huge.

Aim

To determine how the concentration of sodium chloride in water (salinity) affects its density.

Materials

- 100 mL measuring cylinder
- 5 × 100 mL beakers
- 5 pipettes
- food colouring (blue, green, yellow and red)
- sodium chloride
- warm water
- weighing boats
- balance

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1. Copy the results table into your science journal.
2. Using a 100 mL measuring cylinder, measure 60 mL of water and pour it into one of the 100 mL beakers. Repeat four more times so you have five beakers each with 60 mL of water. Label the beakers 1 to 5.

Solution	Mass of sodium chloride (g)	Volume of water (mL)	Amount of food colouring (drops)
1	5	60	2 of blue
2	10	60	2 of green
3	15	60	2 of yellow
4	20	60	1 of yellow, 1 of red
5	25	60	2 of red

3. Add the required drops of food colouring from the table above to each beaker.
4. Using the weighing boats and balance, measure the five different masses of sodium chloride. Pour the sodium chloride into the correct-coloured beaker.
5. Stir the solutions to make sure all the sodium chloride has dissolved.
6. Using a pipette, draw up 2 mL of solution 5 and add to the 10 mL measuring cylinder.
7. Using a pipette, draw up 2 mL of solution 4. Place the pipette along the inside of the measuring cylinder, near the solution added previously. Drop solution 4 drop by drop, allowing it to roll down the side of the measuring cylinder.
8. Repeat step **7** for solutions 3, 2 and 1, adding each in turn to the 10 mL measuring cylinder.

Results

1. Complete the results table. Remember that 1 g water = 1 mL water.

Solution	Mass of sodium chloride (g)	Mass of water (g)	Mass of the solution (g) (mass of sodium chloride + mass of water)	Volume of solution (mL)	Density of the solution (g/mL) (mass of solution ÷ volume)
1	5	60		60	
2	10	60		60	
3	15	60		60	
4	20	60		60	
5	25	60		60	

2. Sketch a coloured diagram of the measuring cylinder you created.
3. Plot a graph of mass of sodium chloride on the horizontal axis and density on the vertical axis.

Discussion

1. Use your graph to describe the link between amount of sodium chloride and the density of a solution.
2. Discuss how rising global temperatures affect the concentration of sodium chloride in the oceans and how this relates to climate change.

Conclusion

State a conclusion about how water salinity affects water density. Support your statement by using your experimental data.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Permafrost

Permafrost, or permanently frozen ground, is sensitive to temperature changes and can provide information about past and present climate conditions. Scientists are monitoring permafrost as it starts to melt as temperatures increase. When permafrost melts, it releases trapped carbon dioxide and methane, both of which are greenhouse gases. The presence, thickness and temperature of permafrost provide scientists with valuable information about the rate of climate change and the potential impacts of these changes.

Figure 9.27 The thawing of permafrost has significant impacts on both the lithosphere and biosphere. As permafrost melts, it releases stored carbon, primarily in the form of methane and carbon dioxide, into the atmosphere. This release exacerbates the greenhouse effect, contributing to further warming and creating a feedback loop that accelerates permafrost thaw.

Sea ice

As global temperatures increase, sea ice melts, and this has wide-ranging effects on global weather patterns, ocean currents and coastal communities. Sea ice is highly sensitive to changes in both air and water temperature, making it an important indicator of climate change. The extent and thickness of sea ice in the polar regions provide scientists with valuable information about the rate of climate change, as a decrease in sea ice over time can signal a warming trend.

One significant process affected by this melting is the albedo effect, which refers to the reflectivity of Earth's surface. Sea ice has a high albedo, meaning it reflects most of the incoming sunlight back into space, helping to regulate Earth's temperature. As sea ice melts and exposes darker ocean water, which has a much lower albedo, more sunlight is absorbed instead of reflected, leading to further warming of the ocean and accelerating the ice melt in a positive feedback loop. This reduction in sea ice also impacts ocean currents, particularly the thermohaline circulation, by altering temperature and salinity gradients.

Disruptions to these currents can shift weather patterns globally, bringing about more intense storms, changes in precipitation and shifts in temperature. In coastal communities, the loss of sea ice and rising sea levels increase the risk of flooding, erosion and damage to infrastructure, threatening both human populations and ecosystems.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Effects on ecosystems

Climate change is one of the biggest threats to ecosystems. It can alter the distribution and abundance of species, leading to changes in biodiversity and species distribution. Rising temperatures can shift the ranges of species and alter their migration patterns, disrupt the timing of seasonal events such as flowering and migration, and change the distribution of disease-causing organisms. Climate change has led to shifting climatic zones, resulting in species moving towards the poles and to cooler, higher elevations on land and deeper ocean waters for some marine species. On average, species are moving towards the poles at 17 km per decade on land and 78 km per decade in the ocean.

Figure 9.28 Blue dragons (Glaucus atlanticus) are small venomous sea slugs found in warm and temperate waters. As ocean temperatures continue to increase, its distribution is expanding. While some species may benefit from climate change in the short term, the long-term effects are often negative and can lead to declines in biodiversity.

Different species are responding to climate change at different rates, leading to changes in the structure of ecosystems. As species move to new locations, they interact with species they may have never encountered before, forming new ecological communities. At the same time, species that had previously relied on each other for food or shelter may be forced apart, disrupting established ecological relationships and potentially leading to ecosystems collapsing.

Figure 9.29 In the biosphere, the thawing and melting can release nutrients and promote the growth of plants, but it can also lead to the loss of critical habitats and biodiversity.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 9.30 The changing climate affects the migration patterns, breeding cycles and food availability for Arctic species. For example, earlier spring melts and later autumn freezes impact the availability of food for caribou, disrupting their life cycles and those of the indigenous communities that rely on them.

Quick check 9.10

1. **Give** one indicator that scientists can use to monitor climate conditions.
2. **Identify** the main problem of melting polar ice caps.
3. **Identify** the problem caused by decreased ocean density as a result of reduced freezing of ice in winter.

Figure 9.31 Climate change has contributed to longer and more severe bushfire seasons in Australia. The 2019–2020 'Black Summer' bushfires, exacerbated by prolonged drought and high temperatures, devastated vast areas of forest and grassland, killing millions of animals and destroying their habitats.

Explore! 9.5

Citizen science

Citizen science is scientific research in which the general public participate in collecting data. This can include monitoring wildlife populations, tracking the spread of invasive species or contributing observations to astronomical studies. The goal is to involve citizens in the scientific process, allowing the collection of large amounts of data that would normally be difficult.

Research the citizen science project Redmap to see how everyday Australians have documented the species on the move around Australia's coasts over the past decade and how this is contributing to our knowledge about climate change.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 9.32 Australia's volunteer tagging database Infofish Australia recently became the first citizen science tagging program in the world to tag one million fish. Over the past 36 years, over 17 000 taggers contributed over 198 600 days (or 544 years) of effort to reach the milestone.

INVESTIGATION

Explore! 9.6

Changing reefs

Climate change has a significant impact on coral reefs, which are some of the most biodiverse ecosystems on the planet.

The main effects of climate change on coral reefs include:

- **Ocean acidification.** Increases in atmospheric carbon dioxide also increases the acidity of the oceans. This makes it more difficult for corals to build and maintain their calcium carbonate skeletons, leading to their degradation.
- **Coral bleaching.** Corals rely on symbiotic single-celled organisms called protists to provide their nutrition. As the temperature of the ocean increases, corals become stressed and expel the protists, leading to coral bleaching.
- **Changes in ocean circulation.** Changes in ocean currents caused by warming of the ocean can affect the availability of food and nutrients for corals.
- **Sea level rise.** As the sea level rises, corals are increasingly at risk of being unable to grow vertically fast enough to maintain their depth at or below the surface. Living under the lower light conditions at greater depth will reduce their growth and threaten survival and increase their exposure to other stressors such as pollutants and disease.

These impacts of climate change on coral reefs will also have consequences for the millions of people who rely on them for food, income and coastal protection.

Figure 9.33 Corals and fish in the Great Barrier Reef

Figure 9.34 Bleached branching coral

Research some of the reasons why coral bleaching is so disastrous for the environment.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 9.3

Investigate consequences of climate change and report using an infographic

Investigate the multiple lines of evidence such as that from polar ice caps, ocean temperatures and extreme weather, of the consequences of climate change on the Earth. Create an infographic to report your findings.

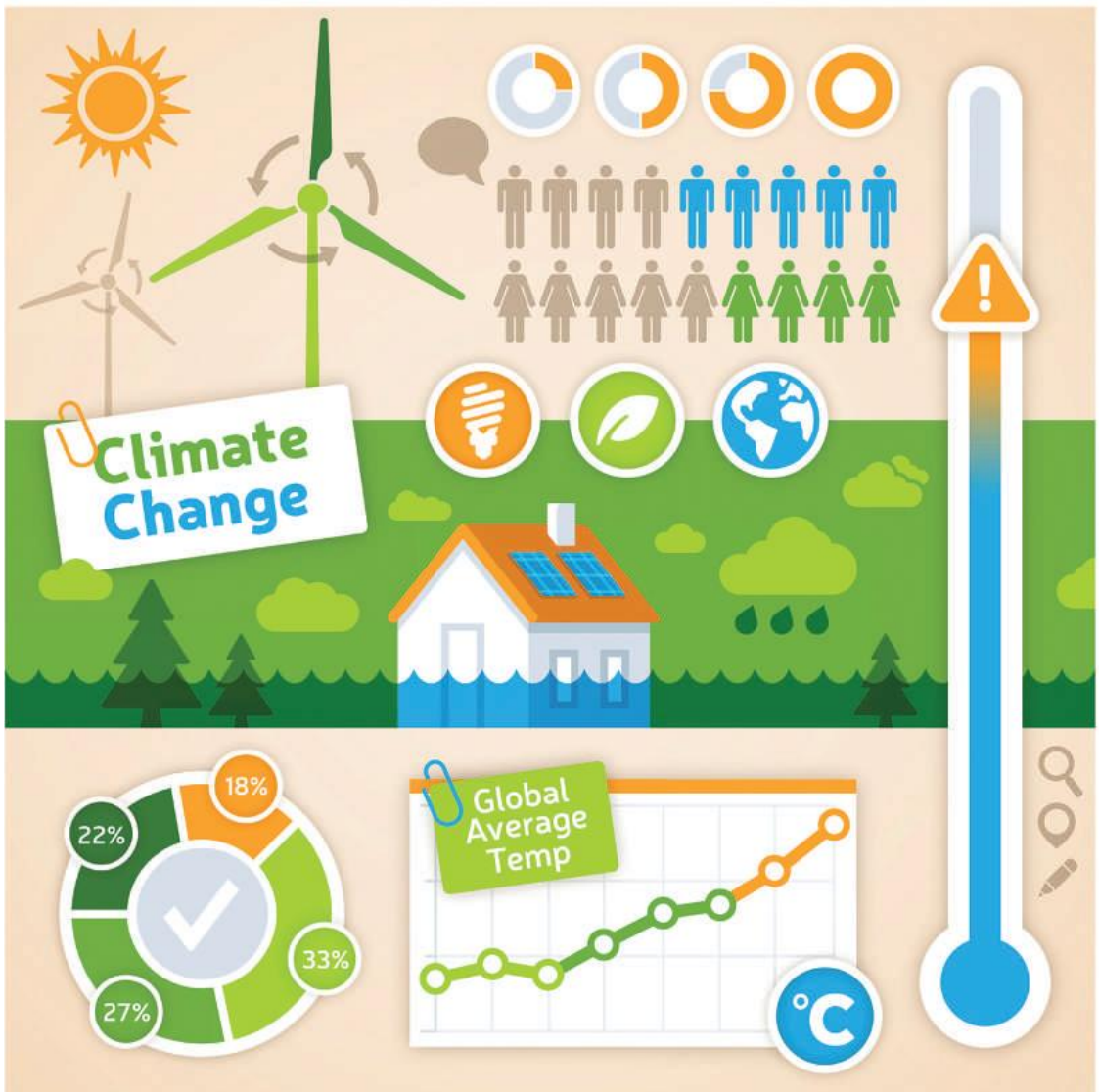


Figure 9.35 Infographic inspiration

Infographics should:

- communicate information concisely
- be visually appealing with a good use of colour and images
- be well organised so viewers can easily see the information
- contain relevant data from credible sources.

Climate change effects on the water cycle

Recall the water cycle from Stage 4 Chapter 6. Climate change can affect all processes in the water cycle, especially evaporation. The higher temperatures associated with global warming, along with the additional energy in the atmosphere and at Earth's surface, increase the rate of evaporation and the amount of water vapour the atmosphere can hold. This often results in heavier precipitation

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

and flooding. However, rising temperatures can also disrupt atmospheric circulation patterns, causing water that evaporates in one area to precipitate far away. As a result, both droughts and floods tend to become more frequent and severe with climate change.

In addition to the effects on the hydrosphere covered earlier in the chapter and above, other effects of climate change in the water cycle include:

- changes to rainfall distribution through the year and in the seasons
- less precipitation as snowfall
- melting of icecaps and glaciers
- changes in soil moisture and groundwater in some areas
- changes to river flow and lake levels
- greater water runoff and erosion of soils and land.

The effects for different geographical locations are more difficult to assess as many decades' worth of data are required to confirm the regional consequences of increased global temperatures. Evidence shows that greenhouse warming is uneven, with more warming at the poles and less in the tropics. However, since the tropics naturally tend to have more intense storms, the smaller temperature increase in the tropics may be more destructive overall.

Using satellites to collect global data to evaluate climate change

Being able to predict changes to the Earth system is important for preparing for the impacts of climate change. This involves collecting data and then using modelling and simulations to understand how Earth's climate and ecosystems are changing and will change in the future, given certain assumptions. The models consider the complex interactions between Earth's spheres and provide information about how the Earth system is likely to respond to various scenarios.

Scientists use satellites to produce global data about ocean temperatures, sea levels, and forest and ice cover. Different properties of Earth's surface and atmosphere can be measured to provide a continuous stream of data that is used to monitor global climate changes.

To measure ocean temperatures, satellites use radiometers that can detect the infrared (heat) and microwave radiation emitted by the ocean surface. This radiation is proportional to the temperature of the surface, so the data can be used to create maps of ocean temperature patterns.

Sea level data is generated by satellite altimeters, which use radar to measure the height of the ocean surface relative to a reference point, providing information on the rise or fall of sea levels over time.

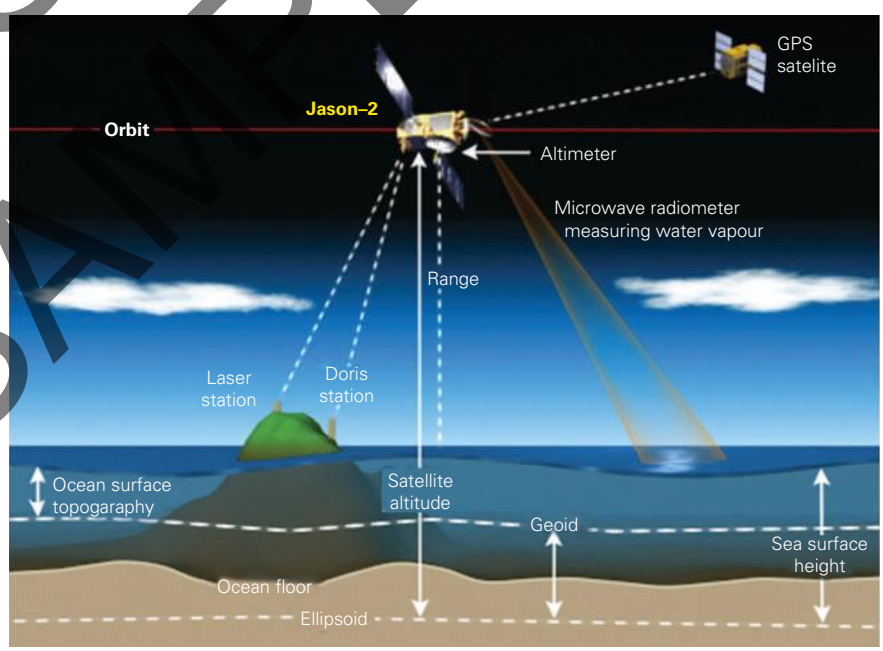


Figure 9.36 Satellite radar altimeters measure sea levels by measuring the time it takes a radar pulse to make a round-trip from the satellite to the sea surface and back.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Satellites also use optical and microwave sensors to monitor changes in forest and ice cover. These instruments can detect changes in the reflection and emission of radiation from Earth's surface, which indicate the amount of vegetation or ice present. This data can be used to track deforestation and the rate of ice melting.

The data generated by satellites is used to monitor the effects of climate change by providing a record of changes over time.

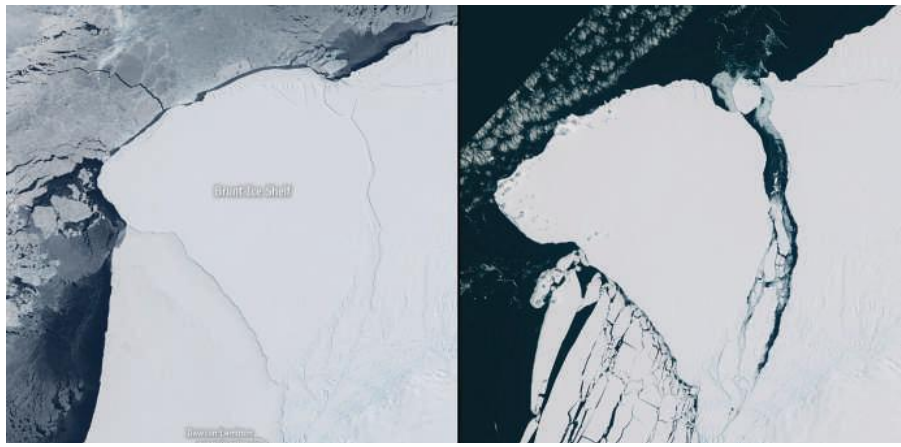


Figure 9.37 The two-satellite mission Copernicus Sentinel-2 has produced before and after photos of the ice slab that broke away from the Brunt Ice Shelf, Antarctica. The image on the left shows cracks on the ice shelf on 25 October 2022 and the image on the right shows the ice breaking away on 24 January 2023.

Using computer modelling to predict changes

Predicting changes to the Earth system is a challenging task, as it involves understanding and representing many complex processes and feedbacks that operate on a wide range of timescales.

Figure 9.38 A supercomputer at the German Climate Computing Centre crunches data about Earth's climate to predict the future effects of climate change.

Computer modelling has improved our knowledge and ability to predict how phenomena such as climate change and atmospheric pollution will develop in the future. Computer simulations can be used to make predictions about Earth's climate thousands and millions of years into the future to see what impact actions taken now will have on the climate in the future. With their high processing power, computers can run numerous simulations repeatedly in a short period of time, something that could take a human over a lifetime to complete. By running numerous simulations, predictions made by computer modelling are much more accurate than those made manually by humans.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Table 9.4 lists some of the applications of computer modelling.

Application	Description
Predicting the weather	Multiple simulations are run by computers. Meteorologists use these simulations to predict the weather conditions for that week (and beyond).
Predicting climate change	Models predicting climate change are based on observational data and fundamental physical laws such as Newton's laws. The most complex models are the general circulation models (GCMs). Data on climate change reported in the media is generated from numerous simulations of the GCMs.
Predicting pollutant effects	Atmospheric dispersion modelling predicts the behaviour of pollutants in the air over a specific period of time. It is used by governments to monitor air quality and to make predictions of the effects of chemical spills.

Table 9.4 Some of the applications of computer modelling

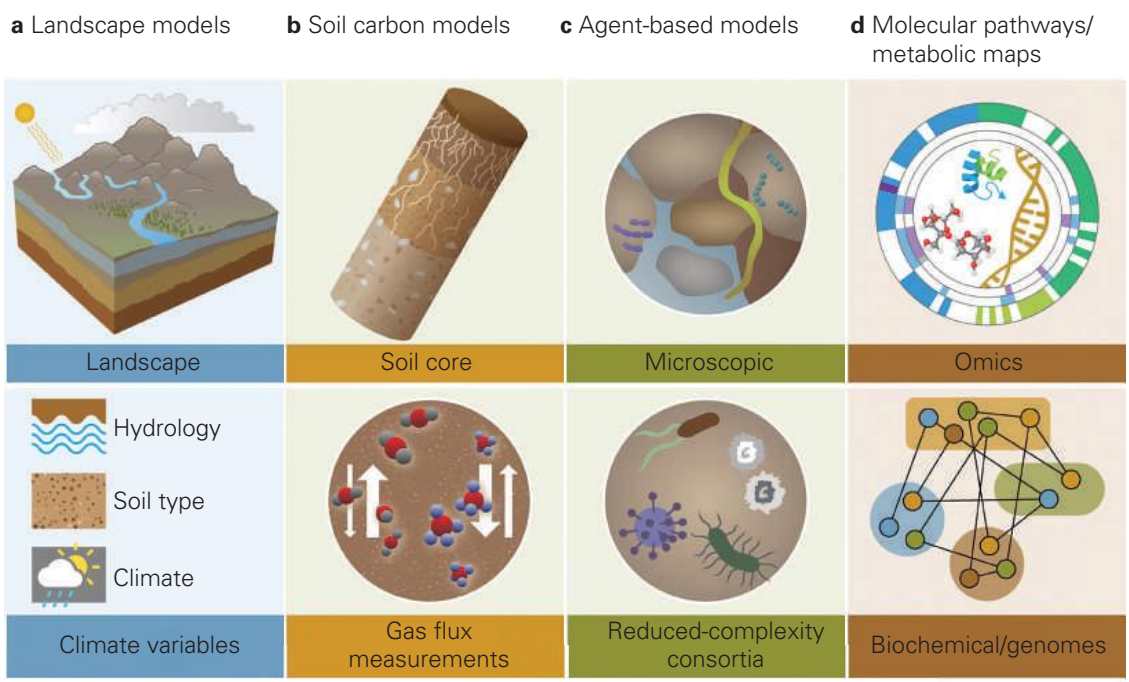


Figure 9.39 Climate change models can predict changes at a range of different levels: from effects on entire landscapes to individual species' genomes.

Naylor D, et al. 2020. *Annu. Rev. Environ. Resour.* 45:29–55

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Rapidly emerging quantum computers will be able to enhance the modelling of complex weather and climate systems by using quantum algorithms to perform simulations that are beyond the reach of classical computers. Unlike classical computers, which store and process information using binary bits that are only in one of two states (0 or 1), quantum computers use quantum bits (qubits) which exist in multiple states simultaneously. This allows quantum algorithms to perform certain tasks such as simulations much faster than classical algorithms.

These simulations will help improve our understanding of how weather patterns and climate interact and change over time, allowing for more accurate forecasting and prediction of weather patterns and the impacts of climate change. Quantum computers will be able to process large amounts of data faster and more efficiently, enabling more detailed simulations.

No model is perfect

Even though there is scientific consensus that climate change is real and is largely driven by human activities, there is still some uncertainty about how things will change in the future. This uncertainty leads to the use of different models and approaches to predict the impacts of climate change based on different scenarios.

Each climate change model uses different assumptions and has different limitations. Models are limited by the amount and quality of input data, and by the fact that real-world processes are subject to complex and random events that lead to unpredictable variations. As a result, models produce different projections of how the climate will change in the future.

Therefore, scientists use multiple models to address this uncertainty. Using multiple models gives a more comprehensive understanding of the potential impacts of climate change and helps guide governmental decision-making about how to mitigate its effects. As more data is collected and our understanding of climate change improves, new models are continually being developed and refined.

Quick check 9.11

1. **Explain** why scientists use computer modelling to predict phenomena.
2. **Give** one application of computer modelling.
3. **Predict** how quantum computers will enhance climate modelling.

Explore! 9.7

Climate change denial

Climate change denial is the rejection of the scientific consensus on the reality, causes and potential impacts of global warming, despite overwhelming evidence. Climate change models are contested by some people in society for a variety of reasons, including political, economic and ideological motivations. Some people may question the validity of climate change models because they challenge their long-held beliefs or economic interests. Others may be sceptical of scientists and question the impartiality and accuracy of the data and methods used to develop climate models.

There is also a belief among some people that the models are too complex and that their predictions are unreliable. These people may also reject the idea of human-caused climate change altogether, and therefore not accept the projections produced by climate change models. Misinformation about climate change has also played a role in contesting the models. Some individuals deliberately spread false information or manipulate data to discredit the models and cause people to doubt the science of climate change.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

One common method of data manipulation involves altering graphs to support a specific agenda. In climate change debates, this tactic can be used to downplay or exaggerate the impacts of global warming. Some techniques used include:

- Adjusting the scale of the axes to make trends appear more or less dramatic. For example, a temperature rise that is relatively small might be made to look insignificant by using a very narrow vertical axis range.
- Presenting data from a limited time frame can mislead viewers about long-term trends. For example, displaying a short period of stable temperatures might suggest that climate change is not occurring, even though longer-term data indicates significant warming.
- Selecting specific data points that fit a desired narrative while ignoring others can skew the perceived trend. For example, focusing on a few cold years in a generally warming trend can give the false impression that global temperatures are decreasing.

While some contest the models, most climate scientists agree that the models provide valuable insights into the future of the climate and are an essential tool for understanding the impacts of human activities on the planet.

In your class, you may want to engage in an evidence-based debate about the role of human activity in global climate change.

Figure 9.40 Greta Thunberg is a Swedish climate activist who is known for her strong stance on the need to address climate change. She has been an outspoken critic of those who deny climate change.

Quick check 9.12

1. **Describe** why computer models are not perfect.
2. **Give** some reasons why people contest climate change models.

INVESTIGATION

Explore! 9.8

Reducing greenhouse gases in the atmosphere

Climate change is a significant global challenge that is affecting the planet in many ways, from rising temperatures and sea levels to extreme weather events and changing ecosystems.

Research how the following strategies reduce greenhouse gas emissions or remove them from the atmosphere:

- carbon capture and storage
- reforestation and forest preservation
- sustainable agriculture
- energy conservation
- public and active transportation
- carbon pricing.

Figure 9.41 A carbon tax is a tax on the carbon content of fossil fuels, such as coal, oil and natural gas. Its aim is to incentivise the shift towards cleaner energy sources.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 9.9

Carbon farming

Carbon farming refers to a set of land management practices that aim to reduce greenhouse gas emissions from agriculture and other land uses while improving the health and productivity of ecosystems. Carbon farming's aim is to sequester (store) carbon in soil and vegetation to reduce atmospheric carbon dioxide.

Traditional Owners are implementing carbon-farming practices that support the management and restoration of natural ecosystems while also mitigating the effects of climate change. Communities are using their traditional knowledge of the land to implement reforestation projects, which not only restore forests but also sequester carbon and therefore reduce the effects of climate change. They are also using their traditional land management practices such as controlled burning to reduce greenhouse gas emissions and improve ecosystem health.

The Aboriginal Carbon Foundation is a non-profit organisation run by Aboriginal and Torres Strait Islander Peoples that provides carbon farming services. The foundation was established in 2010 with the primary aim of promoting sustainable land management practices that reduce greenhouse gas emissions while also generating economic benefits for Indigenous communities.

Figure 9.42 Trees planted in the Daintree rainforest by the Australian Rainforest Foundation will store carbon.

Go online to access the interactive section review and more!

Section 9.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 9.3 questions

Remembering

1. **Name** two indicators of climate change.
2. **Recall** what permafrost is.
3. **Identify** the reasons why coral bleaching is so disastrous for an environment.
4. **Name** the complex models used to make predictions about climate change.
5. **Recall** how satellites measure sea levels.

Understanding

6. **Describe** how permafrost can be used as an indicator of climate change.
7. **Explain** why computer models are useful in predicting future events.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applying

8. As part of a citizen science project, you are collecting data on species distribution. **Identify** how you could you use this data to further understanding of how climate change is affecting biodiversity.
9. **Identify** the advantages of using satellites to collect data about global climate.

Analysing

10. **Critique** the following statement: Global warming will not affect biodiversity.
11. **Critique** the following statement: Global climate models are perfect.

Evaluating

12. **Discuss** how global warming could cause sea levels to rise.
13. **Discuss** why less seawater freezing in winter affects ocean currents.
14.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
9.1	distinguish climate and weather.	
9.1	identify what mainly determines climate on Earth.	
9.1	describe trends in the Earth's climate using evidence.	
9.2	explain how the natural greenhouse effect influences global climate.	
9.2	analyse data on the relationship between industrialisation and global warming.	
9.2	analyse data on atmospheric carbon dioxide concentration and global mean temperature.	
9.2	explain the enhanced greenhouse effect as the cause of global warming.	
9.2	identify actions to reduce greenhouse gas emissions and their advantages and limitations.	
9.3	explain climate change characteristics, effects and consequences on ecosystems.	
9.3	explain climate change characteristics, effects and consequences on the water cycle.	
9.3	investigate how satellites collect global data and how it is used to evaluate the impact of climate change.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Data questions

The Keeling curve in Figure 9.43 illustrates the change in atmospheric carbon dioxide concentration from 1960 to 2005 as measured from the atmosphere above Hawaii, USA. A media outlet is using this data as evidence to suggest that 'climate is changing as there is increasing atmospheric carbon dioxide'.

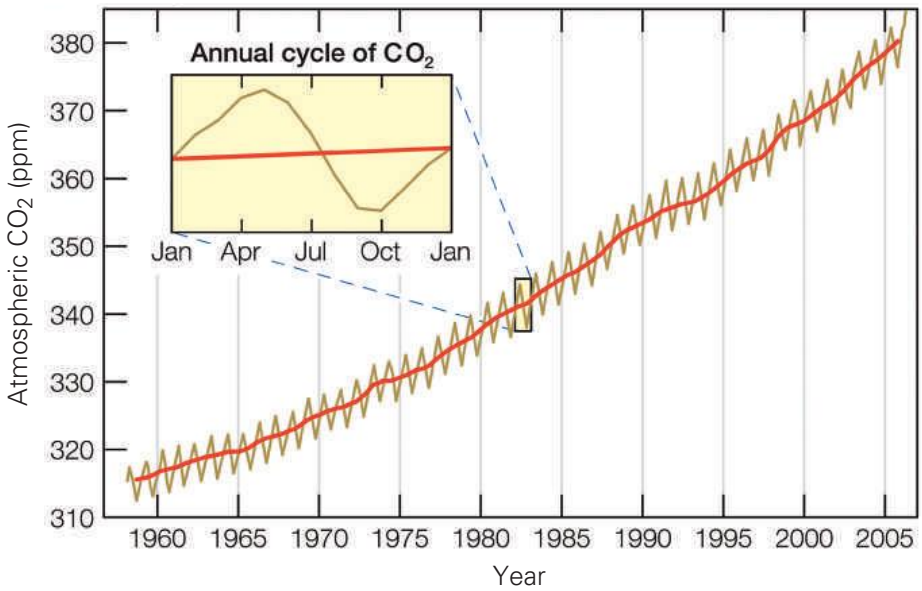


Figure 9.43 Keeling curve showing the atmospheric carbon dioxide concentration over time

1. **Identify** the year which had the lowest average atmospheric CO_2 in the atmosphere.
2. Use the red line to **determine** the concentration of atmospheric CO_2 in 1965.
3. **Determine** the annual cycles observed for the brown line.
4. **Distinguish** the difference between the brown line and the red line.
5. **Identify** the general trend of carbon dioxide concentration as time increases.
6. **Identify** the causes of the pattern/patterns occurring in the brown line.
7. Can the data in Figure 9.43 be used to **justify** the statement 'There is increasing atmospheric carbon dioxide'?
8. Can the data in Figure 9.43 be used to **justify** the statement 'Climate is changing'?
9. **Infer** the atmospheric concentration of CO_2 in 2030, using the trend you have observed in Question 5.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Using aerial imagery to track environmental change

Background information

Aerial photographs were pioneered by the French photographer and balloonist Gaspard-Félix Tournachon in 1858, four decades after the invention of the camera. Soon, governments over the world realised the potential of aerial imagery in gathering information for military use and monitoring territories. Early military aerial photographers fixed small adjustable cameras on the chests of mail pigeons and flew them over enemy positions. Aerial imagery techniques developed rapidly, from using balloons to using aeroplanes with coupled cameras, high-resolution satellite imagery and, most recently, highly sophisticated drones.

Today, we can also use high-tech satellites to gather other high-quality data from our ever- changing world. For example, you probably use a mobile device with an in-built GPS module capable of giving you directions to pretty much all corners of the globe. Importantly, we can now use this amazing technology to help us monitor our impact in our environment.

There is very little doubt that satellite and aerial imagery will play many important roles in our future. We could use aerial imagery to monitor of tracking environmental change over time in specific areas within the council boundaries. They want to demolish several buildings in the area for development and requested your opinion about possible implications for nearby rivers and creeks. You understand the potential for satellite imagery use (available free on Google Earth) in this situation, and you decide to give your advice after creating a time-lapse video (or series of images) that shows changes in landscape use over deforestation in Australia or protect endangered animals. It could be used to survey vulnerable ecosystems or develop more sustainable cities.

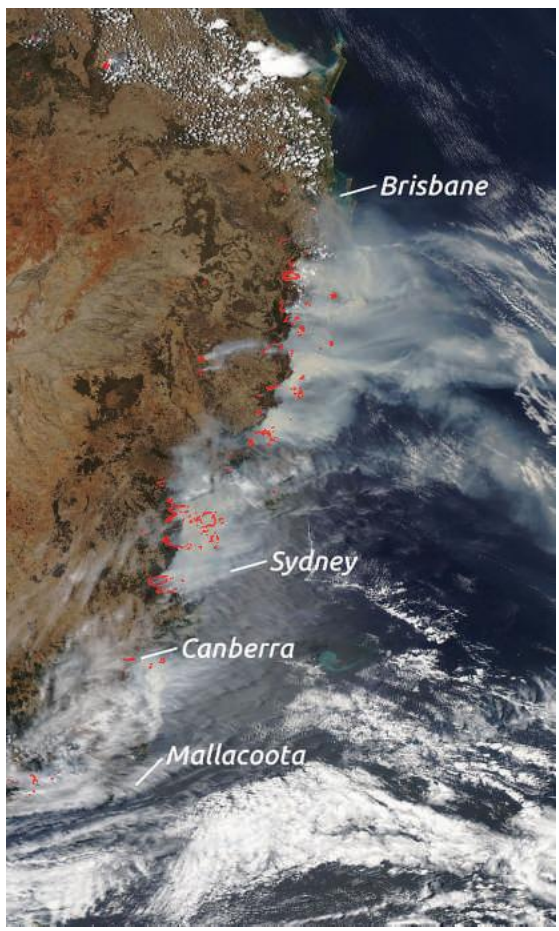


Figure 9.44 Imagery from NASA Aqua Satellite showing MODIS and VIIRS data of Australian bushfires. Fire detections are shown in red.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134

Activity instructions

You are an environmental researcher working for your local council along with a team of other professionals, including engineers, policymakers and designers. The Land Management Team asked you to design an interactive tool capable of tracking environmental change over time in specific areas within the council boundaries. They want to demolish several buildings in the area for development and requested your opinion about possible implications for nearby rivers and creeks. You understand the potential for satellite imagery use (available free on Google Earth) in this situation, and you decide to give your advice after creating a time-lapse video (or series of images) that shows changes in landscape use over time. (Teachers, please check the Online Teaching Suite for a detailed guide and example for this activity.)

Suggested materials

- Google Earth Pro (free to download)
- web browser (any)
- iMovie, Movie Maker or GIFMaker.org (recommended)

Research and feasibility

1. Outline the advantages and disadvantages of using satellite imagery to assess environmental change within your region.
   Describe the expertise (skills) needed to gather and decode these images and the potential benefits to the local economy of using them (for example, possible jobs created or improvement to traffic conditions).

Advantages	Disadvantages
e.g. Economy – predict areas for growth	e.g. Environmental – incorrect use of images without considerations

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

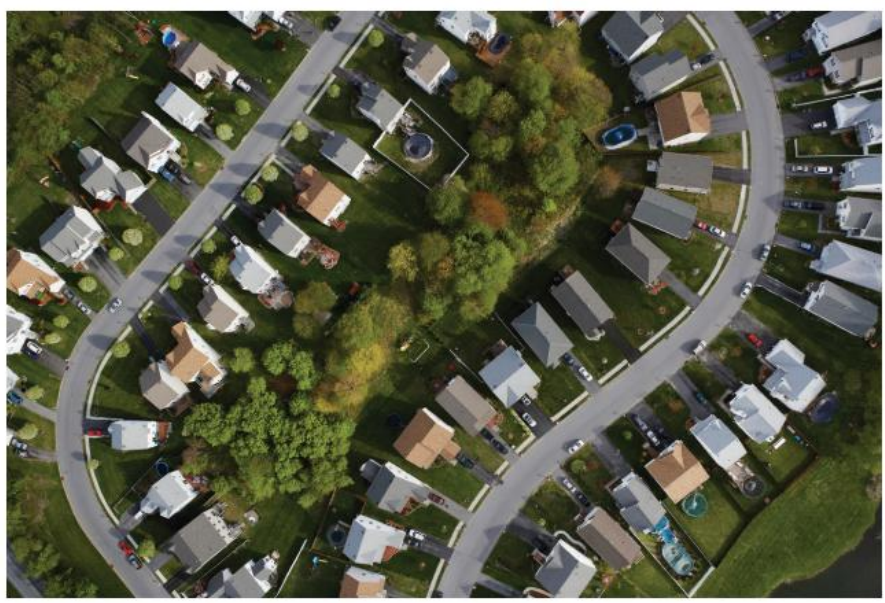


Figure 9.45 Rice terraces in Bali, a quarry, farmland and suburban houses viewed from above

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

521755134

2. Discuss and reflect on the knowledge needed to make predictions about the environmental impact of development.
3. Research and select a local area with a river or creek, and either a combination of natural and built environment or a natural environment, where a development could be proposed.

Design and sustainability

4. List all the environmental issues faced currently by your chosen area and predicted in the future based on current and future infrastructure.
5. As a group, discuss a future development that could be completed in the chosen area. Make a sketch of the future development and annotate the changes; make a list of environmental impacts of the development.
6. Decide on the best possible technology to use to create a time-lapse sequence of how the environment has changed from the past to now.

Create

7. Create a time-lapse sequence of the area and list at least 10 noticeable changes that have occurred in the landscape of your chosen area. What benefits or disadvantages have these changes brought to the local community?

8 Add your future development diagram to your time-lapse video and show likely the environmental impact of your development ideas.

Evaluate and modify

9. In your own words, explain how you could use the skills gained in this activity to enhance environmental conservation in your region.
10. As a class, evaluate the time-lapse sequences created by your peers and reflect on the challenges associated with anonymous aerial image gathering. In your opinion, are there any privacy concerns or implications associated with this technology? What measures are taken to improve privacy for people in relation to aerial image gathering?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 10

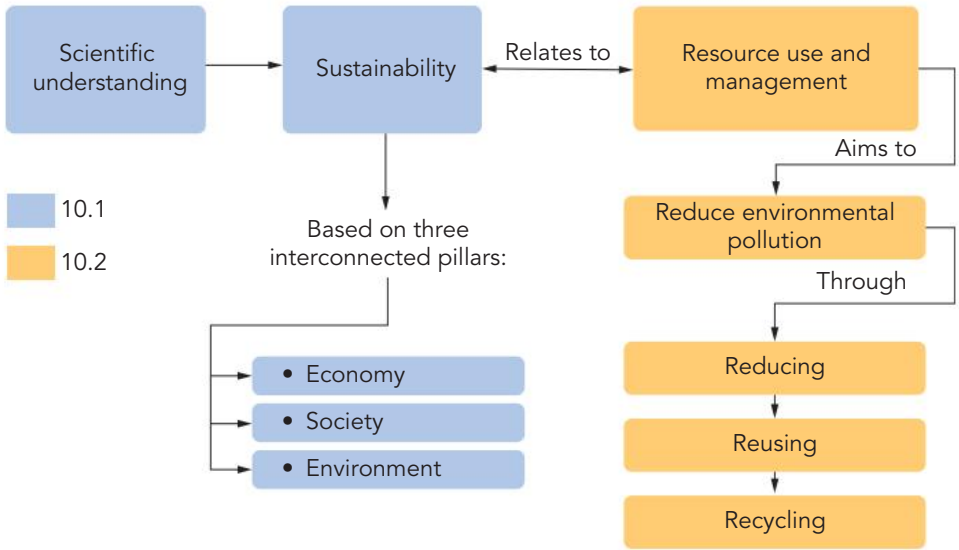
Sustainability and recycling

Chapter introduction

In this chapter, you will learn about the core principles of sustainability necessary for addressing global challenges and ensuring a sustainable future, and explore their application to economic, social and environmental contexts. You will focus on efficient resource use and recycling, exploring how reducing consumption, reusing materials, and recycling waste minimise environmental impact. The chapter considers innovative strategies and the circular economy concept, where materials are continuously cycled back into the economy, reducing waste and resource depletion. You will gain insights into conserving resources, promoting social equity and maintaining ecological integrity, enabling you to contribute to sustainable development and make informed decisions for a healthier planet.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



gettyimages®
Credit: Gary Yeowell

Low-res

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

10.1 Sustainability

WORKSHEET

VIDEO
Sustainability

Learning outcomes

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

1. identify the principles and goals of sustainability.
2. apply scientific understanding to sustainability issues and solutions.
3. investigate an example of how Aboriginal and Torres Strait Islander Peoples have developed a sustainable harvesting practice based on ecological understanding.

Sustainability is a concept that focuses on meeting the needs of the present without compromising the ability of future generations to meet their own needs. This idea is crucial in addressing the challenges our world faces, such as climate change, resource depletion and social inequality.

Principles of sustainability

The principles of sustainability are based on three interconnected pillars: the economy, society and the environment.

The economy

The economic pillar of sustainability involves creating and maintaining economic systems that can support current and future generations. This means developing practices and policies that ensure long-term economic growth and stability without depleting natural resources or harming the environment.

	 Figure 10.1 Metal recycling at Caldwell Molong
Innovation and technology	Promoting technological advancements and innovation to create more sustainable products and processes. For example, smart cities use advanced technology to improve efficiency, sustainability and quality of life in urban areas. **Figure 10.2** Smart bins help people recycle single-use containers.

Table 10.1 Aspects of the economic pillar of sustainability

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Goal	Description
Economic equity	Ensuring fair distribution of wealth and resources so that all people have access to economic opportunities and benefits. This helps reduce poverty and social inequality.

Figure 10.3 The New South Wales Government is committed to gender equality by using gender-responsive budgeting and Gender Impact Assessments (GIAs), which evaluate how proposed policies, programs or projects may differently impact women, men and gender-diverse people.

Table 10.1 *(continued)*

Society

The social pillar of sustainability focuses on the wellbeing of people and communities. It emphasises the importance of social equity, justice and quality of life for all individuals.

Goal	Description
Social inclusion	Ensuring that everyone, regardless of their background or circumstances, has access to essential services and opportunities. This includes education, healthcare and employment.

Figure 10.4 Established in 1984 under the Aboriginal Land Rights Act of 1983 (NSW), Gandangara Local Aboriginal Land Council (GLALC) serves the Southwestern Sydney region. It is one of 120 Local Aboriginal Land Councils in NSW, with objectives that include engaging with members, promoting Aboriginal culture and heritage, educating on Aboriginal identity, managing community benefit schemes and sustaining business enterprises and investments.

Table 10.2 Aspects of the society pillar of sustainability

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Goal	Description
Community development	Supporting the growth and development of communities to create a sense of belonging and social cohesion. This can involve investing in infrastructure, public spaces and community programs. **Figure 10.5** Community inclusion days are events that encourage communities to reconnect and promote acceptance, inclusion and fair treatment of diverse individuals.
Human rights	Protecting and promoting the rights and freedoms of all individuals. This includes fighting discrimination, ensuring gender equality and upholding labour rights. **Figure 10.6** Rosanna Barbero is a social activist and leader known for her work in promoting social justice, environmental sustainability and community empowerment. She is the winner of the 2024 NSW Human Rights Medal.

Table 10.2 *(continued)*

The environment

The environmental pillar of sustainability focusses on protecting and preserving the natural world. It considers the need to reduce human impact on the environment and maintain the health of ecosystems.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Goal	Description
Conservation	Protecting natural habitats, wildlife and biodiversity. This involves creating protected areas, restoring damaged ecosystems and preventing overexploitation of resources. **Figure 10.7** Beni State Conservation Area is home to over 140 bird species, including several threatened woodland and waterbirds.
Preventing pollution	Reducing pollution in all forms, including air, water and soil pollution. This can be achieved through regulations, cleaner production methods and sustainable waste management practices. **Figure 10.8** Clean Up Australia Day occurs on the first Sunday of March.
Resource management	Using natural resources in a way that ensures their availability for future generations. This includes practices like sustainable agriculture, forestry and fishing.

Table 10.3 Aspects of the environment pillar of sustainability

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

While each pillar of sustainability is important on its own, they are most effective when they are interconnected. This means that actions taken to promote economic growth should also consider social and environmental impacts. For example, designing and constructing buildings that are energy-efficient (environmental pillar), cost-effective (economic pillar) and provide healthy living spaces (social pillar).

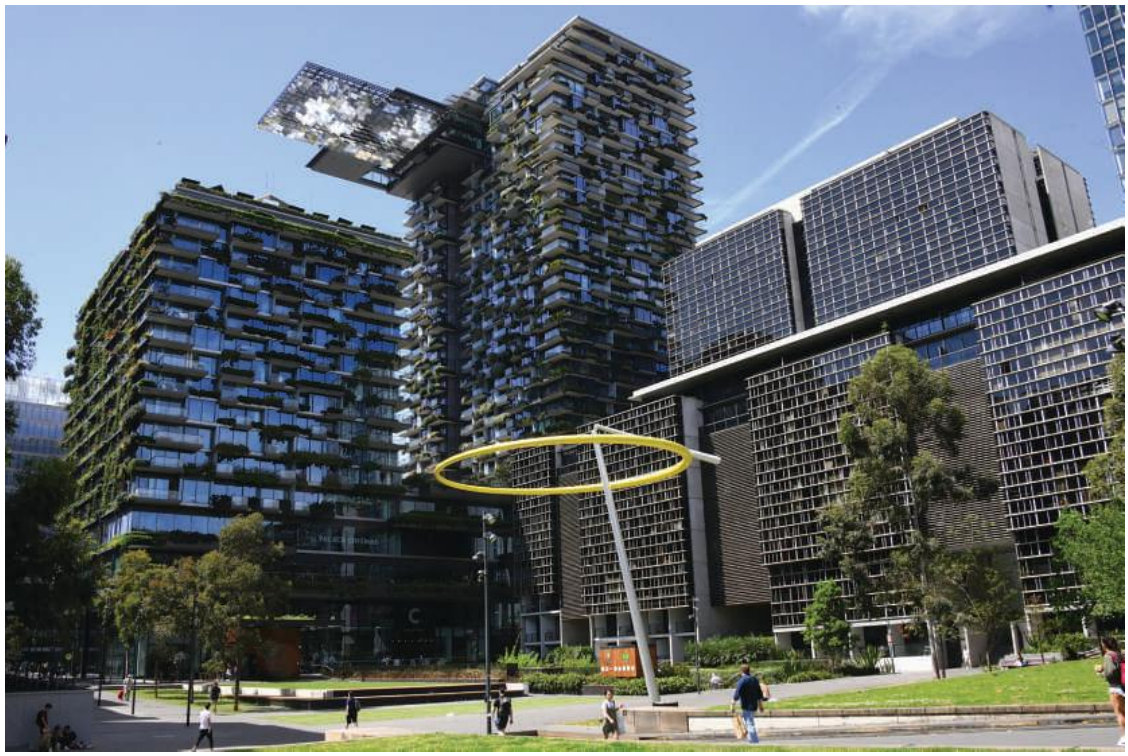


Figure 10.10 One Central Park in Sydney incorporates advanced sustainability practices, including a central thermal plant for efficient heating and cooling and a heliostat system to reflect sunlight into shaded areas. The building features vertical gardens, rainwater harvesting and recycling systems, significantly reducing its environmental footprint while promoting urban biodiversity and energy efficiency.

Figure 10.11 Vertical farming involves growing crops in stacked layers using controlled environments. This method uses less land and water compared to traditional farming and can be implemented closer to consumers, reducing transportation emissions.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 10.12 According to the Australian Fashion Council, approximately 210 000 tonnes of clothing are discarded annually in Australia, with an additional 200 000 tonnes being donated. Much of this textile waste ends up in landfills in countries like Ghana, India and Chile.

Explore! 10.1

Traditional sustainability

Aboriginal and Torres Strait Islander Peoples have a deep understanding of the land and its ecosystems, developed over thousands of years. Their sustainable harvesting practices and cultural protocols are based on extensive ecological knowledge and respect for the environment.

Figure 10.13 A koala rescued from a bushfire

Firestick farming is a land management technique that is traditionally used by many groups of Aboriginal and Torres Strait Islander Peoples for a variety of purposes. The technique involves the controlled use of fire to create a mosaic of different vegetation types and habitats across the landscape. Firestick farming relies on the use of fire-mediated chemical reactions to facilitate energy and nutrient transfer. The practice can be used to achieve both immediate and long-term results. In the short term, it can force prey animals to move towards the hunters, increasing the chances of capture. In the long term, the ash left behind by the burned vegetation provides a source of nutrients for the soil, which in turn supports the growth of new plants that are more nutritious and accessible to grazing animals.

A recent study found that cultural burns can protect koalas by encouraging regeneration of native plants and controlling species such as banksias and wattle, reducing the risk of fire reaching the koalas' canopy. The researchers used drones fitted with thermal cameras and hormone metabolite analysis to monitor koala stress during the burns. The study found no negative impacts on koala population densities or their stress levels.

In small groups, investigate how Aboriginal and Torres Strait Islander Peoples' fire management practices are informing and being adopted in contemporary fire management.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 10.2

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. In Queensland, the species is protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

Figure 10.14 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 of certain areas of Queensland 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.

Quick check 10.1

1. **Name** the three pillars of sustainability.
2. **Recall** which pillar of sustainability focusses on the wellbeing of people and communities.
3. **State** the primary goal of the environmental pillar of sustainability.

Explore! 10.3

Landcare

Landcare is a community organisation that aims to improve the health of the land and waterways in Australia by promoting sustainable land use and management practices. Established in the late 1980s, Landcare brings together farmers, landowners, natural resource managers and community members to collaborate on local projects that address issues such as soil erosion, water quality, biodiversity loss and carbon sequestration.

Landcare is supported by the Australian Government, which provides funding and other resources. Landcare has become a widely recognised and respected initiative that has made significant contributions to environmental sustainability in Australia.

Figure 10.15 A Landcare-funded project between CSIRO and local farmers is investigating the benefits of introducing dung beetles to far north Queensland. Researchers are studying the behaviour of dung beetles in the region, including their preferred habitats and the types of dung they prefer, as well as examining the economic benefits of dung beetle introduction, including increased farm productivity and reduced fertiliser costs.

Examine how government initiatives such as Landcare have supported the adoption of effective land restoration practices that improve soil quality and increase carbon sequestration in soils.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applying science to problems of sustainability

WORKSHEET Applying scientific understanding to a sustainability problem

This section of the chapter has referred to a number of sustainability issues where science has been used to help find a solution:

- protecting natural habitats, wildlife and biodiversity
- reducing pollution through cleaner production methods
- syntropic farming that mimics natural ecosystems, promoting biodiversity and soil health
- designing buildings that are energy-efficient
- designing a central thermal plant for efficient heating and cooling
- designing a heliostat system to reflect sunlight into shaded areas of buildings
- designing vertical gardens featuring rainwater harvesting for high-rise residential blocks
- researching the use of dung beetles to improve soil.

Use the worksheet referred to in the margin to apply scientific understanding to a problem relating to sustainability. Alternatively, you may choose to research the scientific understanding of one of the issues listed above, or choose one of your own that interests you.

Section 10.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 10.1 questions

Remembering

1. **Define** the concept of sustainability.

Understanding

2. **Explain** how the economic pillar of sustainability supports future generations.
3. **Summarise** the goals of sustainability.

Applying

4. **Identify** how recycling practices can contribute to efficient resource use in the economic pillar of sustainability.
5. **Describe** an example of scientific understanding providing a a solution to a sustainability issue.

Analysing

6. **Contrast** the goals of the economic and environmental pillars of sustainability.

Evaluating

7. **Justify** how the integration of the three pillars of sustainability can create more effective outcomes.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

10.2 Resource use and recycling

WORKSHEET

Learning outcomes

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

1. describe the causes of environmental pollution and discuss its implications.
2. discuss how to apply the approach of 'reduce, reuse and recycle' as an alternative to an unsustainable resource use.
3. describe current processes for recycling materials.
4. investigate examples of how scientists have developed innovative ways to recycle materials.
5. discuss the link between human activity and an environmental pollution issue.

In today's world, the way we use and manage resources is crucial for the health of our planet. Alternative resource use and recycling are key strategies in reducing environmental pollution and conserving natural resources for future generations.

Environmental pollution

Environmental pollution is the introduction of harmful substances or forms of energy (such as heat, sound or radioactivity) into the environment at a rate faster than they can be dispersed, diluted, decomposed or recycled. This leads to the degradation of natural ecosystems and poses serious health risks to humans and wildlife.

Table 10.4 summarises the causes of environmental pollution.

Cause	Explanation
Industrial activities	Factories and power plants release pollutants into the air, water and soil. In the air, they emit carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NOx), particulate matter and volatile organic compounds (VOCs). These emissions contribute to air pollution, acid rain and smog. In water, untreated wastewater containing chemicals, heavy metals, and toxins is discharged into rivers, lakes and oceans, harming aquatic life and threatening water sources. In soil, hazardous chemicals like heavy metals and solvents contaminate the land, disrupting plant growth and entering the food chain, leading to long-term environmental damage and health risks.

Table 10.4 Causes of environmental pollution

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Cause	Explanation
Transportation	Petrol, gas and diesel fuelled vehicles emit exhaust gases that contribute to air pollution. These vehicles burn fossil fuels in their engines, producing harmful emissions such as carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), volatile organic compounds (VOCs) and carbon dioxide (CO_2). These pollutants can negatively affect both human health and the environment. For example, nitrogen oxides can contribute to the formation of ground-level ozone, which leads to smog. Particulate matter can cause respiratory issues and aggravate pre-existing lung conditions. The accumulation of carbon dioxide in the atmosphere also contributes to climate change by increasing the greenhouse effect.
Agriculture	The use of pesticides and fertilisers contaminate water supplies and soil. Pesticides can run off into water sources, harming aquatic life, while fertilisers can lead to nutrient pollution, causing algal blooms. In soil, chemicals disrupt ecosystems, affecting plant health and biodiversity.

Table 10.4 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Cause	Explanation
Waste disposal	Improper disposal of waste, including plastics and electronic waste, pollutes land and water. Plastics, when not properly disposed of, can litter the environment, harming wildlife and ecosystems. They break down into microplastics, which contaminate soil and water, affecting both plant and animal life. Electronic waste, often discarded irresponsibly, contains hazardous materials like lead, mercury and cadmium. When it leaches into the soil or water, it poses serious risks to human health, contaminates water sources and disrupts ecosystems.
Urbanisation	Rapid urban growth leads to increased waste and pollution from construction and residential activities. Construction projects generate large amounts of debris, including building materials, dust and chemicals, which can degrade air quality and clog waterways. The rapid expansion of residential areas results in higher energy consumption, increased vehicle emissions, and more household waste, all of which contribute to environmental degradation. Additionally, the development of infrastructure often involves the destruction of natural habitats, further harming ecosystems.

Table 10.4 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 10.2

1. In your own words, **define** environmental pollution.
2. **Outline** how transportation activities contribute to air pollution.
3. **Recall** how rapid urbanisation contributes to pollution.

Explore! 10.4

The Great Pacific Garbage Patch

Plastic, made primarily from petrochemicals derived from crude oil, is durable and slow to degrade, leading to significant environmental problems. Improper disposal, littering and inadequate waste management often result in plastic waste finding its way into the ocean. Ocean currents carry these plastics, accumulating them in specific areas to form massive patches of floating debris.

The Great Pacific Garbage Patch, located between Hawaii and California, is the largest accumulation of plastic in the ocean and is estimated to cover an area nearly twice the size of New South Wales. It consists of millions of tonnes of plastic waste including bottles, bags and microplastics – tiny fragments from the breakdown of larger plastic items. This accumulation poses a direct threat to marine life, which can ingest or become entangled in the debris, disrupting entire marine ecosystems. The presence of plastic also interferes with the natural food chain, as smaller organisms consume microplastics and pass them up to larger predators.

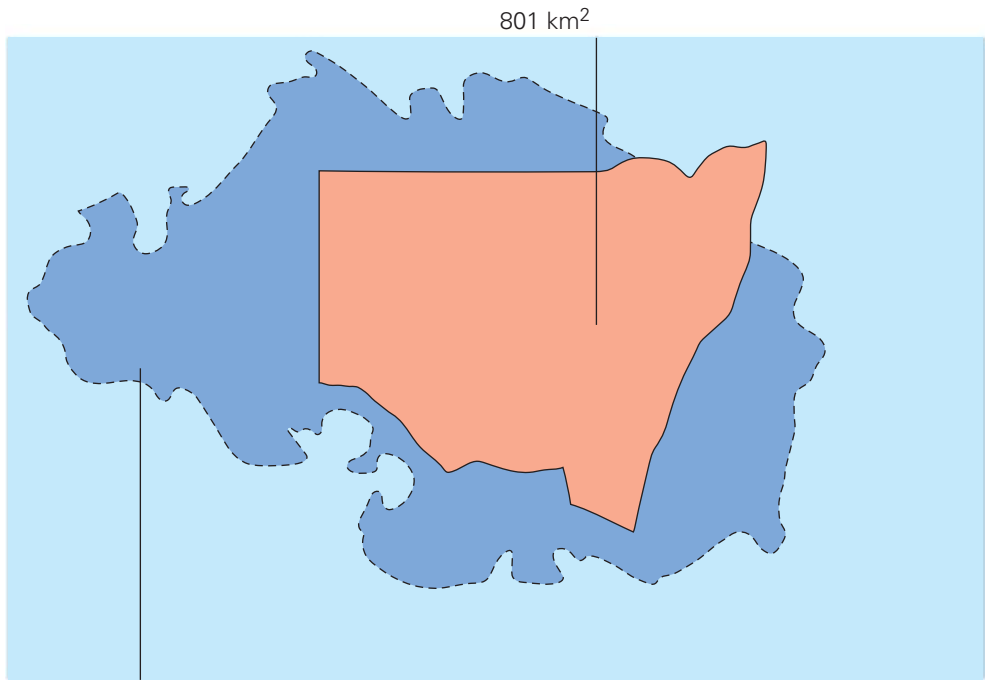


Figure 10.16 The size of the Great Pacific Garbage Patch in comparison to New South Wales

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Implications of environmental pollution

Environmental pollution has significant implications for human health, ecosystems, climate and economies.

Health

Polluted air and water can cause severe health issues, significantly impacting the wellbeing of individuals and communities. For example, exposure to particulate matter (PM), which includes tiny particles from vehicle exhaust, industrial emissions and construction dust, can lead to chronic respiratory illnesses such as asthma, bronchitis and even lung cancer. Long-term exposure to toxic chemicals like carbon monoxide (CO), nitrogen oxides (NOx) and sulfur dioxide (SO_2) from vehicle and industrial emissions can increase the risk of cardiovascular diseases, such as heart attacks and strokes.

In addition to air pollution, contaminated water is another significant health risk. For instance, polluted water from industrial waste, agricultural runoff or untreated sewage can introduce harmful pathogens and chemicals into drinking water supplies. This can lead to gastrointestinal diseases like cholera, dysentery and typhoid fever, which are often caused by waterborne bacteria. Heavy metals like lead and mercury, found in polluted water, can also cause long-term neurological and developmental issues, especially in children. Additionally, exposure to pesticides and fertilisers in water can lead to endocrine disruption and increase the risk of cancers.

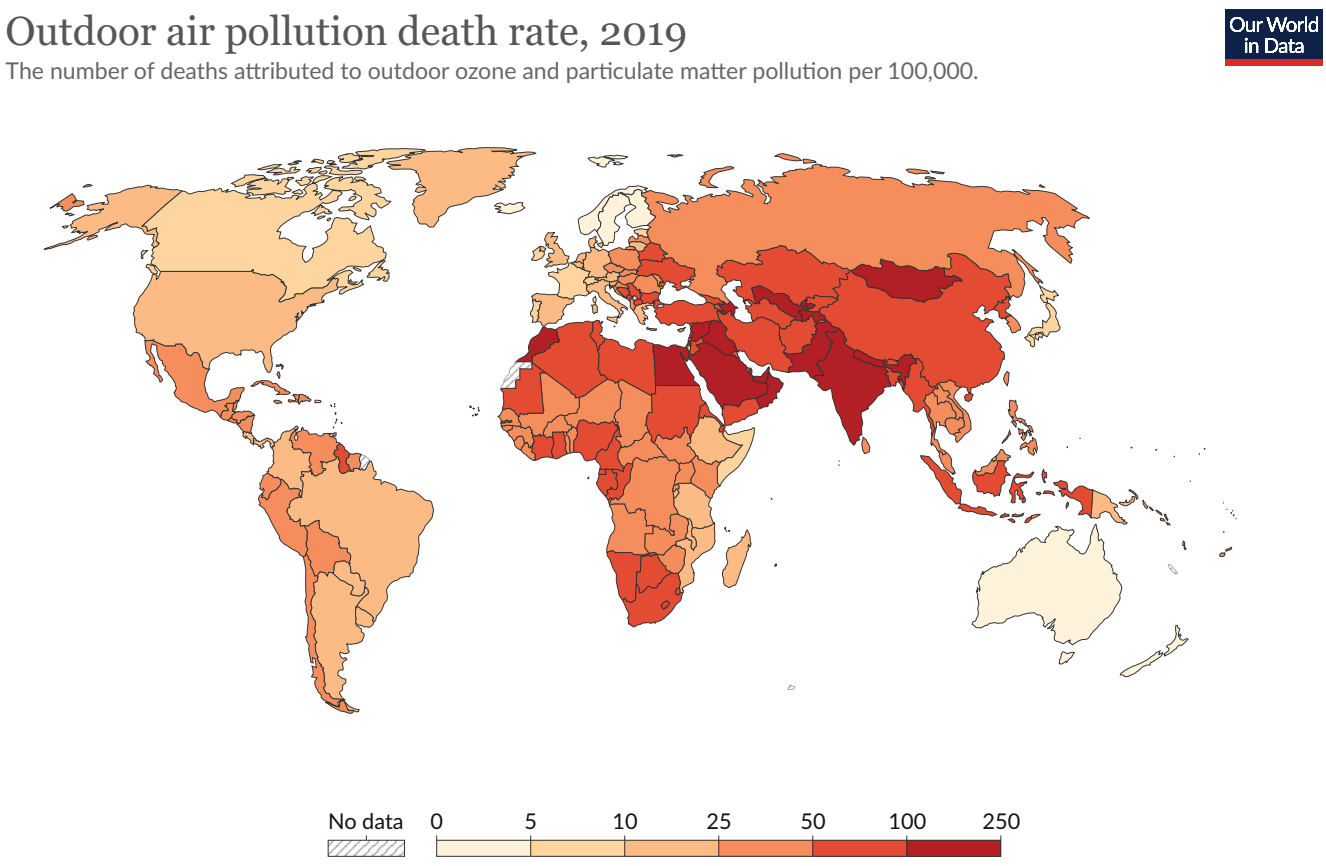


Figure 10.17 The estimated death rates from outdoor air pollution across the world

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Ecosystems

Pollution severely harms wildlife and disrupts ecosystems, causing widespread and often irreversible damage. Pollutants, including chemicals, plastics and industrial waste, can poison animals and contaminate their habitats, leading to a dramatic decline in biodiversity. For instance, heavy metals like mercury and lead – often released into water bodies through industrial discharges – can accumulate in the tissues of aquatic animals, leading to poisoning and reproductive failure. This not only threatens the survival of individual species but also weakens entire ecosystems that depend on these organisms.

Plastic waste in oceans is another critical concern. Marine animals, such as sea turtles, whales and fish, can become entangled in discarded fishing nets or ingest plastic debris, mistaking it for food. This can lead to injury, suffocation, malnutrition and death. Plastics also break down into smaller particles known as microplastics, which are ingested by a wide range of marine species, including those at the bottom of the food chain. These microplastics can enter the food web, affecting species all the way up to humans.

Chemical runoff from agriculture, particularly the use of fertilisers and pesticides, further compounds the problem. When excess nutrients, such as nitrogen and phosphorus, enter water systems through rainfall or irrigation, they can lead to eutrophication, a process where water bodies become overloaded with nutrients. This triggers the rapid growth of algae, which blocks sunlight and depletes oxygen levels in the water. In some cases, this creates dead zones – areas in oceans, rivers and lakes where oxygen levels are so low that most marine organisms cannot survive. These dead zones can result in the collapse of local fisheries, with devastating economic and ecological consequences.

Figure 10.18 It is estimated that more than one million sea turtles die each year from becoming tangled in fishing nets oringesting plastic and other types of debris.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Climate

Climate change is also a consequence of environmental pollution. As you learned in Chapter 9, greenhouse gases such as carbon dioxide and methane, released from burning fossil fuels and other human activities, trap heat in the Earth's atmosphere, leading to global warming. This warming causes changes in weather patterns, more frequent and severe natural disasters and rising sea levels, which pose significant risks to both natural and human systems.

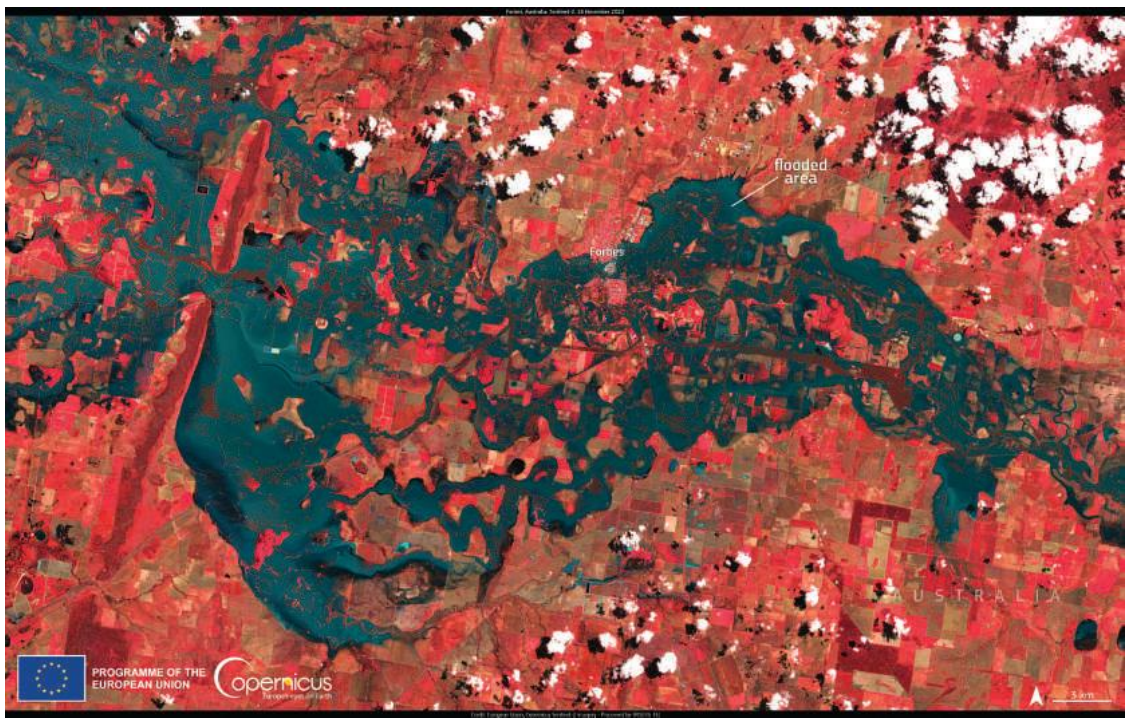


Figure 10.19 In 2022, severe floods impacted New South Wales, with the west-central region experiencing their worst flooding in 70 years. This image of Forbes, one of the towns that experienced the most damage, was taken by the Copernicus Sentinel-2 satellite, which helps monitor and assess the extent of global disasters.

Economy

The economic costs of pollution are substantial. Cleaning up polluted areas, treating health problems caused by pollution and dealing with the broader impacts of environmental degradation can be expensive. For example, studies have estimated that air pollution in Australia costs around $24 billion annually in health-related costs, including hospital admissions, lost productivity and premature deaths. These costs place a heavy burden on governments and economies, diverting resources from other essential areas such as education and infrastructure.

Figure 10.20 The costs associated with air pollution alone, including healthcare expenses and lost labour productivity, amount to billions of dollars annually in many countries.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 10.3

1. **Recall** the health impacts of air and water pollution.
2. **Describe** how pollution affects ecosystems and wildlife.
3. **List** some economic costs associated with environmental pollution.

Alternatives to current resource use

To reduce environmental impact, it is important to adopt more sustainable ways of using resources. This includes reducing, reusing and recycling materials.

Reducing

One effective way to minimise waste is by using products more efficiently and choosing sustainable options. For example, opting for products with minimal packaging and avoiding single-use items can significantly decrease the amount of waste generated. Using energy-efficient appliances and adopting practices such as turning off lights when not in use can help lower overall energy consumption and reduce environmental impact.

Figure 10.21 By 2050, plastic consumption in Australia is projected to more than double. Despite government efforts to establish a circular economy, only 14% of plastic waste is currently diverted from landfill.

Reusing

Repairing and repurposing broken or old items, rather than discarding them, can significantly extend their lifecycle and reduce the environmental impact associated with manufacturing new products. This approach helps conserve resources, lowers energy consumption and reduces waste. For instance, studies have shown that have a significantly lower environmental footprint than. While a plastic bag might be used once before being discarded, a reusable fabric bag can replace hundreds of single-use plastic bags over its lifetime, resulting in a substantial reduction in plastic waste and petroleum consumption.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Second-hand goods also contribute to sustainability. By purchasing pre-owned items, we reduce the demand for new products, which would otherwise require additional resources and energy to manufacture. For example, choosing second-hand clothing or furniture lowers the demand for new production and helps reduce the environmental impact of the textile and wood industries, both of which can be resource intensive.

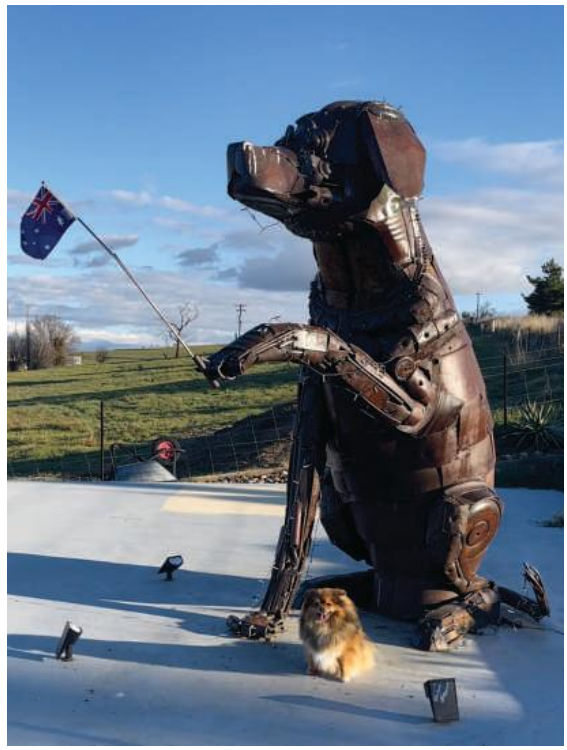


Figure 10.22 Located in Dunkeld, Big Dog is made of discarded farm equipment.

Recycling

Material recycling involves converting waste materials into new products, which helps reduce the need for raw materials and decreases environmental strain. For example, composting organic waste, such as food scraps and garden clippings, creates nutrient-rich soil that can be used for gardening and agriculture. This process not only diverts waste from landfills but also enriches the soil, promoting healthier plant growth.

Figure 10.23 A recycled road at Engadine

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Effective recycling processes help reduce the burden on natural resources and minimises the environmental impact of waste. The current recycling processes involve a series of steps designed to convert waste materials into reusable products, promoting a circular economy. A circular economy is an economic model that emphasises the continual use of resources by designing products and systems that reduce waste and extend the lifecycle of materials. Unlike the traditional linear economy, which follows a 'take, make, use, dispose' approach, the circular economy aims to keep resources in use for as long as possible. This involves not only recycling but also designing products for durability, repairability and ease of disassembly, so that materials can be efficiently recovered and reused.

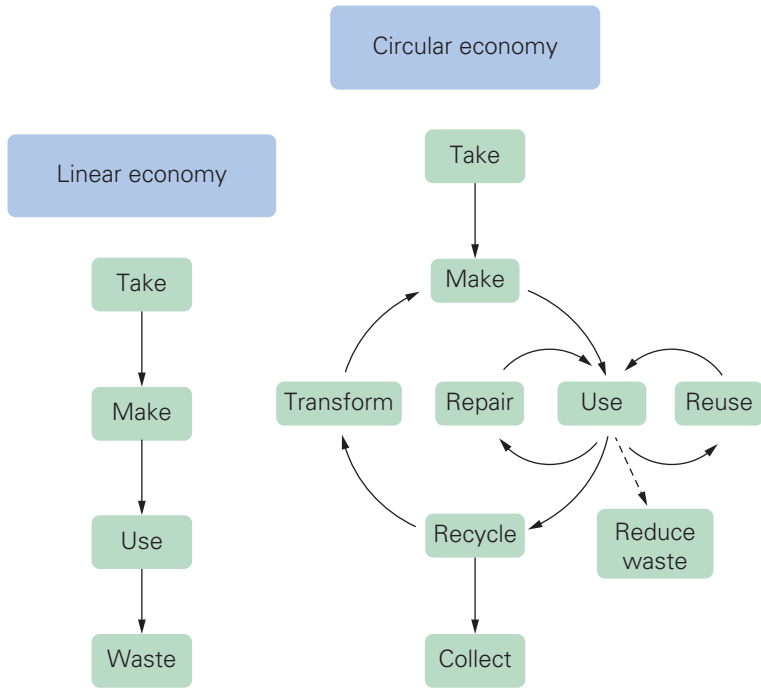


Figure 10.24 The difference between the linear and circular economy

Paper recycling

Paper recycling starts with the collection of used paper products, which are then sorted by grade and type. Sorting is essential because different types of paper, such as newspaper, office paper, or cardboard, have different fibre qualities and require specific processing methods. Sorting ensures that only compatible materials are mixed together, improving the quality of the recycled paper.

Once sorted, the paper is shredded into small pieces and mixed with water to create a slurry or pulp. This mixture of water and paper fibres is the basis for the recycling process. The pulp is then cleaned to remove contaminants, such as ink, glue, and plastic coatings, which could affect the quality of the final product. Cleaning often involves physical methods, like screens, and chemical treatments, such as the use of detergents or solvents, to break down the ink.

The next step is de-inking, which is crucial for removing the ink and ensuring the final product is clean and suitable for reuse. De-inking is typically achieved through a process known as flotation, where the ink particles are separated from the paper fibres and removed. Once the pulp is clean, it is refined, which involves further breaking down the fibres and making them uniform in size and texture. This step helps to improve the quality and strength of the new paper.

After refining, the pulp is spread onto screens where the water is drained, leaving behind a mat of paper fibres. This mat is then pressed and dried to form solid paper sheets. Once dried, the sheets are rolled into large rolls, which can be cut and shaped into new paper products, such as office paper, newspapers or cardboard.

Recycled paper retains much of the original paper's fibres, which can be reused multiple times. This significantly reduces the need for virgin paper made from trees, helping conserve forests and reduce the environmental impact of paper production. Recycling paper also reduces energy consumption, as producing paper from recycled pulp uses less energy than making it from raw wood fibres.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 10.25 Paper recycling in action

Plastic recycling

Plastic recycling begins with the collection and sorting of plastic waste. Plastics are classified according to their type, often using the symbols found on packaging, such as #1 (PET), #2 (HDPE) and #5 (PP), each representing a different polymer with distinct properties. Thermoplastics, such as PET and HDPE, can be melted and reshaped repeatedly, making them ideal for recycling. In contrast, thermosetting plastics, such as epoxy or bakelite, cannot be re-melted once hardened and are typically not recyclable, as their molecular structure forms permanent bonds that prevent them from being reshaped.

Once sorted, plastics are shredded into small flakes or pellets and washed to remove contaminants like labels and adhesives. Sorting is crucial because plastics have unique chemical properties and can differ in terms of density, melting point, and chemical structure. Mixing different types of plastic can result in an inferior product, as their properties may not blend well. For example, HDPE (high-density polyethylene) has a different melting point and structural integrity compared to PVC (polyvinyl chloride), so mixing them can lead to weak or unstable recycled products.

Colour sorting is also essential. Different coloured plastics can create visual inconsistency in the final product. For example, clear PET can be recycled into new clear containers or textiles, while coloured plastics may be used for products where colour is less critical, such as park benches or outdoor furniture. If clear and coloured plastics are not separated, the final recycled material can have an unwanted tint or inconsistency, reducing its marketability and functionality.

After the plastics are cleaned and sorted, they are melted and formed into new pellets, which can be used for various applications. These pellets may be mixed with additives to enhance certain properties, such as plasticisers, which make the plastic more flexible, or stabilisers, which prevent degradation from UV exposure or heat. For example, flame retardants can be added to create

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

fire-resistant materials, while reinforcing agents, like glass fibres, can improve the strength of the final product. The specific additives used depend on the intended application, aiming to improve the plastic's durability, flexibility, or resistance to certain conditions.

Figure 10.26 Sorted shredded plastic

Metal recycling

Metal recycling starts with the collection of metal waste, which is then sorted by type using methods such as magnets. Magnets are used to separate ferrous metals (which contain iron, like steel and iron) from non-ferrous metals (such as aluminium, copper and brass).

Once sorted, the metals are shredded into smaller pieces to make them easier to melt. Shredding also helps remove contaminants, such as plastics, coatings and other impurities, which could affect the quality of the recycled metal. The shredded metal is then melted in furnaces at high temperatures, a process that allows it to be purified. Impurities such as dirt or paint are separated out during the melting process.

After purification, the molten metal is often alloyed by adding other metals or elements to enhance specific properties, depending on the intended use. For example, adding carbon to iron creates steel, which is stronger and more durable, while aluminium can be alloyed with copper or magnesium to improve its strength and resistance to corrosion. These alloys are then cast into new shapes, such as ingots, sheets or bars, which can be used in the production of a wide range of products, from car parts to construction materials.

The sorting and melting processes are crucial for ensuring that recycled metals maintain the desired properties for reuse. For example, aluminium, which is often used in packaging and automotive parts, is particularly valuable in recycling because it retains its quality and strength after being melted down and reused. The energy savings from recycling metals are significant, as producing metals from raw ores requires much higher energy inputs compared to recycling.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 10.27 Recycled aluminium ingots

Glass recycling

Glass recycling begins with the collection and sorting of glass by colour and type, as different glass materials have distinct properties that affect the recycling process. Clear glass is often separated from coloured glass to prevent the final product from having an undesirable tint. Sorting by type also ensures that bottle glass and window glass are handled appropriately, as the chemical composition and melting points can vary.

Once sorted, the glass is crushed into small pieces called cullet. Cullet is valuable because it melts at a lower temperature compared to raw materials, making it more energy-efficient to process. The cullet is then cleaned to remove any contaminants, such as labels, adhesives, or food residues, which could affect the quality of the final product. Cleaning is an important step, as impurities can interfere with the melting and shaping processes and lower the quality of the recycled glass.

The cleaned cullet is then melted in high-temperature furnaces, where it is heated to around 1400°C. The molten glass is then formed into new shapes such as containers, tiles or other products. During this process, the glass may be mixed with small amounts of raw materials like sand, soda ash and limestone, which are often used to adjust the composition of the glass or enhance its properties. The ability to reuse cullet in the production of new glass containers or products is particularly valuable, as it reduces the need for raw materials.

Recycled glass can be used to make new glass containers, such as bottles and jars, or products like glass tiles, insulation materials, or fibreglass. Using recycled glass in production helps conserve natural resources, reduces energy consumption, and lowers emissions. For example, producing glass from cullet uses 40% less energy than making glass from raw materials, making it a highly efficient recycling process.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 10.28 Glass bottles and cullet

Quick check 10.4

1. **Elaborate** on why reusing items is better than discarding them.
2. **Define** composting and describe how it benefits the environment.
3. **Define** cullet and describe how is it used in glass recycling.

INVESTIGATION

Explore! 10.5

Innovative recycling

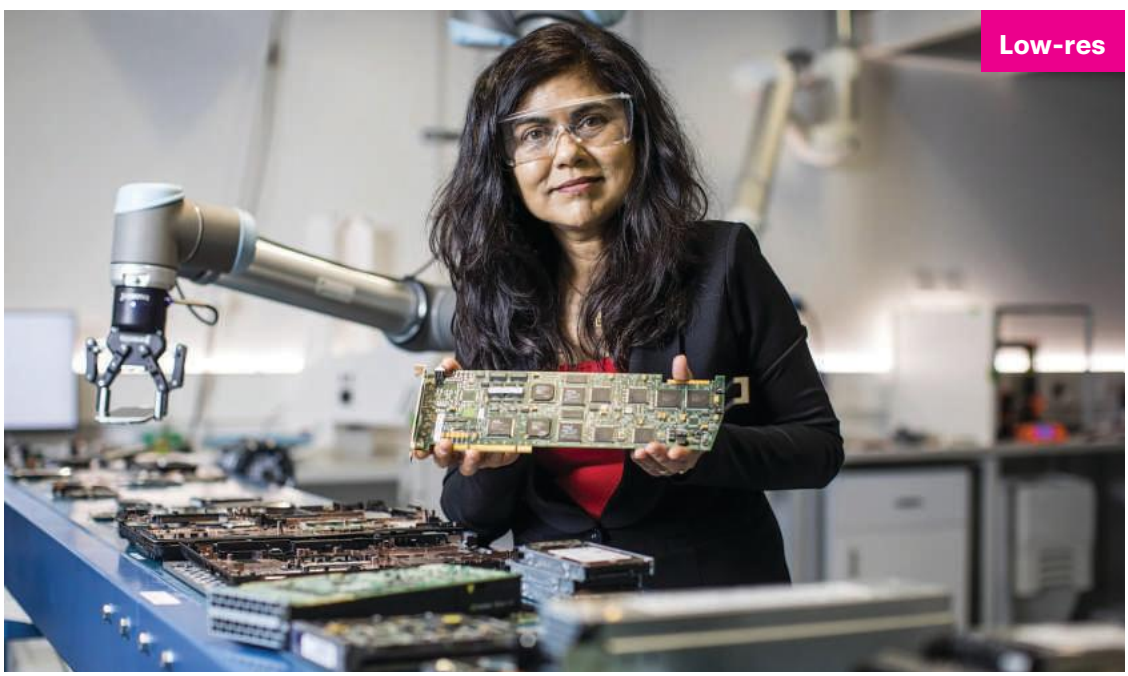


Figure 10.29 Professor Veena Sahajwalla from the University of NSW developed a 'microrecycling' process that transforms old electronics into new materials.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Scientists are continuously developing new methods to improve recycling processes and make them more efficient. One notable example is the work of Professor Veena Sahajwalla, an Australian scientist known for her innovative recycling techniques. She launched the first e-waste microfactory, recycling electronic waste by transforming it into valuable materials such as metals and ceramics using energy-efficient techniques. She has also worked on making steel production more sustainable by using waste plastics as a substitute for coke in the process of extracting iron. Plastics help produce carbon monoxide, which is used to reduce iron oxides to iron. Although the process still produces carbon dioxide, using plastics improves the efficiency of steelmaking. The plastics create a more stable slag, which helps the furnace operate more efficiently, using less electricity. This reduces carbon dioxide emissions from electricity generation, especially if the power comes from sources that release greenhouse gases, while also helping to keep plastics out of landfills.

Investigate some of the following innovative ways to recycle materials:

- recycled bricks
- plastic roads
- biodegradable plastic
- AI for sorting waste
- composting machines.

Figure 10.30 Fishing line disposal unit at Ballina

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 10.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 10.2 questions

Remembering

1. **Name** three causes of environmental pollution.
2. **Recall** the types of pollutants released by industrial activities.

Understanding

3. **Explain** how industrial activities contribute to environmental pollution.
4. During the recycling process for glass, **explain** why it is important to remove contaminants such as food and adhesives.

Applying

5. **Illustrate** the steps involved in recycling glass.
6. **Decide** whether the following use of resources are examples of reusing, reducing, or recycling.
   - **a.** Crushing glass bottles before reforming the glass into new containers
   - **b.** Taking reuseable shopping bags to the supermarket
   - **c.** Purchasing and using a 'keep cup' to purchase takeaway coffee
   - **d.** Setting the air conditioner to a warmer temperature in summer to save electricity
   - **e.** Turning the lights off when leaving a room
   - **f.** Purchasing loose, whole vegetables, instead of cut-up vegetables in plastic packaging
   - **g.** Placing paper and cardboard in the household recycling bin
7. When sorting recycled plastic, **explain** why a pipe, made of PVC, should be separated from a water bottle, made of HDPE, before melting.

Analysing

8. **Analyse** the impact of single-use plastics on marine ecosystems.

Evaluating

9. **Discuss** some of the long-term economic impacts of failing to address environmental pollution.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
10.1	identify the principles and goals of sustainability.	
10.1	apply scientific understanding to sustainability issues and solutions.	
10.1	investigate an example of how Aboriginal and Torres Strait Islander Peoples have developed a sustainable harvesting practice based on ecological understanding.	
10.2	describe the causes of environmental pollution and discuss its implications.	
10.2	discuss how to apply the approach of 'reduce, reuse and recycle' as an alternative to an unsustainable resource use.	
10.2	describe current processes for recycling materials.	
10.2	investigate examples of how scientists have developed innovative ways to recycle materials.	
10.2	discuss the link between human activity and an environmental pollution issue.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Data questions

The data on domestic waste generation and recycling rates, shown in Table 10.5, provides insight into the performance of New South Wales in improving waste management outcomes. This includes efforts to reduce waste generation and increase recycling rates by diverting materials from landfill.

Stream	Waste (tonnes)			
	Collected	Recycled	Disposed	Recycling rate (%)
Recyclables	815 257	752 968	62 290	92.4
Sydney Metropolitan Area	379 153	345 877	33 276	91.2
Extended Regulated Area	174 147	164 629	9518	94.5
Regional Regulated Area	108 572	99 089	9483	91.3
Rest of state	153 385	143 372	10 012	93.5

Table 10.5 Total domestic waste generation and recycling rates for New South Wales in 2021–22

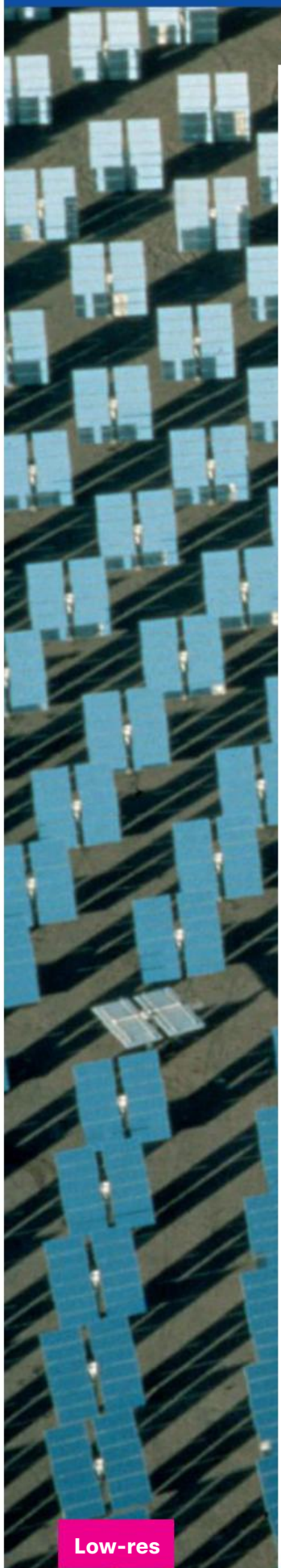
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Organics	936 022	922 355	13 667	98.5
Sydney Metropolitan Area	384 519	379 391	5128	
Extended Regulated Area	236 334	235 202	1132	99.5
Regional Regulated Area	141 708	140 193	1515	98.9
Rest of state	173 461	167 569	5892	96.6
Residual waste	2 340 727	219 471	2 121 256	9.4
Sydney Metropolitan Area	1 264 373	190 528	1 073 845	15.1
Extended Regulated Area	468 773	10 189	458 584	2.2
Regional Regulated Area	221 589	5876	215 713	2.7
Rest of state	385 992	12 878	373 114	3.3
Total generation	4 092 006	1 894 794	2 197 213	46.3
Sydney Metropolitan Area	2 028 045	915 796	1 112 249	45.2
Extended Regulated Area	879 254	410 020	469 234	46.6
Regional Regulated Area	471 869	245 158	226 711	52.0
Rest of state	712 837	323 819	389 018	45.4

Table 10.5 *(continued)*

1. **Identify** the total amount of recyclables collected in the Extended Regulated Area.
2. **Calculate** the percentage of organics recycled in the Sydney Metropolitan Area.
3. **Compare** the recycling rates of the Regional Regulated Area and the Rest of state for residual waste.
4. **Identify** the area with the highest amount of residual waste disposed.
5. **Calculate** the difference in the amount of organics recycled between the Sydney Metropolitan Area and the Extended Regulated Area.
6. **Compare** the total generation of waste to the total recycled waste in the Rest of state.
7. **Infer** the potential impact on recycling rates if the Regional Regulated Area improves its waste management practices to match the Extended Regulated Area's recycling rate for organics.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



STEM activity: Reusing waste materials

Background information

The growing amount of waste produced globally highlights the need for innovative approaches to reusing materials. By repurposing waste materials, we can conserve natural resources, reduce pollution and lower greenhouse gas emissions.

DESIGN BRIEF

Create a practical item using only waste materials and demonstrate its potential environmental benefits.

Activity instructions

You are tasked with designing a useful and innovative item using waste materials. Your creation should showcase how repurposing waste can reduce environmental harm and conserve valuable resources. Once completed, present your item to a panel and explain its environmental advantages.

Suggested materials

- cardboard boxes
- plastic bottles
- aluminium cans
- old newspapers and magazines
- fabric scraps
- used electronic components
- glue, tape and other adhesives
- scissors, cutters and other tools

Research and feasibility

1. Outline the advantages and disadvantages of using waste materials to create an item.

Advantages	Disadvantages
e.g. Reduces waste in landfill	e.g. Possible limitations in material strength

2. Identify environmental issues associated with waste and resource use. Discuss how creating items from recycled materials can mitigate these issues.
3. Research and brainstorm potential items that can be made from waste materials. Consider items that solve everyday problems or have practical applications, such as furniture, toys, tools, clothing or decorative pieces.

Low-res
Uncorrected 4th sample pages • Cambridge University Press and Assessment © [illegible] et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134

Figure 10.31 A dress made of magazine paper

Figure 10.32 Chess pieces made of old cans and bottles

Figure 10.33 A greenhouse made of old plastic bottles

Figure 10.34 Armchairs made of tyres

Design and sustainability

4. Create a detailed sketch of your item, labelling the materials you will use and noting any special features.
5. Decide on the best methods and tools to use for assembling your item. Consider the durability and functionality of your design.

Create

6. Using your sketch and plan, construct your item from the selected waste materials. Ensure the final product is functional and aesthetically pleasing.
7. Take photos or videos of each step of your creation process, highlighting the use of waste materials and any challenges you encounter.

Evaluate and modify

8. Assess the functionality, durability and aesthetics of your item. Identify any areas for improvement and consider modifications that could enhance its performance or appearance.
9. Prepare a presentation showcasing your item. Explain the materials used, the construction process and the environmental benefits of your design. Consider how this project can inspire others to use waste materials creatively.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

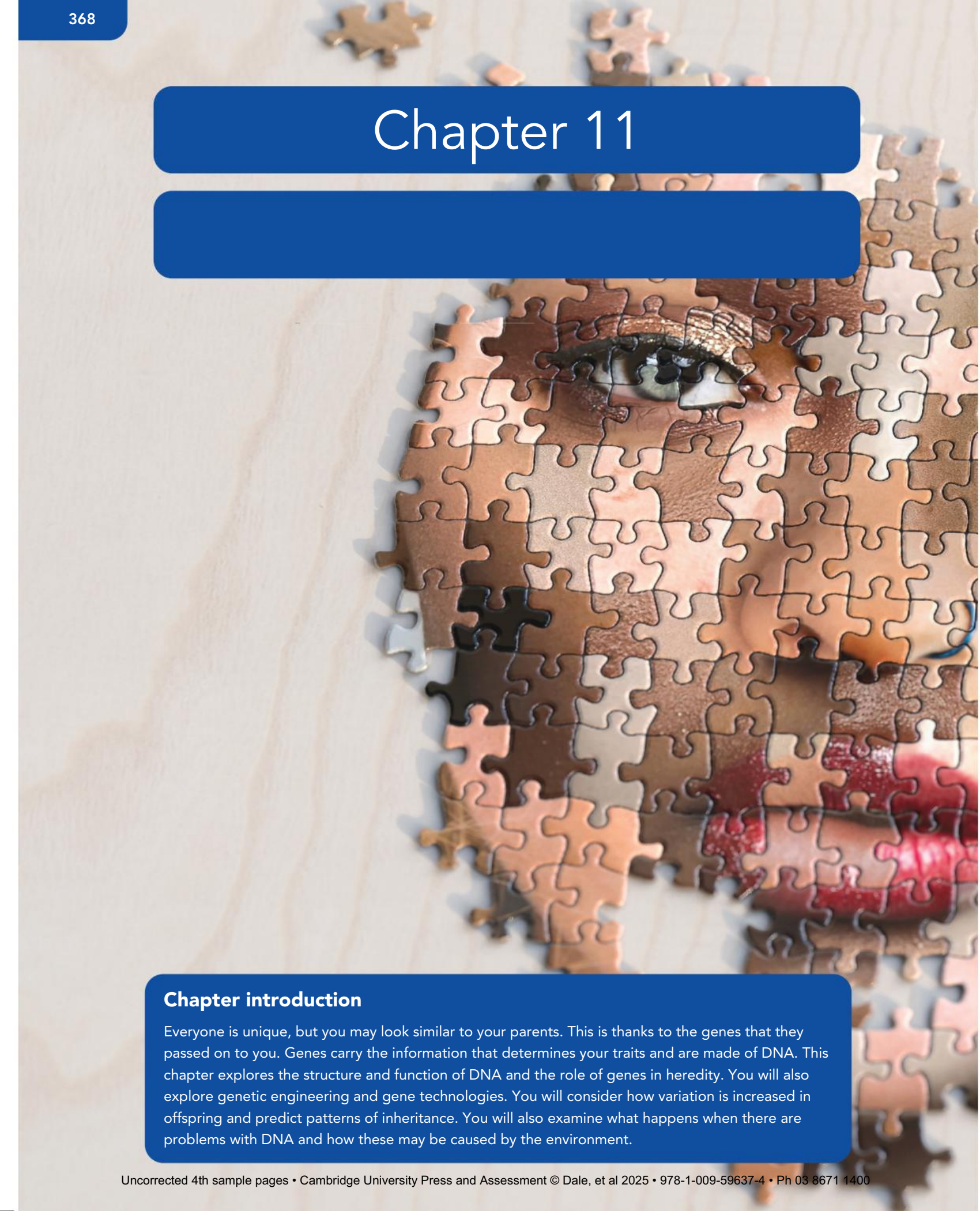
CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 11

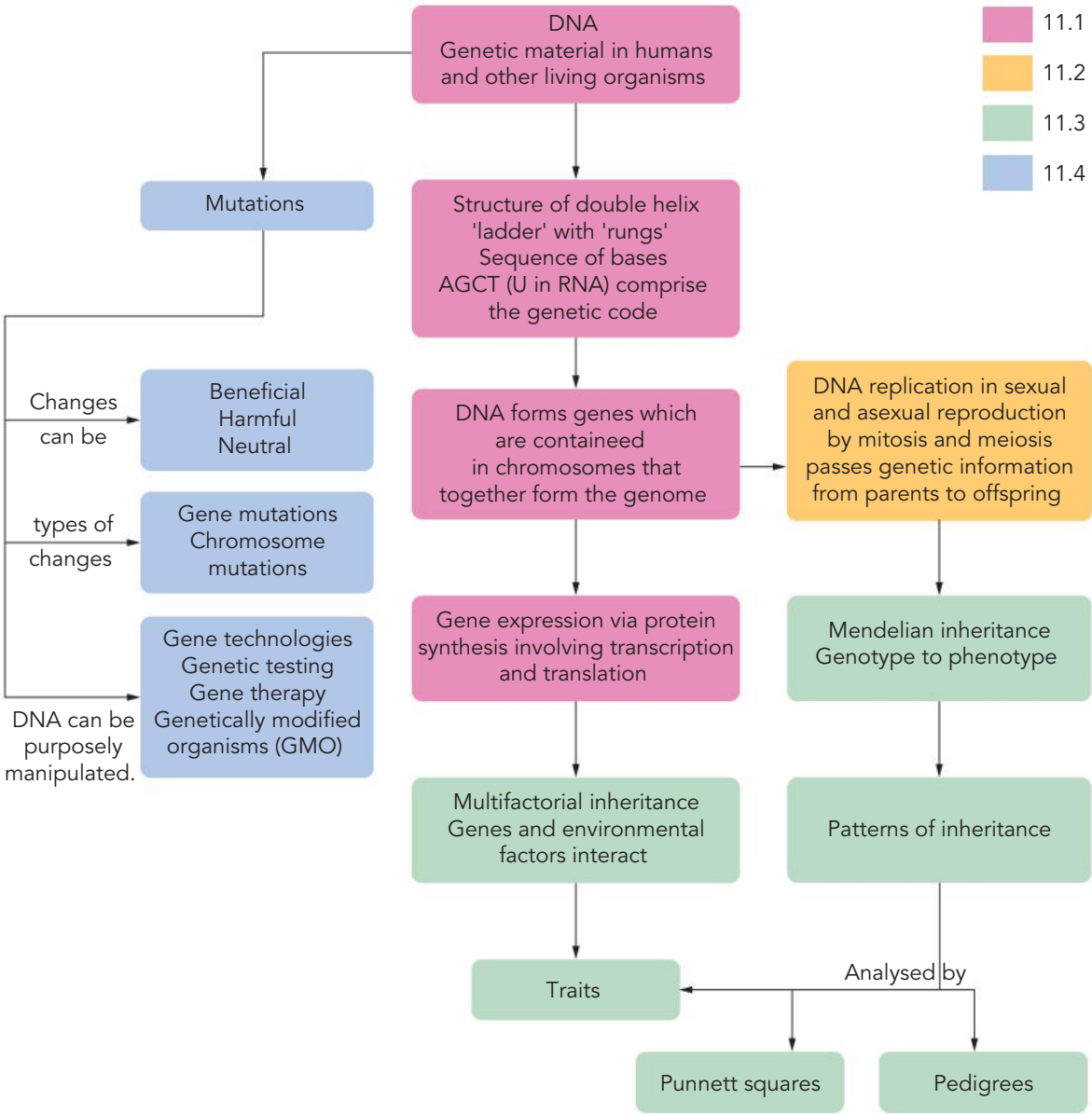


Chapter introduction

Everyone is unique, but you may look similar to your parents. This is thanks to the genes that they passed on to you. Genes carry the information that determines your traits and are made of DNA. This chapter explores the structure and function of DNA and the role of genes in heredity. You will also explore genetic engineering and gene technologies. You will consider how variation is increased in offspring and predict patterns of inheritance. You will also examine what happens when there are problems with DNA and how these may be caused by the environment.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

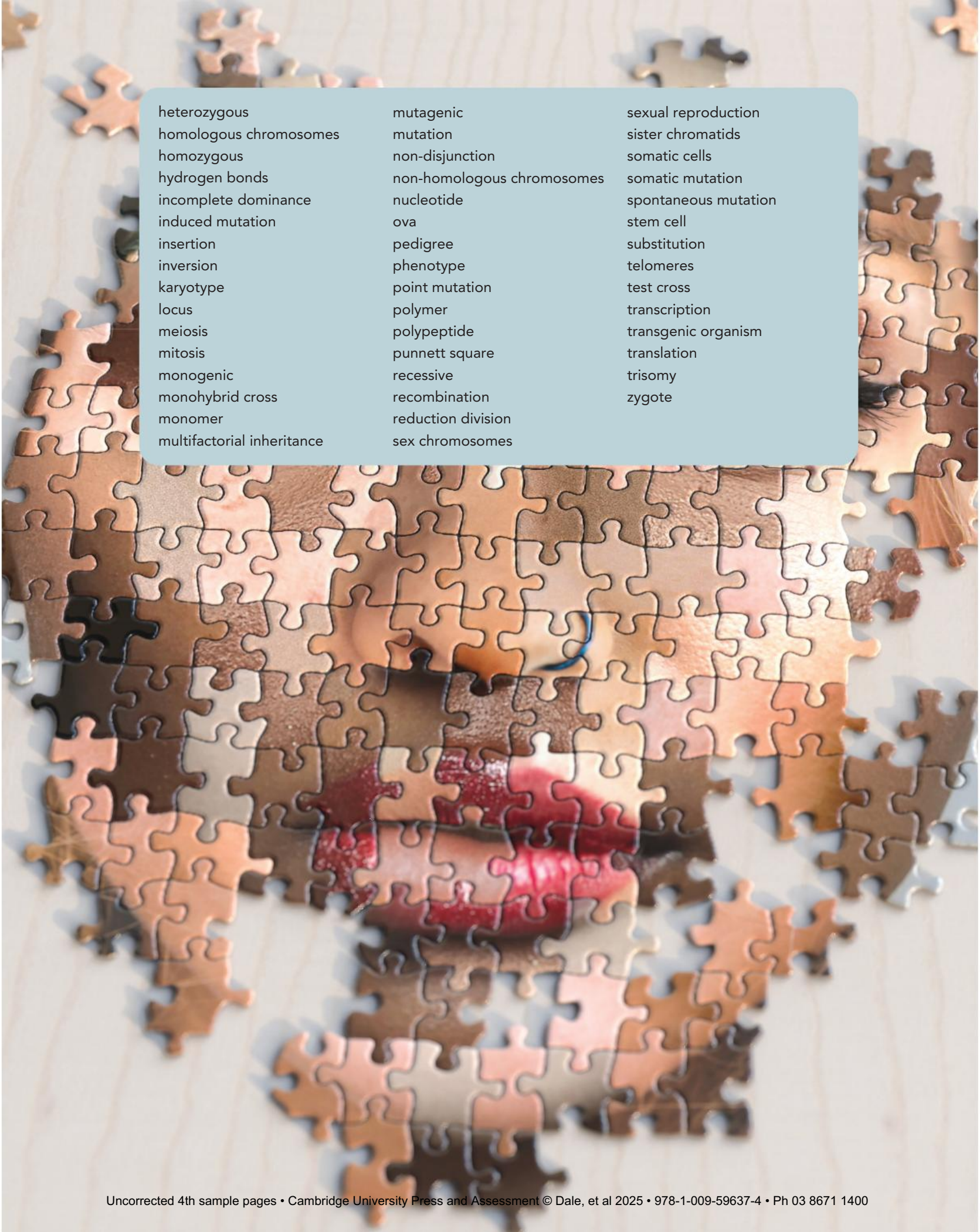
Chapter map



Glossary terms

allele
aneuploidy
autosome
base triplet/codon
carrier
centromere
chromatin
chromosome
chromosome mutation
codominance
codon
complementary base pairing
crossing over
deletion
diploid (2*n*)
dna
dominant
embryo
fertilisation
gametes
gene
gene mutation
gene therapy
genetic engineering
genetic screening
genetically modified organism
genetics
genome
genotype
germline mutation
gonads
haploid (n)
heredity

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



heterozygous
homologous chromosomes
homozygous
hydrogen bonds
incomplete dominance
induced mutation
insertion
inversion
karyotype
locus
meiosis
mitosis
monogenic
monohybrid cross
monomer
multifactorial inheritance
mutagenic
mutation
non-disjunction
non-homologous chromosomes
nucleotide
ova
pedigree
phenotype
point mutation
polymer
polypeptide
punnett square
recessive
recombination
reduction division
sex chromosomes
sexual reproduction
sister chromatids
somatic cells
somatic mutation
spontaneous mutation
stem cell
substitution
telomeres
test cross
transcription
transgenic organism
translation
trisomy
zygote

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

11.1 DNA structure and function

Learning outcomes

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

1. identify that all organisms contain genetic information.
2. investigate and model the arrangement of genetic information in an organism.
3. define and compare the terms DNA, gene, chromosome and genome.
4. relate the structure of DNA to its functions.
5. as an example of scientific discovery, compare the contributions of scientists involved in the discovery of the structure of DNA.

WORKSHEET
DNA structure

VIDEO
Structure of DNA

Genetics

Genetics is the study of how certain traits (characteristics) can be inherited from a previous generation. It involves the study of **genes**, genetic variation and **heredity**. Genes are considered the basic unit of inheritance. They are made of **d**eoxyribo**n**ucleic **a**cid, or **DNA** for short. This hereditary material is passed from parents to offspring and contains the information needed to specify traits.

genetics
the study of genes, genetic variation and heredity

gene
a length of chromosome made of DNA, the basic unit of inheritance

heredity
the genetic passing on of traits from one generation to the next

DNA
the molecular unit of heredity, containing the genetic information responsible for the development and function of an organism (deoxyribonucleic acid)

Structure of DNA

DNA is a double-stranded molecule that forms a 'double helix' shape, like a twisted ladder. DNA is a **polymer** as it is made up of many **monomer** subunits called **nucleotides**.

The nucleotides that make up DNA have three major components:

- a five-carbon (pentose) deoxyribose sugar
- a nitrogenous base – one of adenine (A), guanine (G), cytosine (C) or thymine (T)
- a negatively charged phosphate group.

The nucleotides bind together to form two long strands that wind around each other. Each strand has a backbone made of alternating deoxyribose sugar and phosphate groups.

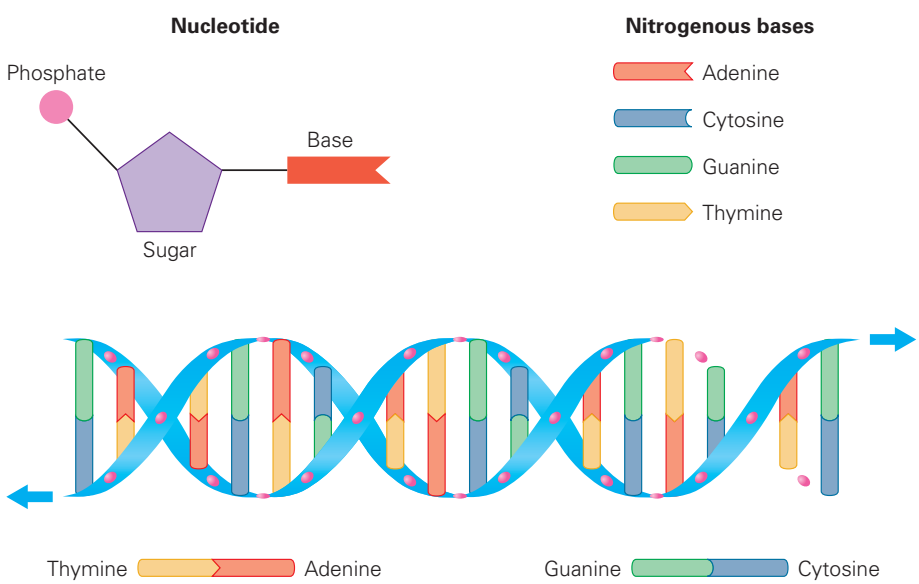


Figure 11.1 The double helix structure of DNA: the subunits called nucleotides all join up to form the double-stranded DNA. Note the sugar–phosphate backbone on the edge of the DNA molecule and the nitrogenous bases joining in the centre.

polymer
a molecule made from many repeating subunits called monomers

monomer
a single subunit that when joined together repeatedly makes a polymer

nucleotide
a monomer subunit of a nucleic acid, consisting of a phosphate group bound to a five-carbon sugar, which in turn is bound to a nitrogenous base

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

hydrogen bonds chemical bonds that hold the two DNA strands together

complementary base pairing adenine only binds with thymine and cytosine only binds with guanine

The nitrogenous bases from one strand bind to complementary bases on the other strand using **hydrogen bonds**.

Adenine (A) always pairs with thymine (T), and guanine (G) always pairs with cytosine (C). One way to remember the A–T and G–C pairings is 'AT the Gold Coast'. This **complementary base pairing** occurs because of the shape of the nitrogenous bases and the number of hydrogen bonds they can form (Figure 11.3).

Figure 11.2 Traits are passed on from generation to generation.

Guanine and adenine have a double-ring structure, which means they belong to a group of chemical molecules called purines. A helpful way to remember that adenine and guanine are purines is 'Pure As Gold'. Cytosine and thymine have a single-ring structure and belong to the group called pyrimidines. Purines always pair with pyrimidines, but the number of hydrogen bonds between them depends on the structure. Guanine binds with cytosine with three hydrogen bonds, while adenine and thymine form two hydrogen bonds.

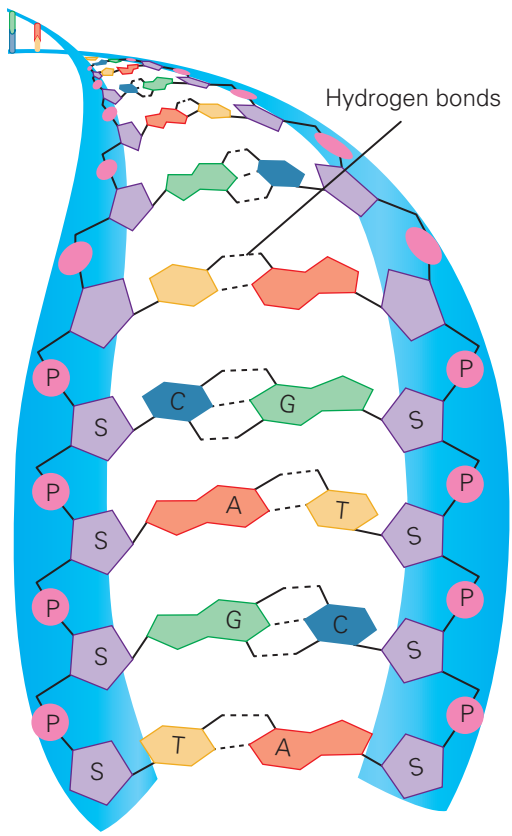


Figure 11.3 A closer look at the structure of DNA. The sugar–phosphate backbone forms the outer edge of the helix and the nitrogenous bases form complementary pairs in the centre. Hydrogen bonds hold the two strands together.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 11.1

Modelling DNA using lollies

Be careful

Do not consume lollies in the laboratory. Beware of allergies.

Materials

- licorice ribbons or sour strips
- a handful of jelly babies
- cocktail sticks

Procedure

1. Sort the jelly babies into four groups of colours.
2. Pair up the jelly babies so that one particular colour always goes with another particular colour, for example, red with yellow and orange with green.
3. Place a pair of jelly babies onto each cocktail stick as if you were making lolly kebabs. Ensure that the pairs are always of matched colours.
4. Attach your lolly kebabs to the long strips of licorice.
5. Keep doing this until you have about 5–7 horizontal cocktail sticks attached and it starts to look a bit like a ladder.
6. The paired coloured sweets represent the base pairs, while the licorice is the sugar–phosphate backbone.
7. Pick up your lolly ladder and twist it to represent the double helix shape of DNA.

INVESTIGATION

Investigation 11.1

Extracting DNA from cells

Time period

Approximately 1 hour

Aim

To investigate and extract DNA from strawberries.

Materials

- plastic sandwich bag (or other material to contain strawberry and liquid)
- strawberry
- DNA extraction solution provided (10 mL)
- filter funnel and gauze (or another gauze-style filter)
- cold ethanol solution
- test tube (or small beaker)
- stirring rod
- plastic pipette
- DNA extraction mixture:
- dishwashing liquid or shampoo (5 mL)
- table salt (0.75 g)
- water (45 mL)

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1. Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
2. Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
3. Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.
4. Pour the strawberry mixture through a filter funnel lined with gauze into a test tube.
5. Discard the gauze and strawberry remains into a bin.
6. Add an equal volume of cold ethanol to the test tube using a plastic pipette.
7. Slowly mix the two layers of liquid with a stirring rod.
8. Collect the white solid that forms on the stirring rod. This is DNA.

Results

Write observations for what occurs during each step of the method.

Discussion

1. Describe whether the white solid could contain all of the DNA of the strawberry.
2. Visually compare the amount of solid you collected to that of other groups in the classroom. Were results consistent? Explain your answer.
3. Describe the variables that were not kept consistent between groups in the classroom.
4. Suggest any changes that could be made to the method to improve the quality of the recorded data in future experiments. Justify your suggestions by explaining how each change would improve the data quality.

Conclusion

Draw a conclusion regarding the efficiency of this method at extracting all the DNA from a strawberry, based on your and other groups' observations.

Did you know? 11.1

How long is DNA?

The DNA found in only one cell, if fully unravelled, would be around two or more metres long! The length of a piece of double-stranded DNA is commonly expressed as the number of complementary nitrogenous base pairs it contains. The DNA in an average human cell has an estimated 63 000 000 base pairs.

1. **Recall** the three key components that make up a nucleotide.
2. **Describe** the overall shape of DNA.
3. If a strand of DNA contained the nitrogenous bases seen below, **state** the bases in its complementary strand. DNA strand: ATATAGATAGATCAGACA.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 11.1

The discovery of DNA

Friedrich Miescher was a Swiss biochemist who first observed DNA in 1869. However, it took almost a century for scientists to understand the structure of DNA and the mechanisms by which it carries genetic information.

Research the following scientists who, among many others, contributed to our understanding of DNA:

- Friedrich Miescher
- Erwin Chargaff
- Oswald Avery, Colin MacLeod and Maclyn McCarty
- Francis Crick and James Watson
- Rosalind Franklin and Ray Gosling
- Maurice Wilkins.

Summarise their contributions and place them on a timeline.

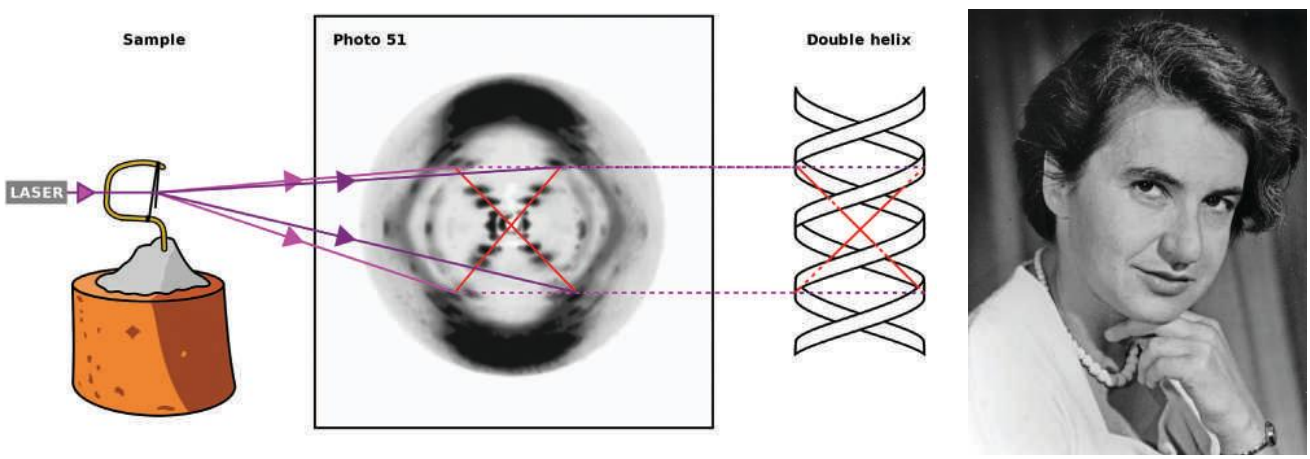


Figure 11.4 Dr Rosalind Franklin (right) and Ray Gosling fired X-rays at a DNA strand stretched across a paperclip in 1952. The resulting picture was critical to the discovery of the double helix structure of DNA, providing key information that enabled James Watson and Francis Crick to build the first correct model of the structure of DNA.

The structure of DNA as a case study in scientific discovery

The discovery of the structure of DNA and how it carries and expresses genetic information is one of the most studied examples of scientific discovery. Access the worksheet linked in the Interactive Textbook to analyse what it reveals about how scientists build on the work of others and contribute, collaborate and often compete to make scientific discoveries in practice.

DOC
WORKSHEET
DNA: Scientific discovery in action

What is a chromosome?

The DNA found in the nucleus of a cell is usually in a form called **chromatin**. This is a highly organised complex of DNA and associated proteins such as histones. By wrapping around histones, the long strands of DNA can fit inside the nucleus.

When it is time for the cell to replicate, the DNA is copied, and the chromatin condenses into structures called **chromosomes**. Each molecule of DNA forms one chromosome. Along the chromosome are genes, which are the units of inheritance. Genes are sections of DNA that hold the specific instructions required for making every protein in our bodies.

chromatin
a mixture of DNA and proteins that form chromosomes

chromosome
a thread-like structure of tightly wound DNA and proteins

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

genome
the complete set of genetic material in an organism

A complete set of chromosomes for a eukaryotic individual or a species is a **genome**. It contains all the genes, all the genetic information for that organism. Each chromosome is a single DNA molecule, so that means the nucleus of a eukaryotic cell contains the same number of molecules of DNA as it has chromosomes.

Did you know? 11.2

The genome

The genome refers to all the genetic material in the chromosomes of an organism, including its genes and DNA sequences. The human genome is made of approximately 3.2 billion nitrogenous base pairs, which make up about 20 000 genes on 23 pairs of chromosomes. Other organisms have different genome sizes.

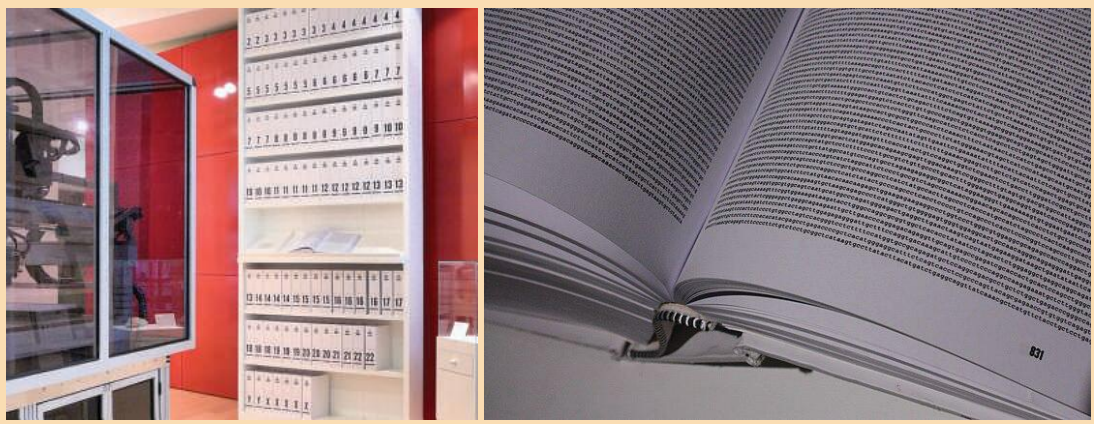


Figure 11.5 The first publication of the human genome was printed as 109 books in 23 volumes. The around three billion units of human DNA code are printed in a small font, and each book is a thousand pages long.

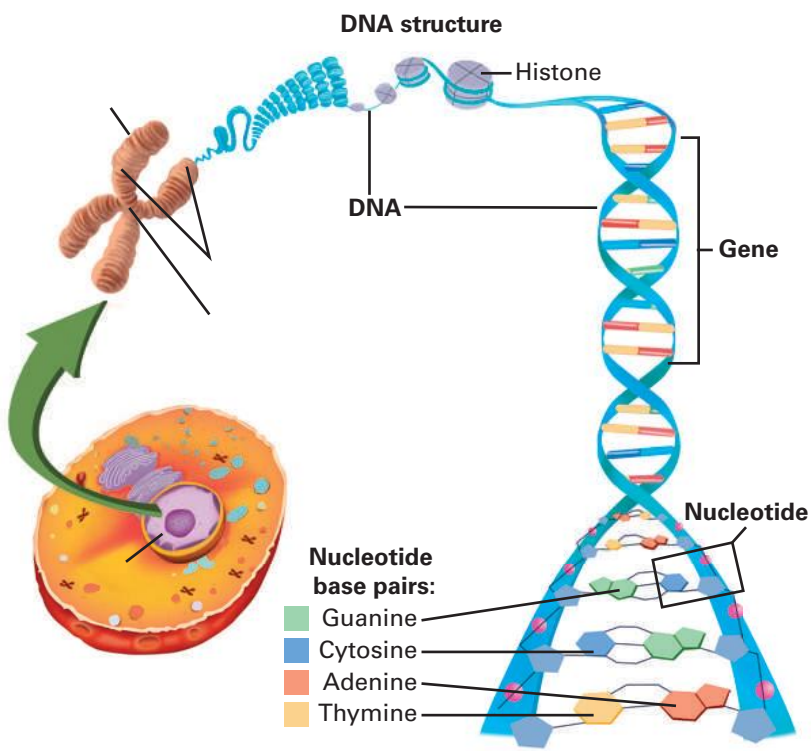


Figure 11.6 The relationship between DNA and chromosomes

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The familiar X-shape of a chromosome is only seen after DNA replication has occurred. DNA replication produces two identical **sister chromatids** that are joined together by **centromeres** to form the distinct X-shape (Figure 11.7). At the ends of each chromosome are protective structures made of DNA and protein called **telomeres**. These protect the chromosomes, but every time DNA replicates, the telomeres shorten. Eventually, the telomeres shorten to the extent that replication can no longer occur.

sister chromatids two copies of the same chromosome, connected at a centromere

centromere a structure that holds two sister chromatids together

telomeres structures made from DNA and proteins that protect the ends of chromosomes

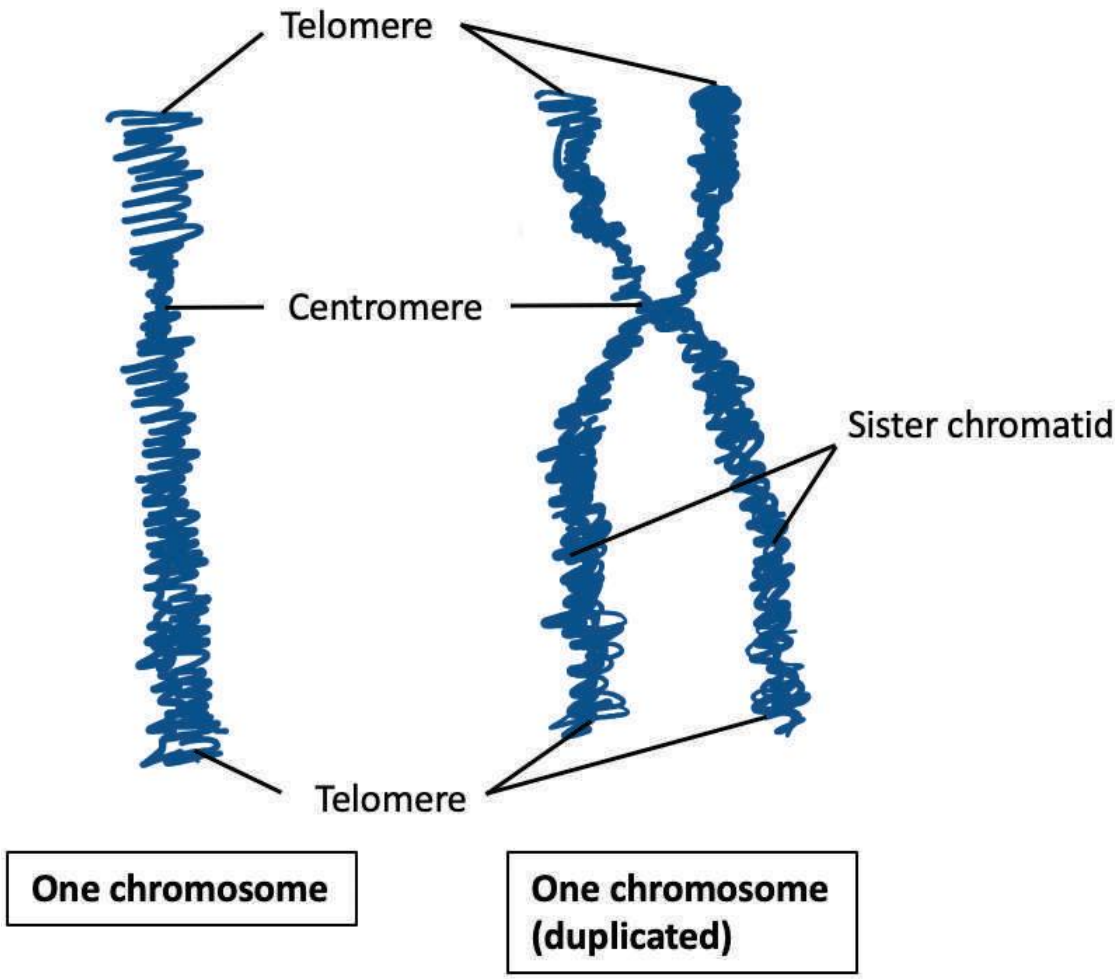


Figure 11.7 Before replication, a chromosome is a single molecule (left). After DNA replication, each chromosome consists of two molecules called sister chromatids (right).

Different forms of nucleic acids

There are four types of biological macromolecules: proteins, carbohydrates, lipids (fats and oils) and nucleic acids. Nucleic acids are found in two forms: DNA and **r**ibo**n**ucleic **a**cid (RNA). The two types of nucleic acids differ in several key ways, which are outlined in Table 11.1 and shown in Figure 11.11.

VIDEO
DNA and RNA

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

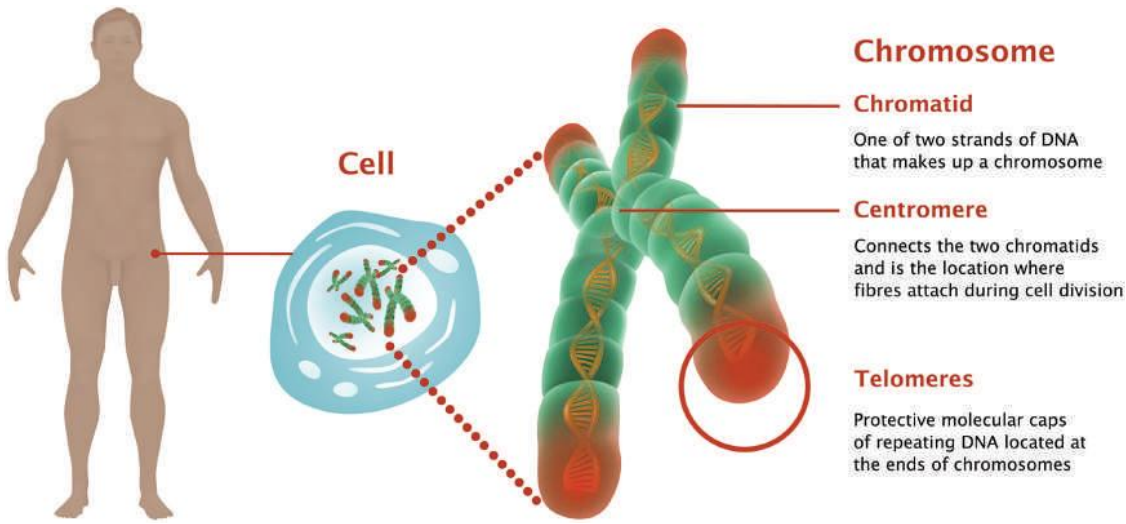


Figure 11.8 The distinct X-shaped chromosome, showing the two sister chromatids and the centromere

Figure 11.9 A scanning electron micrograph of a duplicated human chromosome

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 11.3

Telomeres and immortality

Telomeres contain thousands of repeated copies of the base sequence TTAGGG. When we are infants, our telomeres are approximately 10 000 bases long, but each time the cell divides, they slowly get shorter. A cell will die when its telomeres become too short. By the time we are in our 80s, our telomeres may only be 5000 bases long, but this varies from tissue to tissue and from person to person. A person in their 30s may well have telomere lengths of a person in their 90s and vice versa.

This means that telomeres are a key component of ageing, and there are efforts to use them to slow down or reverse the ageing process. Some companies say they can measure your telomere length, suggesting that it will indicate your true, biological age. Despite limited evidence, there are also companies that sell products that they claim can maintain or lengthen telomeres – in effect, making you younger or possibly allowing immortality.

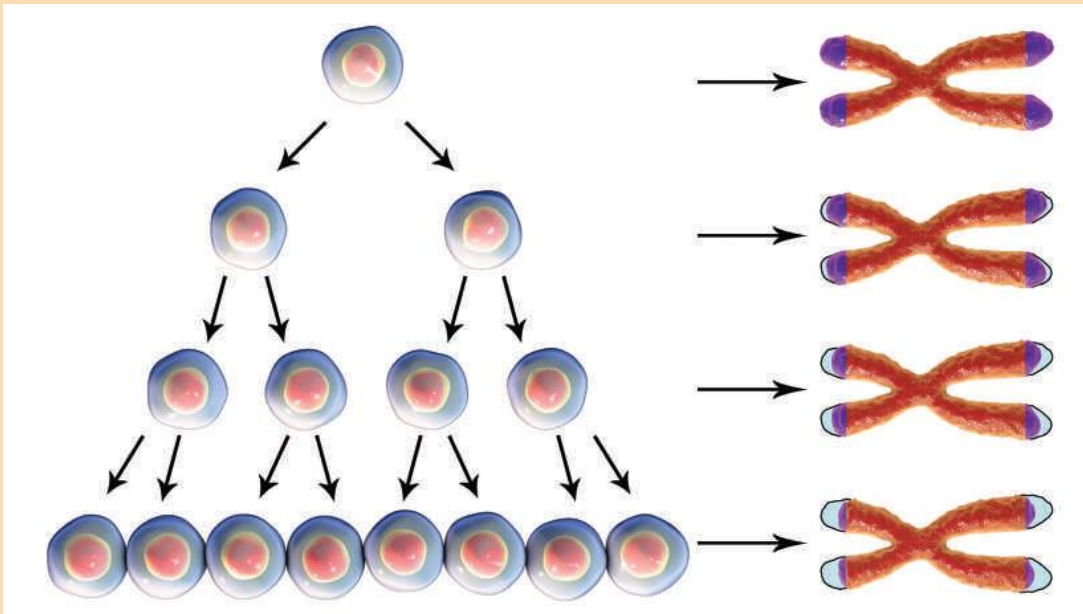


Figure 11.10 Telomeres shorten every time a cell divides.

	DNA	RNA
Number of strands	Two	One
Type of sugar	Deoxyribose	Ribose
Nitrogenous bases	Guanine Cytosine Adenine Thymine	Guanine Cytosine Adenine Uracil
Where is the molecule found?	Nucleus, mitochondria and chloroplasts (in eukaryotes) Cytoplasm (in prokaryotes)	Cytoplasm Nucleus Ribosomes
Different forms	DNA Mitochondrial DNA (mtDNA) Chloroplast DNA (cpDNA)	Messenger RNA (mRNA) Transfer RNA (tRNA) Ribosomal RNA (rRNA)

Table 11.1 The main differences between the two nucleic acids, DNA and RNA

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

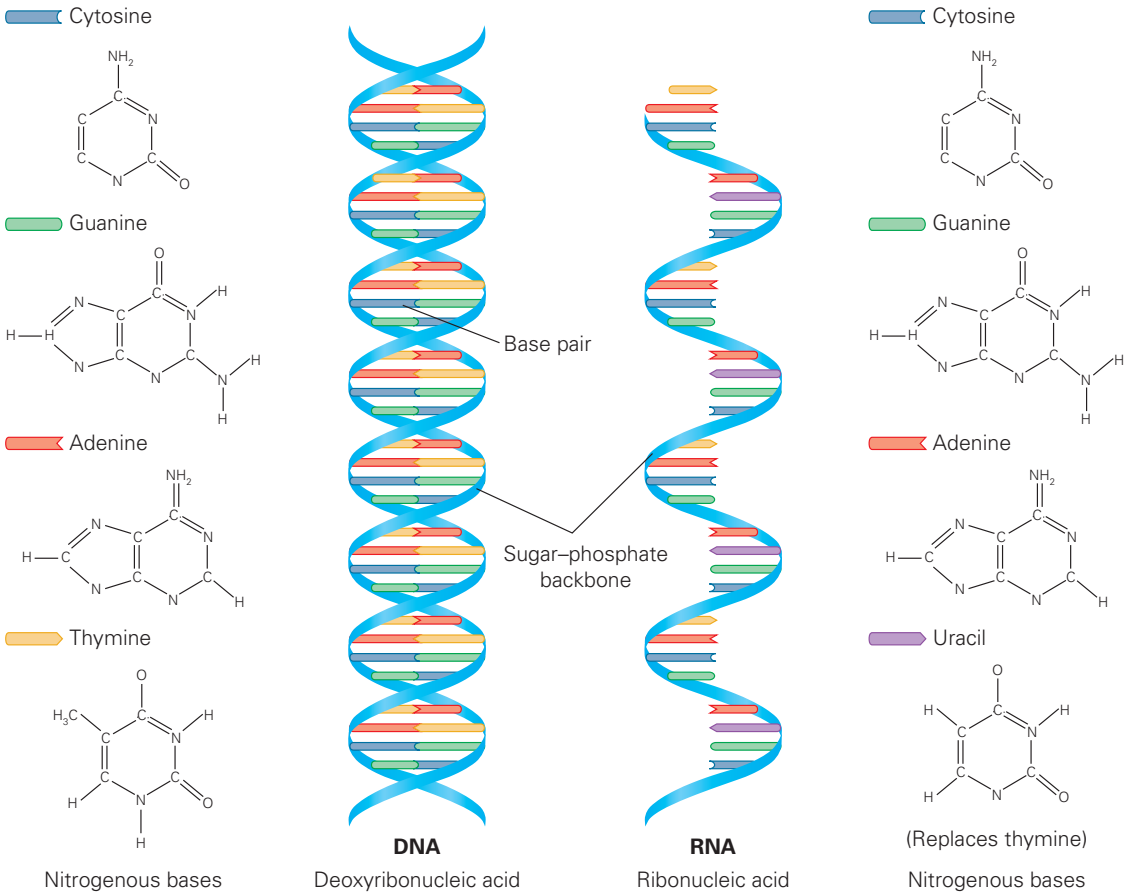


Figure 11.11 DNA and RNA

Quick check 11.2

1 **Describe** the relationship between chromosomes, genes, DNA and base pairs.
2 **Contrast** the structures of DNA and RNA.

WORKSHEET
Protein synthesis

The purpose of DNA: Making proteins

Why do we need proteins?

Proteins are complex molecules that play a critical role in many body functions. We use approximately one billion proteins every day, just to function normally. Proteins help provide structure to cells and build and repair tissue. Protein molecules play many other varied roles in the body; they include haemoglobin molecules that carry oxygen around our body and the hormones that regulate our glucose levels and development. Collagen and keratin are structural proteins, making up the structural components of organs. Enzymes such as amylase and lipase are catalytic proteins that help control the rates of reactions. Other proteins help us fight pathogens, transport molecules and move our muscles.

The link between DNA and proteins

base triplet/codon
a set of three nitrogenous bases that code for an amino acid

Genes are sections of DNA that hold the specific instructions required for making each of the proteins in our bodies. The sequence of the nitrogenous bases in a gene provides the instructions (or code) to produce a protein. A group of three nitrogenous bases is called a **base triplet** or **codon**, and these code for a particular amino acid. Amino acids are the monomers of proteins, so the order of nitrogenous bases specifies the sequence of amino acids that forms a particular protein.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 11.2

Protein functions

The many roles of protein include structural, contractile, transport, catalytic, regulatory and immunological functions. Research the following proteins and determine their function.

Protein	Function
Oxytocin	
Actin	
Ferritin	
Insulin	

Quick check 11.3

1. **Recall** why proteins are important.
2. **Describe** the relationship between DNA, amino acids and proteins.

Protein synthesis

To synthesise (or build) proteins using the DNA code in genes, the gene must be expressed; that is, the instruction in the DNA is converted into a protein. This means two processes need to occur: **transcription** and **translation**.

transcription the first stage of protein synthesis in which the base sequence of DNA is copied into mRNA

translation the second stage of protein synthesis in which a sequence of mRNA is translated into a sequence of amino acids

To transcribe means to put into written form, so in this process the DNA code for a specific protein is 'written down' in the form of mRNA (messenger RNA).

To translate means to convert into another form, so in this process the code (written down as mRNA) is converted into a chain of amino acids known as a polypeptide chain. This can then be folded to become a protein.

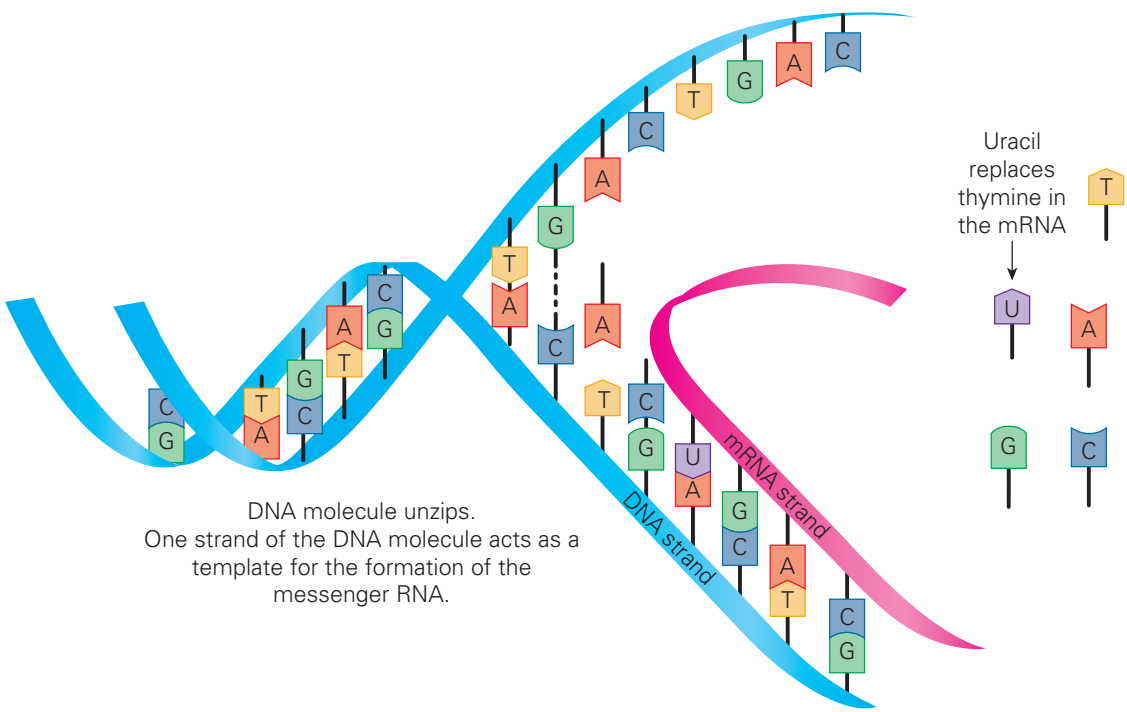


Figure 11.12 When the DNA double helix unwinds and unzips, one strand of the DNA acts as the template on which messenger RNA strand is formed.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Transcription

Transcription happens in the nucleus of the cell. The transcription process requires getting access to the DNA code in the genes, otherwise the code cannot be copied. Transcription begins when an enzyme (RNA polymerase) binds to the gene being copied. This causes the DNA double helix to unwind, allowing the enzyme to read the code on one of the DNA strands (called the DNA template strand). As the enzyme reads the code, it builds a complementary copy of the gene using RNA nucleotides: C, G, A and U. RNA follows the same complementary pairing rules as DNA, with one exception. Where DNA has the nitrogenous base thymine (T), RNA has uracil (U). The newly formed single-stranded RNA is called messenger RNA (mRNA).

When the mRNA peels away from the DNA template strand, the DNA double strands rejoin and wind back up into a helix. The mRNA then leaves the nucleus and goes to the site of protein production, the ribosomes.

Try this 11.2

Base pairings

Complete the base sequence of the DNA complementary strand and then the mRNA strand formed from the DNA template strand given below.

Complementary DNA	
DNA template	T A C C C G A A A G T G
mRNA	

Translation

WIDGET Building a protein

Once mRNA reaches the ribosomes in the cytoplasm, it must be 'decoded' or translated to make the necessary protein. The nitrogenous bases in the mRNA are decoded in groups of three called **codons** (base triplets in the original DNA template strand). Each codon in the mRNA specifies which amino acid is added to the **polypeptide** chain.

codon three nucleotides (base triplet) on mRNA that code for an amino acid

polypeptide a chain of amino acids, forming part or the whole of a protein molecule

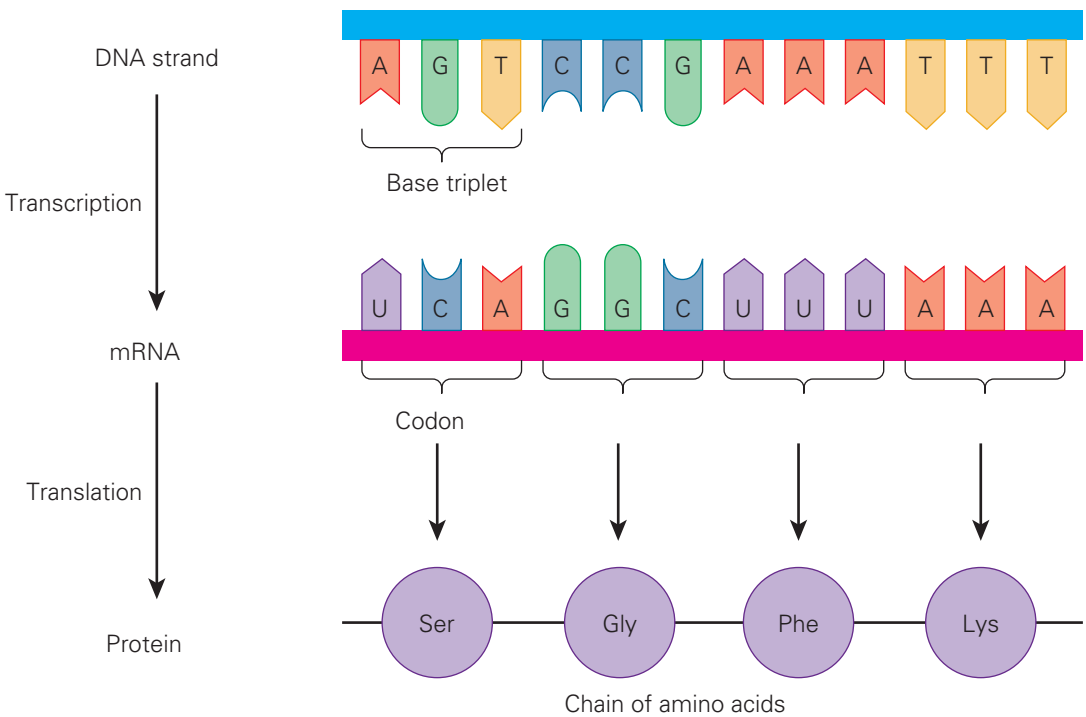


Figure 11.13 The process of transcription and translation from a DNA molecule to an amino acid chain

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Second letter in the codon

First letter in the codon	U			C			A			G			Third letter in the codon
U	UUU	Phe (F)		UCU	Ser (S)		UAU	Tyr (Y)		UGU	Cys (C)		U
	UUC			UCC			UAC			UGC			C
	UUA	Leu (L)		UCA			UAA	STOP		UGA	STOP		A
	UUG			UCG			UAG	STOP		UGG	Trp (W)		G
C	CUU	Leu (L)		CCU	Pro (P)		CAU	His (H)		CGU	Arg (R)		U
	CUC			CCC			CAC			CGC			C
	CUA			CCA			CAA	Gin (Q)		CGA			A
	CUG			CCG			CAG			CGG			G
A	AUU	Ile (I)		ACU	Thr (T)		AAU	Asn (N)		AGU	Ser (S)		U
	AUC			ACC			AAC			AGC			C
	AUA			ACA			AAA	Lys (K)		AGA	Arg (R)		A
	AUG	Met (M) START		ACG			AAG			AGG			G
G	GUU	Val (V)		GCU	Ala (A)		GAU	Asp (D)		GGU	Gly (G)		U
	GUC			GCC			GAC			GGC			C
	GUA			GCA			GAA	Glu (E)		GGA			A
	GUG			GCG			GAG			GGG			G

Table 11.2 Table of amino acids showing that the genetic code is degenerate, which means that more than one codon can code for a single amino acid. This redundancy means that 61 of the 64 codons code for the 20 amino acids (the other three are stop codons).

Figure 11.13 simplifies the process of translation. In reality, translation requires several enzymes and another type of RNA called transfer RNA (tRNA). It occurs at the ribosomes, which may be freely floating in the cytoplasm or attached to the endoplasmic reticulum (ER). Each tRNA molecule transports one specific amino acid towards the ribosome for delivery.

Table 11.2 shows the 20 different amino acids that form the building blocks for every protein. Using this table, you can identify the amino acid that each codon codes for. For example, if the first codon of your mRNA strand is AUG, you locate the A in the left column and the U in the top row and find where they intersect. At that spot is a box containing four different codons. You then find where the G in the right column of the table intersects, and you will see your codon AUG. Next to the codon it says Met, which means AUG codes for the amino acid methionine in eukaryotes. The codon AUG is unique as it is also a START codon. This means that it always is the first codon in the transcribed mRNA that undergoes translation. There are also three STOP codons which signal for the process of translation to stop rather than coding for another amino acid.

Explore! 11.3

Using biotechnology to produce therapeutic proteins

Traditionally, vaccines contain a weakened virus, or a protein of the virus, to trigger the body's immune response and provide immunity.

Two of the common COVID-19 vaccines work in that way. AstraZeneca (a viral vector vaccine) contains material from the SARS-CoV-2 virus within the shell of another virus. Novavax (a protein subunit vaccine) contains part of the coronavirus spike protein which is injected directly.

mRNA vaccines have been in development for decades but had been progressing slowly. Financial backing from governments and commercial organisations is critical for research, and the significant funding provided worldwide to address the COVID-19 pandemic accelerated mRNA vaccine biotechnology.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

mRNA vaccines work differently to traditional vaccines. Instead of delivering a viral protein, the vaccines deliver mRNA. COVID-19 mRNA vaccines contain instructions for making the spike protein from the SARS-CoV-2 virus. The Pfizer and Moderna vaccines package the mRNA into a lipid nanoparticle that can pass through the cell membrane.

Vaccine mRNA is modified to be more efficient at protein synthesis and resistant to degradation. This means it can be used as a template many times. Manufacturers use computer-controlled techniques for generating the required strands of RNA. This method is cheaper and safer than manufacturing proteins or growing viruses. mRNA vaccines have huge potential for preventing and controlling future epidemics and pandemics.

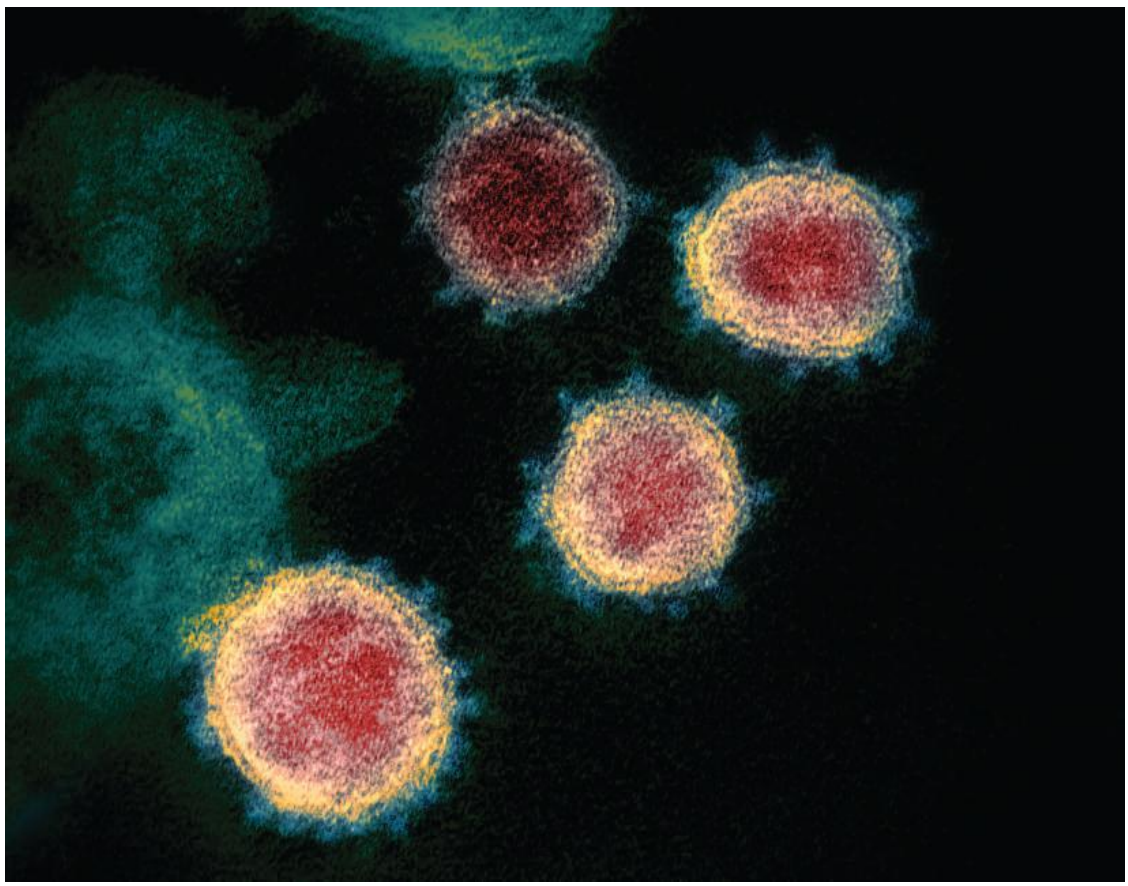


Figure 11.14 A colourised electron microscope image of SARS-CoV-2 virus particles. The spike proteins around the edge give coronaviruses their name, as corona is Latin for crown.

Quick check 11.4

1. The following codons are found in a strand of DNA: TAA TTA TCG ACT ACT AGC. **State** the complementary mRNA strand.
2. **Contrast** transcription and translation.
3. **Explain** why you do not need to read the code on both strands of DNA when transcribing DNA into mRNA.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

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. **Name** the basic building blocks or subunits of DNA.
2. **Recall** where proteins are created (synthesised) in the cell.
3. **Recall** the name for the shape of DNA.
4. **Illustrate** and label a nucleotide.
5. **Recall** the four bases found in DNA and the complementary base pair rule.
6. **Recall** why all mRNA strands start with the codon AUG.
7. A template strand of DNA is found to contain the following bases: TAC GGA TCA TCG TGG GAA GCA GGC ATT.
   a. **State** the complementary DNA strand.
   b. Using the above template strand of DNA, **state** the bases on the mRNA strand.
   c. Using Table 11.2, **identify** the amino acids that this strand of DNA would code for.

Understanding

8. **Describe** the purpose of DNA.
9. **Describe** the relationship between DNA, genes and chromosomes.
10. **Explain** how the body produces so many different proteins with only four different nitrogenous bases.
11. **Explain** how the genetic information found in the chromosomes within the nucleus of a cell reaches the ribosomes for protein synthesis.

Applying

12. **Construct** a flow chart to summarise the key steps in transcription and translation.

Analysing

13. **Contrast** the structures of mRNA and DNA.
14. **Differentiate** between a structural protein and a catalytic protein, providing examples of each.

Evaluating

15. A template strand of DNA is found to contain the following bases: TCC TGA TGA TGG GGG GCA AAA CGC GTA.
    Something went wrong during the transcription of this template strand, and the mRNA strand contains the following bases:
    AGG ACU ACU ACC CUC CGU UUU GCG CAU.
    a. **Determine** the mistake in the mRNA strand above.
    b. **Propose** the outcome of this mistake on the protein produced.
16. **Propose** what may occur if there was a problem with a certain protein in your body.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

11.2 Passing on genetic information

WORKSHEET
DNA replication and reproduction

Learning outcomes

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

1. relate the structure of DNA to its ability to replicate.
2. describe how genetic information is passed to offspring through sexual and asexual reproduction.

VIDEO
Sexual reproduction

Sexual reproduction

Two different forms of reproduction occur among organisms: asexual and **sexual reproduction**. Sexual reproduction requires two organisms to each contribute a **gamete**; these are the sex cells that combine to produce a unique offspring. Gametes are formed in the **gonads** of the male (testes) and the female (ovaries). Each gamete contains half the genetic information needed to form a new organism of the same species. When the gametes – sperm and **ova** (eggs) – meet and fertilise, they form a **zygote** with a full set of genetic information. The zygote divides and as the number of cells increases, cells begin to take on special functions. Eventually, the zygote becomes an **embryo**.

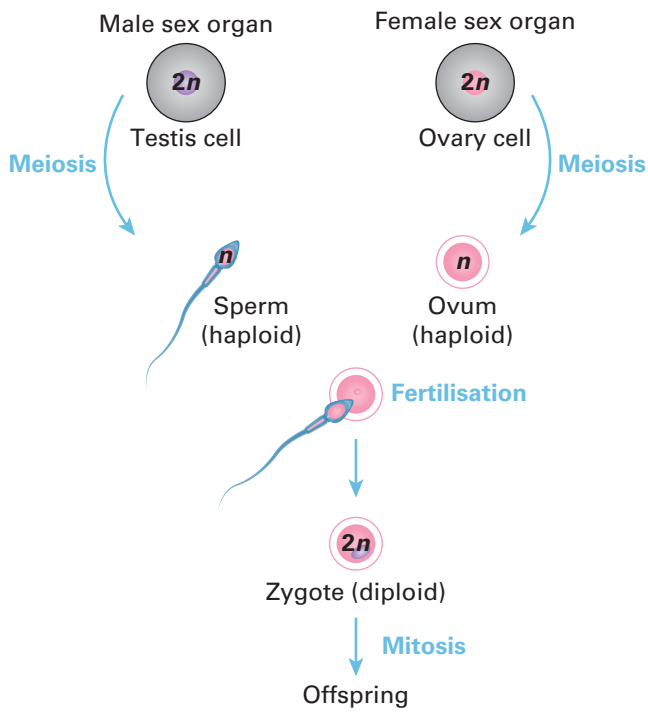


Figure 11.15 Sexual reproduction involves a gamete from a male and a female combining to form a zygote.

You will notice that Figure 11.15 has some new terms:

- Cells that contain only one set of chromosomes are known as **haploid (*n*)**. Gametes are haploid.
- Cells that contain two sets of chromosomes are known as **diploid (2*n*)**. **Somatic cells** (body cells) and the zygote are all diploid.
- **Meiosis** is the name of the process by which the gonads make the haploid gametes.
- **Mitosis** is the name of the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair.

sexual reproduction form of reproduction that involves two parents and introduces variation to the offspring

gametes sex cells (sperm and ova) with half the usual number of chromosomes

gonads the sexual organs: testes in males and ovaries in females

ova (singular: ovum) mature female reproductive cells

zygote a fertilised egg produced by the fusion of male (sperm) and female (ovum) gametes

embryo the initial stage of early development in multicellular organisms

haploid (n) a cell containing only one set of unpaired chromosomes

diploid (2n) a cell containing two sets of chromosomes

somatic cells the body cells of an organism

meiosis the process by which the gonads make the haploid gametes

mitosis the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

In humans, the haploid number (n) is 23. This means that gametes contain 23 single unpaired chromosomes. When the egg and sperm meet and fertilise, the two sets of chromosomes come together and form the diploid zygote ($2n$). The zygote contains 23 pairs of chromosomes, meaning the diploid number ($2n$) in humans is 46. The haploid and diploid numbers vary between species but always remain the same for all the organisms within that species. For example, the platypus has a diploid number ($2n$) of 52, which means it has 26 pairs of chromosomes in its somatic cells. This also means the egg and sperm of the platypus contain half this amount of genetic information, so its haploid number (n) is 26 chromosomes.

Did you know? 11.4

Different diploid numbers

The diploid number of chromosomes in a species is not related to whether an organism is bigger or more complicated. For example, a koala, a tammar wallaby and garlic all have a diploid number of 16 but are very different!

Figure 11.16 Some very different organisms contain the same number of diploid chromosomes.

Quick check 11.5

1. **Differentiate** between the terms 'haploid cell' and 'diploid cell', providing an example of each.
2. If a sheep's body (somatic) cell contained 54 chromosomes, **calculate** how many chromosomes would be found in their gametes.

How does DNA copy itself?

Before a cell divides, the DNA must be replicated to provide two copies of each chromosome, one for each new cell. This occurs before the processes of mitosis and meiosis. DNA replication must be precise, otherwise errors can affect the code in the DNA and lead to **mutations** (permanent changes in the DNA). The steps involved in DNA replication are outlined below and summarised in Figure 11.17.

mutation
a change in the genetic code of a cell

1. The DNA molecule unwinds and 'unzips' (breaks the hydrogen bonds) between the nitrogenous bases. This happens with the help of an enzyme called DNA helicase.
2. Another enzyme called DNA polymerase attaches new nucleotides to the exposed nitrogenous bases. The enzyme follows the complementary pairing rule, where adenine can only join with thymine, and cytosine can only join with guanine. The two new strands of DNA will be identical to the original parent strand.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

3. The newly added nucleotides are connected with new hydrogen bonds, which results in two identical strands of double-stranded DNA being formed. Each new strand is one-half of the original strand and one-half that was newly built. For this reason, replication is sometimes described as being semi-conservative.

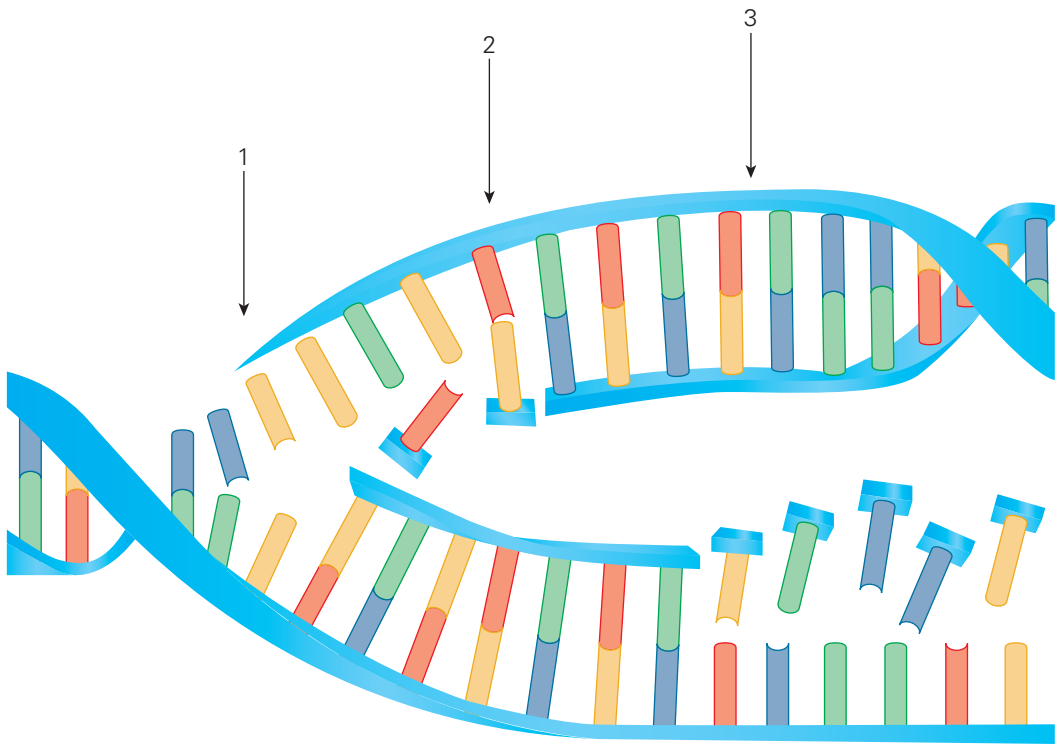


Figure 11.17 DNA replication: (1) the DNA must first unwind and unzip and then (2) the new DNA nucleotides can be added following complementary base pairing rules. (3) This results in two identical strands of DNA.

Quick check 11.6

1. **Explain** the purpose of DNA replication.
2. **Summarise** the steps of DNA replication.

Mitosis

Growth and repair of damaged tissues requires a form of cell division called mitosis. Mitosis is also important in asexual reproduction to make identical copies of cells. The diploid ($2n$) parent cell divides to form two diploid cells that are genetically identical, called daughter cells. The sequence of steps in mitosis is shown in Table 11.3. Mitosis produces every cell in the human body, except gametes, which are produced by meiosis and result in haploid (n) cells.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

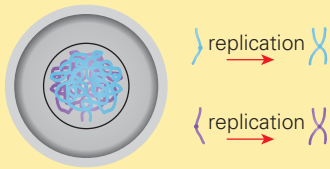
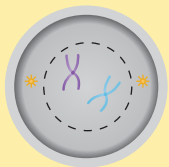
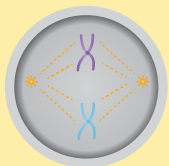
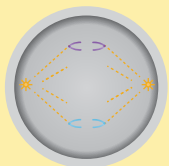
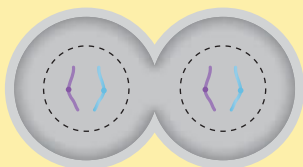
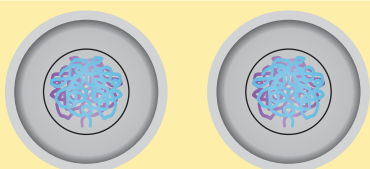
The stages of mitosis		
Interphase 2*n* (before mitosis)		• Parent cell is diploid (2*n*). • DNA replication occurs. • Chromosomes are not visible. • The cell gets bigger. • Organelles replicate.
Prophase		• The nuclear membrane breaks down, DNA condenses and appears as distinct chromosomes. • Spindle fibres begin to form.
Metaphase		• Chromosomes are arranged along the centre of the cell. • Each chromosome is attached to a spindle fibre by the centromere.
Anaphase		• The chromatids split at the centromere and are pulled to either end of the cell by the spindle, centromere first. • Spindle fibres then begin to disappear.
Telophase		• The nuclear membrane re-forms around the two sets of chromosomes, forming two new nuclei. • The chromosomes decondense and are no longer visible.
Cytokinesis 2 × 2*n* (after mitosis)		• Division of cytoplasm starts. • The cell pinches in half and divides into two genetically identical diploid daughter cells.

Table 11.3 The stages of mitosis

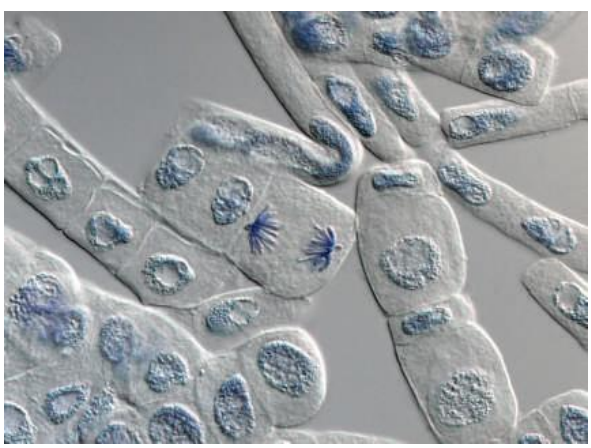


Figure 11.18 Plant cells in the process of mitosis viewed under a light microscope. The central cell shows the chromosomes moving to each end of the cell in anaphase. Can you identify some of the other stages?

Quick check 11.7

1. **State** which cells undergo mitosis.
2. **Summarise** the steps of mitosis.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 11.2

Observing cells in a dividing root tip

Be careful

Ensure you carry the microscope appropriately: hold the arm with one hand and place one hand under the base. Ensure you don't make big changes in magnification, so as not to damage the glass slide.

Aim

To observe cells carrying out mitosis in a growing onion root tip.

Materials

- prepared, stained slide of the growing section of an onion root tip caught at different stages of cell division
- microscope

Procedure

1. Using the lowest magnification, place a prepared slide of a growing onion root tip on the stage of the microscope.
2. Position the slide so that the pointed narrow end of the root tip is clearly visible.
3. Look for a cluster of rapidly growing cells near this region.
4. Observe several different cells at various stages of cell division under the highest magnification of the microscope.

Results

Carefully choose one cell with a clearly outlined cell wall and showing chromosomes in a certain stage of cell division. Sketch a copy of what you observed, labelling the cell wall and the chromosomes. Remember to use a sharp pencil and to document the magnification the sketch is taken at.

Data processing

1. The mitotic index is a quantitative expression of the amount of cell division that a particular tissue is undergoing. It is the ratio of the number of cells undergoing mitosis to the number of cells that are not undergoing mitosis. It can be calculated using the following equation:

$$\text{mitotic index} = \frac{\text{number of cells in the field of view undergoing division}}{\text{total number of cells in the field of view}}$$

   Calculate the mitotic index for the tissue sample you have observed in your microscope.
2. Using the field of view in your microscope, complete the table and calculate the percentage of cells in each cell cycle stage.

Cell cycle stage	Number of cells in that stage	Percentage of cells in that stage
Interphase		
Prophase		
Metaphase		
Anaphase		
Telophase		
Total		

3. Use the calculated percentages to predict which cell cycle stage is the longest and which is the shortest in your sample of cells. Explain your answer.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Analysis

1. Explain how you could tell which cells were dividing.
2. Describe the main features of each stage of cell division. Could you use these to identify the stage of mitosis for a particular cell?
3. List the structures in the cells you could observe. Which structures were present that you could not observe? Why might this be the case?

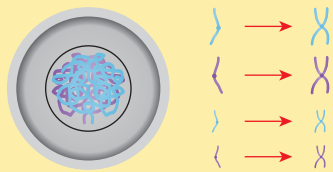
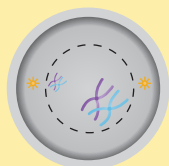
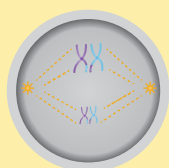
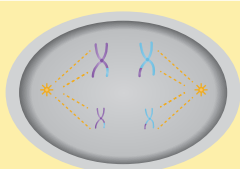
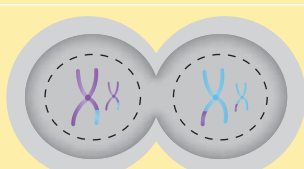
Meiosis

Meiosis is the process by which animals and plants produce gametes for sexual reproduction. The process begins with a diploid ($2n$) parent cell and results in four daughter cells (the gametes), which are haploid (n). Because of this reduction in genetic material between the parent and daughter cells, meiosis is also known as a **reduction division**.

reduction division cell division which results in a reduction of genetic material in the daughter cells

The process of meiosis involves two divisions, called meiosis I and meiosis II. These steps are further subdivided into distinct stages, as shown in Table 11.4.

VIDEO Mitosis and meiosis

Meiosis I		
Interphase $2n$ (before meiosis)		• Parent cell is diploid ($2n$). • DNA replication occurs.
Prophase I		• The nuclear membrane breaks down, the DNA condenses and chromosomes become visible. • **Homologous chromosomes** pair up and **crossing over** can occur.
Metaphase I		• Homologous chromosomes align at the equator.
Anaphase I		• Paired homologous chromosomes separate from each other and are pulled to opposite ends of the cell by the spindle fibres.
Telophase I		• The cell membrane pinches in. • The nuclear membranes re-form. • Two separate nuclei form.
Cytokinesis (after meiosis I)		• Division of cytoplasm starts. • The cell pinches completely into two haploid (n) daughter cells.

homologous chromosomes a matching pair of chromosomes, with one having been inherited from each parent

crossing over the exchange of genetic material between homologous chromosomes during meiosis, leading to genetic diversity in gamete

Table 11.4 The stages of meiosis I and meiosis II

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

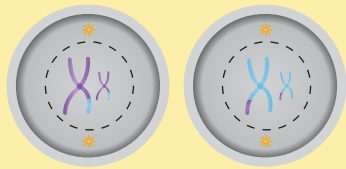
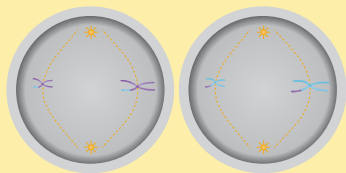
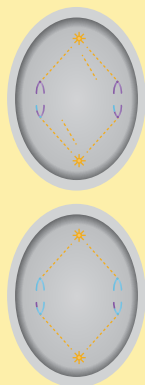
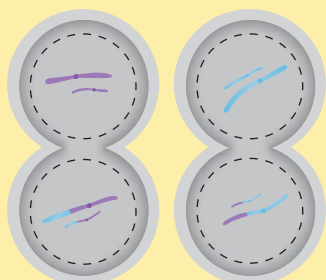
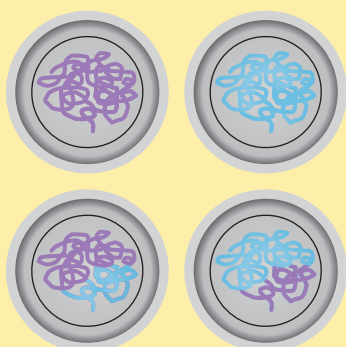
Meiosis II		
Prophase II		• Nuclear membranes disappear. • Spindle fibres re-form in both cells.
Metaphase II		• Chromosomes line up at the equator.
Anaphase II		• The chromosomes are pulled apart, separating the sister chromatids, which are pulled to opposite sides of the cell. • The spindle fibres disappear.
Telophase II		• The nuclear membrane re-forms. • The chromosomes start to become less visible.
Cytokinesis 4 × *n* (after meiosis II)		• Division of cytoplasm starts. • The cells produce four genetically different haploid daughter cells (*n*), each containing half the amount of DNA that was in the parent cell.

Table 11.4 *(continued)*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 11.5

Creating variation

Crossing over can occur in prophase I of meiosis I when homologous chromosomes get so close together that some of their genetic material gets swapped. It results in the chromosomes recombining to form a new combination of **alleles**, increasing the diversity of a species and therefore increasing the ability to respond to changing environments over time. This is how meiosis can increase genetic variation.

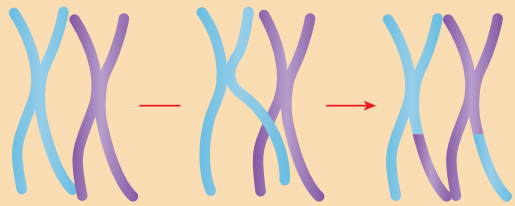


Figure 11.19 Recombination occurs when homologous chromosomes undergo crossing over in prophase I.

allele
different form of the same gene

recombination
the rearrangement of genetic material, especially by crossing over

Quick check 11.8

1. **Describe** why the process of meiosis is also known as 'reduction' cell division.
2. **Recall** where meiosis occurs in humans.
3. **Explain** why crossing over is an important process during meiosis.

Fertilisation

In humans, **fertilisation** occurs when two haploid gametes fuse to form a diploid zygote. For fertilisation to occur, the sperm must complete the acrosome reaction. The acrosome is a structure, located in the head of the sperm, that is filled with enzymes. These enzymes are released to digest their way through the corona radiata and zona pellucida, the outer layers of the ovum. Once the sperm penetrate the next layer of the ovum (zona pellucida), the cell membranes of one of the sperm cells and the ovum fuse together, and the sperm nucleus can enter the ovum. The fusing of cell membranes also triggers a reaction that causes the zona pellucida to harden. This is called the cortical reaction, and it prevents any more sperm cells from entering.

fertilisation
the fusion of male and female gametes to form a zygote

stem cell
undifferentiated cells with the ability to develop into various specialised cell types

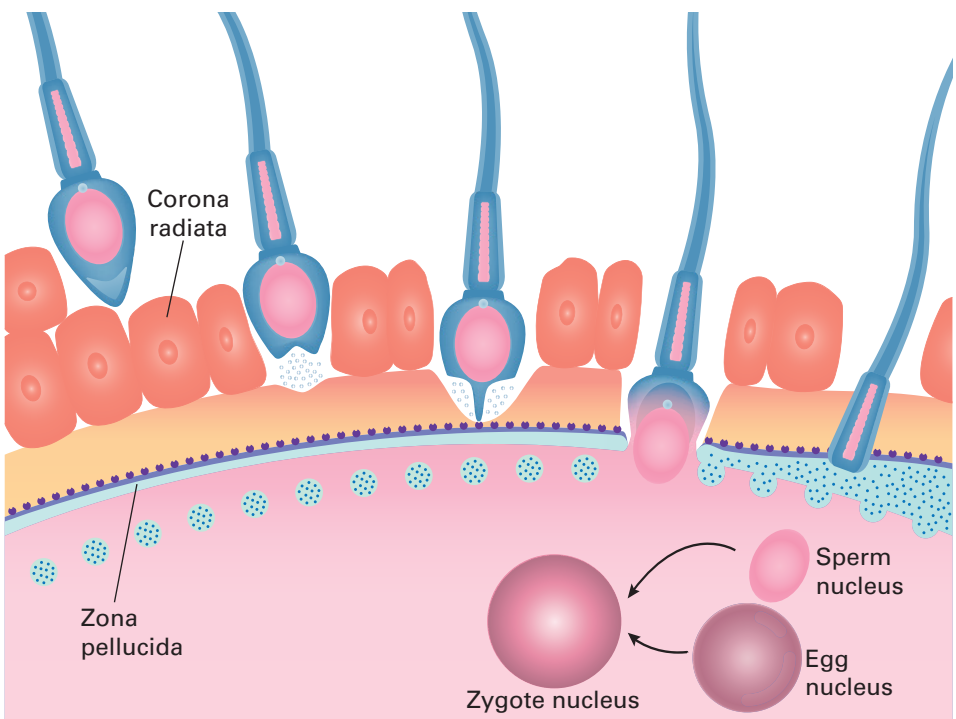


Figure 11.20 Once a sperm fertilises the egg, the nucleus of the sperm and the egg fuse.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

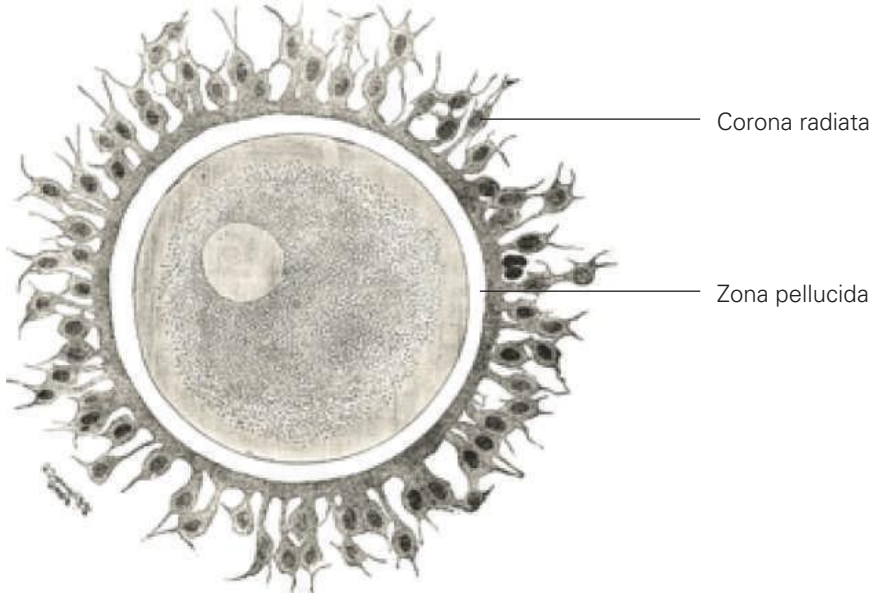


Figure 11.21 A human ovum

Stem cells

The zygote will develop into an embryo, which initially consists of **stem cells**. These cells are undifferentiated and have the potential to become any cell type if removed from the embryo.

As the embryo grows, the stem cells can differentiate into specialised cells that form various tissues and organs.

These embryonic stem cells, derived from early embryos, can differentiate into a wide range of cell types but are challenging to obtain.

In contrast, adult stem cells, found in specific body tissues like bone marrow and skin, have a more limited differentiation potential but are more accessible.

Stem cells hold significant promise for medical treatments, including replacing damaged cells in conditions like type 1 diabetes and spinal cord injuries.

Explore! 11.4

Types of twins

You, or someone you know, might have a twin sister or brother. There are two main types of twins: identical (monozygotic) and fraternal (dizygotic). However, there is another, very rare form of twins known as semi-identical (sesquizygotic). Only two cases have ever been recorded, one in the US and one in South East Queensland.

Conduct some research and answer the following questions.

1. Describe how monozygotic and dizygotic twins are formed.
2. Draw a diagram to show how these different types of twins are formed.
3. Discuss why sesquizygotic twins are so rare.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 11.5

HeLa cells

HeLa cells are a line of human cancer stem cells that have been widely used in scientific research since their discovery in 1951. These cells originated from a tissue sample taken from Henrietta Lacks, an African American woman diagnosed with cervical cancer. Without her knowledge or consent, cells from her tumour were cultured and found to have the ability to survive and proliferate indefinitely.

Figure 11.22 Henrietta Lacks was 31 when she died of cancer in 1951, but her importance in medical history was not widely known until the 1990s.

Complete the following.

- Investigate the history of HeLa cells, including the story of Henrietta Lacks and the ethical controversies surrounding the use of her cells without consent.
- Explore various genetic technologies that utilise HeLa cells, such as cancer research, drug development and vaccine production.
- Choose an ethical framework to guide your analysis (e.g. utilitarianism, deontology, virtue ethics, rights-based, care-based). For more information on ethical frameworks, access the linked worksheet in the Interactive Textbook.
- Reflect on the ethical concerns related to consent, ownership and the use of biological materials.
- Construct a well-organised written argument that incorporates evidence from your research. Clearly outline your chosen ethical framework and how it applies to the use of HeLa cells.
- Discuss the ethical implications of continuing to use HeLa cells in genetic research, considering both the benefits and the controversies.

DOC
WORKSHEET
Unpacking ethical frameworks

Meiosis versus mitosis

Although the processes of meiosis and mitosis have similarities, there are some differences:

- In meiosis, chromosomes recombine by crossing over, producing chromosomes with new combinations of genes. In mitosis, chromosomes are replicated to make identical copies of themselves.
- Meiosis involves two divisions that produce four haploid (n) daughter cells containing unique genetic material that is different to the parent cells. Mitosis involves one division that produces two diploid ($2n$) daughter cells with genetic material identical to the parent cell.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

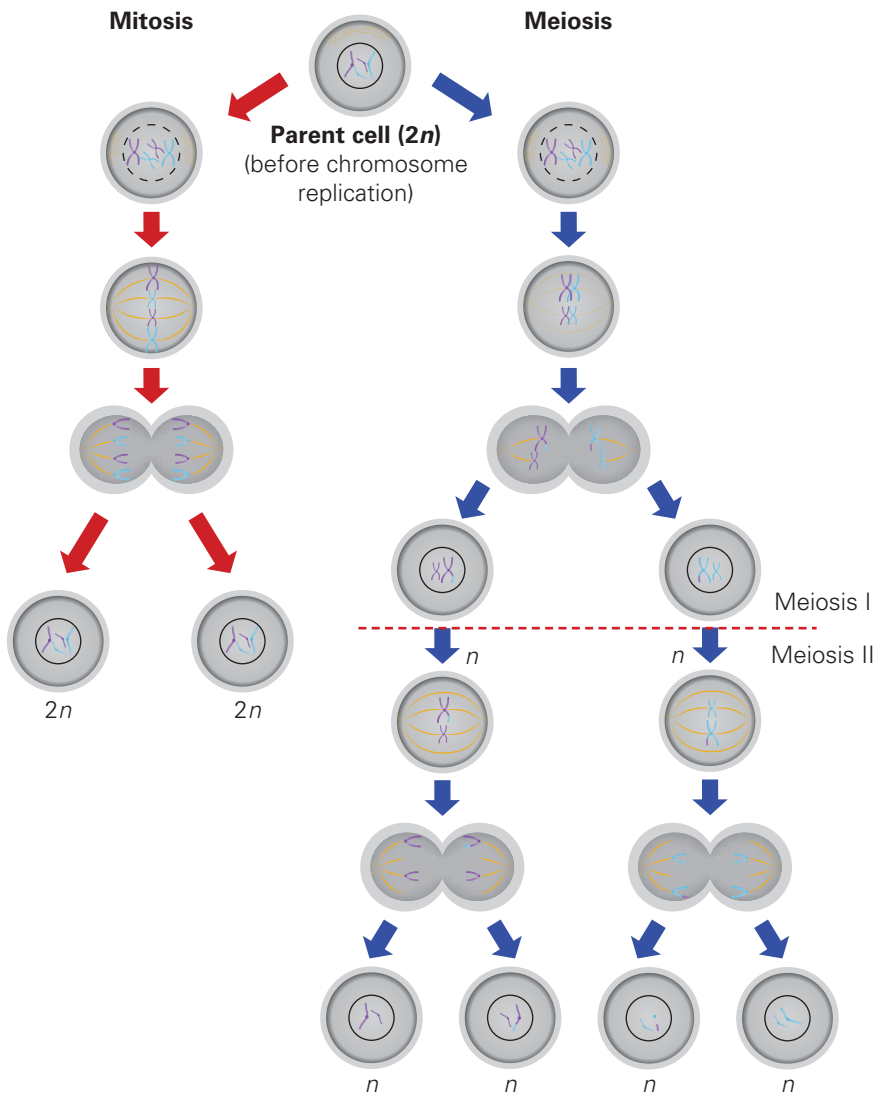


Figure 11.23 A summary of the processes of mitosis and meiosis

Quick check 11.9

1. Copy the table below and **define** the terms.

Term	Definition
Meiosis	
Fertilisation	
Zygote	
Haploid	
Diploid	

2. **Identify** the missing words in the following sentence.
Male gametes are called _____, whereas female gametes are called _____.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Karyotypes: Analysing chromosomes

The number of chromosomes varies between species, but the chromosomes in each body cell are always present in pairs. For example, humans have a total of 46 chromosomes, or 23 pairs of homologous chromosomes in the nucleus of every body cell. However, within the gametes, there are only 23 chromosomes. We can take a photo of a cell when it has undergone DNA replication and clearly see the chromosomes. The image can be processed to create a chart of the chromosomes called a **karyotype**, used in genetics, medicine and prenatal screening, and shown in Figure 11.25. Chromosomes that have the same length, centromere position and gene band patterns are matched up in the karyotype, and in animals it will be found that these occur in pairs. This is a result of meiosis, as they are the homologous chromosomes introduced in Table 11.4 on meiosis. There is an exception, the males of most mammals will have a pair of chromosomes left over that don't match, the X and Y sex chromosomes which are discussed below.

Chromosomes that do not match (chromosomes from different pairs) are called **non-homologous chromosomes**.

karyotype the chromosomes of an individual, often displayed according to size and gene band patterns

non-homologous chromosomes chromosomes that do not belong to the same pair

autosome any chromosome that is not a sex chromosome. In humans, these are chromosome pairs 1 to 22

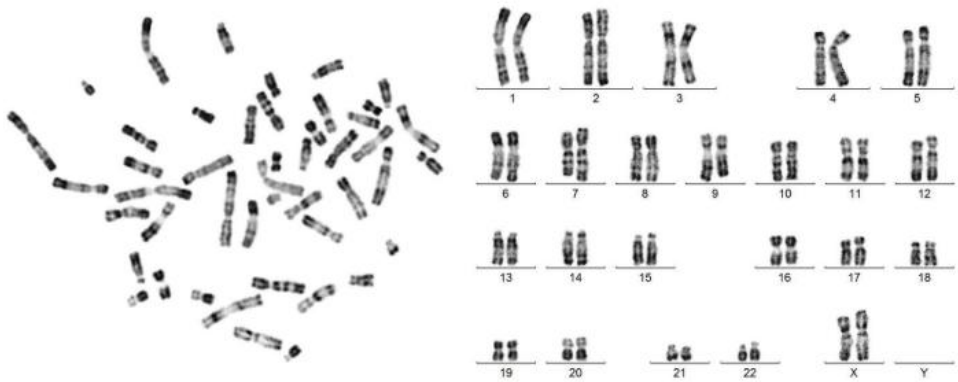


Figure 11.24 The homologous chromosomes seen under a microscope (left) can be arranged according to size in a karyotype (right). Pairs 1–22 are autosomes while pair 23 is the sex chromosomes.

Autosomes

Of the 23 pairs of chromosomes, pairs 1 to 22 are known as **autosomes**. These 44 chromosomes are found in both males and females.

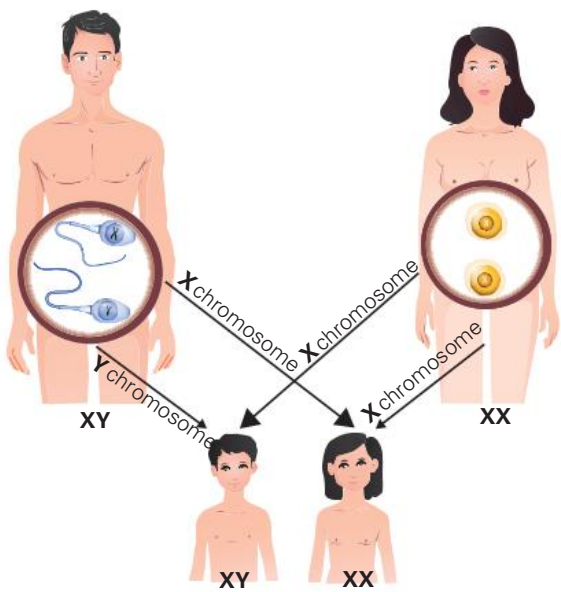


Figure 11.25 If an egg is fertilised by a sperm carrying an X chromosome, the child will be female. If an egg is fertilised by a sperm carrying a Y chromosome, the child will be male. Therefore, it is the male's sperm that determines the sex of the child.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Sex chromosomes

INVESTIGATION

In humans, the chromosomes making up the 23rd pair are the **sex chromosomes**. They contain genes that determine the sex of the individual. Females receive two X chromosomes (one from each parent), whereas males receive an X chromosome from the mother and a Y chromosome from the father (Figure 11.25).

sex chromosomes chromosomes that determine the sex of an organism

Investigation 11.3

What are the chances?

Aim

To investigate the chances of conceiving a male or female at fertilisation.

Useful formulas

$$\text{theoretical probability (\%)} = \frac{\text{number of a particular outcome e.g. heads}}{\text{total number of all possible outcomes (e.g. heads and tails)}} \times 100$$

$$\text{experimental probability (\%)} = \frac{\text{number of a particular outcome e.g. heads}}{\text{total number of all experimental trials (e.g. heads and tails)}} \times 100$$

$$\text{percentage error (\%)} = \frac{(\text{experimental probability} - \text{theoretical probability})}{\text{theoretical probability}} \times 100$$

Materials

- one coin

Procedure

1. Copy the results table into your science journal.
2. Calculate the theoretical probability of landing heads during a toss.
3. You will now calculate the experimental probability of your own experiment by tossing the coin 50 times, recording the number of heads and tails in the table.

Results

1. Calculate the experimental probability of receiving a head and a tail based on both the experimental data for your own and the class results.
2. Calculate the percentage error, comparing the difference between the theoretical and experimental probabilities for both your own data and the class data.
3. Optional: Graph the relationships between the number of trials and percentage error.

	Individual results	Class results
Number of heads		
Number of tails		
Total number of trials (throws)		
Experimental probability		
Percentage error		

Analysis

1. Compare the experimental probabilities of your own and the class results.
2. If a head represents the Y chromosome and a tail represents the X chromosome, explain how accurately this models the process of fertilisation. What would the coin represent?
3. Make a claim about the chances of conceiving a male or female based on this activity.

Discussion

Reliability

Discuss whether increasing the number of trials affects the percentage error of the experiment.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 11.6

Sex chromosomes in the animal kingdom

In some animals, such as birds, females have two different sex chromosomes (ZW) while males have two of the same (ZZ). In some reptiles, the temperature of the incubating environment determines the sex of the embryo. In some insects, females are XX and males have one X chromosome (written XO).

Monotremes have a complex sex chromosome system.

Figure 11.26 Female platypuses have five pairs of X chromosomes.

Female platypuses have five pairs of X chromosomes and males five X and five Y chromosomes. Female echidnas have five pairs of X chromosomes and males five X and four Y chromosomes.

Try this 11.3

Can you sort chromosomes into a karyotype?

Go online and find an online karyotype activity. There are many interactives that allow you to sort chromosomes into order and ones that allow you to analyse karyotypes.

Advances in science 11.1

Genetic testing

When a person is pregnant, their doctor may conduct several tests to screen for genetic and chromosomal abnormalities in the foetus. Creating a karyotype lets the doctor check for abnormalities in the number or length of chromosomes. If anything appears abnormal, the doctor can undertake further genetic tests to check for specific disorders. One such test is chromosomal microarray (CMA) testing, which is much more detailed genetic testing than karyotyping. Chromosomal microarray testing detects around one abnormality in every 70 foetal samples with a normal karyotype. Scientists think that CMA testing will replace karyotyping for prenatal testing.

Genetic testing will identify carriers of genetic mutations and help people make informed decisions, such as in embryo selection. Genetic counsellors work with people who are concerned about having, or have been diagnosed with, a genetic condition.

Many people are also having genetic testing to discover more information about their ancestry or to connect with unknown relatives. Although it is against the law to be discriminated against because of genetic information, there is some concern regarding its use, either personally or by organisations such as insurance companies or medical facilities.

Have a class discussion regarding the ethical issues of non-therapeutic genetic testing performed by commercial companies. You may want to consider privacy concerns, the emotional impact, potential lack of medical knowledge and possible exploitation of vulnerable individuals.

The karyotype shows a female with Down syndrome. Note the three chromosomes in position 21.

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

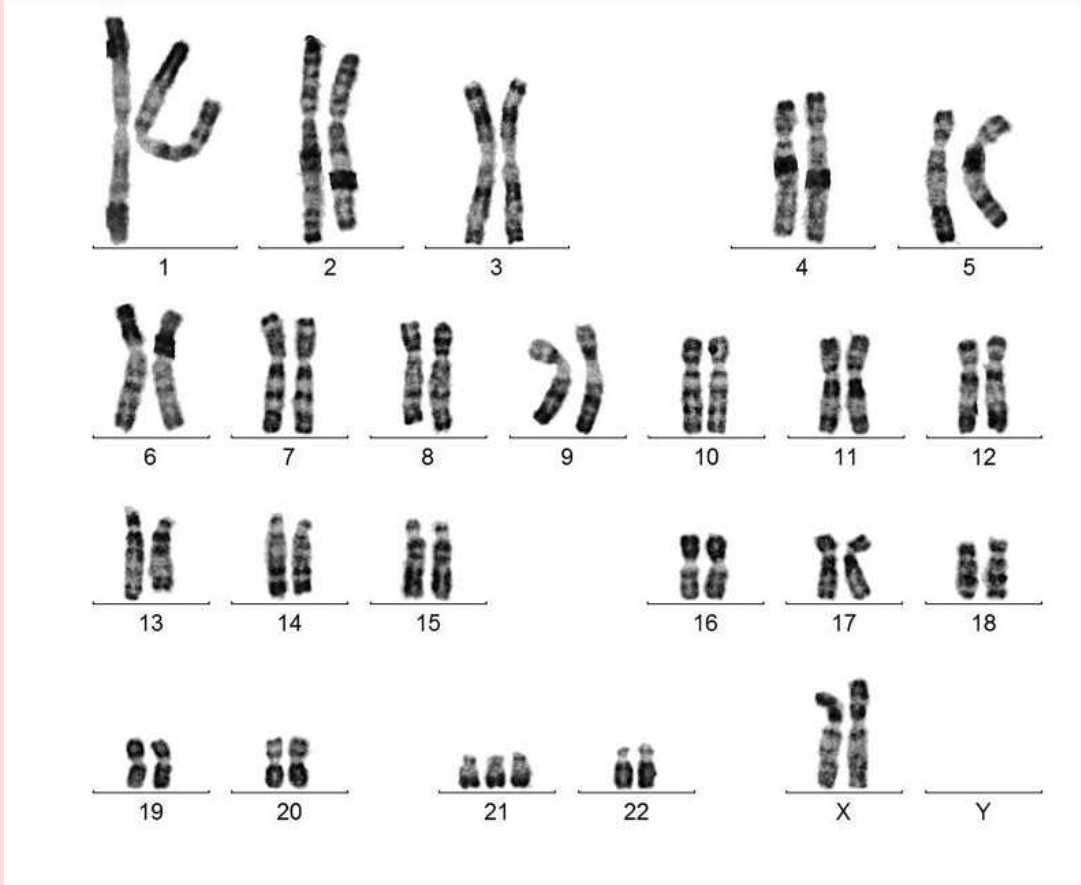


Figure 11.27 A well-known chromosomal abnormality is trisomy 21 or Down syndrome, where the foetus has three copies (instead of two) of chromosome 21.

Asexual reproduction

Asexual reproduction is a mode of reproduction in which a single parent produces offspring that are genetically identical to itself, meaning they are clones of the parent organism. Unlike sexual reproduction, which requires the combination of genetic material from two parents, asexual reproduction doesn't involve gametes or fertilisation.

There are various forms of asexual reproduction, each suited to different organisms:

- **Binary fission:** Common in single-celled organisms like bacteria, where the cell divides into two, each becoming an identical organism.
- **Budding:** Seen in organisms like yeast and hydra, where a new individual grows off the parent organism and eventually detaches to live independently.
- **Fragmentation:** Certain animals, like starfish and some plants, can grow into a complete organism from a fragment of the parent body.
- **Vegetative propagation:** In plants, new individuals grow from stems, roots, or leaves. Examples include strawberry runners and potato tubers.
- **Spore formation:** Many fungi, algae and some plants reproduce through spores, small structures that develop into new organisms without fertilisation.
- **Parthenogenesis:** Found in some reptiles, insects, and fish, where an egg cell develops into a new organism without fertilisation, producing offspring genetically similar to the mother.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

A key advantage of asexual reproduction is its efficiency; organisms can reproduce quickly and in stable environments, allowing populations to grow rapidly. However, because offspring are genetically identical to the parent, there is less genetic variation, which can make the population vulnerable to diseases and changing environmental conditions.

Low-res

Figure 11.28 Vegetative propagation

Quick check 11.10

1. **Compare** mitosis and meiosis in a Venn diagram.
2. **Explain** what karyotypes can show and why this is useful.

Section 11.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 11.2 questions

Remembering

1. **State** one key difference between mitosis and meiosis.
2. **Recall** the phase of meiosis when pairs of matching chromosomes separate.
3. **State** the name of the syndrome that arises from trisomy 21.
4. **State** what the term 'homologous chromosomes' means.

Understanding

5. **Explain** why gametes need to be haploid.
6. **Explain** what is meant by the term 'reduction division'.
7. **Explain** why a chromosome missing a part may lead to a disorder or syndrome.
8. **Explain** why the cells produced during meiosis are genetically unique.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applying

9. **Complete** the following table to differentiate between mitosis and meiosis.

	Where it occurs	Purpose	Features of daughter cells
Mitosis			
Meiosis			

Analysing

10. **Contrast** the daughter cells produced in mitosis versus meiosis.
11. **Illustrate** a diagram to represent the steps of mitosis for a cell with two pairs of chromosomes. Be sure to use a different colour for each pair of chromosomes.
12. **Contrast** anaphase I in meiosis and anaphase in mitosis.
13. **Contrast** prophase I and prophase II in meiosis.

Evaluating

14. **Critique** the following claim: It is the male that determines the sex of the child.
15. **Predict** the chances of a woman giving birth to a girl if she has already given birth to three boys, giving reasons for your response.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

11.3 Patterns of inheritance

Learning outcomes

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

1. identify that genes and environmental factors interact to produce traits.
2. use Mendelian inheritance to explain the connection between genotype and phenotype.
3. use pedigrees to show how a single gene affects a trait and can be used to predict patterns of inheritance.
4. use Punnett squares to show how a single gene affects a trait and can be used to predict patterns of inheritance.

WORKSHEET
Inheritance

Indigenous kinship systems

Figure 11.29 This artwork from Kakadu National Park shows Namondjok, a Creation ancestor who broke kinship laws.

Many Aboriginal and Torres Strait Islander communities have understood inheritance patterns for a long time. They recognise how traits can be passed down to the next generation and how negative traits and illnesses often appear in the children of closely related parents. Their knowledge of heredity created complex and sophisticated kinship systems which allow individuals to understand who they are and how they fit into the social structure and even the universe. These kinship systems are strictly adhered to and dictate who can or cannot marry through marriage laws. Kinship and family structures also determine how individuals behave towards others and the responsibilities each person has towards others, natural resources and the land.

For example, a person may be obliged to care for their sibling's offspring. These children might address their aunt or uncle as 'mother' or 'father' and their cousins as 'brothers' or 'sisters'. Although they are aware of their biological parents, the societal (kinship) laws assign equal importance to other relatives.

When conversing with one another, Aboriginal and Torres Strait Islander Peoples frequently use the terms 'brother' or 'sister', which are derived from the kinship terminology and connections.

Inheriting traits from our parents

Each characteristic or trait that we inherit is controlled by one or more pairs of genes.

Members of each gene pair are found at the same location on their respective homologous chromosomes. This is called the **locus** of a gene.

locus the location of a gene on a chromosome

genotype the combination of alleles an organism has for a particular gene

Genotype

Genes are sections of DNA that code for a particular protein which contributes to our characteristics, such as a gene for eye colour. However, not all forms of a gene are the same; for example, different people can have different eye colours. We use the term 'allele' to describe the different forms of a gene. We get one copy of each chromosome from each parent, so although we inherit the same genes, we don't necessarily inherit the same alleles. The combination of alleles an organism has for a particular gene is known as the organism's **genotype**.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

homozygous having two identical alleles at a particular gene locus

heterozygous having two different alleles at a particular gene locus

dominant a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

recessive a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

If two identical alleles are present in a person's genotype, they are known as **homozygous** for that particular trait. However, if there are two different alleles present for the same trait, then the person is **heterozygous** for that trait.

For example, consider the trait of freckles. This trait is controlled by a single gene that is represented using two alleles. The allele of the **dominant** trait is the presence of freckles (we assign it the capital letter 'F' to show it is dominant), and the allele for the **recessive** trait is the lack of freckles (assigned a lower case 'f' to show it represents the recessive trait). A trait or characteristic is described as dominant if you need only one allele for it to be expressed (FF or Ff). For a recessive characteristic, the allele needs to be inherited from both parents for it to be expressed (ff).

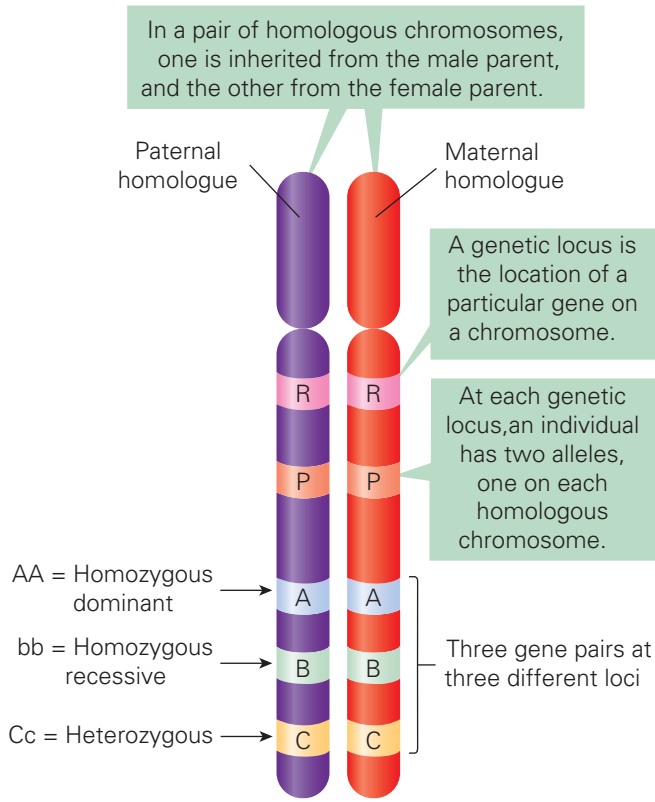


Figure 11.30 In a pair of homologous chromosomes, one is inherited from the male parent, and the other from the female parent.

If you inherit the freckles allele from both parents, you are homozygous dominant for that trait and your genotype will be FF. If you inherit the no-freckles allele from both parents, you are homozygous recessive for that trait and your genotype will be ff. If you inherit a freckles allele from one parent and a no-freckles allele from the other parent, you are heterozygous for that trait and your genotype will be Ff.

Phenotype

phenotype the observable characteristics of an organism, resulting from both genotype and the environment

The interaction of an organism's genotype with the environment results in its **phenotype**, or its physical appearance. Typically, multiple genes and multiple environmental factors interact in the development of most traits. In the example in Figure 11.31, the presence of freckles is the person's phenotype for that trait. The freckles are present due to the person's genotype and their environmental exposure to UV light.

Figure 11.31 The presence of freckles is an example of a dominant trait.

To determine whether an allele represents a trait that is dominant or recessive, scientists look at the phenotype of a heterozygous organism. If the trait is expressed in this phenotype, it must be the dominant trait.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 11.11

1. **Copy** the table below and define the terms.

Term	Definition
Locus	
Allele	
Genotype	
Phenotype	
Dominant	
Recessive	
Heterozygous	
Homozygous dominant	
Homozygous recessive	

2. **Explain** why a person with the genotype for freckles may not have many freckles on their face.

Try this 11.4

Inherited features

1. Attached ear lobes: are your earlobes attached or unattached to the side of your head?
2. Widow's peak: do you have a V-shaped peak in the centre of your hairline as shown in Figure 11.32?
3. Tongue roll: can you roll your tongue as shown in Figure 11.33?
4. Front tooth gap: is there a definite gap between your two top front teeth as shown in Figure 11.34?
5. Mid-digital hair: is there any hair on the second joint of at least one of your fingers?
6. Long second toe: is your second toe longer than your big toe as shown in Figure 11.35?
7. Dimples: do you have indentations on your cheeks when you smile?

Figure 11.32 This girl has a widow's peak (V-shaped peak) in the centre of her hairline.

Figure 11.33 This woman can roll her tongue.

Figure 11.34 This man has an obvious gap between his top front teeth.

Figure 11.35 The second toe is longer than the big toe on this foot.

Determining chances of inheritance

Gregor Mendel

Gregor Mendel is known as the father of genetics. Born in 1822, he was an Austrian monk who carried out experiments in his garden using pea plants and discovered some of the fundamental laws of heredity we still rely on today.

Mendel looked at the features of pea plants, which could be tall or short (dwarf). He assigned the following letters to represent these alternative characteristics (known today as alleles): T = tall and t

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

= dwarf. Mendel bred the plants and observed the height of the plants in the next generation. He discovered that tall pea plants could be either pure breeding (TT or homozygous dominant) or hybrid (Tt or heterozygous). The dwarf plants could only be tt (homozygous recessive).

Today, we call this the plant's genotype.

Mendel also used the following notation to represent different levels of generations:

- P = parent generation
- F_1 = first filial generation (first generation of offspring)
-

Punnett square
a specialised grid to show genetic crosses

monohybrid cross
a type of genetic cross or breeding experiment that considers the inheritance of a single trait or characteristic, typically controlled by a single gene with two alleles

monogenic
a trait that is controlled by a single gene

Figure 11.36 Gregor Johann Mendel was the founder of the science of genetics, using pea plants to show dominant and recessive traits. He produced large amounts of data which all supported his theory, but later statistical analysis suggests that he may have falsified his data – it was simply too good to be true! Large data sets and statistical analyses are vital for validating scientific findings.

Worked example 11.1

Cross between a pure-breeding tall plant and a pure-breeding dwarf plant

Parents: TT × tt

gametes	T	T
t	Tt	Tt
t	Tt	Tt

You will notice that all the predicted F_1 offspring (shaded) have the genotype Tt. We can write this as:

F_1 genotype: 100% Tt

We can also see that offspring with Tt would all physically appear tall, as T stands for the tall allele which is dominant over the dwarf allele (t). So, we can write this as: F_1 phenotype: 100% tall plants

Worked example 11.2

Cross between two of the hybrid F_1 plants from worked example 11.1

F_1: Tt × Tt

gametes	T	t
T	TT	Tt
t	Tt	tt

F_2 genotype: 25% TT; 50% Tt; 25% tt

F_2 phenotype: 75% tall plants; 25% dwarf plants

We can also write the predicted outcomes as ratios. In this case, when two heterozygous tall pea plants were crossed, there was a genotypic ratio of 1TT : 2Tt : 1tt and a phenotypic ratio of 3 tall : 1 dwarf.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

If we let H = abnormal Huntington's protein allele (Huntington's disease) and h = 'normal' protein allele (unaffected), then we can use these notations to help work out probable outcomes in the offspring.

Worked example 11.3

Cross between two individuals unaffected by Huntington's disease

Parents: hh × hh

gametes	h	h
h	hh	hh
h	hh	hh

F_1 genotype: 100% hh

F_1 phenotype: 100% unaffected

Worked example 11.4

Cross between an individual with Huntington's disease and an unaffected individual

Parents: Hh × hh (Someone with two H alleles will not survive birth so the individual with Huntington's disease must be Hh).

gametes	H	h
h	Hh	hh
h	Hh	hh

F_1 genotype: 50% Hh; 50% hh

F_1 phenotype: 50% with Huntington's disease; 50% unaffected

Try this 11.5

Punnett squares

1. A black mouse mates with a brown mouse. There is a large number of offspring and all of them are black.
   a. Which trait is dominant?
   b. Draw a Punnett square and determine the genotypes of the offspring.
2. A recessive gene causes a condition called cystic fibrosis. If a homozygous recessive individual mates with a heterozygous individual, what are their chances of producing offspring with cystic fibrosis?

Quick check 11.12

1. **Contrast** genotype and phenotype.
2. Brown eyes are dominant to blue eyes.
   a. **Select** letters for the brown eye and blue eye alleles.
   b. **Create** a Punnett square for a couple who are both heterozygous.
   c. **State** the genotypic and phenotypic ratios of the offspring.
   d. **State** the chances of this couple producing a blue-eyed child.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Test cross

test cross
a genetic cross between a homozygous recessive individual and an individual of unknown genotype showing the dominant trait to determine the unknown genotype

A **test cross** can be used to discover whether an organism showing a dominant trait is homozygous dominant or heterozygous.

It involves observing the offspring of the individual in question if it mates with a homozygous recessive individual (for example, aa). This means the individual of unknown genotype mates with an individual of known genotype. By looking at the offspring ratio, we can deduce the unknown genotype of the individual in question.

For example, in mice, coat colour may be black (B) or white (b). You can find out if a black mouse is homozygous black (BB) or heterozygous black (Bb) by doing a test cross between the black mouse and a white mouse (bb).

If the unknown black mouse is BB, the cross would look like this:

Parents: BB × bb

gametes	B	B
b	Bb	Bb
b	Bb	Bb

F_1 genotype: 100% Bb

F_1 phenotype: 100% black

This means if all the offspring are black, the unknown black mouse is probably BB (or homozygous dominant).

If the unknown black mouse is Bb, the cross would look like this:

Parents: Bb × bb

gametes	B	b
b	Bb	bb
b	Bb	bb

F_1 genotype: 50% Bb; 50% bb

F_1 phenotype: 50% black; 50% white

This means if roughly half the offspring are black and half are white, the unknown black mouse is probably Bb (or heterozygous). Note that these expectations are only true when based on large numbers of offspring because they are probabilities. However, if even one white offspring is born, the black mouse must be heterozygous in order to have passed on a recessive b gene.

Quick check 11.13

1. **Explain** the importance of a test cross.
2. Silky feathers in a bird species are caused by a gene with a trait recessive to normal feathers. If you had a normal-feathered bird, describe a way to **determine** whether it is heterozygous or homozygous. **Use** Punnett squares to help with your answer.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 11.6

Blood type: Positive or negative

One vital gene located on chromosome 1 in humans is the gene controlling for Rhesus (Rh) blood type. Rh positive blood is dominant to Rh negative blood, so we can assign the alleles D (Rh positive) and d (Rh negative). Therefore, an Rh positive person can be either DD or Dd with respect to this gene, but an Rh negative blood type can only be homozygous, dd.

Instructions

In this activity, we will use coloured counters and felt-tipped pens to model the passing of Rh alleles from heterozygous individuals to their offspring.

1. Copy the results table into your science journal.
2. Choose one coloured counter. Print D on one side and d on the other to represent the alleles of the chromosomes. This counter represents an individual who is Dd for Rh blood type, that is, able to produce gametes (eggs or sperm) of the type D and d in equal proportions.
3. Find a partner in the room with a different coloured counter.
4. Make an unbiased toss of your two counters to produce an offspring. The labels facing up on the counters will represent the alleles of the gametes produced by the parents. Record the genotype of the offspring in the Family 1 row of the following table. Repeat this step three more times to produce a total of four children.
5. Generate a total of four families (by pairing up with three different students) with each having produced four children.
6. Record the number of each type of genotype found in the children of each family in the table following table. Pool your total results with those of the class.

Results

	Genotype of children		
	DD	**Dd**	**dd**
Family 1			
Family 2			
Family 3			
Family 4			
Total numbers across the class			

Analysis

1. Using the class data, calculate the probability of obtaining the offspring genotypes:
   - **a.** DD
   - **b.** Dd
   - **c.** dd
2. What are the proportions of the different genotypes in your group of 16 children compared to those generated across the whole class? Discuss whether this is expected.
3. A woman with Rh positive blood insisted that she was the daughter of a rich, elderly couple who both had Rh negative blood. Use a Punnett square to show your working out to explain whether this woman's statement could be valid.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Key concept: Multiple gene-environment interactions produce traits

multifactorial inheritance
the key concept in genetics that traits develop in individuals by interactions between their genes, and environmental factors

carrier
an individual with a recessive allele for a disease but who does not have the disease due to being heterozygous

Most traits in organisms are shaped through interactions between multiple genes and a range of environmental factors. This concept, known as **multifactorial inheritance**, recognises that genes don't work in isolation. Instead, different genes may each contribute small effects that, combined, influence traits like height, skin colour, and even the risk of developing certain diseases. These genetic contributions are then influenced by various environmental factors – such as diet, lifestyle, climate and exposure to toxins – which can further modify trait expression. So the same genotype in a different environment can produce a different phenotype. This is a *key concept* in genetics.

For example, height is determined by numerous genes that each play a role in growth, bone structure, and metabolism. However, factors like nutrition during childhood and adolescent development also significantly impact height, showing that genes set a potential range, while the environment helps determine where an individual falls within that range.

Sex linkage

As we have seen, in humans the sex chromosomes are the 23rd pair. Human females are homogametic for the X chromosome while males are heterogametic with one X and one Y chromosome.

The X chromosome also contains many genes not related to sex determination (in contrast, the Y chromosome has very few). Characteristics that are not related to determining the sex of the individual but are coded for by X chromosome genes are termed X-linked. When we predict X-linked traits using a Punnett square, we must use the sex chromosomes and superscripted letters above the sex chromosomes to represent the trait.

For example, Duchenne muscular dystrophy (DMD), a disorder where the muscles progressively degenerate, is inherited as an X-linked recessive trait. The genotype for an unaffected female would be X^DX^D, a **carrier** female (who has a recessive allele for the disease but is heterozygous so does not have the disease) would be X^DX^d, and a female with DMD would be X^dX^d. On the other hand, an unaffected male would be XDY and a male with DMD would be X^dY. As there is no gene for this condition found on the Y chromosome, we do not write ^{D} or ^{d} next to the Y. Because males have only a single copy of the X chromosome, they are more likely to be affected by sex-linked disorders. A single allele of a mutated gene on an X chromosome will cause the disease in a male but not in a female (who would need two DMD alleles).

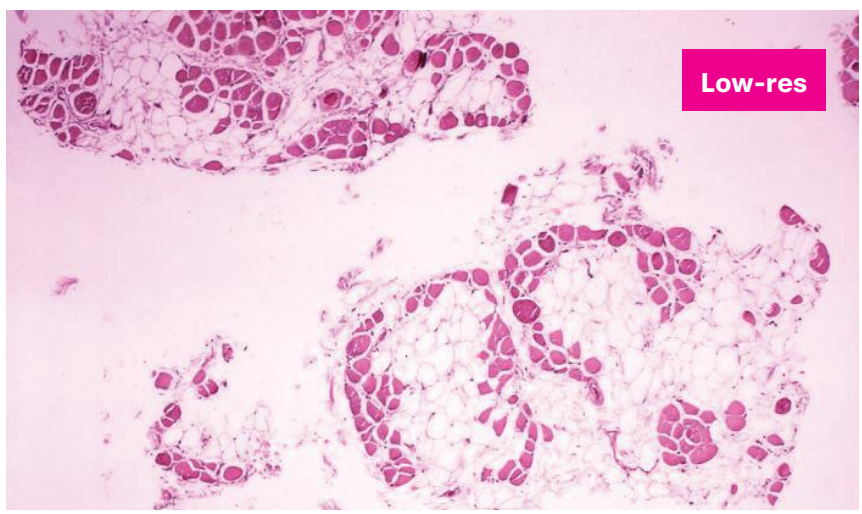


Figure 11.37 In Duchenne muscular dystrophy, muscle fibres (red) are replaced by fat cells (white).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 11.5

Cross between a heterozygous normal-vision female (carrier) and a normal-vision male

Colour blindness is inherited as an X-linked recessive trait. The genotype of a heterozygous normal-vision (carrier) female is X^BX^b and of a colour-blind male is X^bY.

Parents: $X^BX^b \times X^bY$

gametes	B	b
X^B	X^BX^B	X^BX^b
Y	X^BY	X^bY

F_1 genotype: 25% X^BX^B; 25% X^BY; 25% X^BX^b; 25% X^bY

F_1 phenotype: 25% normal-vision female; 25% normal-vision male; 25% carrier normal-vision female; 25% colour-blind male

Try this 11.7

Sex-linked inheritance

Now it is your turn to practise. Remember that the gametes need to include the sex chromosomes, and the genotype and phenotype both need to include the sex chromosomes as well.

1 Using a Punnett square, cross a normal-vision female (homozygote) with a colour-blind male.
2 Using a Punnett square, cross a colour-blind female with a normal-vision male.
3 Explain why more males than females have colour blindness.

Codominance

When there are two equally dominant alleles for a trait, they will both be expressed in the phenotype of a heterozygote. This is **codominance**. Look at the picture of the chickens in Figure 11.38. The colours black and white are equally dominant (their alleles are both given capital letters), so when you cross a pure black chicken with a pure white chicken, you get a heterozygote. In the heterozygote, both colours are expressed equally, so you get a speckled chicken with black feathers and white feathers!

VIDEO
An example of codominance

codominance
both alleles are expressed equally in the phenotype

Genotype	WW	BB	BW
Phenotype	White	Black	Speckled

Figure 11.38 White and black are equally dominant alleles and are said to be codominant. The evidence of this is their heterozygote offspring that has a mix of black and white feathers.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Blood types

In humans, our blood type is a codominant trait. Our red blood cells have proteins on the surface called antigens, and these determine whether our blood is A, B, AB or O.

Each person has two copies of the ABO blood type gene, one from their mother and one from their father. The blood type gene is found on chromosome 9, and there are three possible alleles:

- I^A = production of antigen A (type A blood) is dominant.
- I^B = production of antigen B (type B blood) is dominant.
- i = production of neither antigen (type O blood) is recessive.

As we have two copies of chromosome 9, there can be six different allele combinations:

- Type A blood can have genotypes $I^A I^A$ or I^A i.
- Type B blood can have genotypes $I^B I^B$ or I^B i.
- Type AB blood can only have the genotype $I^A I^B$.
- Type O blood can only have the genotype ii. I^A an I^B are both dominant over i, but are codominant to each other.

VIDEO
Blood types

Worked example 11.6

Cross between heterozygous blood type A and heterozygous blood type B

Parents: $I^Ai \times I^Bi$

gametes	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

F_1 genotype: 25% $I^A I^B$; 25% I^B i; 25% I^A i; 25% ii

F_1 phenotype: 25% AB blood type; 25% B blood type; 25% A blood type; 25% O blood type

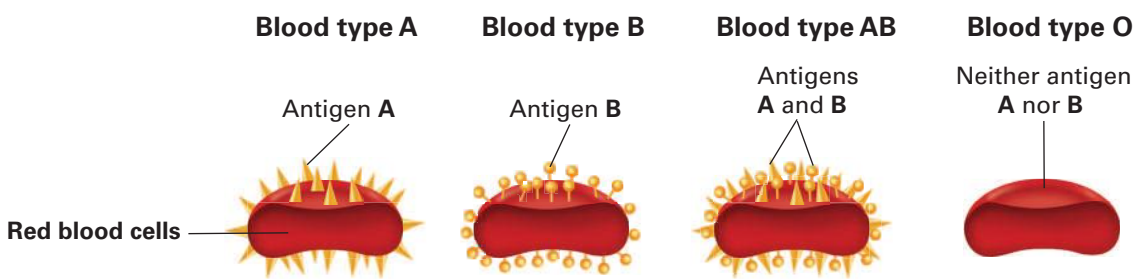


Figure 11.39 Illustration of the different antigens on the surface of red blood cells

Explore! 11.6

Incomplete dominance

incomplete dominance a form of inheritance in which both alleles are partially expressed, producing a third intermediate phenotype

Incomplete dominance occurs when neither of the alleles is dominant over the other, resulting in a third phenotype which is an intermediate form of both alleles. Wavy hair is an example of incomplete dominance. A person with two curly hair alleles will have curly hair. A person with two straight hair alleles will have straight hair. However, a person with one curly and one straight allele will have wavy hair.

1. The flower colour of snapdragons is an example of incomplete dominance. Draw an example of a cross for a white flower (C^WC^W) and a red flower (C^RC^R).
2. Eggplant colour is another example of incomplete dominance. Explain how the three colours of eggplant shown in Figure 11.41 are possible.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 11.40 Wavy hair is an example of incomplete dominance.

Figure 11.41 Deep purple (left), violet (middle) and light green (right) eggplants

Quick check 11.14

1. **Explain** why males are more likely to be affected by recessive X-linked disorders than are females.
2. **Describe** codominance.

WORKSHEET
Pedigrees

Pedigrees

One way of finding out how a trait is inherited is to follow the inheritance pattern over two or more generations. This technique is called pedigree analysis. To study patterns of inheritance in humans, geneticists investigate the frequency and occurrence of a particular gene over many generations to determine whether the traits are dominant or recessive. The chart formed is called a **pedigree** and it is like a family tree.

pedigree
a chart that shows relationships between family members and indicates which individuals have certain genetic traits

Each generation is numbered in Roman numerals and forms a row on the pedigree. Individuals are numbered using Arabic numerals (1, 2, 3 etc.) from left to right on each row. The symbols used are:

- Unaffected female
- Unaffected male
- Female with the trait being investigated
- Male with the trait being investigated
- Carrier of trait or
- Mating is represented by a horizontal line
- A vertical line connects offspring to parents

Reading a pedigree

There are some points to keep in mind when reading a pedigree and determining inheritance:

- A trait that is common in a population is not necessarily dominant.
- When asked to determine a genotype in a pedigree, you will need to establish the mode of inheritance. You can use Punnett squares to help you.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

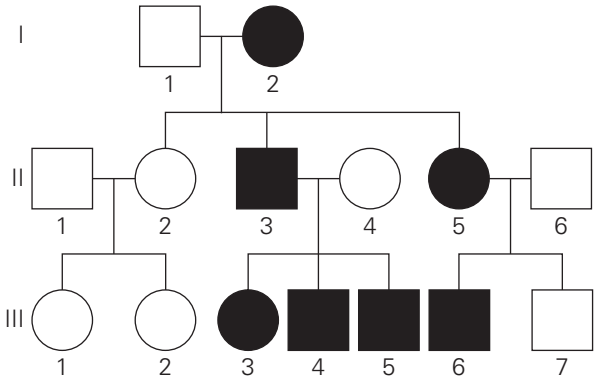


Figure 11.42 An example of a pedigree showing three generations of a family. Individuals affected by a particular trait are shown in black. Note how male I-1 and female I-2 had three children, and their eldest is an unaffected female (II-2).

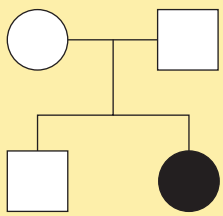
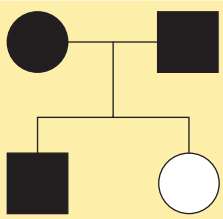
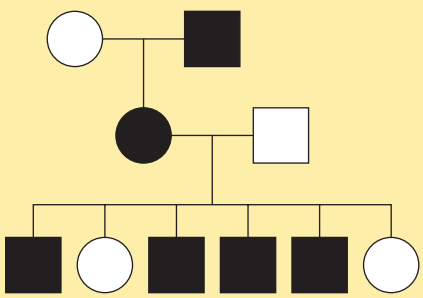
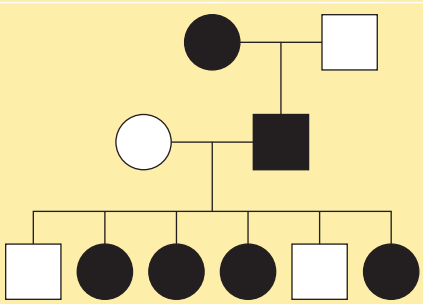
Mode of inheritance	Pedigree chart	What to look for	Examples
Autosomal recessive		Two unaffected parents can have an affected child. Males and females are equally affected. The trait may disappear from a branch of pedigree and then reappear in later generations. Two affected recessive parents must have all affected recessive children.	Albinism, cystic fibrosis, sickle cell anaemia and thalassaemia
Autosomal dominant		Two affected parents can have an unaffected child. Males and females can be equally affected, yet all of the affected individuals must have at least one parent affected.	Huntington's disease and haemochromatosis
X-linked recessive		Affected mothers produce affected sons. Affected fathers *cannot* pass the trait to their sons.	Colour blindness, haemophilia and Duchenne muscular dystrophy
X-linked dominant		Affected fathers produce daughters that are all affected. Affected fathers *cannot* pass the trait to their sons, but affected homozygous females will pass the trait on to all of their daughters and sons.	X-linked hypophosphatemic rickets

Table 11.5 Different modes of inheritance and how to identify them in a pedigree chart

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 11.7

Famous people have genetic disorders too!

Megan Fox has a condition called brachydactyly. This is an autosomal dominant condition that causes shortened fingers or toes. Jessie J has Wolff-Parkinson-White Syndrome, an autosomal dominant condition that causes a very fast heart rate.

Figure 11.43 Megan Fox and Jessie J both have genetic disorders.

Quick check 11.15

1. Study the pedigree chart in Figure 11.44. It illustrates the inheritance of achondroplasia (dwarfism) in humans.

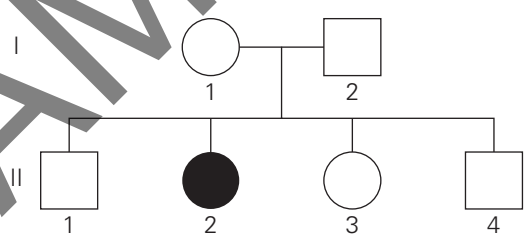


Figure 11.44 Pedigree chart

   a. **Identify** a piece of evidence that suggests that this condition is recessive and not dominant.
   b. **Identify** the genotype of individuals I-1, I-2, II-1 and II-2.
   c. Suppose individual II-2 has children with a man who does not have achondroplasia but is a carrier for the condition. **Determine** the chance of having a child with achondroplasia and the chance of having a child without achondroplasia. **Use** a Punnett square to show how you arrived at your answer.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive section review and more!

Section 11.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 11.3 questions

Remembering

1. **State** how many copies of each gene we have and where they come from.
2. **Recall** the name of the person known for being the father of genetics.
3. The pedigree chart in Figure 11.45 shows the inheritance pattern of a disease that is caused by a single gene.
   a. **Identify** the sex of the person labelled II-5.
   b. **State** whether the disease is dominant or recessive, giving reasons for your answer.
   c. **State** the genotype of individual II-5, giving reasons for your response.

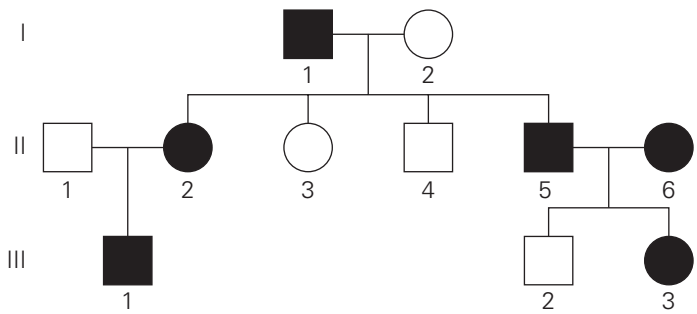


Figure 11.45 Pedigree chart

Understanding

4. **Explain** using genetics how a trait is produced.
5. **Describe** what pedigrees are useful for.
6. **Explain** how sex linkage is different from other types of inheritance.
7. **Explain** why, for a particular characteristic, two homozygous recessive individuals can only produce homozygous recessive children.
8. **Explain** what is meant by the term 'carrier'.
9. **Explain** why a test cross is useful.

Applying

10. Dimples are dominant to no dimples.
    a. **Select** appropriate letters for these alleles.
    b. **Identify** the genotype and phenotype of a person who is:
       i homozygous recessive for dimples
       ii heterozygous for dimples
       iii homozygous dominant for dimples.

Analysing

11. **Contrast** codominance and incomplete dominance using examples.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Evaluating

12. In fruit flies, eye colour is sex linked. The eye colour allele is located on the X chromosome. The red eye allele is dominant over the white eye allele.

- **a.** **Select** appropriate letters for the alleles.
- **b.** Using a Punnett diagram, **determine** the offspring a male heterozygous fly that mates with a female homozygous recessive fly will produce.
- **c.** **Decide** the genotypic and phenotypic ratios of the offspring.

13. In mice, black hair is dominant to brown hair. Mice with black hair can be either homozygous or heterozygous.
Propose how you would find out if a mouse with black hair was homozygous or heterozygous. Support your response with a Punnett square.

14. The pedigree chart in Figure 11.46 shows the inheritance patterns for haemophilia. Haemophilia is an X-linked recessive disorder.
Use evidence from the pedigree to **justify** that haemophilia is recessive.

Figure 11.46 A haemophilia pedigree

15. A brown-eyed male and a blue-eyed female produced all blue-eyed children. **Discuss** whether that means blue eyes is the dominant trait.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

11.4 Changes in DNA

WORKSHEET Changes in DNA

Learning outcomes

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

1. explain how mutation in DNA results in genetic variation with beneficial, harmful or minimal effects on organisms' functioning.
2. identify examples of current and emerging genetic technologies.
3. discuss applications of genetic technologies in conservation, agriculture, industry and medicine.
4. discuss applications of genetic testing and associated social, economic and ethical implications.
5. use scientific understanding, factual evidence and ethical principles to describe the ethical implications of the continued use of the HeLa stem cell line.

Mutations

Sometimes, the process of DNA replication makes errors, which cause changes to the genetic code. Often these errors are repaired, but when they are not, they become permanent changes in the genome of the cel. This is known asl a mutation. Mutations may be small, such as a change in a single nucleotide (**point mutation**), or large, involving entire segments of DNA within a chromosome (**chromosome mutation**). Mutation is the only way that new alleles can be created within a population.

point mutation a mutation in which a single nucleotide is changed

chromosome mutation a mutation involving large segments of DNA

spontaneous mutation a naturally occurring mutation

induced mutation a mutation produced by environmental factors

mutagenic causing mutations in DNA

germline mutation a mutation of DNA in gametes which can be inherited

somatic mutation a mutation that occurs in somatic (body) cells which cannot be inherited

A mutation can be described as **spontaneous** (naturally occurring) or **induced**. Induced mutations are caused by exposure to **mutagenic** agents in the environment like radiation (X-rays, ultraviolet rays or nuclear radiation) or chemicals. Mutations that occur within the gametes are called **germline mutations**. These can be inherited and will influence the next generation. Mutations that occur within somatic cells will only affect the individual and will not be passed down to future generations. This form of mutation is known as a **somatic mutation**.

Beneficial, harmful, and neutral mutations

Mutations have three possible consequences:

- **No effect – neutral.** Neutral mutations are non-lethal and make no difference to the organism's ability to survive and reproduce in its environment.
- **Negative effect – harmful.** Harmful mutations produce proteins that malfunction or cause proteins not to be produced at all. They can cause genetic disorders or cancer and result in organisms that are less likely to survive, reducing the likelihood that the genetic material will be passed on to the next generation.
- **Positive effect – beneficial.** Beneficial or advantageous mutations give rise to new versions of proteins that increase the chance that the organism will survive and reproduce to pass its genetic material to the next generation. Beneficial mutations increase genetic variation in a population and are essential for evolution to occur.

Explore! 11.7

Mutagens

Many factors in the environment are known as 'mutagens' – that is, they cause mutations.

1. Research some environmental mutagens.
2. From the list created in Question 1, divide your mutagens into categories according to their source, such as chemical mutagens, radiation and mutagens in food.

Figure 11.47 Melanoma is linked to UV light exposure as well as gene changes. A mole may be a sign of skin cancer if it has irregular borders, an asymmetrical shape or if it changes in colour, shape, size or height.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 11.8

The Black Death left a genetic mark

Many individuals with European ancestry carry genetic mutations that protected their ancestors from the bubonic plague, a disease caused by Yersinia pestis, a species of bacterium spread by fleas. When plague struck Europe in 1348 and again in 1665, millions of people were killed.

However, some people had mutations that made them more likely to survive.

By examining the DNA of people who died before, during and after the Black Death, researchers have found that carrying two copies of a mutated ERAP2 gene improved a person's survival by 40%. The allele codes for a protein that is involved in the immune response, and the mutation produced a heightened response. This meant that the survivors of bubonic plague passed on this beneficial trait to their offspring. However, this mutation is also problematic. Individuals who carry the mutated ERAP2 gene are at an increased risk of autoimmune diseases.

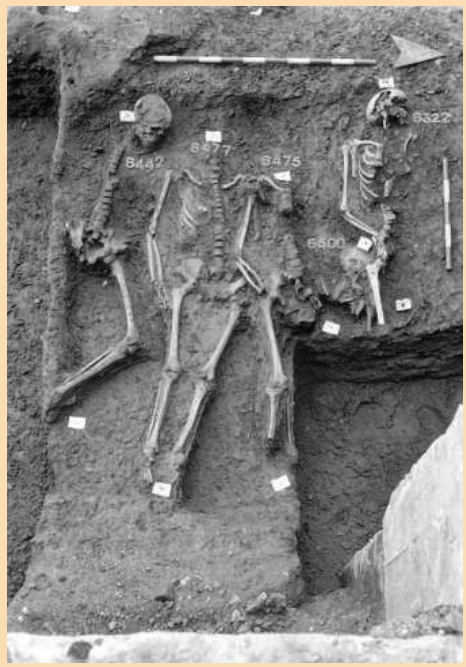


Figure 11.48 A small mass burial pit of plague victims excavated in East Smithfield, London. The significant number of deaths during plague outbreaks resulted in many similar mass burials across Europe.

Quick check 11.16

1. If a mutation is to be passed on to the next generation, **recall** where it must occur.
2. **Summarise** the possible effects of mutations that occur in somatic cells.

Gene mutations

Gene mutations refer to changes in the DNA sequence that make up a gene. This involves changes to any of the four nitrogenous bases in the nucleotides that make up the genes.

gene mutation a permanent alteration in the DNA sequence that makes up a gene

substitution where one nucleotide is swapped for another

There are several types of gene mutations, including point mutations, insertions, deletions and inversions.

Changing the nucleotides could change the message carried by the gene, which may change the order of amino acids making up the protein.

- A point mutation is the most common type of gene mutation and involves the **substitution** of one nucleotide for another (for example, ATG becomes ACG). This mutation only changes the DNA code for a single amino acid. If the new sequence codes for the same amino acid, it is called a silent mutation. An example of a disease caused by a substitution mutation is sickle cell anaemia.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

insertion
where one or more extra nucleotides are inserted into the DNA

deletion
where a nucleotide is deleted from the sequence

inversion
where two nucleotides reverse their order

- An **insertion** mutation occurs when an extra nucleotide (or more than one) is inserted into the DNA sequence (for example, ATG becomes ATCG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a disease caused by an insertion mutation is fragile X syndrome.
- A **deletion** mutation occurs when a nucleotide is deleted from the sequence (for example, ATG becomes AG). This type of mutation changes the DNA code for all amino acids that follow and is also a frameshift mutation. An example of a disease caused by a deletion mutation is Duchenne muscular dystrophy.
- An **inversion** mutation occurs when two nucleotides reverse their order in the DNA (for example, ATG becomes AGT). This mutation only changes the DNA code for a single amino acid, and it could code for the same amino acid (silent mutation). An example of a disease caused by an inversion mutation is haemophilia.

Try this 11.8

Remembering deletions

Find a way to remember the different types of mutations using normal words. For example:

- Normal code – WING
- Deletion – WIG
- Substitution – WIND
- Insertion – WRING.

Chromosome mutations

If a mutation occurs in a gene on one of the pair of homologous chromosomes, there will still be a normal copy of the gene on the other chromosome. The same applies with chromosome mutations. As chromosomes occur as homologous pairs, if one chromosome is abnormal, the other is still likely to be normal. The different types of chromosome mutations are illustrated in Figure 11.49.

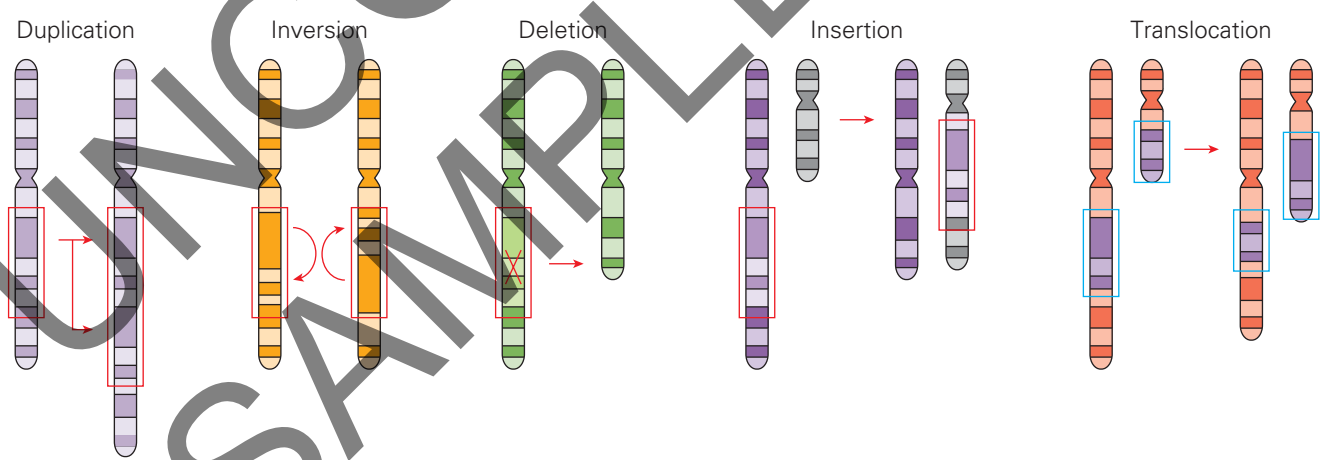


Figure 11.49 The five different types of chromosome mutation. Can you identify what is changing in each type?

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 11.8

Sickle cell anaemia

Sickle cell anaemia is a disease caused by a mutation in a gene that codes for a subunit of haemoglobin, a protein found in red blood cells. The mutation causes changes to the shape of haemoglobin, which causes the red blood cells to become misshapen and block blood vessels. Despite this, the sickle cell trait protects against the development of malaria. Research the following questions.

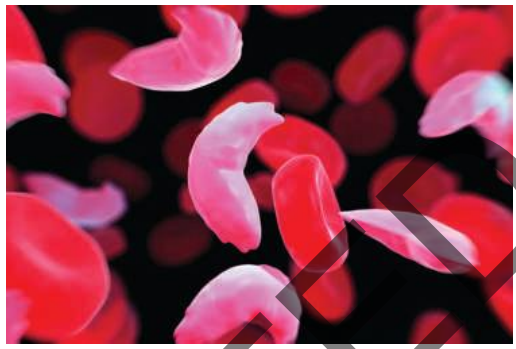


Figure 11.50 Red blood cells are misshapen and resemble sickles in people with sickle cell anaemia.

1. Which amino acid is changed in sickle cell anaemia?
2. Sickle cell anaemia is an example of both a harmful and a beneficial mutation. Explain what these terms mean.
3. What is the correlation between the distribution of the mutated gene and the distribution of malaria in Africa?
4. Why is sickle cell anaemia harmful in a non-malarial zone and beneficial in a malarial zone?

Chromosome number abnormalities

Certain individuals may have one more or one fewer chromosome because of **non-disjunction** during meiosis. Non-disjunction means that the chromosomes failed to separate correctly when making gametes, so the gametes end up with an abnormal number of chromosomes (**aneuploidy**).

Trisomy occurs when an organism has a third copy of a chromosome that should only be present in two copies. Trisomy is therefore an example of aneuploidy. The most common trisomy among embryos that survive to birth is Down syndrome, or trisomy 21. People with this inherited disorder have distinct facial characteristics and experience developmental delays.

Did you know? 11.9

Sex chromosome abnormalities

Sex chromosome abnormalities occur when a person is missing a whole sex chromosome or has an extra sex chromosome due to non-disjunction. Problems can also occur when a person is missing part of a sex chromosome. Some disorders of sex chromosome are Klinefelter syndrome, XX male, XYY male, Turner syndrome, XXX female and XY female. Some of these disorders are surprisingly common. For example, many men with Klinefelter syndrome (who have two X chromosomes and one Y) have no signs or symptoms, and it is estimated that only one in six are ever diagnosed.

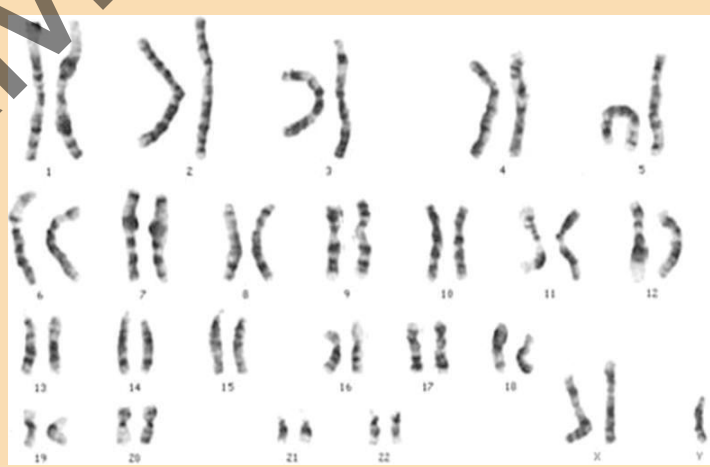


Figure 11.51 A karyotype of a male with Klinefelter syndrome

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 11.17

1. **Describe** a substitution mutation.
2. **Recall** what the term 'aneuploidy' means.

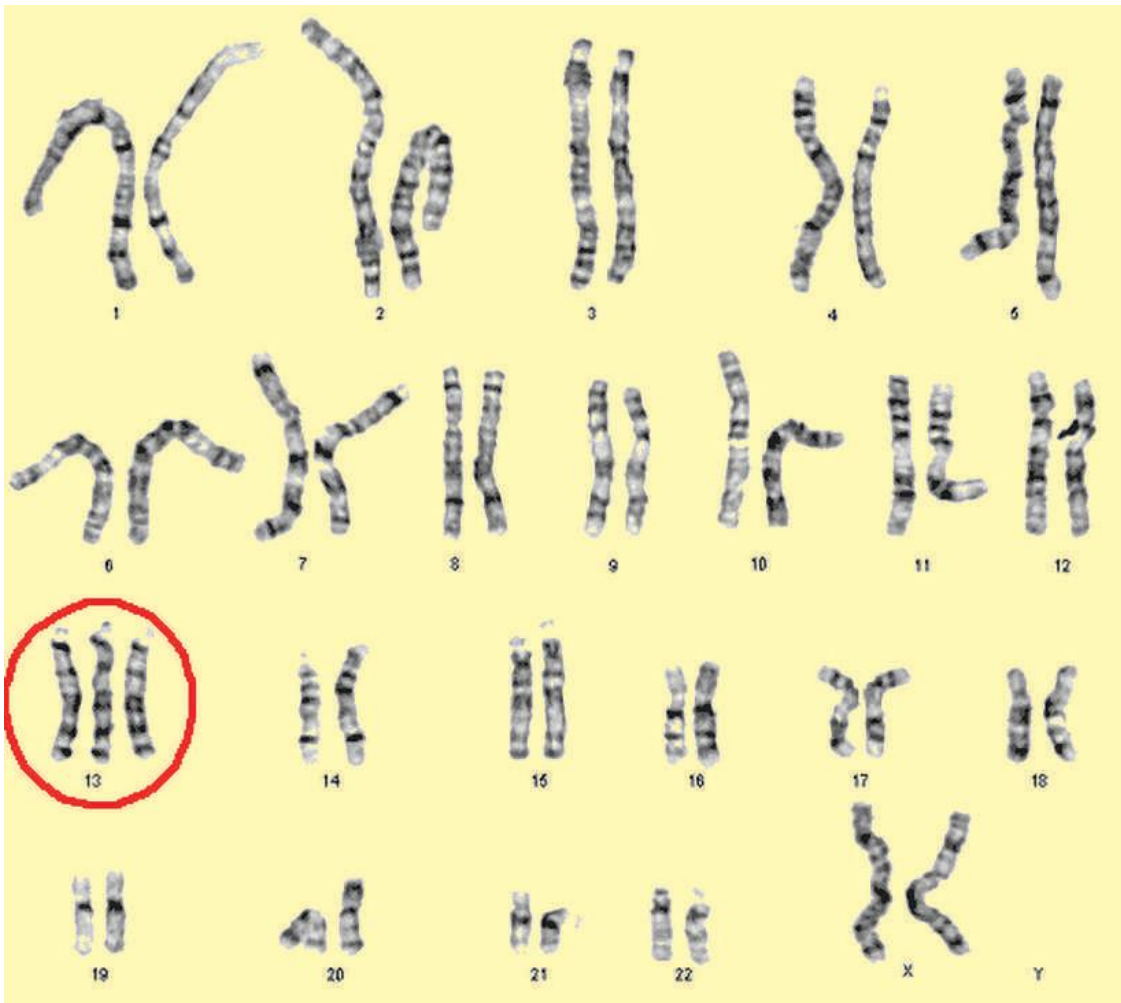


Figure 11.52 There are other types of trisomy apart from trisomy 21. Trisomy 13 and 18 result in more severe conditions. Which trisomy is depicted in this karyotype?

Did you know? 11.10

Madeline Stuart

Madeline Stuart is the first professional model with Down syndrome, and she is Australian!

Although the fashion industry has a long way to go in terms of diversity, Madeline is one of the women who are changing the game. As well as being a model, she has also represented Queensland at the Special Olympics in cricket and basketball.

Figure 11.53 Madeline Stuart models at the New York Fashion Week

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

DNA testing

A person's DNA can provide information relating to their ancestry or parentage, confirm if they have a hereditary disease, and inform whether they are a carrier for genetic disorders that may affect their children.

genetic screening genetic tests carried out across the population to identify people at risk of genetic disorders

Genetic screening is a type of genetic testing, but instead of identifying a genetic condition, it is used to evaluate an individual's risk of developing a certain disease. These tests are routinely done for anyone in the population, even if they have not shown a family history of the disease. Genetic screening is usually done during pregnancy and at birth. In Australia, about 99% of babies are screened every year. Of the babies screened, around one in every thousand has a condition that would otherwise have gone undetected.

WORKSHEET Social, economic and ethical implications of genetic testing

Genetic screening provides an opportunity for preventive measures and early treatment. However there are numerous associated social, economic and ethical implications. Access the worksheet in the interactive textbook to explore these.

Figure 11.54 In New South Wales, the newborn bloodspot screening test screens for cystic fibrosis, phenylketonuria, hypothyroidism, MCAD and congenital adrenal hyperplasia.

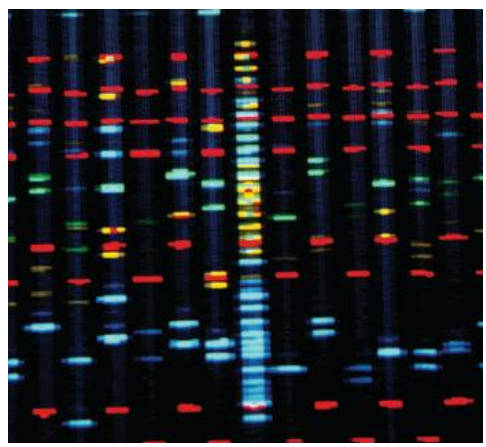


Figure 11.55 A DNA sequence or 'genetic fingerprint' on a computer monitor. The development of fast computers made the analysis of DNA sequences possible.

Try this 11.9

Genetic screening

In your class, divide into teams and engage in a discussion about perspectives within a scenario about genetic testing. You may wish to consider the following scenario, although your teacher may provide you with an alternative.

A woman who is 12 weeks pregnant attends a clinic and expresses her concern about her husband's family history of Huntington's disease (HD). Her sister-in-law tested positive last year, although she is not yet showing symptoms of the disease, but the woman's husband refuses to be tested. Due to this, the woman is asking for her unborn baby to be screened to determine whether it carries the HD gene. If the test comes back positive, which means that her husband carries the HD gene, the woman will discuss terminating the pregnancy with her husband.

Consider each person's perspective in this scenario. Reflect on what they might understand, how they might respond, and what they value regarding the issues raised. Don't forget to consider the legal and ethical issues.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Advances in science 11.2

Precision medicine

Pharmacogenomic tests look for genetic variants that are associated with an individual's response to specific medicines, by testing genes that affect drug metabolism. Its goal is to help doctors to select the drugs and doses that are best suited to each person.

Figure 11.56 Research has shown that people with red hair tolerate pain differently to people with other hair colours. Due to a mutation on the MC1R gene, they require more anaesthesia but need lower doses of opioids as they are more responsive to those painkillers.

Quick check 11.18

1. **Explain** why an individual might choose to be screened for genetic diseases.
2. **Identify** some ethical issues with genetic testing.

Manipulating DNA: Applications of genetic technologies

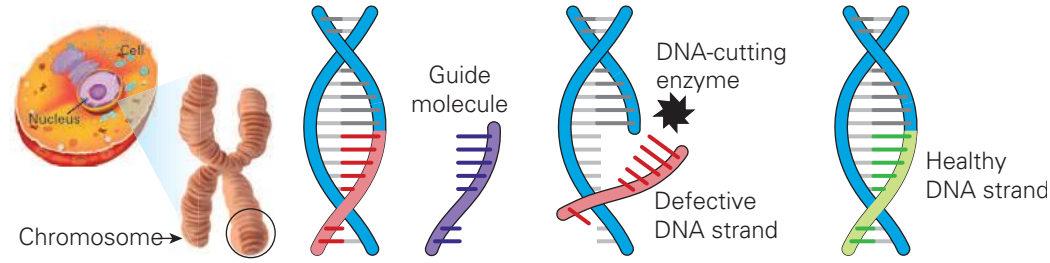
genetic engineering deliberately modifying genetic material to manipulate the characteristics of an organism

Genetic engineering technology allows scientists to manipulate genetic material and transfer genes between different organisms.

One of the most exciting developments of the last decade is CRISPR, a technology that can edit genetic material quickly and cheaply. Developed by Jennifer Doudna and Emmanuelle Charpentier, the CRISPR tool lets scientists change or delete DNA bases and insert entirely new genes. The gene editing technology has almost endless potential, including editing crops so they're more nutritious or able to survive in different conditions, curing genetic diseases, producing powerful new drugs or even resurrecting extinct species. In 2022, a New Zealand woman became the first to receive CRISPR treatment to treat heart disease by permanently lowering her cholesterol.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



VIDEO CRISPR

Figure 11.57 CRISPR gene editing technology allows DNA to be manipulated in a highly precise way.

Genetically modified organisms

A **genetically modified organism** (GMO) is an organism whose genome has been altered by humans. Commonly, they are crop species that have been modified to improve growth rates, yield, quality and nutritional value. Genetic modification can decrease pest and disease susceptibility, reducing the need for pesticides.

genetically modified organism an organism that has had its genome altered using genetic engineering techniques

Agricultural practices have changed to include the widespread use of genetically engineered crops. Crop plants are modified to have a greater tolerance to environmental stressors such as drought or heavy metals, allowing plants to grow in new areas. For example, some plants have been genetically engineered to grow with less water so that they are more resistant to climate change. Until recently, only three GM crops were approved to be grown in every mainland Australian state: canola (oilseed rape), cotton and safflower. After a ban was lifted, a wider range of GM crops can now be grown in every mainland state.

Figure 11.58 Golden rice and normal rice

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 11.59 Mosquitoes have been genetically modified to slow the growth of malaria-causing parasites in their gut, preventing transmission of the disease to humans.

Genetic engineering is also helping to alleviate global malnutrition and disease. A type of rice called golden rice has been engineered to prevent blindness in children caused by vitamin A deficiency. Another type of GM rice has been developed that has four times more iron than normal rice.

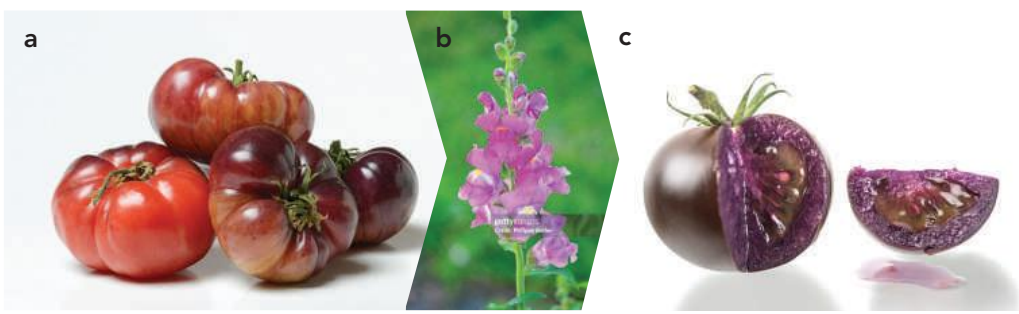
INVESTIGATION

Explore! 11.9

Genetically modified tomatoes

Many foods come from genetically modified organisms, and we call them GM foods. The Flavr Savr tomato was the first commercially grown GM food that was granted a licence for human consumption. Released in 1994, the tomato had an improved shelf life and was developed for long-distance shipping. Recently, a GM tomato has been developed that contains higher levels of anthocyanins, a pigment that occurs naturally in purple or blue fruits and vegetables such as blueberries or red cabbage. By transferring a snapdragon gene into a tomato's genome, they have produced a purple tomato that has the same levels of anthocyanins as blueberries.

1. Research why the team chose to genetically modify a tomato.
2. The high levels of anthocyanins in the purple tomatoes are beneficial for several reasons. Research the effect of anthocyanins on:
   - plant reproduction and survival
   - human health.



(a) Existing, purple-skinned tomatoes do not contain useful levels of anthocyanins.

(b) Genes from purple snapdragon flowers were added to the tomato. The snapdragon genes act like 'on switches', causing the purple pigment to be expressed throughout the tomato, instead of just in the skin.

(c) The resulting purple tomato is high in anthocyanins, which have a range of benefits for human health.

Figure 11.60 The process by which the John Innes Centre and the Sainsbury Laboratory created a GM purple tomato, which was approved for growing and breeding in the US in 2022

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 11.61 Cassava root has been genetically modified to have increased levels of beta carotene (right). This decreases post-harvest deterioration and also improves the nutritional value of the crop.

Did you know? 11.11

De-extinction

De-extinction is the process of bringing an extinct species back to life through genetic engineering by using fragments of DNA from preserved specimens.

De-extincting species is a controversial idea, and many scientists argue that funding would be better spent conserving existing species and their habitats. A start-up biotechnology company called Colossal Biosciences quickly raised millions of dollars after announcing plans to de-extinct the woolly mammoth, the thylacine and the dodo.

Figure 11.62 A model reconstruction of a dodo on display in the Birds gallery at the Natural History Museum in London.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 11.63 Transgenic C5 plums contain a gene that makes them resistant to plum pox virus.

Transgenic organisms

transgenic organism an organism that possesses a foreign gene or segment of foreign DNA in its genome because of human experimentation

Transgenic organisms (TGOs) are the result of a type of genetic modification where a 'foreign' gene, or a segment of 'foreign' DNA is inserted into an organism's genome. A foreign gene is one that is taken from another species. All transgenic organisms are GMOs, but not all GMOs are transgenic.

By inserting human genes into mice, human diseases can be mimicked, particularly as the genome and physiology of mice are so similar to humans. Transgenic mice are being used to study conditions such as obesity, heart disease, diabetes and Alzheimer's disease. Transgenic pigs are being investigated as a source of organs for transplants, which could address severe donor organ shortages. CRISPR technology has greatly reduced the complexity of the creation of transgenic animals, making the process faster and cheaper.

Human genes have been engineered into other mammals to supply the protein products of those genes, usually for medical purposes.

For example, transgenic goats have been genetically engineered to produce milk that contains human antithrombin III. This is a protein that is used to prevent clots in patients with hereditary antithrombin deficiency when they are in surgery or giving birth. A herd of approximately 80 goats could supply enough human antithrombin III for all of Europe.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 11.64 A CSIRO study found that genetically modified sheep grow bigger and faster and can produce more milk and wool. However, they required more care than non-GM sheep.

Gene therapy

Gene therapy is a process by which a copy of a functional gene is introduced into an organism. The gene is then switched on to produce the functional protein that is missing. This technique aims to treat inherited disorders like cystic fibrosis by directly targeting the genotype (unlike treatments that target the symptoms). Technical difficulties may arise when trying to specifically target the cells of affected tissue, and when targeting one specific gene without interfering with the function of other essential genes. Ethical issues also arise. Some people argue that gene therapy should be restricted to somatic tissue only, so the introduced gene is not transmitted through to the next generation. What do you think about this issue?

gene therapy a process by which a copy of a functional gene is introduced into an organism

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Advances in science 11.3

DNA data storage

Digital technology currently works on the binary system, which only uses the digits 0 and 1. Any information that is input digitally is converted to this system, and digital devices will change those values to the necessary form of information. It's predicted that by 2035 the total volume of digital data generated by humans is expected to reach 2142 zettabytes (a zettabyte is equivalent to 1 000 000 000 000 000 000 000 bytes). Currently, most data are stored in the 'cloud', but the cloud is actually huge data centres stored in warehouses that require large amounts of energy to run.

However, by translating binary (0 or 1) values into one of the four DNA bases, it is possible for DNA to be reliably used to store huge amounts of digital data. Some scientists say that the entire world's data could be stored in DNA that would fill a shoebox.

Rather than storing 0s and 1s individually, DNA allows them to be stored in pairs such as this:

- 00 A
- 01 T
- 10 C
- 11 G.

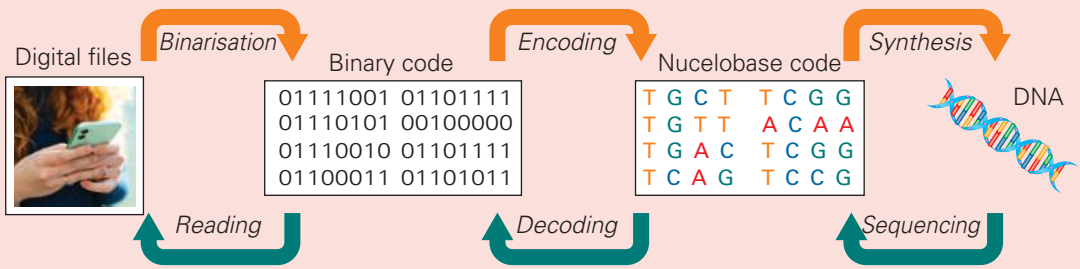


Figure 11.65 Encoding data into DNA code might be the future of efficient data storage.

After storing data in DNA, it can then be read using a DNA sequencer. This reads all of the bases and then converts it to binary. Improvements in sequencing techniques allow for billions of DNA sequences to be easily read at once and, when kept in suitable conditions, DNA can be preserved for hundreds of thousands of years without any energy input.

New sequencing techniques are also allowing sections of DNA to be used as identification tags. This DNA barcoding is accelerating the pace of research in fields such as chemical engineering, materials science and nanotechnology.

Quick check 11.19

1. **Recall** what GMO stands for.
2. **Describe** the process of gene therapy.
3. **State** an example of the application of genetic screening.
4. **Discuss** the reasons for the adoption of genetic screening by groups in society.
5. **State** five conditions that are screened for in New South Wales through the newborn bloodspot screening tests.

WORKSHEET Applications of gene technology in conservation

Applications of gene technology in conservation

Wildlife conservation in Australia has started using gene technologies in innovative ways to help direct conservation management. Genome mapping of vulnerable or endangered species such as koalas is undertaken to help identify suitable habitats and potential threats from disease, with the possibility of enabling vaccine development. Another initiative collects genetic material shed by organisms (fur, feathers, scales, excreta) from which DNA is extracted and sequenced. The organisms can then be identified for specific locations. This non-invasive method of monitoring

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

populations and their distribution ensures that the right management strategies are selected and implemented.

Use the worksheet linked in the Interactive Textbook to explore these conservation applications further.

Applications of gene technology in industry

Microorganisms including bacteria and yeasts have widespread and economically important uses in industry to produce pharmaceuticals and other therapeutic agents, enzymes, organic compounds, fuels, novel materials, foods, beer and other fermentation products, as well as to decompose waste, remove toxins and recycle materials. Microorganisms sourced from nature and bred for desirable traits have been used for more than a century, but gene technologies offer rapid, productive and cost-effective improvements as well as completely new technologies. For example, proteins can now be synthesised in the laboratory without using living cells. DNA, RNA, enzymes and ribosomes can make proteins *in vitro* (using laboratory equipment).

Use the worksheet linked in the Interactive Textbook to explore these industrial applications further.

WORKSHEET Applications of gene technology in industry

Section 11.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 11.4 questions

Remembering

1. If a mutation is to be passed on to the next generation, **state** where it must have occurred.
2. **Define** the term 'mutagen'.
3. **Recall** the definition of a genetically modified organism.
4. Using the table below, answer the following questions.

Second letter in the codon

First letter in the codon	U		C		A		G		Third letter in the codon
U	UUU	Phe (F)	UCU	Ser (S)	UAU	Tyr (Y)	UGU	Cys (C)	U
	UUC		UCC		UAC		UGC		C
	UUA	Leu (L)	UCA		UAA	STOP	UGA	STOP	A
	UUG		UCG		UAG	STOP	UGG	Trp (W)	G
C	CUU	Leu (L)	CCU	Pro (P)	CAU	His (H)	CGU	Arg (R)	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Gln (Q)	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Ile (I)	ACU	Thr (T)	AAU	Asn (N)	AGU	Ser (S)	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lys (K)	AGA	Arg (R)	A
	AUG	Met (M) START	ACG		AAG		AGG		G
G	GUU	Val (V)	GCU	Ala (A)	GAU	Asp (D)	GGU	Gly (G)	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glu (E)	GGA		A
	GUG		GCG		GAG		GGG		G

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The original DNA strand is GTC GGG ATA CGG CTC.
A gene mutation occurs, whereby the C in the first codon is replaced with a T, resulting in GTT GGG ATA CGG CTC.

a. **State** the name of this gene mutation.
b. **State** the mRNA strand that was copied from the original DNA strand.
c. **State** the new mRNA strand produced from the mutated DNA strand.
d. **State** whether the amino acids stay the same or change.
e. Another mutation occurs, whereby a C was added to the beginning of the above original DNA strand, giving CGTC GGG ATT CGG CTC.
State the name of this mutation and describe how it would affect the subsequent amino acids that it codes for.
f. Write out the mRNA code for this mutation and **identify** the corresponding amino acids.

Understanding

5. **Explain** what will happen if a nucleotide is deleted from the sequence of nucleotides within a gene.
6. **Explain** what usually results when mutations occur in non-germ (somatic) cells.
7. **Explain** whether or not all mutations are detrimental (harmful).
8. **Explain** how a mutated gene can lead to a genetic disorder.

Applying

9. **Illustrate** a diagram to outline how non-disjunction may occur and cause aneuploidy.
10. **Describe** an example of how gene modification has been used in the agricultural industry.

Analysing

11. **Contrast** a genetically modified organism and a transgenic organism.
12. **Contrast** a spontaneous mutation and an induced mutation.

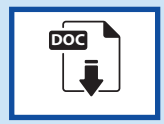
Evaluating

13. Using the DNA sequence ACAATTGGTAGCTGAGTTGGCCCGTA, **create** an example of the following mutations:
    a. substitution
    b. inversion
    c. deletion
    d. insertion.
14. **Discuss** why the substitution of one nucleotide may not be as critical to the functioning of the protein as the deletion or insertion of a nucleotide.
15. **Propose** an explanation for the relationship between increased rates of skin cancer and the thinning of the ozone layer.
16. **Construct** a mind map that shows the different types of mutations that may occur.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist



Success criteria I am now able to…		**Linked questions**
11.1	identify that all organisms contain genetic information.	
11.1	investigate and model the arrangement of genetic information in an organism.	
11.1	define and compare the terms DNA, gene, chromosome and genome.	
11.1	relate the structure of DNA to its functions.	
11.1	as an example of scientific discovery, compare the contributions of scientists involved in the discovery of the structure of DNA.	
11.2	relate the structure of DNA to its ability to replicate.	
11.2	describe how genetic information is passed to offspring through sexual and asexual reproduction.	
11.3	identify that genes and environmental factors interact to produce traits.	
11.3	use Mendelian inheritance to explain the connection between genotype and phenotype.	
11.3	use pedigrees to show how a single gene affects a trait and can be used to predict patterns of inheritance.	
11.3	use Punnett squares to show how a single gene affects a trait and can be used to predict patterns of inheritance.	
11.4	explain how mutation in DNA results in genetic variation with beneficial, harmful or minimal effects on organisms' functioning.	
11.4	identify examples of current and emerging genetic technologies.	
11.4	discuss applications of genetic technologies in conservation, agriculture, industry and medicine.	
11.4	discuss applications of genetic testing and associated social, economic and ethical implications.	
11.4	use scientific understanding, factual evidence and ethical principles to describe the ethical implications of the continued use of the HeLa stem cell line.	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Data questions

A student prepared an onion root tip slide and examined the cells using a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

Stage of cell cycle	Number of cells recorded
Interphase	340
Prophase	13
Metaphase	4
Anaphase	3
Telophase	6

She then calculated the mitotic index for different areas of the root tip. The graph shows her results.

1. The mitotic index of dividing tissue is calculated with the following formula:

$$\text{mitotic index} = \frac{\text{number of cells seen that were undergoing mitosis}}{\text{total number of cells seen}}$$

Calculate the mitotic index of the tissue shown in the table.

2. The duration of any phase of the cell cycle can be calculated with the following formula:

$$\text{phase duration (minutes)} = \frac{\text{number of cells seen in that phase}}{\text{total number of cells seen}} \times \text{cell cycle duration of the organism}$$

The cell cycle duration for the onion is 24 hours.

Calculate the duration of metaphase.

3. **Identify** the trend shown in the graph.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4. **Extrapolate** the data in the graph to estimate the mitotic index of the cells found 2 mm from the root tip.

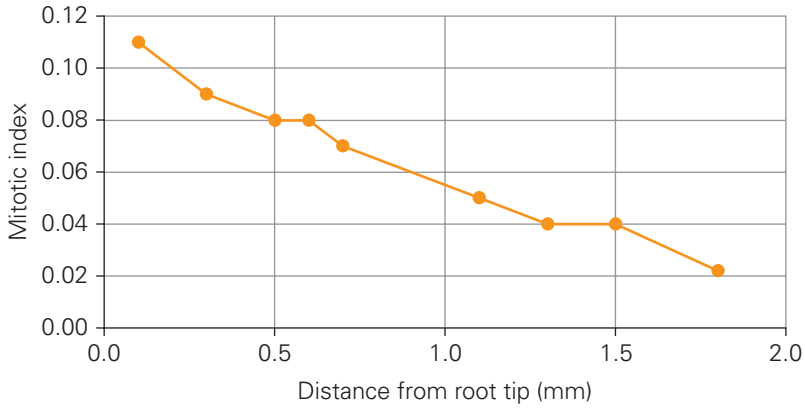


Figure 11.66 Mitotic index plotted against distance from root tip

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

M activity: Designing and prototyping an assistive device for individuals with a genetic disease

Background information

When a mutation occurs that is not beneficial, complications occur. An example of a disease with genetic causes is scoliosis. Scoliosis is a sideways curvature of the spine that usually occurs before puberty. Genetic diseases such as cerebral palsy and muscular dystrophy can cause scoliosis, but the cause of most scoliosis is unknown.

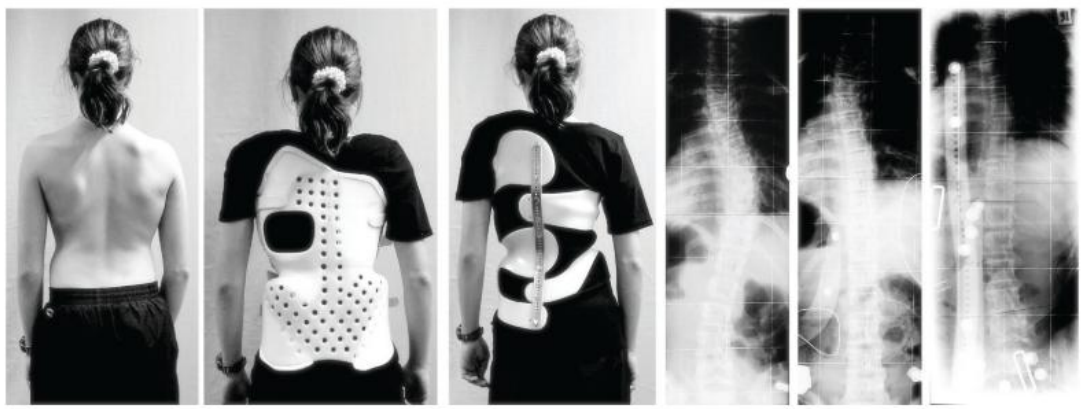


Figure 11.67 Various brace designs can be used for the treatment of scoliosis.

DESIGN BRIEF

Research a genetic disease. Design and build an apparatus that can help to improve the quality of life for people with the selected disease.

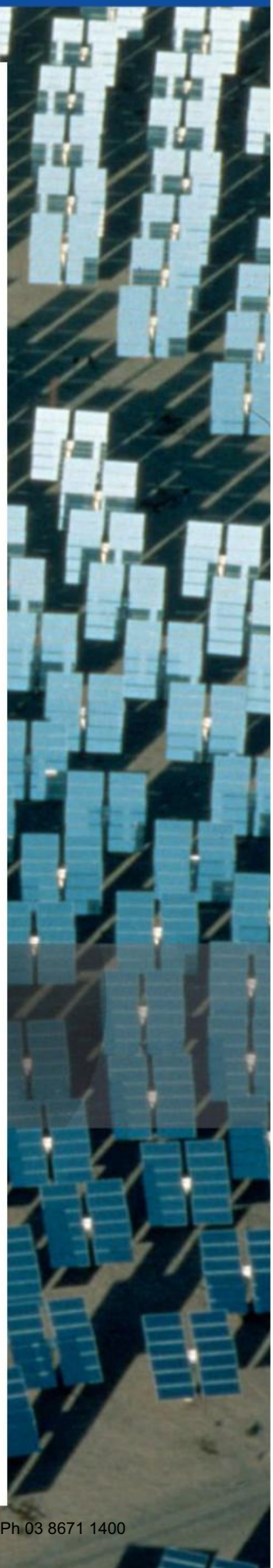
Activity instructions

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life for people with that condition. Consider how the product would be built and marketed. Each team member needs to have a clear role but must be able to contribute to all aspects of the project.

Suggested materials

- computer
- pencil
- paper
- ruler
- balsa wood
- plaster
- papier mâché
- chicken wire
- 3D printer
- cardboard
- poster paper

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134



Research and feasibility

1. Research genetic diseases and as a group decide which genetic disease will be the focus.
2. Create a table of the causes and effects of the disease.

Genetic disease cause	Effects on part of body	Ideas to help
Muscular dystrophy Muscle loss	Reduced joint movement	Brace and orthotics for feet
Haemophilia Blood doesn't clot effectively	Whole body can be bruised easily	1 Creation of children's play suit 2 Creation of some type of buffing edging that could be applied to furniture

3. Find pictures or diagrams of current equipment used and annotate them with features and characteristics that relate to assisting people living with this disease.

Design and sustainability

4. Sketch potential design solutions (at least two) and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current aids or tools (if any)?
5. Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

Create

6. Build a prototype of your design using available construction materials.

Evaluate and modify

7. Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.
8. Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.
9. Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 12

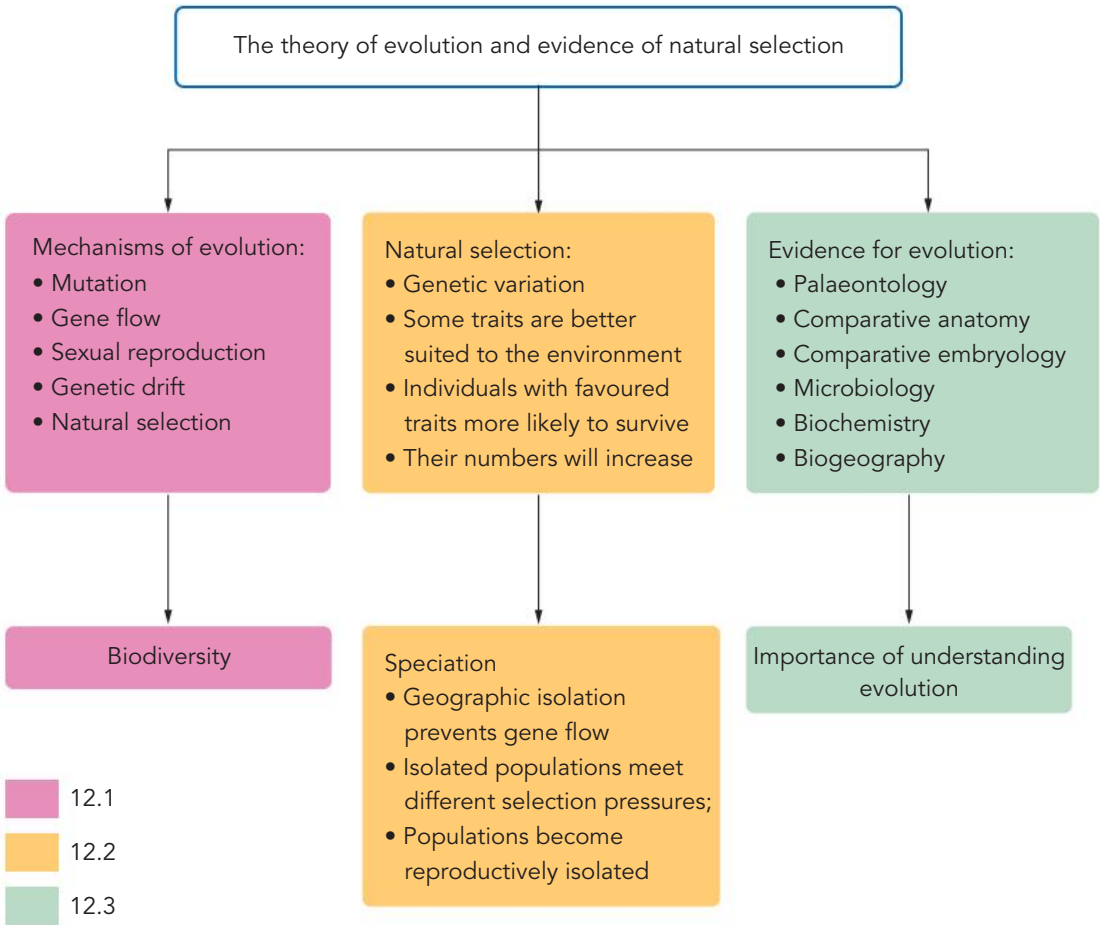
Evolution

Chapter introduction

Life on Earth has been evolving for billions of years, resulting in an enormous diversity of organisms. But despite the differences, there are also similarities. While koalas, quolls, frogs and dolphins all look different, their skeletons are organised in the same way. This can be explained by evolution: the idea that all organisms on Earth are the living descendants of common ancestors that have changed over a long period. The evidence we see in the fossil record, molecular biology and other fields of science supports the theory of evolution. In this chapter, we will look at the evidence that supports the theory for evolution and evaluate the key processes involved.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

absolute dating
adaptation
allele frequency
analogous structures
artificial selection
biodiversity
biogeography
biostratigraphy
biota
bottleneck effect
convergent evolution
direct (evidence)
divergent evolution
DNA hybridisation
ecosystem diversity
endangered
endemism
evolution
evolutionary tree
extinct
fertile
fossil
fossil record
fossilisation
founder effect
gene flow
genetic diversity
genetic drift
genetic variation
half-life
homologous structure
index fossil
indirect (evidence)
megafauna
natural selection
population (ecological)
radioisotope
relative dating
reproductive isolation
selection pressure
selective advantage
selective breeding
speciation
species
species diversity
stratigraphy
trace fossil
variation
viable

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

12.1 Evolutionary change

WORKSHEET
Mechanisms for evolution

Learning outcomes

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

1. describe the place of natural selection within an outline of the processes of evolution.
2. outline how natural selection can lead to changes within and between species.
3. outline how isolation (geographical or reproductive) following natural selection can lead to changes within and between species.
4. using evidence, investigate and explain how the diversity of organisms has changed over time.
5. describe how Aboriginal and/or Torres Strait Islander Peoples' artwork indicates changes in plants and animals, including megafauna.

evolution change in the genetic composition of a population during successive generations, which may result in the development of new species

population (ecological) a group of a particular species living and interbreeding in the same geographical area

genetic variation the differences in DNA sequences between individuals within a population

allele frequency the relative proportion of a specific allele within a population

variation the range of differences or diversity in traits, characteristics or genetic make-up among individuals

Evolution is a complex process that encompasses genetic changes occurring over extended periods within **populations**. These changes, in conjunction with environmental influences, give rise to phenotypic variation among individuals. The primary source of **genetic variation** is mutation, which introduces new genetic material into a population. Additionally, meiosis and the random fertilisation of gametes during sexual reproduction contribute to the reshuffling and mixing of existing genetic material.

Within a population, individuals possessing phenotypic traits that enhance their ability to survive and reproduce in a particular environment have a higher likelihood of passing on their advantageous alleles to their offspring. Over time, these advantageous alleles become more prevalent in the population, causing a shift in **allele frequency**.

The effect of these genetic changes, driven by natural selection, genetic drift, migration, and other evolutionary forces, leads to the changes in populations and the potential emergence of new species.

Mechanisms of evolution

Evolution can take place through five key drivers:

- mutation
- gene flow
- genetic drift
- natural selection
- sexual reproduction – including meiosis and random fertilisation (as discussed in Chapter 11).

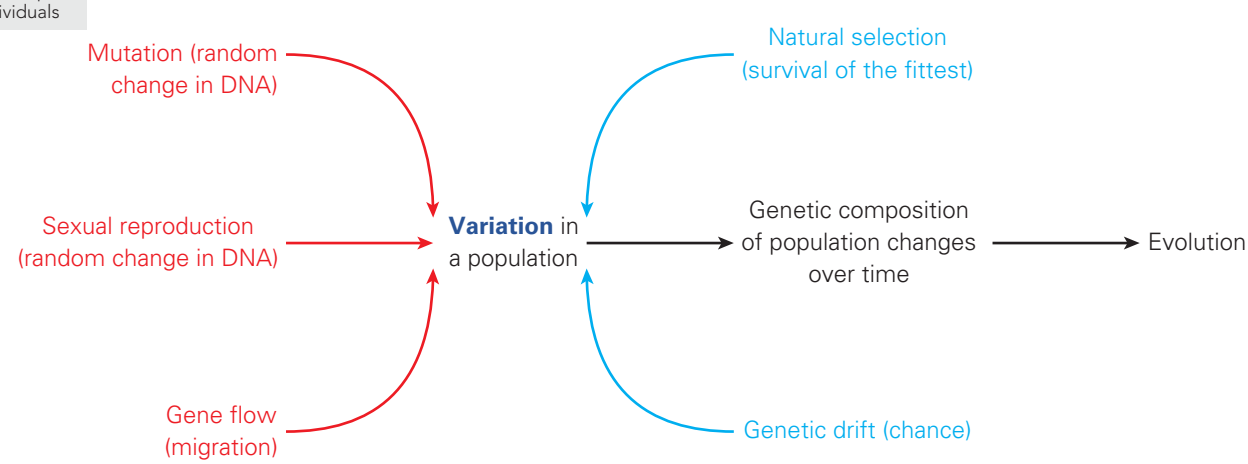


Figure 12.1 Changing genetic information changes the variation within a population. This leads to an overall change in the genetic composition of a population, which means evolution is occurring.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Mutation

For evolution to occur, there must be a change in the genetic make-up of at least one individual. Recall from Chapter 11 that a mutation is a spontaneous or induced change in the genetic sequence of an organism's DNA. A mutation must be in the gamete cells (sperm or ova in animals) for the mutations to be passed down to future generations (Figure 12.2). Mutations in somatic cells (all other cells) cannot be passed down and therefore do not have a role in evolution.

Mutation is a random process, and changes can occur anywhere in the DNA of the gametes. Mutations may have various effects on the phenotype of organisms, ranging from no change to large changes. These large changes include genetic diseases that are associated with a loss of function. Since genetic disease reduces an individual's chance of survival, these are often not passed on to future generations. However, in specific circumstances, mutations that are usually detrimental or harmful can be beneficial.

Mutations are the ultimate source of genetic variation as they introduce new alleles. If the mutation is advantageous and occurs in the gametes, it may lead to a shift in the genetic composition in the population. This links to another driver of evolution called natural selection, which will be covered later. Along with natural selection, mutations are one of the main drivers of evolution and without them, evolution cannot occur.

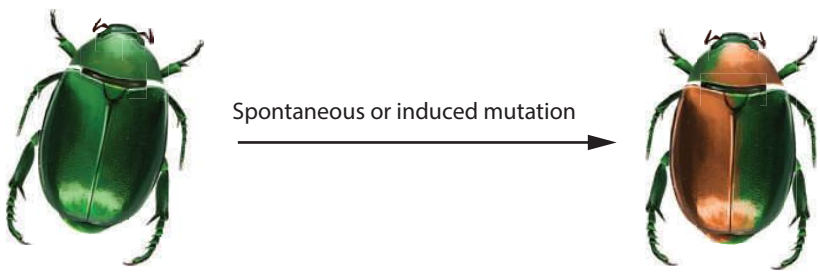


Figure 12.2 A spontaneous or induced mutation in a gamete can cause a change in the DNA code passed onto the next generation, contributing to evolution.

Genetic disease	Outcomes
Albinism	No or little colour in skin, hair and eyes Reduced sun protection
Cystic fibrosis	Thicker mucus lining organs Respiratory and other health problems Fatigue
Duchenne muscular dystrophy	Progressive muscle weakness
Haemophilia	Blood cannot clot properly Abnormal bleeding
Sickle cell anaemia	Sickle-shaped red blood cells can interrupt blood flow Pain and fatigue Resistance to malaria which is beneficial in areas where malaria is common

Table 12.1 Some examples of genetic diseases caused by mutations

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Gene flow

gene flow the movement of genetic information from one population to another through migration

Another way genetic variation can be introduced into a population is through **gene flow**, which is enabled by migration. Migration is the movement of individuals from one population to another, while gene flow specifically refers to the movement of alleles from one population to another. Gene flow can only occur between separate populations of the same species because they must be able to interbreed and reproduce (Figure 12.3).

Gene flow can occur through different kinds of events, such as seed dispersal, animals moving to different areas or movement forced by natural disasters such as fires or floods.

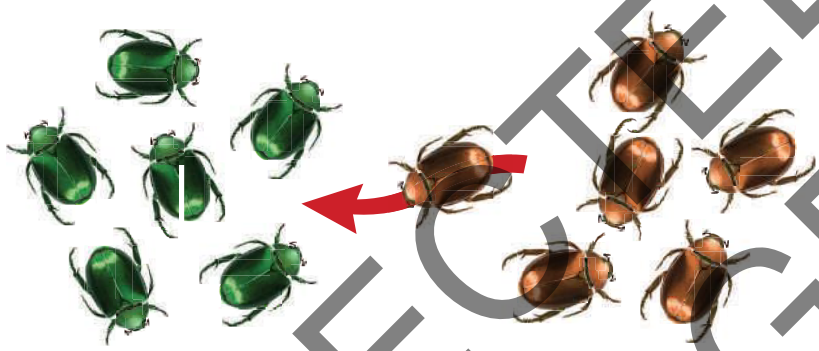


Figure 12.3 Unlike alleles created by mutations, the alleles brought in by gene flow already exist within the species but are absent from some populations.

UNCORRECTED SAMPLE PAGES

Did you know? 12.1

Koalas and gene flow

While the koala is one species, there are five distinctly different genetic populations across Australia's east coast. The loss of genetic diversity from small, fragmented koala populations increases their risk of extinction due to both inbreeding and an inability to adapt when the environment changes. Maintaining genetic diversity in koalas is critical to their survival. This can be achieved by maintaining large, interconnected natural populations or through wildlife translocation, which is an artificial form of gene flow.

Wildlife translocation is being used with increasing frequency to conserve a variety of species, but it is also controversial, even among conservationists. Potential problems include the spread of diseases, increased stress and mortality of relocated animals and negative impacts on the organisms at release sites.

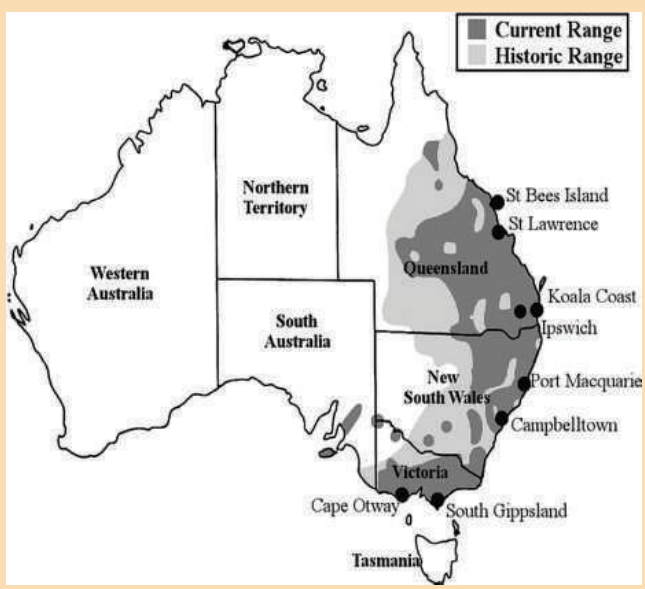


Figure 12.4 The survival of koalas depends on maintaining gene flow between increasingly isolated populations.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Genetic drift

Genetic drift is random changes in allele frequencies in a population over time. Genetic drift is always happening in a population, as chance outcomes of meiosis, crossing over and fertilisation affect the genetic composition of each new generation. The effects of genetic drift are greater in smaller populations. Two extreme examples of genetic drift are the **founder effect** and the **bottleneck effect**.

genetic drift the random change in allele frequencies in a population from generation to generation

founder effect the decrease in genetic diversity that occurs when a population is descended from a small population that separated from a larger one

bottleneck effect the decrease in genetic diversity resulting from a rapid reduction in the size of a population, due to events such as natural disasters or human activities such as overhunting

The founder effect occurs when a small number of individuals leave a population and establish their own colony. Simply by chance it is likely that allele frequencies in the small founder population will be different from those in the larger population they came from.

A population 'bottleneck' occurs when the size of at least one generation of the population is severely reduced, perhaps by a chance event such as an environmental disaster or because of human activities such as habitat destruction or overhunting. This results in the deaths of many organisms, leaving behind a small, random population of survivors (Figure 12.6).

The bottleneck effect and the founder effect both result in populations with an allele frequency that differs in a random way from their source or original population. In both cases, because the remaining population is much smaller than the original population, genetic drift is amplified and there is also less genetic diversity. These factors may result in the new population becoming genetically distinct from the original population over time.

Figure 12.5 Norfolk Island, which is located between New Zealand and New Caledonia, was used as a penal colony and then abandoned in 1855. Most present-day islanders are the descendants of a founder population made up of a small number of the descendants of the HMS Bounty mutineers and Tahitian women who relocated from Pitcairn Island in 1856. The founder effect has significantly affected height and the prevalence of cardiovascular diseases of the islanders.

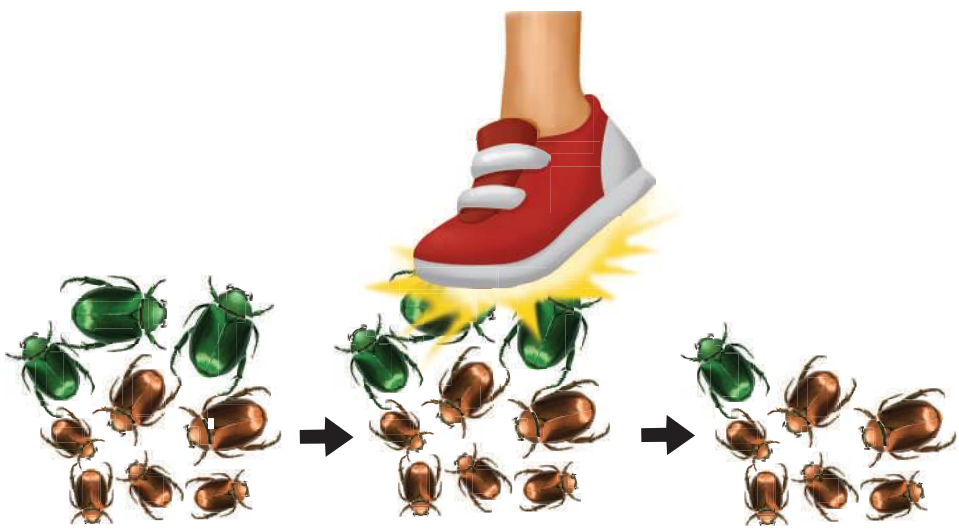


Figure 12.6 Someone standing on some beetles by accident is a random or chance event. If the population size is greatly reduced to the extent that the genetic composition of the beetles' population has changed, this is an example of how the bottleneck effect contributes to evolution.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 12.2

The black robin bottleneck

Before European colonisation, black robins (*Petroica traversi*) were common on Rēkohu/Chatham Islands, New Zealand. However, their population crashed once rats invaded the archipelago, and by 1976, only seven birds survived. The birds were moved to a predator- free island, but scientists were not confident that the population, which had only one breeding pair (called Old Blue and Old Yellow), would recover due to the severe genetic bottleneck. However, as of 2022, there are approximately 290 surviving birds, and surprisingly, although the bird is certainly one of the most inbred in the world, genome analysis has shown that the frequency of harmful genetic alleles in the population did not increase as a result of the bottleneck.

Figure 12.7 The black robin (*Petroica traversi*)

VIDEO
Natural selection

An outline of natural selection

Individuals in a population show a wide range of phenotypes. Some of these phenotypes may provide **selective advantages**, meaning those individuals are more likely to survive and reproduce, passing on those advantageous alleles to their offspring. This is **natural selection**. Often, the term 'survival of the fittest' is used to describe this: the organisms that are best suited to their environment – that is, have the best **adaptations** – are more likely to survive and pass on their genetic information. For example, look at Figure 12.8. These beetles live in the leaf litter on the forest floor and have natural variation in their colour that is heritable: they can be green or brown. The birds eat more green beetles, because they are easier to spot. The green beetles are at a selective disadvantage (they have a lower fitness value), so fewer green beetles will survive to reproduce and fewer alleles that code for green colouring will be passed on to the next generation. The brown beetles are better adapted to their environment and have the better colour for survival (that is, the brown beetle is at a selective advantage; it has a higher fitness value). Alleles that code for brown colouring are more likely to be passed on to the next generation. Natural selection is covered in more detail in the next section.

selective advantage
the characteristic of an organism that enables it to survive and reproduce better than other organisms in a population

natural selection
a process in which organisms whose phenotype is best adapted to their environment are more likely to survive and reproduce

adaptation
a characteristic that contributes to an individual's ability to survive in its environment

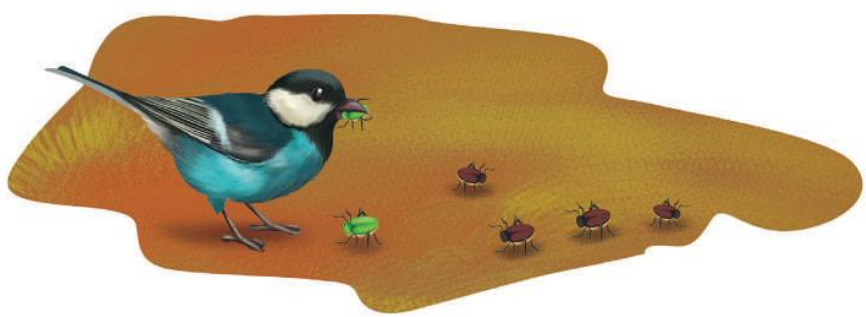


Figure 12.8 Alleles within a population are less likely to be passed on to the next generation if they are disadvantageous. Brightly coloured beetles are more likely to be spotted by predators, which puts these organisms at a disadvantage.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigtion 12.1

Modelling genetic drift, natural selection and gene flow

Be careful

Do not consume food items.

Aim

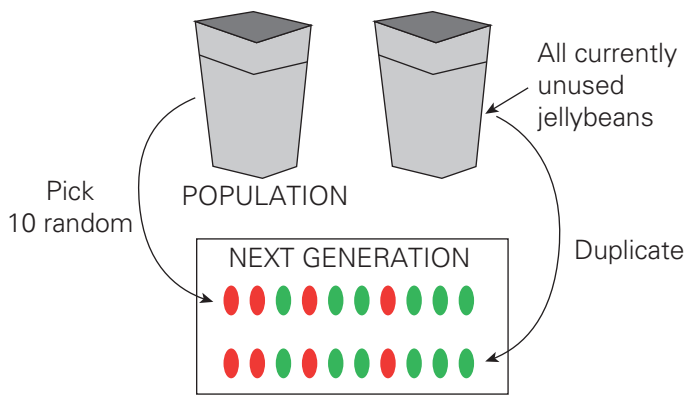
To simulate genetic drift, natural selection and gene flow in a population of jellybeans and analyse the consequences of each.

Materials

- jellybeans: 20 red, 20 green and 20 blue (or anything similar e.g. coloured paper)
- 2 cups, one labelled 'Population'
- 1 piece of paper labelled 'Next generation'

Procedure for genetic drift

1. Copy the results table into your science journal.
2. Place 10 red jellybeans and 10 green jellybeans in your 'Population' cup. These represent the alleles of the population. Place all other jellybeans in the other cup for unused jellybeans. Record the current population in your results table.
3. With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the 'Next generation' piece of paper. These are the alleles that will be passed on.
4. Duplicate the 10 jellybeans (e.g. if you picked out 4 red and 6 green, pick out another 4 red and 6 green from the other cup and place them on the paper.)
5. Record this in the next row of your results table.
6. Place the remaining beans from your 'Population' cup into the cup for unused jellybeans and place the new generation alleles on the piece of paper into the 'Population' cup.
7. Repeat steps **3–6** until you have 10 rows of data or until one colour is eliminated.



Procedure for natural selection

1. Copy the results table into your science journal.
2. Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
3. Imagine that green has a selective disadvantage (the opposite of a selective advantage). Pick out 3 green jellybeans from the population and move them into the cup for unused jellybeans.
4. With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the piece of paper.
5. Duplicate the 10 jellybeans on the piece of paper. Record this in the next row of your results table.

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6. Place the remaining beans from your 'Population' cup into the cup for unused jellybeans and place the new generation alleles on the piece of paper into the 'Population' cup.
7. Repeat steps **3–6** until you have 10 rows of data or until one colour is eliminated.

Results for genetic drift and natural selection

Generation	Number of alleles	
	Red	Green
1	10	10

Procedure for gene flow

1. Copy the results table into your science journal.
2. Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
3. Add 5 blue jellybeans into the 'Population' cup.
4. With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the piece of paper.
5. Duplicate the 10 jellybeans. Record this in the next row of your results table.
6. Place the remaining beans from your 'Population' cup into the cup for unused jellybeans and place the new generation alleles on the piece of paper into the 'Population' cup.
7. Repeat steps **4–6** until you have 10 rows of data or until two colours are eliminated.

Results for gene flow

Generation	Number of alleles		
	Red	Green	Blue
1 (before migration)	10	10	0

Discussion

1. Plot your results on a graph. There should be one each for the genetic drift, natural selection and gene flow simulations.
2. Describe what happened in each case. How do the results compare to what you would expect for each process?
3. Did your results show any colour becoming extinct in your population?
4. Compare your results for genetic drift with those of another classmate or group. Account for any contradicting trends in the results.
5. Propose what step **6** could represent in the genetic drift simulation.
6. Propose what step **3** could represent in the natural selection simulation.
7. Propose what step **3** represents in the gene flow simulation.
8. Imagine that the introduced blue allele also had a selective advantage in the gene flow simulation. How would you simulate this scenario?
9. Imagine that there was a mutation in one of the jellybeans that turned it orange. How could this affect future generations?
10. What assumptions have we made about the red, green and blue alleles in this simulation?
11. Can reliable conclusions and predictions be drawn from the results? Justify your answer.
12. List some limitations of this simulation compared to what happens in real life. Justify your response.
13. What are some ways the simulations can be improved?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 12.1

1. **Define** the terms 'evolution', 'population', 'variation' and 'adaptation'.
2. **Identify** the five drivers of evolution.

Figure 12.9 Cane toads in rural areas have larger parotid (toxin) glands than those in urban areas. This may be because bush toads are at a higher risk of predation, so it is a selective advantage to have glands that can produce more bufotoxin.

Try this 12.1

Drivers of evolution

Summarise the five drivers of evolution you have learned by copying and completing the following table.

Mechanism	Definition	Contribution to evolution?
Mutation		
Gene flow		
Genetic drift		
Natural selection		
Sexual reproduction		

Biodiversity as a function of evolution

Biodiversity (biological diversity) refers to the variety of life on Earth. It includes **species diversity** (the number of different species within an ecosystem), **genetic diversity** (the number of different alleles of genes in a population) and **ecosystem diversity** (the variation in ecosystems in a given area). Over time, populations within a species can become so different that they become a different species, increasing biodiversity. Therefore, it is evolutionary processes that have resulted in the biodiversity we see today.

biodiversity the variety of life on Earth, including the diversity of species, the genetic differences within a species, and the ecosystems where species are found

species diversity the number and abundance of different species in a given area

genetic diversity the number of different alleles of genes in a population

ecosystem diversity the variation in ecosystems in a given area

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Australia's unique biodiversity is best explained by isolation. Australia was once part of a supercontinent called Gondwana that even earlier was the southern part of a giant land mass called Pangaea. Gondwana was made up of the continents and countries that we know today as South America, Africa, Australia, India and Antarctica. Gondwana is thought to have begun breaking up approximately 140 million years ago. As a result, our plants and animals have been isolated over a long period of time from the plants and animals of other continents and land masses.

As the continents moved across the surface of Earth, so too did their assemblages of plants and animals. This not only created geographical barriers (like oceans, mountain ranges and large rivers), but over time it also brought new combinations of species together.

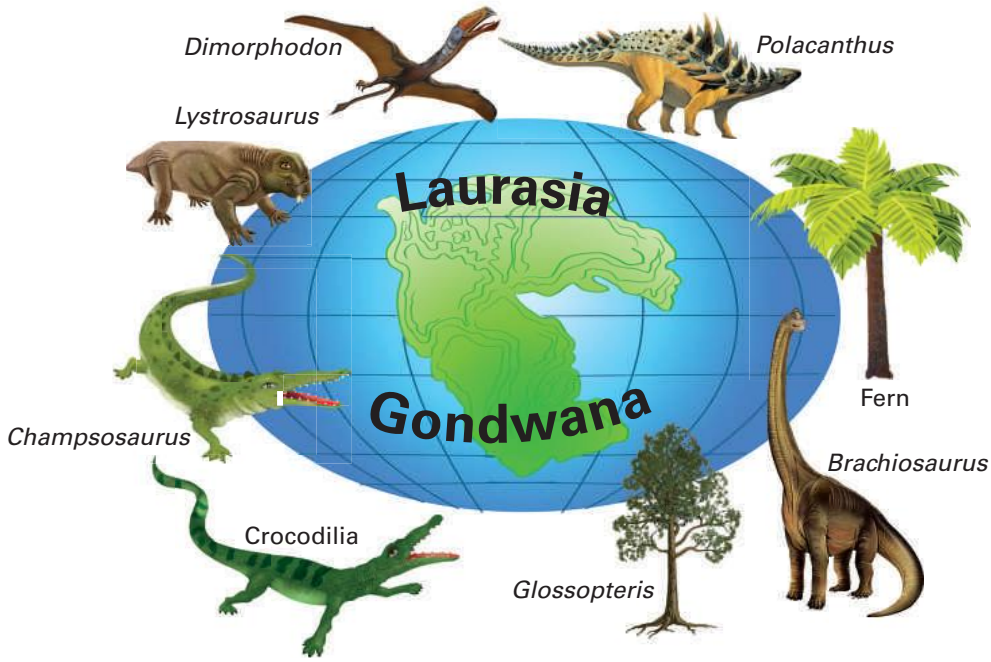


Figure 12.10 This map shows the supercontinent Pangaea before it separated into a northern Laurasia and a southern Gondwana.

Quick check 12.2

1. **State** what is meant by the term 'biodiversity'.
2. **Recall** what supercontinent Australia was once part of.
3. **Explain** how the movement of continents led to increased species diversity.

Biodiversity through time

Our understanding of the origin of life on Earth is based upon the scientific evidence of the fossil record and genetic comparisons to modern life forms. Earth is approximately 4.5 billion years old, and the most primitive cells first developed some 3.5 billion years ago. Although life appeared early in Earth's history, evolution beyond the simple cell stage did not occur until much later – approximately 600 million years ago. Since then, the biodiversity that exists on Earth has fluctuated depending on changes in the environment. Figure 12.11 shows a timeline of the major stages in the development of life on Earth.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Biodiversity has been affected by five mass extinction periods. In mass extinctions, a huge number of Earth's species die off over thousands or even millions of years. One of the best-known causes of a mass extinction is an asteroid impact that may have killed off the dinosaurs. An asteroid is suspected to be involved in just one case of mass extinction, but volcanic activity has been implicated in at least four. Here are some hypothesised causes for the biggest mass extinctions on Earth:

- volcanic activity
- climate change
- changes in deep ocean oxygen levels
- changes in sea level.

A combination of the above causes may have contributed to mass extinctions, which caused major and rapid changes in the Earth's **biota**. If there is sufficient genetic variation in a species when an environmental change occurs, such as when there is a volcanic eruption, some organisms within a population will be better suited to that new environment than others. The survival of the better-adapted individuals will result in a change in the genetic composition of the species' population, resulting in their evolution over time.

biota
all the living organisms found within a particular region or ecosystem

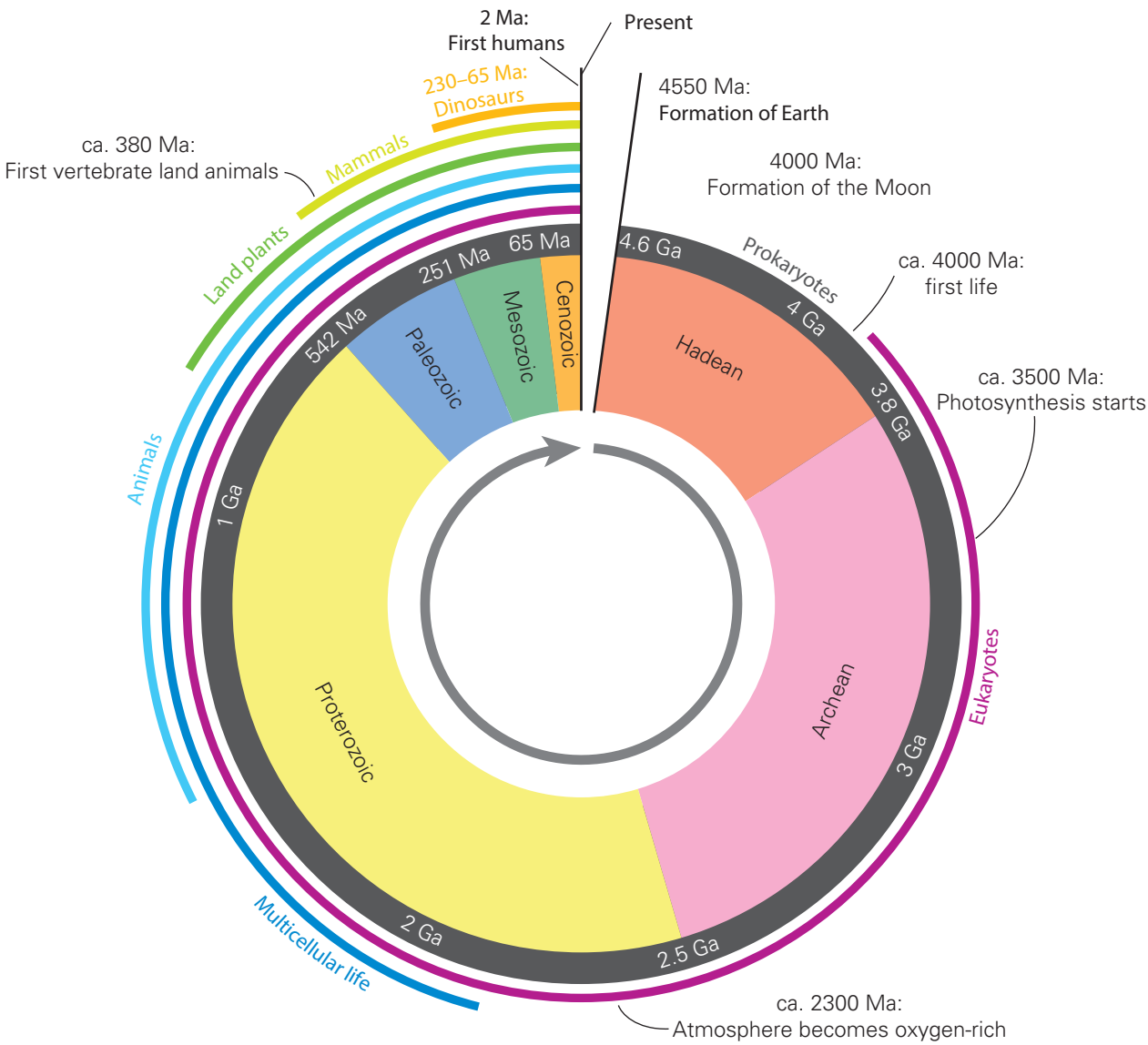


Figure 12.11 A timeline of Earth's history (ages are abbreviated from Latin: Ga (giga-annum) represents a billion years, Ma (mega-annum) is a million years)

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 12.12 Eastern Australia is littered with the remnants of hundreds of volcanoes. The region was affected by repeated volcanic super eruptions between 256 and 252 million years ago. Evidence of this can be seen in light-coloured layers of volcanic ash in sedimentary rock (left). There is also evidence that large areas of forest disappeared, and many species of animals became extinct after the supervolcanoes erupted, contributing to the global Permian–Triassic mass extinction. Wollumbin (Mount Warning) is the central volcanic remnant of an ancient shield volcano that last erupted around 23 million years ago.

The biodiversity of Australia

endemism
a state of being confined to a small defined geographic location

Australia's biodiversity is rich and unique; estimates suggest that between 7% and 10% of all species on Earth are found here. This unique biodiversity developed in isolation over millions of years, producing a high level of **endemism**. This means a large number of species found in Australia are unique to the region and are not naturally found anywhere else in the world. This high level of endemism is attributed to Australia's geographical isolation and long evolutionary history, which allowed the development of species adapted to the specific Australian environment. Australia's biodiversity is also influenced by its unique environmental conditions, which include high fire frequency, nutrient-poor soils, climatic variability and a relatively flat landscape.

Human settlement, both by Aboriginal and Torres Strait Islander Peoples and then by Europeans, has affected Australia's biodiversity. It is likely that the initial Aboriginal and Torres Strait Islander Peoples arrived in Australia via south-east Asia when ocean levels were lower and there were more land bridge connections between landmasses. Many researchers believe that humans first arrived in Australia 60 000 years ago. Since then, the landscape has been modified by burning, habitat clearing and fragmentation, overhunting and the spread of invasive species, much of the change happening since European settlement.

Australian megafauna

When Aboriginal and Torres Strait Islander Peoples first arrived, **megafauna** would have been common. These were large land animals that evolved millions of years after the dinosaurs became extinct. In Australia, they included *Diprotodon optatum*, the largest marsupial ever to have lived, with a shoulder height of 1.8 metres and weighing close to 3 tonnes; *Palorchestes azael*, a marsupial about the size of a horse; *Thylacoleo carnifex*, a 1.5-metre-long marsupial lion; and *Wonambi naracoortensis*, a 50 kilogram, 5-metre-long snake.

Climate change and the arrival and spread of modern humans in Australia are believed to have led to the extinction of many megafaunal species. The fossil record suggests that the Australian megafauna went extinct after the arrival of Aboriginal and Torres Strait Islander Peoples, due to overhunting or gradual destruction of megafaunal habitats by traditional techniques such as firestick burning. However, rock art and fossil evidence also suggest that megafauna coexisted with humans for many thousands of years.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Some experts have suggested that the climate getting drier and more arid caused the extinction of megafauna. Analysis of fossil teeth has found that climate change had a significant impact on megafaunal diets. This is due to sustained changes in water and vegetation availability, as well as increased fire frequency.

Figure 12.13 Illustrations of *Palorchestes azael* (left) and *Diprotodon optatum* (right), two extinct species classified as Australian megafauna

Explore! 12.1

Ancient artwork

Aboriginal and Torres Strait Islander Peoples have a cultural heritage closely tied to their environment. Their artwork, including rock engravings and paintings, reflects their connection with the land and its biodiversity.

These artworks often depict changes in plants and animals over time, including the presence of megafauna.

Use the internet to research Aboriginal and Torres Strait Islander art to find specific examples of rock engravings, paintings, and other forms of art that depict changes in plants and animals over time. Focus on artwork that illustrates megafauna.

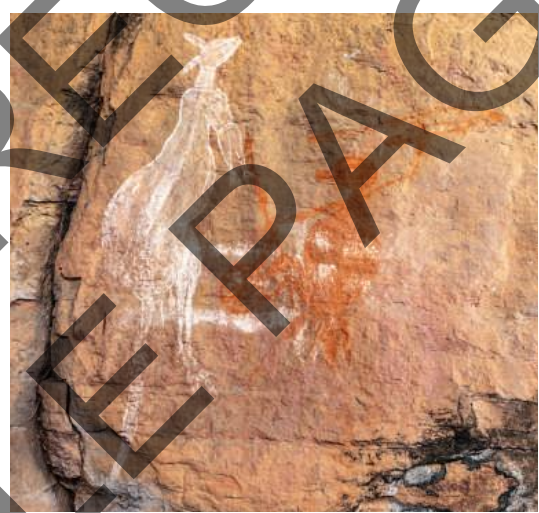


Figure 12.14 Rock art depicting a hunter and a giant kangaroo in Anbangbang Shelter at Burrunggui, Kakadu National Park

For each example, provide the following details:

- when it is believed the artwork was created
- where the artwork is found (e.g., specific rock sites, regions)
- describe the artwork, including the plants and animals depicted.

Once you have selected your examples, explain how the artwork may be used to indicate changes in plants and animals over time.

Figure 12.15 Rock art at Ubirr, Kakadu National Park (left) and Keep River National Park (right)

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Maintaining biodiversity

Maintaining biodiversity is extremely important.

A reduction in biodiversity can have huge impacts on ecosystems and result in loss of species that are beneficial to other species, including humans. Maintaining diversity means keeping a full range of species in ecosystems in order to conserve the variety of organisms on Earth. Species are considered **endangered** if they meet the criteria set by the International Union for Conservation of Nature (IUCN). These include species whose numbers have experienced a reduction of 70% in a decade and species with fewer than 250 mature individuals living in a single population.

endangered
a species that is in danger of becoming extinct

extinct
a species that has no living members

Endangered species are at risk of becoming **extinct**, especially if there is not enough genetic variation in the population. However, species can be at risk even if their population is large. Changes in the environment that may cause extinction include new diseases, new predators, competition with a better-adapted species and loss of habitat.

There are ways that humans can help to maintain biodiversity. In situ protection occurs within their natural habitat, such as in conservation reserves. Ex situ conservation occurs outside natural habitat, such as in zoos or seed banks. Many zoos have captive breeding programs in which they breed captive animals to help the survival of endangered species. Such programs aim to reintroduce the species back into the wild, which would aid in keeping population numbers up and limiting inbreeding.

Figure 12.16 The Bellinger River snapping turtle is listed as critically endangered after a virus caused mass mortality of the turtles in early 2015, wiping out an estimated 90% of the population in just six weeks. Under the Saving our Species program, the NSW Government is funding several actions to conserve the turtle, including captive breeding and habitat restoration.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Explore! 12.2

Conservation of Australian species

Australia has the fourth-highest level of species extinctions in the world and is in the top three for critically endangered animals. Since 2016, 202 animal and plant species have been listed as threatened, including the regent honeyeater, northern quoll and the black-flanked rock wallaby. Conduct some research to answer the following questions.

1. Choose an endangered Australian species and research conservation efforts put into place for the species. These may include education programs, captive breeding, legal protection of habitats and ecosystems created artificially.
2. Many of today's species have survived by adapting where other species, less well adapted, died out. Do you think we should try to protect endangered species to preserve biodiversity? Why?

Figure 12.17 A regent honeyeater (*Anthochaera phrygia*)

Quick check 12.3

1. **Define** the terms 'biodiversity', 'endangered' and 'extinct'.
2.
3. **Name** one change in the environment that may lead to the extinction of a species.
4. **Discuss** how humans have affected biodiversity and therefore evolution.

INVESTIGATION

Explore! 12.3

Cat curfew

Australia has the highest mammal extinction rate in the world: 34 mammal species have disappeared since European settlement. Introduced predators, particularly feral cats and the European red fox, have caused most of these extinctions. Extinctions have been particularly high in arid and semi-arid regions. One report found that every year each individual feral cat in Australia kills 390 mammals, 225 reptiles and 130 birds. Combined with those killed by domestic cats, over two billion native animals are killed by cats each year in Australia.

In many Australian local council areas, cat owners must now keep their pets on their own land. In some areas, there is a curfew, so cats are not allowed outside after dark; in other areas, cats are not allowed outside at all.

Investigate different strategies that have been implemented or proposed to address the issue of mammal extinctions caused by cats in Australia. These might include, but are not limited to:

- legal restrictions (e.g. curfews, containment laws)
- culling of feral cats
- use of technology (e.g. GPS tracking, cat-proof fencing)
- community education and awareness programs
- Trap-Neuter-Return (TNR) programs
- habitat restoration and protection.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

For each approach, consider the following:

- How successful is this strategy in reducing the number of native animals killed by cats?
- Is this approach practical and achievable in the Australian context? Consider factors such as cost, resources and public acceptance.
- Are there any moral or ethical concerns associated with this approach?
- Will this strategy provide a long-term solution, or is it only a temporary fix?

Compare the different approaches, highlighting their strengths and weaknesses. Consider which approaches might work well in combination with others to provide a more comprehensive solution.

Based on your research and evaluation, formulate a proposal to address the issue of mammal extinctions caused by cats in Australia.

Figure 12.18 The Christmas Island pipistrelle (*Pipistrellus murrayi*, left) and the Bramble Cay melomys (*Melomys rubicola*, right) were the first Australian mammals to go extinct in the past 50 years.

Go online to access the interactive section review and more!

Section 12.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 12.1 questions

Remembering

1. **Define** the terms 'evolution' and 'population'.
2. **Name** one extinct Australian species.
3. **Name** one species deemed critically endangered within Australia.
4. **Define** the term 'variation' and give four different examples of variation within a species not provided in the text.
5. **Recall** where variation in a population comes from.
6. **Identify** an example of variation within a species that:
   a. increases an individual's chances of survival
   b. decreases the species' chance of survival
   c. does not affect the species' chance of survival.

Understanding

7. **Explain** how mutations contribute to variation within a species and, consequently, evolution.
8. **Explain** how gene flow can contribute to a change in the allele frequency of a population.
9. **Summarise** how a change of only one nucleotide in DNA can result in a different phenotype and eventually cause evolution.

Applying

10. **Construct** a diagram that links the terms 'evolution', 'gene flow', 'genetic drift and 'natural selection'.
11. **Explain** how extinctions can stimulate new biodiversity among species.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Analysing

12. **Distinguish** between species diversity and genetic diversity.
13. **Distinguish** between extinct species and endangered species.

Evaluating

14. **Discuss** why genetic biodiversity is important for the survival of a species.
15. In Earth's past, some species have been wiped out after an environmental change. **Decide** if this suggests the species had low or high genetic biodiversity and give reasons why this would occur.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

12.2 Natural selection and speciation

WORKSHEET Natural selection

Learning outcomes

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

1. explain the process of natural selection in detailed steps.
2. explain how isolation leads to speciation.

In Section 12.1, you read that there are five drivers of evolution: mutation, gene flow, genetic drift, natural selection and sexual reproduction. In this section, natural selection will be considered in more detail.

Darwin's finches

In 1831, at the age of 22, the naturalist Charles Darwin set out on a five-year voyage around the world to study and collect animal, plant and rock specimens. He visited the remote Galapágos Islands off the coast of Ecuador and recorded the plant and animal species of the islands.

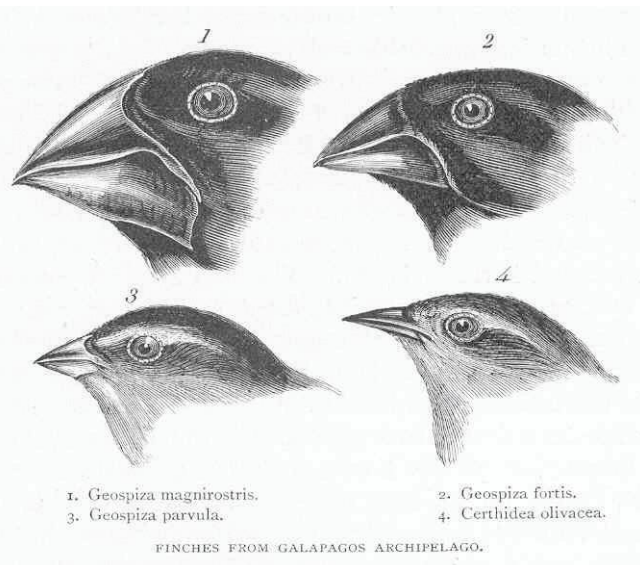


Figure 12.19 On the Galápagos, finches evolved based on different food sources.

Figure 12.20 John Gould published the first comprehensive survey of birds in Australia. He was accompanied by his wife, Elizabeth Gould, who was a talented ornithologist and illustrator in her own right. This image was taken from his book The Birds of Australia, which was published from 1840 to 1848 in seven volumes.

Initially, Darwin took little interest in a collection of finches taken from the islands, but this changed when the eminent ornithologist John Gould classified them as 12 new species. Gould had noticed that they showed great variation in their beaks. It was his observations that helped Darwin develop his theory of evolution.

Before Darwin, Jean-Baptiste Lamarck had proposed an early theory of evolution, suggesting that organisms could acquire traits during their lifetime and pass them on to their offspring. Although Lamarck's ideas were later challenged and largely replaced by Darwin's theory of natural selection, they laid important groundwork for the discussion of evolution.

Darwin speculated that although the different islands had similar animals and plants, many species seemed to have specialised features that were particularly suited to their local environments. For example, the different finch species had beaks suited to eating the food source that was available in the habitat they occupied on their island. Darwin explained how species change over time,

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

using the theory we know today as 'natural selection'. His insights were further supported by other scientists, such as Alfred Russel Wallace, who had independently also explored the relationships between species and environmental factors, helping to solidify the principles of natural selection.

Did you know? 12.3

Adaptations of Galapágos tortoises

Galapágos tortoises have variations in their shell shapes and sizes. Those with dome-shaped shells typically live on islands with lush, low-lying vegetation. Their dome-shaped shells and shorter necks are advantageous for grazing on the abundant vegetation found close to the ground. These tortoises don't need to stretch their necks much to reach food, so a more rounded shell provides better protection and stability.

Tortoises with saddleback shells are found on drier islands where vegetation is sparse and often elevated. Their shells are shaped like saddles, with a raised front that allows them to stretch their necks higher to reach food. This adaptation helps them access vegetation that is otherwise out of reach for dome-shaped tortoises.

Figure 12.21 Tortoise with dome shell

Figure 12.22 Tortoise with saddleback shell

The process of natural selection

WIDGET
Natural selection

Natural selection occurs when an environmental factor acts on the phenotype. That is, some individuals in the population are different from others and those differences provide an advantage or disadvantage for survival and reproduction. The following steps outline the process of evolution through natural selection.

1. Genetic variation naturally exists in the population due to processes such as sexual reproduction, genetic drift, mutations and gene flow.
2. This genetic variation means that some individuals within the population have traits better suited to their environment.
3. Individuals with favourable traits are more likely to survive and reproduce than others of their species and thus pass on those traits to the next generation. Those favourable traits are said to be 'selected for' by environmental (or selection) pressures.
4. Over time, individuals with the favourable traits become more numerous in the population.

An example is the case of the light and dark peppered moths (*Biston betularia*) in Britain. There are two varieties within the one species – one is light coloured, the other is dark coloured – and the colour is genetically determined. Look at the moths in Figure 12.23 – the light-coloured variety of the peppered moth initially had the favourable trait (selective advantage) as it blended well with the lighter lichen-covered bark of the trees. This meant that a hungry bird (the selecting agent) would be more likely to see the dark-coloured moth and eat them more often. Consequently, dark-coloured moths were rare. Light-coloured moths were better adapted to survive and reproduce, so they were able to pass on their genetic information to the next generation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

However, during the Industrial Revolution, pollution darkened the bark of trees. This gave the dark-coloured moths a selective advantage, as they were now better camouflaged against the trees and not as easily spotted by predators. Now the roles were reversed: light-coloured moths were at a disadvantage and their numbers fell. The darker moth was the 'fittest' or best adapted in this new environment and so was able to survive, reproduce and pass on its genetic information to the next generation. The proportion of dark moths rose. Interestingly, cleaner air in recent decades has seen the light-coloured moths favoured once again. This example also illustrates why genetic variation enables species to survive and adapt to new circumstances.

Figure 12.23 There are two variations of peppered moth: light and dark coloured. Can you see both moths in each image? The picture on the left shows the moths against a light tree bark. The picture on the right shows the moths against a dark tree bark.

Explore! 12.4

Doomed race theory

Use your preferred search engine to research how policies and attitudes towards Aboriginal and Torres Strait Islander Peoples in the 19th and early 20th centuries were influenced by scientific misconceptions about heredity and evolution. What were the misconceptions? How does it contrast to what we know now?

Quick check 12.4

1. **Recall** where Charles Darwin collected his finch specimens.
2. **Create** a flow chart of the four steps involved in the process of evolution by natural selection. Then annotate your flow chart to show how each step relates to the peppered moth example.

Selection pressures

Those organisms best suited to the pressures of their environment are more likely than others to survive, reproduce and pass on their genetic information to the next generation.

selection pressure a factor that affects the relative fitness or reproductive success of individuals within a population, leading to natural selection and potential changes in allele frequencies over time

We call these pressures **selection pressures** because they determine which variations provide individuals with better survival chances. Selection pressures refer to the factors that exert an influence on the fitness and reproductive success of individuals within a population. These pressures can be natural, such as predation, competition for resources, or climate conditions, or they can be anthropogenic, including human activities like habitat destruction or pollution. Selection pressures act as the driving forces behind natural selection, shaping the survival and reproductive outcomes of individuals based on their traits and adaptations.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Selective agents are specific factors or agents that directly cause the selection pressure.

Selective agents are often associated with specific traits or features of the environment that directly impact an organism's survival or reproductive success. For example, a selective agent could be a particular predator species that preys on individuals with certain characteristics, leading to the selection for traits that enhance evasion or defence against that predator.

VIDEO
Selection pressures

Selection pressures can increase or decrease the occurrence of a trait in a population. Selection pressures are not static and may change with time or with changes in the environment.

Figure 12.24 Variations of adult males of the frog species *Pristimantis leopardus* may experience different levels of reproductive success due to the selective pressures exerted by predation, competition for mates, and environmental conditions, thereby driving natural selection.

Density-dependent factors	Density-independent factors
Predators	Natural disasters
Resource availability (e.g. water, shelter, nutrients)	Abiotic factors (e.g. CO_2 concentration, temperature)
Disease	
Waste accumulation	

Table 12.2 Selection pressures can be either density independent or density dependent. Density-independent pressures are typically abiotic factors (such as natural disasters or climate events that affect populations regardless of their size). Density-dependent pressures are often biotic factors (such as predation or competition for resources), which vary in impact depending on the population's size or density.

Try this 12.2

Drug-resistant bacteria and traditional medicines

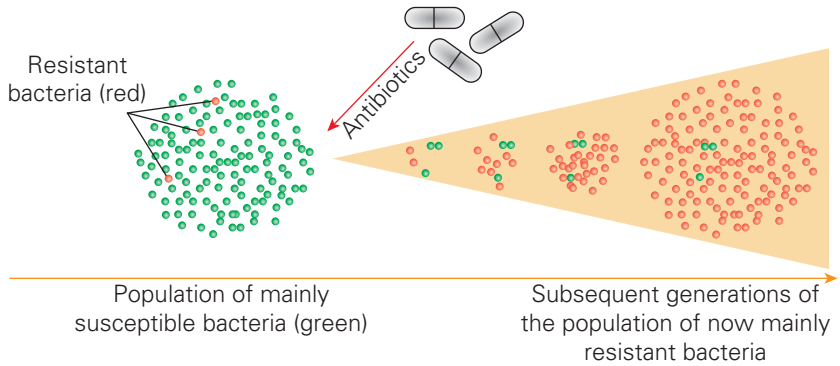
Antibiotics are medicines used to prevent and treat bacterial infections. However, some bacteria have mutations that make them resistant to the effects of the drugs. The World Health Organization has identified antibiotic resistance as one of the greatest threats to human health today, potentially causing up to 10 million deaths per year by 2050 if not overcome.

Some researchers are studying traditional bush medicines that have been used by Aboriginal and Torres Strait Islander Peoples for generations as alternatives to pharmaceutical antibiotics. Plants such as tea tree (*Melaleuca alternifolia*) and emu bush (*Eremophila* species) have been found to be as effective as some established antibiotics and may provide a solution for the current resistance crisis.

Figure 12.25 *Eremophila longifolia* is one of many species of plants commonly known as 'emu bush'.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Consider the following diagram carefully and then answer the questions that follow.



1. What variation between bacteria can you see in the original population?
2. Which phenotype is selected for (the fittest)? Which was selected against?
3. Which phenotype will contribute less to the next generation?
4. Which phenotype will survive in greater numbers to reproduce and pass on its genetic information to the next generation?
5. Identify the selecting agent.

Explore! 12.5

Bush medicines

The diagram in *Try this 12.2* demonstrates how bacteria can become resistant to certain drugs. The combination of evolutionary pressures and high use of antibiotics in contemporary society has seen the emergence of strains of diseases that are resistant to many drugs.

Since the first European settlers came to Australia, they have looked to Aboriginal and Torres Strait Islander Peoples' Knowledge of bush medicines. These medicines have developed over millennia through observation and experimentation, and that knowledge has been passed down from generation to generation. Now, there is increasing research directed at identifying compounds in traditional medicines for use in pharmaceuticals.

Unfortunately, there has been a historical tendency for non-Indigenous scientists to treat Aboriginal and Torres Strait Islander Peoples as merely as sources of information rather than collaborators in the production of new medicine. Today, however, there is a greater appreciation for the valuable input Aboriginal and Torres Strait Islander communities provide. One example is a dual patent that was granted to Griffith University and the Jarlmadangah Burru Aboriginal Corporation for an invention that relates to new analgesic (pain-relieving) compounds. John Watson, an elder from the Jarlmadangah Burru community, had his finger bitten off while on a crocodile hunting trip. He chewed the bark of the marjala plant and applied it to his wound, then travelled to a hospital. The pain had been stopped so effectively that it led to a collaboration with Griffith University to explore the commercial benefits of the plant.

Conduct some research into at least one of the plants used in the Aboriginal and Torres Strait Islander Peoples' pharmacopoeia and shown in Figure 12.26 to find out:

- what ailment it treats
- which part of the plant is used as a remedy or medicine
- how it is processed
- what new medicines (if any) scientists are trying to develop using the plant.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 12.26 Left to right, top to bottom: tea tree (*Melaleuca alternifolia*), corkwood tree (*Duboisia myoporoides*), kangaroo apple (*Solanum laciniatum*), Moreton Bay chestnut (*Castanospermum australe*), pale flax-lily (*Dianella longifolia*) and crimson turkey-bush (*Eremophila latrobei*)

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 12.2

Modelling natural selection

Aim

To model a beetle population to simulate natural selection and some of its consequences.

Background information

Let us make the following assumptions about a beetle population:

- The original population of 30 beetles consists of 10 red, 10 yellow and 10 green.
- Each year the beetles mate once at random, and each pair produces one offspring (30 beetles produce 15 offspring, increasing the total population to 45 beetles).
- The colour of the offspring is determined by these rules:

Parent colour		Offspring colour
Parent 1 colour	Parent 2 colour	
Red	Red	All red
Yellow	Yellow	All yellow
Red	Yellow	All green
Green	Yellow	½ green : ½ yellow
Green	Red	½ green : ½ red
Green	Green	¼ red : ½ green : ¼ yellow

- After the beetles have produced their offspring, a predator kills 1/3 of the total population (15 beetles) each year. Therefore, the population of beetles returns to 30 at the beginning of each breeding season.
- On average, the colour ratio of beetles lost to predation is: 3 red : 2 green : 1 yellow (this ratio is reflected in the coloured sides of the dice).
- Other than the deaths caused by the predator mentioned, there will be no further deaths or migration.

Materials

- small circular, coloured stickers (three red, two green, one yellow) that are added to the sides of a die
- 60 coloured cards of each type (20 red, 20 green and 20 yellow)

Procedure

1. Copy the results table into your science journal.
2. To create your original population of 30 beetles, take 10 red, 10 yellow and 10 green cards.
3. Shuffle these 30 cards to model the process of random mating and deal them out into 15 pairs.
4. Using the rules from the table, determine the colour of the offspring for each of the 15 pairs.
5. Take a beetle card that represents the colour produced for each of the 15 offspring and add them to the population, creating an overall population size of 45.
6. Due to predation, 15 beetles will die and be removed each year. This will be modelled by rolling the coloured die on 15 different occasions and removing the corresponding beetle colour from the population each time. If the die lands on a particular colour of beetle that has disappeared altogether from population, roll it again.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

7. After one year of mating and predation, complete column for year 1 in the results table, showing the total number of red, green and yellow beetles that remain in the population of 30.
8. Repeat the process of mating and predation by repeating steps **3–7** for as many trials as possible (up to a maximum of 10 trials, modelling 10 years).

Results

Record the total number of red, yellow and green beetles at the end of each year in the results table.

Colour of beetle	Number of beetles after year									
	1	2	3	4	5	6	7	8	9	10
Red										
Green										
Yellow										
Total	30	30	30	30	30	30	30	30	30	30

Discussion

1. Within the population of beetles you created, identify the beetle's phenotypic trait that was observed, and its variations.
2. Explain the crucial role that variation plays in natural selection.
3. Based on your observations, did any beetle colour give a greater chance of survival than other colours in the population? Explain your answer using the data from your results table.
4. Describe how the process of natural selection relates to genetics.
5. Was there any evidence of natural selection taking place in your population of beetles? Refer to your results in your answer.
6. Did your results show any coloured beetle becoming extinct in your population over the generations?
7. **a.** Think of another possible ratio of a beetle predation according to colour that differs from the 3 red : 2 green : 1 yellow used in this experiment.
   b. Using the predation ratio of beetles you provided in part **a**, write a hypothesis for this experiment.
8. Another group of students obtained a beetle population of 10 red : 10 green : 10 yellow after completing the same experiment and modelling the same mating and predation rules for 10 trials. What possible explanation could be given for these results?

Evaluation

Reliability

1. Compare the results between different student groups.
2. Can reliable conclusions and predictions be drawn from the results? Justify your response.

Limitations

3. Can you identify possible limitations of this method when applied to a real-life scenario? Justify your response.

Improvements

4. 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.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 12.5

1. Variation is essential for the process of natural selection to occur. **Explain** what 'variation' means, including where it comes from in a population.
2. **Define** the term 'selection pressure' and describe how it contributes to natural selection.

Speciation

speciation the process by which populations evolve to become distinct species

species a group of organisms consisting of similar individuals who can interbreed with one another

fertile able to reproduce

viable able to survive

Sometimes, natural selection can lead to a new species forming, which is called **speciation**. For this to occur, there needs to be one extra step in the process of natural selection: isolation.

A **species** is often described as a group of organisms that are phenotypically and genetically similar and are capable of interbreeding with each other to produce **fertile** and **viable** offspring. However, there are at least 26 recognised ways to define a species!

For example, the offspring of a male and female horse will be a horse that is able to mate and produce offspring with another horse. However, the offspring of a female horse and a male donkey is a mule. A mule is infertile, which means it is unable to produce offspring. This is evidence that horses and donkeys are two different species: they cannot produce fertile offspring.

Hybrids are usually sterile because they either have an extra chromosome that prevents the usual meiosis process, or the chromosomes are incompatible, which means that viable gametes are not produced. However, this is not always the case. A few female hybrids have successfully bred with individuals in the original parent population.

Geographical isolation

An essential feature in speciation is isolation of populations from one another to prevent gene flow. Isolation is not required for natural selection but is necessary for speciation.

Isolation may be caused by a geographical or physical barrier (for example, a large river, a desert or mountain range) or even a natural disaster like a fire, flood or volcanic eruption. The consequence is the original population is divided into two populations, not necessarily the same size.

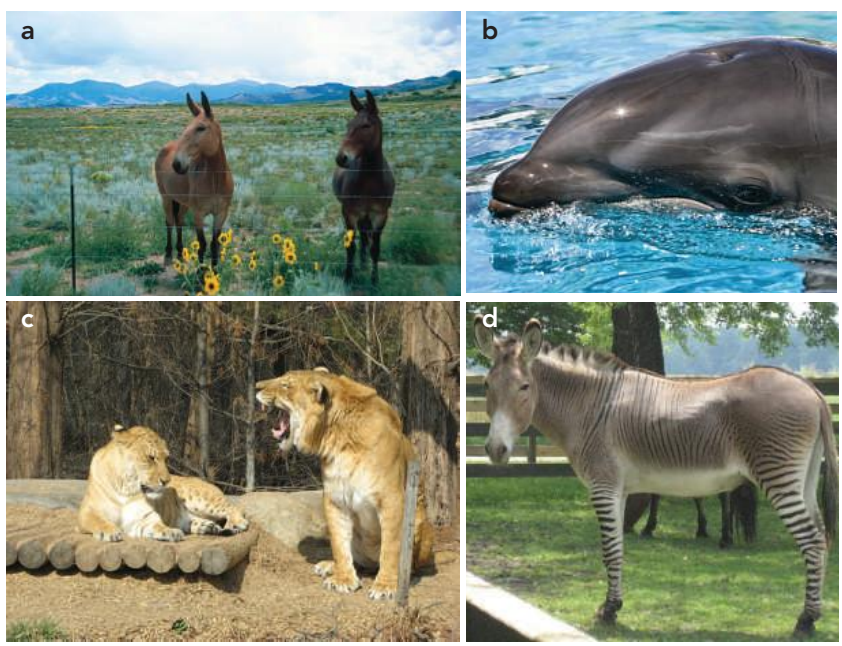


Figure 12.27 Examples of hybrids: **(a)** mule, **(b)** 'wolphin', **(c)** liger, **(d)** zonkey

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Selection

The isolated populations may now be exposed to different selection pressures; for example, one environment may be cooler than the other. Those organisms best suited to their environment will survive, reproduce and pass on their genetic information to the next generation. On the cold side of the mountain, individuals with thicker fur will be selected for, while on the sunny side of the mountain, those with a thinner coat will be selected for.

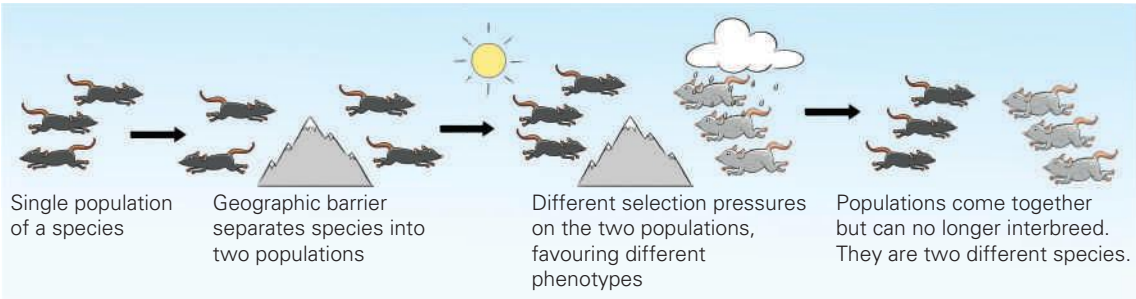


Figure 12.28 Natural selection with isolation can cause speciation.

Reproductive isolation

Over time, the different selection pressures on the two populations will change the genetic composition of the two populations in different ways. Eventually, enough differences may accumulate between the two populations that individuals cannot interbreed with one another to produce fertile and viable offspring. The two populations are now **reproductively isolated** and are two separate species.

reproductive isolation when members of two related populations can no longer interbreed

Advances in science 12.1

Rock wallabies

The brush-tailed rock wallaby (*Petrogale penicillata*) is facing extinction in New South Wales due to a combination of historical and ongoing threats.

Initially, their decline was driven by hunting, predation by introduced species like foxes and dogs, and competition from non-native herbivores such as feral goats and rabbits. These factors, coupled with habitat modification from human activities like fire and clearing, have led to significant population fragmentation.

Figure 12.29 A yellow-footed rock wallaby

The remaining populations are now small and isolated, which has disrupted gene flow and reduced genetic diversity. This genetic bottleneck makes them more susceptible to diseases and less adaptable to environmental changes.

Quick check 12.6

1. **Define** the term 'species'.
2. Speciation can occur as a consequence of natural selection with one additional step. **Recall** what must also occur and its role in speciation.
3. **Describe** how you could determine if two populations were the same species.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 12.3

Speciation story time

With a classmate, take turns telling stories of speciation. You may like to use the images below as inspiration. To tell a story of speciation, use all the scientific terms you have learned that relate to natural selection and speciation. Begin by talking about the possible variation that naturally exists in your organism's population, then a possible geographical barrier that could divide and isolate the population, finishing up with the process of selection and how this leads to the creation of a new species.

Figure 12.30 These Australian animals are perfectly suited to their environment and so can survive, reproduce and pass on their genetic information to the next generation.

Online natural selection simulations and computer-based applications

Simulations of natural selection are available on the internet. Search for 'PhET Interactive Simulation – Natural Selection' for a free example. It allows you to set up a population with certain characteristics, set some environmental conditions, and see what happens. Since natural selection is a process that can be modelled mathematically, it should not be a surprise that it can be simulated on a computer.

There are a number of computer-based applications that use the principles and mathematics of natural selection to improve designs or solutions. These apps set up and 'breed' a population of many designs or solutions each with a slight random 'mutation', leading to variation. The population is then tested in a simulation in which those best suited to chosen conditions 'survive' into the next generation. These are allowed to randomly mutate and breed, and the simulation is repeated, and so on, until a 'winning' design or solution is found.

Figure 12.31 Since 1900, 76% of genetic diversity in agricultural crops has been lost, but there is renewed interest in heirloom or heritage crops. Heritage apples are those that were grown before World War II. Some remain, but many have been lost after commercial orchards that grow mass-produced apples such as pink lady, Granny Smith and gala became more popular. New varieties of apples are constantly being developed to bring novelty to the apple industry. One example is the yello, a cross between a golden delicious apple and a heritage apple from Japan called senshu.

Artificial selection

Artificial selection is selection that does not happen naturally but is directed by humans. In other words, humans choose the characteristics they want passed on to the next generation and breed organisms with those traits. Thus, humans, not the environment, select who reproduces. For example, a farmer wants her cows to produce lots of milk, so she selectively breeds the best milk-producing cows and prevents the poorer producers from mating. Artificial selection is also called **selective breeding**, and humans have been using these techniques for thousands of years. Can you think of any other examples?

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Artificial selection is certainly beneficial for humans, but this manipulation typically reduces biodiversity and alters the course of evolution. The outcome is often a population that is genetically very similar and has low variation. For example, there is a worldwide decline in agricultural crop diversity. A 2021 WWF report found that 75% of the food that humans eat comes from just 12 plant sources and 5 animal sources. Of the plants, just three crops make up 60% of the plant-derived calories in the human diet.

These crops are artificially selected for their production values, but what are the chances of the population surviving if it is exposed to a change in environment or a new disease? Reduced variation in the population may mean the crop is more susceptible to threats like these.

Figure 12.32 Artificial selection in action: each of these organisms was selectively bred for particular characteristics.

Did you know? 12.4

Broccoli and kale are the same

Did you know that broccoli, kale, cabbage, brussels sprouts, cauliflower and gai lan are just some of the variations of the plant species *Brassica oleracea*? Each variation is called a 'cultivar', which is a plant variety produced by selective breeding.

Figure 12.33 Some of the many varieties of *Brassica oleracea*

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 12.6

Dog breeds

All domestic dogs belong to one species, *Canis familiaris*, so how can they appear so different? Go online to research the following topics.

1. Choose one dog breed and identify its unique characteristics.
2. Critique some of the ethical considerations involved in breeding a dog for a particular characteristic that may be detrimental for their health. For example, the cocker spaniel's long floppy ears make it particularly susceptible to ear infections. The pug's wrinkled face is susceptible to infections resulting from dead skin cells and moisture being trapped in the folds of skin.

Figure 12.34 Despite their differences, domestic dogs are all the same species!

Human reproductive technologies

To assist human reproduction today, we use many reproductive technologies that involve artificially selecting the genetic information that is passed to the next generation. In this way, humans are affecting their own genetic diversity and consequently affecting our own evolution.

For example, in vitro fertilisation (IVF) involves selecting viable sperm and combining them with eggs in a test tube.

After fertilisation, the healthiest embryo is selected for development and the remainder are frozen.

Medical technology lets us genetically test embryos prior to their implantation and genetically screen babies. Decisions made based on information gained by using these technologies can change the genetic composition of the human population in the next generation. Evolution takes an extremely long time, so the results of our actions will not be seen for thousands of years.

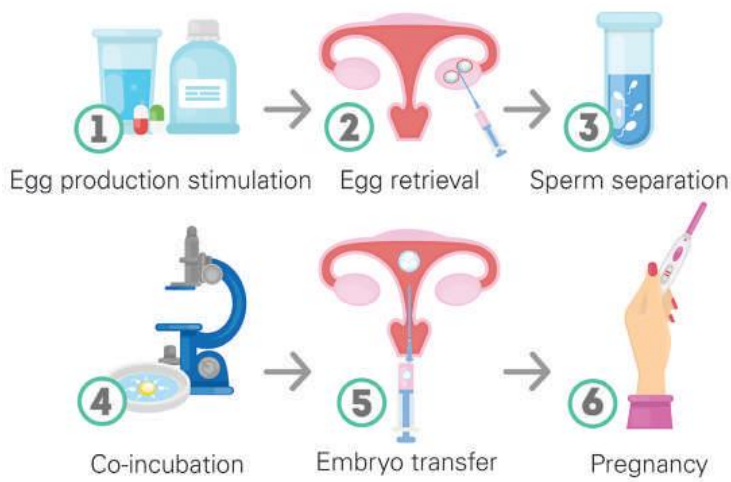


Figure 12.36 The process of IVF artificially selects the eggs, sperm and embryos that have the best chance of survival.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Gene technologies

Desirable traits can also be acquired using gene technology, rather than relying on selective breeding. Gene technology lets us transfer genes from one individual or species to another. Gene therapy allows faulty genes found in an organism to be replaced by the normally functioning gene. Genetically modified organisms (GMOs) are produced when an organism has its DNA altered or modified using genetic engineering.

Consider how gene therapy could change the biodiversity of the human population. Would there be more or less variation? And what would this mean for the process of evolution? What about GMOs? Genetically engineered cotton crops (*Bacillus thuringiensis* cotton; Bt cotton for short), were created to produce an insecticide to combat bollworm. GM cotton was first grown in Australia in 1996, and now, over 99.5% of cotton grown in the country is genetically modified. What effects could GMOs have on biodiversity and evolution?

Figure 12.35 Worldwide, bollworm causes millions of dollar's worth of damage a year to crops such as cotton and vegetables.

Try this 12.4

Genetic technologies

Choose a genetic technology (e.g. CRISPR, gene therapy, DNA sequencing) and identify a specific purpose for its use (e.g. medical treatment, agricultural improvements, forensic analysis). Conduct research on your chosen genetic technology, including its development, mechanism of action, applications, benefits and potential ethical concerns.

Present your findings in one of the following formats:

- **Journal article:** Write a detailed article with sections including an abstract, introduction, methodology, results, discussion and conclusion. Include references to your sources.
- **Video news piece:** Create a 3–5-minute video presenting the technology, its purpose and your findings. Use visuals, interviews and clear narration to engage the audience.
- **Brochure:** Design an informative brochure with sections covering the key aspects of the technology. Use images, graphs and bullet points for clarity and visual appeal.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 12.7

What will humans look like in 10 000 years?

Some scientists have argued that civilisation has ended natural selection in humans. To a large degree, the selection pressures of the past (such as predation) no longer affect us in the same way. Humans modify their surroundings to survive in a wide range of environmental conditions, and vaccines and antibiotics help us to address disease.

However, there have been evolutionary changes since the earliest civilisations. As diets changed to include grains and dairy, genes that coded for enzymes to digest starch and lactose were selected for. People now live in densely populated regions which could allow the rapid spread of disease but also have mutations that code for disease resistance.

Today, evolution has become less about survival and more about reproduction. Some scientists have suggested that this greater focus on reproductive success might increase selection for attractiveness. And humans might also become more uniform in appearance as travel leads to mixing of populations and easy access to worldwide media may create a set standard of beauty.

Scientists have suggested that the following changes may take place in humans over the next 10 000 years. Complete some research and discuss why future humans may have:

- longer lifespans
- taller stature
- lighter, less-dense skeletons
- reduced muscle, especially in the upper body
- smaller jaws
- fewer wisdom teeth
- smaller brains
- less aggressive behaviour.

Quick check 12.7

1. **Define** the term 'artificial selection' and provide an example.
2. **Contrast** natural selection and artificial selection.
3. **Discuss** whether artificial selection increases or decreases variation and therefore biodiversity.
4. **Explain** how reproductive technologies can affect human biodiversity.

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. **Recall** the key processes involved in natural selection.
2. **Identify** geographical barriers that could divide a bird population, an eel population and a mammal population.
3. **State** the different sources of variation in an individual and in a population.
4. **Identify** three examples of abiotic selection pressures and three examples of biotic selection pressures.
5. **Name** some different ways that technology can affect the biodiversity of the human population.

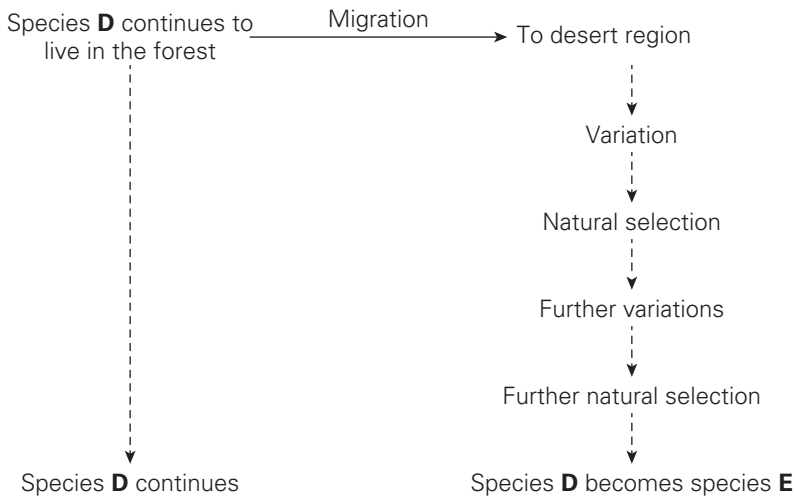
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

6. **Describe** what is meant by the term 'selective advantage'.
7. **Summarise** the three processes in speciation.
8. **Explain** why variation is necessary for natural selection to occur.
9. **Explain** why isolation is necessary for speciation to occur.

Applying

10. The following diagram represents the process of speciation.



Explain, using the information from the diagram, the key drivers behind the creation of the new species E in the desert.

Analysing

11. Tomato breeders have created the sweetest and juiciest tomato ever. **Reflect** on how they would have done this, given that they started with a not-so-sweet and not-so-juicy crop of tomatoes.
12. **Distinguish** between artificial and natural selection, providing examples for each.

Evaluating

13. The Galapágos finches share similar features but are recognised as distinct species. **Propose** a test that could be used to identify if two similar kinds of finch are different species or subspecies of the one species.
14. **Determine** how speciation, biodiversity and evolution are linked.
15. **Decide** if humans are evolving by natural selection.
16. **Predict** what will happen if a particular species has low genetic variation and there are changes in the environment in which they live.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

12.3 Developing the theory from evidence

WORKSHEET
Evidence for evolution

Learning outcomes

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

1. discuss the evidence that drives the development of the theory of evolution.
2. explain why an understanding of evolution is important.

The theory of evolution has developed from a number of fields of science, using evidence from various sources, as summarised in Table 12.3. It continues to be refined from discoveries in these fields.

VIDEO
Palaeontology

Field of science	Evidence
Palaeontology	The study of fossils, including their identification and interpretation, enabling the identification and interpretation of ancient organisms, which contributes to our understanding of past life forms and evolutionary history
Comparative anatomy	The study of the structure of specific organs and limbs of different organisms, providing insights into their functional adaptations and evolutionary relationships
Embryology	The study of the development of the embryo in different organisms, providing information about shared developmental processes and evolutionary patterns
Biochemistry and molecular biology	Similarities and differences in the biochemical make-up of organisms that can help distinguish differences and similarities. The ability to sequence DNA to indicate the degree of relatedness between organisms, aiding in the construction of evolutionary trees and understanding evolutionary relationships
Microbiology	Because their life-cycles are so rapid, natural selection can be observed in action in bacteria and viruses, particularly in research to test and develop new antibiotics and anti-viral drugs.
Biogeography	The study of the geographic distribution of organisms which can help ascertain the origins, dispersal and adaptation of species in different regions

Table 12.3 Fields of science that yield evidence for the development of the theory of evolution

fossil
the shape or impression of a bone, a shell or a once living organism that has been preserved for a very long period of time

direct (evidence)
evidence that supports an assertion without intervening inferences

indirect (evidence)
evidence that requires inferences to be made

trace fossil
a trace of an animal, such as footprint or imprint, that has become fossilised

fossilisation
the process of forming a fossil

fossil record
the record of past life and evolution inferred from fossils

Palaeontology

The term **fossil** refers to any parts of, or impressions made by, a plant or animal that is preserved following death. Normally, an organism decomposes after it dies, and after a time, no trace of it remains. On rare occasions, evidence of the organism is preserved in the form of a fossil. Fossils may be the hard parts of an organism, like its bones and teeth (called **direct** evidence), or evidence of an organism's presence, like footprints, burrows and faeces (called **indirect** evidence or **trace fossils**.). The process of forming a fossil is called **fossilisation**. However, because fossilisation is rare, and organisms with hard parts are more likely to form fossils, there are gaps in our **fossil record**. Also, we cannot dig everywhere looking for fossils, so many go undiscovered.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Fossilisation

Fossils are formed in many ways, but they are most likely to be found in sedimentary rock. When an organism dies, soft tissues normally decompose, leaving only the hard parts behind. The organism gets buried under sediment, volcanic ash or lava. Over time, minerals can fill up empty spaces or replace material, eventually changing to rock.

Figure 12.37 Many opalised fossils have been found on the opal fields of Coober Pedy, South Australia. This phenomenon occurs when opal, instead of the usual minerals found in groundwater, replaces the skeletal material. The photos show a drawing of an extinct, squid-like belemnite (left), a belemnite fossil found in shale (middle) and an opalised belemnite found in Coober Pedy (right).

Other ways in which fossils can be formed are presented in Table 12.4.

Method of fossil formation	Description	
Impression	The organism's remains are washed away, but an empty space is left in the shape of the organism. If it remains empty, it is a mould. If it fills with minerals, then it is a cast.	**Figure 12.38** An impression fossil of a pterosaur
Amber	Organisms become trapped in tree resin that then hardens.	**Figure 12.39** A 100-million-year-old spider attacking its prey

Table 12.4 Methods of fossilisation

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Method of fossil formation	Description	
Trace fossils	Trace fossils, such as footprints, burrows or faeces, give some insight into an organism's behaviour, how they lived and how they interacted with the environment.	**Figure 12.40** Lark Quarry Conservation Park near Winton in Queensland is the only known site of a dinosaur stampede, providing the most concentrated set of dinosaur footprints in the world. Over 3000 footprints can be seen in an area approximately the size of a tennis court. Trace fossils can provide important information relating to the size and walking or running posture of an extinct species.
Soft tissue	It is extremely rare for soft tissues to survive the pressure, heat and chemical changes needed for fossilisation to occur. But nowadays, scientists are increasingly reporting finding fossilised skin and even brain material preserved along with bones.	**Figure 12.41** In 2018, researchers found what they believe are fossilised lungs preserved inside a 120-million-year-old bird. Scientists have previously found four fossils of this ancient bird, *Archaeorhynchus spathula*, but never with plumage or suspected lungs.

Table 12.4 *(continued)*

Fossilisation requires the following conditions:

- Burial is rapid. Organisms must be buried quickly in oxygen-poor sediments. Usually this happens when organisms die in seas, lakes, floods or mud slides. Organisms can also be preserved in ice or amber or buried under ash from volcanic eruptions (lava will usually incinerate any remains).
-

Remains lie undisturbed. Predators and scavengers do not dig up the remains.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 12.42 In 2024, six new monotreme species were discovered from fossils unearthed in the opal fields of Lightning Ridge in outback New South Wales. Identified from opalised jaw and teeth bones, one of these species was named 'echidnapus' due to its combination of features characteristic of both the platypus and echidna.

Figure 12.43 A team of scientists are currently investigating an important new fossil site in New South Wales. The site, located near Gulgong in the Central Tablelands, contains exceptionally well-preserved fossils of animals and plants from the Miocene Epoch, including trapdoor spiders, giant cicadas and wasps.

Quick check 12.8

1. **State** two sources of evidence for evolution.
2. **Recall** some of the information you can find out from fossils that helps explain evolution.
3.
4. **Summarise** the conditions required for fossilisation.
5. **Describe** what is meant by a 'trace' fossil.

Did you know? 12.5

Living fossils

Charles Darwin coined the phrase 'living fossils' and, despite not being a scientific term, it has remained in use. It describes modern species of plants and animals that are almost identical to species that lived in ancient geological ages. This means they have survived mass extinctions, ice ages and comets hitting Earth! Examples include the Wollemi pine, the Australian lungfish, mountain shrimp and the Australian ghostshark.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 12.44 The Australia ghostshark is not actually a true shark, but belongs to a group called ratfish, which diverged from sharks around 400 million years ago.

Dating fossils: Relative dating

relative dating determining the order of past events without the specific age

stratigraphy the branch of geology studying the rock layers

Until last century, **relative dating** was the only method available for dating fossils. As the term suggests, relative dating techniques only work out how the age of a fossil compares to the ages of other fossils. For example, it can tell you that fossil X is older than fossil Y, but it cannot tell you the actual numerical age of the fossil. Relative dating is used to order the layers of rocks and geological events into a time sequence. The study of the order of the layers of rock (strata) is called **stratigraphy**.

Try this 12.5

Stratigraphy

Where the sediments in which fossils are found have not been disturbed by later events, they nearly always show an age sequence, with the oldest fossils deepest under the ground and the youngest at the top. Often these fossil sequences let us see the change in a species over time. This highlights how the fossil record is valuable for collecting evidence of evolution. For example, fossils have provided evidence for the evolution of modern horses from the ancient four-toed mammal, and the discovery of *Archaeopteryx* gave us evidence for the link between reptiles and birds. The fossil record also tells us more about organisms that are now extinct and what Earth was like when a particular species existed.

The diagrams in Figure 12.45 represent the strata (rock layers) found at two different locations (1 and 2). Each layer has a letter associated with it, and you can see the different fossils found in each layer. Knowing that the youngest layers are on the top and the oldest down below, work out the relative age of all the layers in both locations from oldest to youngest. Then list the clues you used to work this out.

For example, layer G is younger than layer B, but older than layer A.

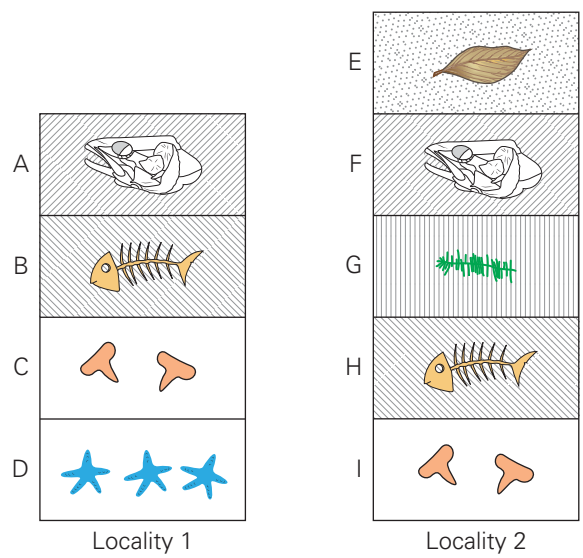


Figure 12.45 Relative dating: the different strata and their relative positions at locations 1 and 2 help us date the fossils in each layer relative to other fossils.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Biostratigraphy

Fossils are important for working out the relative ages of sedimentary rocks too.

Similar fossils in different rocks, even if a great distance apart, suggest the rocks are the same age. This matching process is called correlation, and it has been important in constructing geological timescales.

Throughout the history of life, different organisms have appeared, flourished and become extinct. Some of these organisms became fossilised in sedimentary rocks. The geological study of their patterns of appearance and disappearance over time is called **biostratigraphy**.

biostratigraphy a branch of stratigraphy focused on dating rock layers using the fossils found in them

index fossil a fossil used as the basis for dating the strata it occupied

To help identify matching strata, and to compare strata in different locations, indicator or **index fossils** can be used. An index fossil is a fossil of known age found in a particular type of sedimentary rock layer. It can be used to indicate the age of any deposit in which it is found, at any locality. For example, trilobites are good index fossils as they were very common at the time they existed (between 488 and 225 million years ago), easy to recognise, well preserved because of their hard exoskeleton and they evolved rapidly, which means there were different species present at different times.

Figure 12.46 Fossil of a trilobite, *Albertella helena*

Did you know? 12.6

Two legs better than four?

The fossil record shows that kangaroo ancestors were quadrupedal (walking on four legs) and had teeth adapted to eating woody vegetation. These adaptations were advantageous in forested habitats, but as the environment started to dry out, giving way to open grassland, the selection pressures of the environment were very different. Over millions of years, what we now know as kangaroos became bipedal and their teeth evolved to be able to graze on grass.

Figure 12.47 At low speeds, bipedal hopping is energy inefficient for a kangaroo. It only becomes useful at high speeds. Since their environment changed millions of years ago, hopping has provided a useful adaptation to evade predators in wide open grasslands.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Dating fossils: Absolute dating

absolute dating determining the actual age of a material

radioisotope a radioactive isotope of a chemical element with an unstable nucleus that emits excess energy (radiation)

half-life the length of time needed for the radioactivity of a radioactive substance to be reduced by half

Absolute dating gives a precise age (within certain error margins) for a fossil or, more commonly, for the rock or soil in which a fossil is found. Absolute dating uses radiometric techniques, which means looking at the level of radioactivity detected in rocks containing certain naturally occurring radioactive isotopes (**radioisotopes**). These isotopes occur in living things and have a known rate of radioactive decay. By measuring the amount of radioactive isotope left in a sample, we can work out how long the organism has been dead. The time in which half of the sample of the radioactive isotope (parent) has decayed to a more stable form (daughter) is known as its **half-life** and is unique to each isotope. Knowing this helps us determine the best isotope to use to work out the absolute age of a fossil. The longer the half-life of the isotope used, the older the fossil or rock that can be dated.

Radioactive isotopes (parent to daughter)	Half-life (years)	Estimated age range of fossils they can date
Carbon-14 to nitrogen-14	5730	Up to 55 000 years ago
Uranium-235 to lead-207	710 000 000	1 million to 1 billion years ago
Potassium-40 to argon-40	1 300 000 000	500 000 years and older

Table 12.5 Each radioactive isotope has a different half-life. The longer the half-life, the older the fossil or rock that can be dated.

Did you know? 12.7

Dating megafauna 'both ways'

Zygomaturus trilobus was a large wombat-like marsupial approximately the size of a bull. Dating using uranium–thorium shows that a fossil specimen of *Zygomaturus* died 33 000 years ago. We know that Aboriginal and Torres Strait Islander Peoples arrived in the same area at least 50 000 years ago, so the uranium–thorium dating shows that people and megafauna coexisted for at least 17 000 years. The coexistence of Aboriginal and Torres Strait Islander Peoples and Australian megafauna is further supported by paintings in Arnhem Land rock shelters of species such as *Genyornis newtoni* and *Palorchestes parvus*.

Figure 12.48 This rock painting of the megafauna herbivore in the genus *Palorchestes* displays two prominent tufts of chest hair and is accompanied by a smaller (perhaps younger) version of the same animal.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 12.6

Modelling half-lives

Be careful

Do not consume food items.

Materials

- 100 M&Ms or counters with one side marked
- graph paper
- plastic container with lid
- gloves

Instructions

1. Copy the results table into your science journal.
2. Predict the number of M&Ms that will 'decay' into daughter isotopes each time trial. Place all 100 M&Ms parent isotopes on your plastic tray with the 'm' side up.
3. Record your original number of parent isotopes in your results table for time 0.

4. Place all the isotopes in the plastic container and shake for 10 seconds.
5. Pour your isotopes back onto the plastic tray.
6. With your gloves on, remove all the stable daughter isotopes (m side down) from the tray and set them aside.
7. Count the remaining M&Ms (parent isotopes), which will be a percentage of the original number since that was 100, and record this in your results table for time 1.
8. Repeat steps **4–7** another eight times, ensuring that you only place parent isotopes back in the container each time.
9. Collate the class results on the board and calculate means for each time.
10. Calculate the percentage of undecayed parent isotopes for each time period.
11. Draw a graph of the time (horizontal axis) versus percentage undecayed parent isotopes (vertical axis) using the class results.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Time	Number of removed daughter isotopes	Number of remaining parent isotopes	Percentage undecayed parent isotopes $\frac{\text{number of remaining parent isotopes}}{\text{starting number of parent isotopes}} \times 100$	Class mean percentage undecayed parent isotopes
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

12. Calculate the half-life of your isotope by using your graph to identify the time in which half of the parent isotopes had decayed into daughter isotopes.

Quick check 12.9

1. **Describe** relative dating.
2. **Define** the terms 'stratigraphy' and 'index fossil'.
3. **Describe** absolute dating.
4. **Name** one isotope that could be used to accurately measure the absolute age of a fossil.

Advances in science 12.2

The latest fossil finds

In 2022, an international team of palaeontologists identified the world's oldest meal in a 550-million-year-old fossil.

Analysing the fossilised remains of a slug-like Ediacarian called *Kimberella* showed that it had a mouth and a gut and ate algae and bacteria from the ocean floor. The organism was advanced for the time period, as most other species did not have a gut that went through their entire body.

Figure 12.49 New fossils are providing key insights into the evolution of life on Earth.

The fossil record as evidence for evolution

The fossil record provides the main evidence that different species existed in the past, and most became extinct. Furthermore, most of today's species are not found in the early fossil record. These observations led to questions about the origin of species, which inspired scientists to develop hypotheses that species evolve. The fossil record also records where and when species existed in the past. The timelines and distributions led to ideas about which species evolved into other species, ideas which can be checked against evidence from other sources.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Comparative anatomy

Genetic variation can produce a huge diversity of forms among closely related organisms. But some animals display physical likeness despite not being closely related at all. Think about a bird and a bat, a dolphin and a shark, a sugar glider and a flying squirrel. The members of each pair, despite not being closely related, share some obvious structural characteristics. For example, sugar gliders and flying squirrels look alike, sharing similar characteristics such as size, big eyes and a white belly. Their most striking similarity is that they both have thin, loose skin between their limbs which keeps them stable when stretched while they glide.

However, sugar gliders (native to Australia) and flying squirrels (native to Asia, central and North America, and Europe) also have many differences. Sugar gliders are marsupials, so they have a pouch to protect their young, whereas flying squirrels are placental mammals, having larger babies and no pouch.

By studying their genes and other traits, biologists discovered that sugar gliders and flying squirrels are not very closely related at all. So why do they share some common physical characteristics?

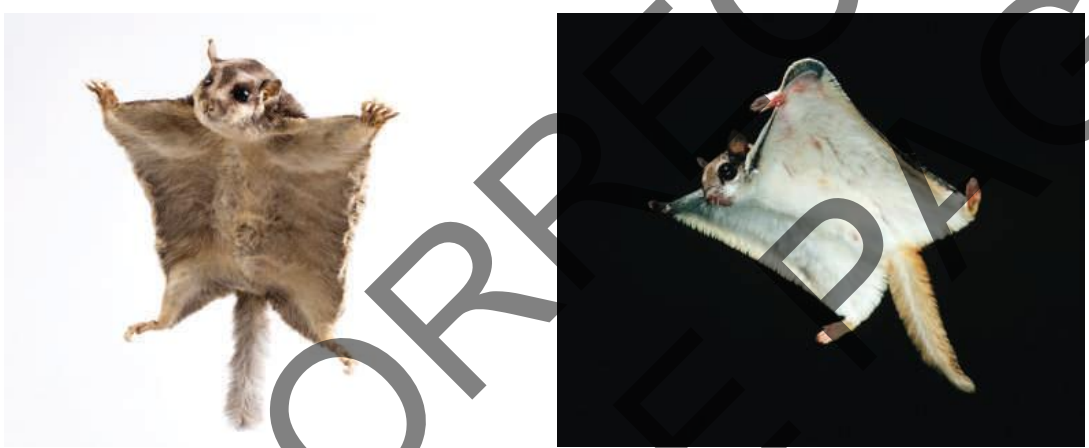


Figure 12.50 A sugar glider (left) and a flying squirrel (right) have many common characteristics, but they are not closely related.

The characteristic 'wings', which are flaps of skin, are known as **analogous structures**. These are structures that have a similar function but have evolved independently, a phenomenon known as **convergent evolution**. The two organisms have evolved from different ancestors but in similar environments, so the same selection pressures have caused the same feature to be selected for. The fin shape of sharks (a fish), penguins (a bird) and dolphins (a mammal) are another example of an analogous structure (Figure 12.51).

The shape of their fin (or the wing of the penguin) is adapted for swimming through water. The three types of animals faced similar selection pressures in their aquatic environment, and evolved into a similar shape, but they do not share a recent common ancestor.

Homologous structures are structures that organisms inherit from a common ancestor. 'Homo' comes from the Greek word homos meaning 'same'; hence, they inherited the same general body plan from the same ancestor. We say these structures have a common evolutionary origin. This process, known as **divergent evolution**, means these structures have a common evolutionary origin. Homologous structures have similar underlying anatomy but have evolved in different ways over time due to different selection pressures. An example of a homologous structure is the pentadactyl limb, the five-digit limb typical of tetrapod (four-limbed) vertebrates (that is, amphibians, reptiles, birds and mammals). The limbs of different species show basic similarities in the bones present and how they are arranged, even though the limbs may serve different functions (Figure 12.52).

analogous structures structures that have a similar function but evolved separately

convergent evolution the process by which unrelated species independently evolve similar traits due to similar environmental pressures

homologous structure a similar physical feature in organisms that have evolved from the same common ancestor

divergent evolution when closely related species evolve different traits, adapting to different environments or selection pressures from a common ancestral form

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The different limbs are the same bones arranged for different uses. If homologous structures are found in different organisms, that suggests they had a relatively recent common ancestor, which helps to explain their evolutionary path.

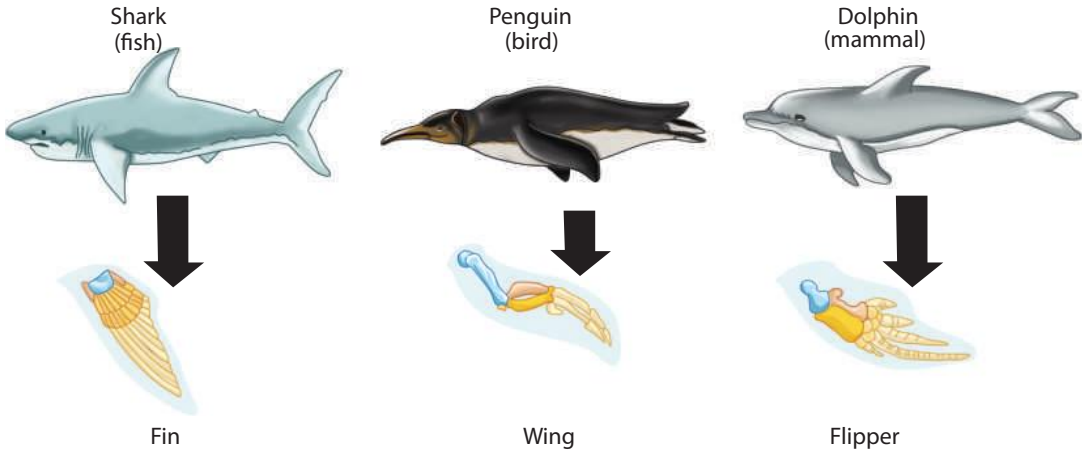


Figure 12.51 The shark, penguin and dolphin have analogous structures, that is, structures with the same function. These arose because they live in similar environments and face similar selection pressures.

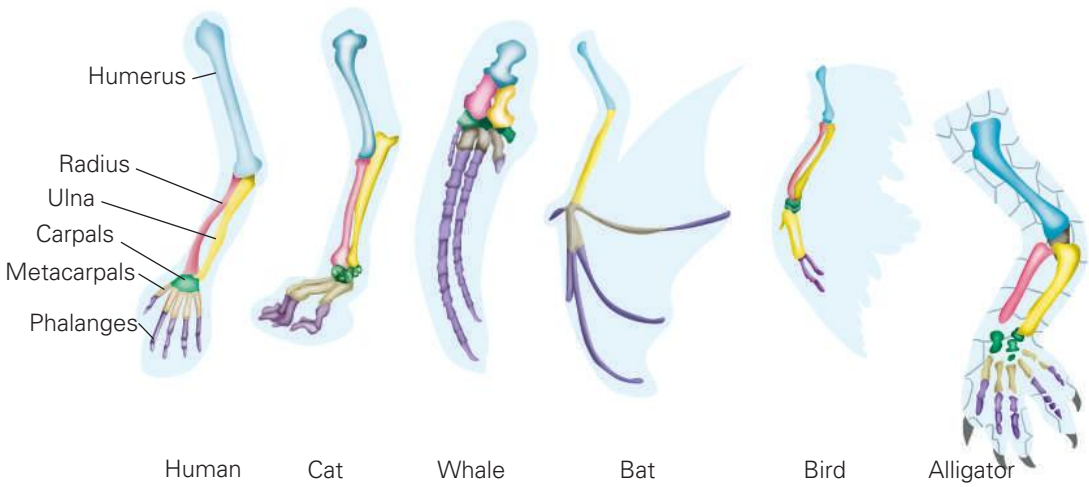


Figure 12.52 The limbs of different tetrapod vertebrates have a common structure and are called homologous, despite having different functions, such as grasping, swimming or flying.

Figure 12.53 The hair of mammals (left), feathers of birds (middle) and scales of reptiles (right) are structures that share a common ancestry in reptilian scales; they have been inherited and modified over time. The fibres in each are composed of keratin complexes.

Quick check 12.10

1. **Describe** analogous structures, providing an appropriate example.
2. **Describe** homologous structures, providing an appropriate example.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 12.3

Dissection of a chicken wing

Aim

To compare the structure of a chicken wing to the structure of a human arm.

Materials

- fresh chicken wing
- dissecting board
- dissecting scissors
- probe
- disposable gloves
- human skeleton model

Procedure

Part 1: Examining the chicken wing

1. Hold the chicken wing at the shoulder and the tip and then stretch out the wing. Identify where the joints are and in which direction they bend.
2. Use your fingers to feel the bones and muscle under the skin.
3. Using dissecting scissors, carefully remove the skin from the chicken wing, taking care not to cut the muscles, ligaments and tendons.
4. Identify the muscles of the wing and see if you can work out how each one is attached to the bones of the wing.
5. Look for the tendon, which is white and tough and attaches the muscle to the bone.
6. Try squeezing the muscle in the wings and observe what happens to the bones. You may notice there are two muscles which can flex or extend the wing.
7. Look at the surface of each bone where it forms a joint. It should appear white, shiny and slippery – this is called cartilage. Can you find the cartilage at the joint between the humerus and the radius and ulna?

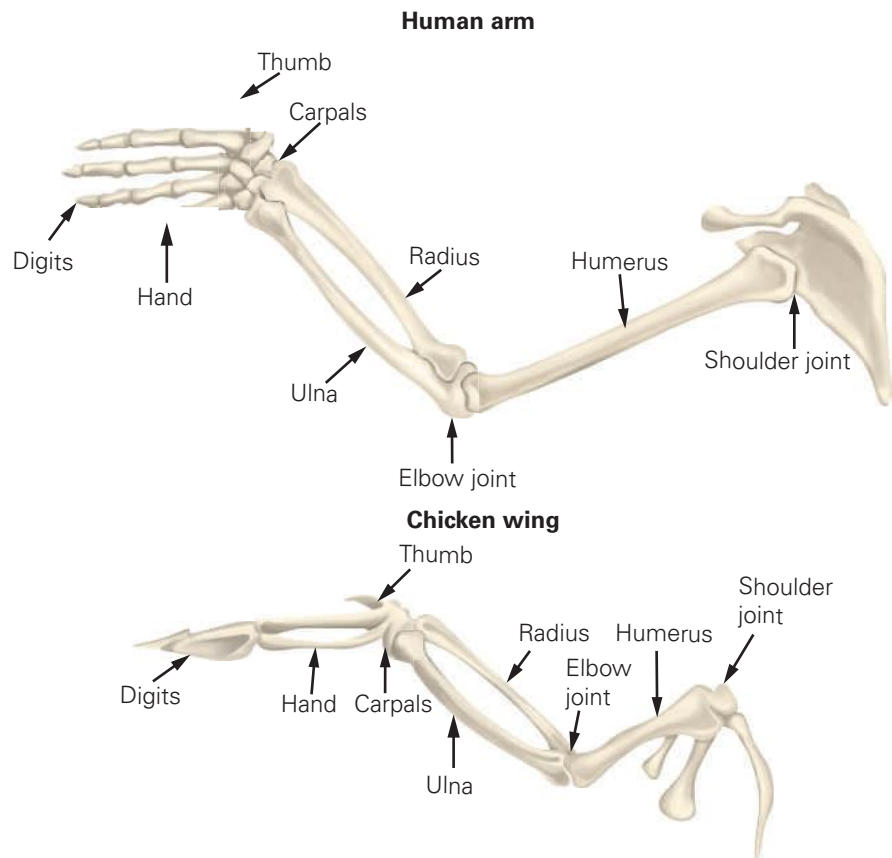


Figure 12.54 The bones of a human arm and a chicken wing

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Part 2: Examining your arm

1. Identify the humerus, ulna and radius in your arm. What other features of the chicken wing and your arm are similar?
2. Bend your arm at the elbow and hold it tight. Notice that your bicep muscle shortens. Now, extend your arm and feel your bicep lengthen.
3. Now, look at your hand and identify where the muscles are that move your fingers. You may need to press on your wrist or forearm to figure this out.
4. With a partner, raise and lower a textbook by bending your arm at the elbow. Which muscles were acting as you raise and lower?

Results

Take a photo of the finished dissection of the chicken wing.

Discussion

1. Compare the structure of a chicken wing with a human arm.
2. Define the term 'analogous structures' and explain what they can tell us about the evolution of a species.
3. Define the term 'homologous structures' and explain what they can tell us about the evolution of a species.
4. Would the chicken bones and human bones be considered homologous or analogous structures? Discuss.

evolutionary tree a diagram used to represent evolutionary relationships between organisms

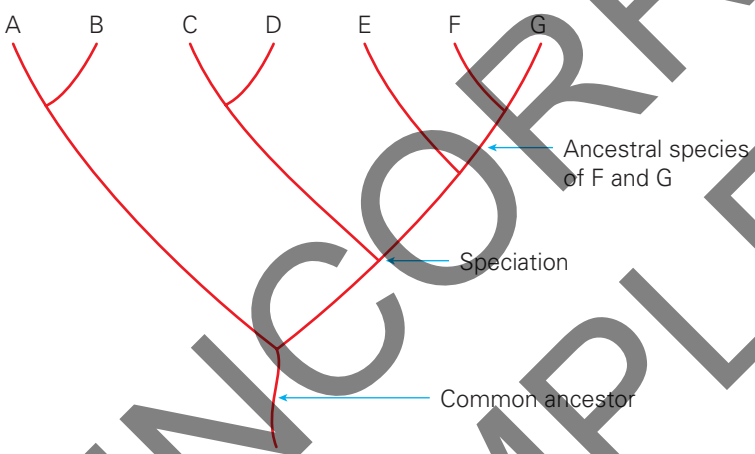


Figure 12.55 A model or template for an evolutionary tree; these can also be drawn on their sides, so time runs left to right not upwards.

Evolutionary trees

Scientists can construct **evolutionary trees** using fossil evidence and radiometric dating to estimate when different groups of species diverged from a common ancestor. Evolutionary trees can be constructed when scientists have studied the anatomy of different species to determine which ones have homologous structures. Only homologous traits are evidence of a shared ancestry. An example of an evolutionary tree is shown in Figure 12.55.

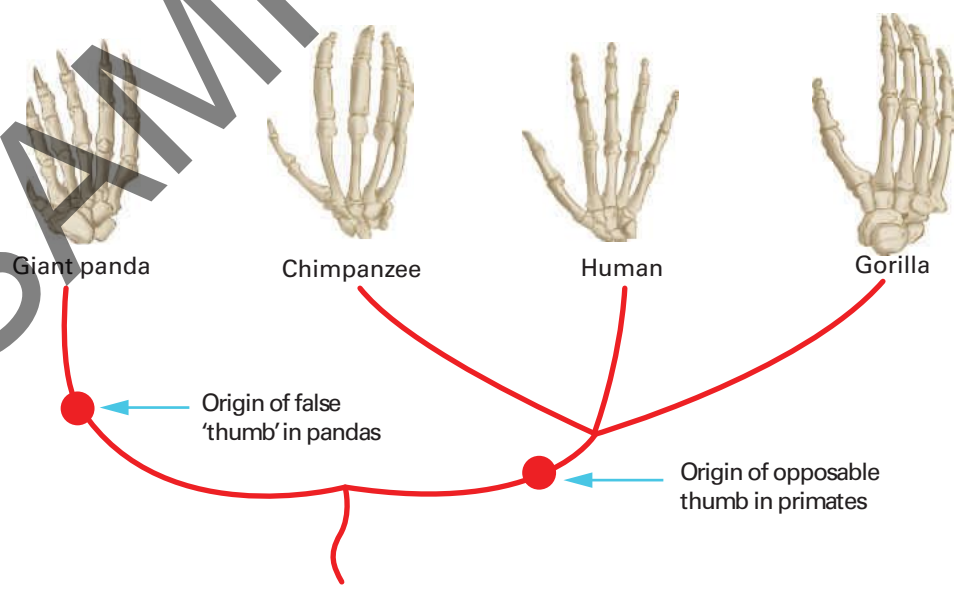


Figure 12.56 An evolutionary tree showing how their homologous opposable thumbs mean that humans, chimpanzees and gorillas have a recent common ancestor.

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

For example, humans, chimpanzees and gorillas all have thumbs that are very similar anatomically and are considered to be homologous (Figure 12.56). The giant panda also has a thumb, but it has been found to be analogous to these primate thumbs – it serves the same function but is structurally formed by different bones, so it evolved separately. This suggests that humans, chimpanzees and gorillas are much more closely related to one another than any of them is related to giant pandas.

Comparative embryology

The embryos of vertebrate animals look very similar in the early stages, which suggests that they inherited some of the genetic information that contributes to embryo development from a common ancestor. For example, a very early-stage human embryo has gill slits, a tail and a simple heart, similar to that of a fish. At later stages, the human embryo develops body proportions similar to the embryos of reptiles and then apes.

Comparative embryology also finds evidence for evolution in the circulatory system of fish and mammals. Adult fish and mammals have quite different circulatory systems. However, during embryonic development you can clearly see that the circulatory systems are based on the same pattern. This suggests that the genetic information responsible for the development of the fish and mammalian circulatory systems has been inherited from a common ancestor.

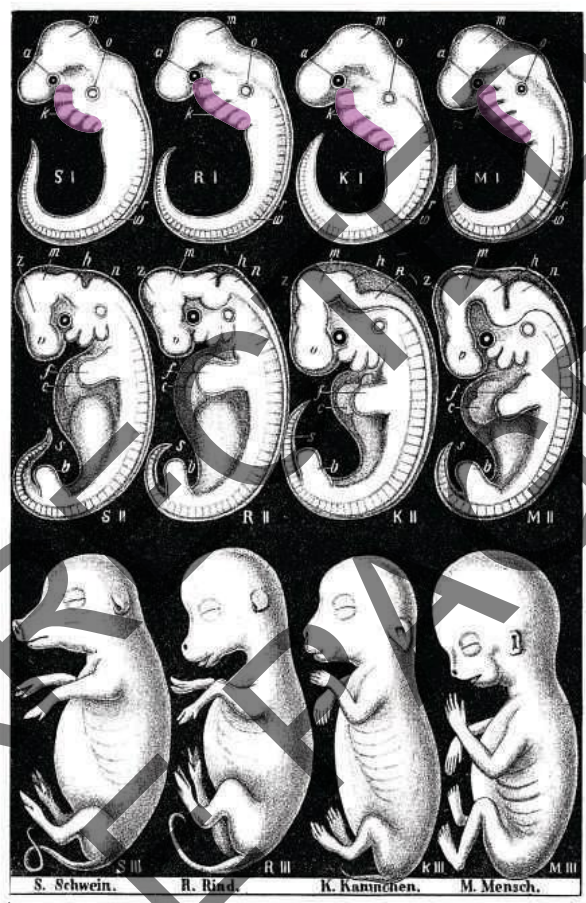


Figure 12.57 Comparative embryology drawings of embryos at three stages from (left to right): a pig, cow, rabbit and human. In the top row, gill slits are highlighted.

Quick check 12.11

1. **Describe** an evolutionary tree.
2. **Explain** how embryology provides evidence for evolution.

Biochemistry and molecular biology

Substances that are found in most or all living things are very useful in the investigation of evolutionary relationships. For example, all living things contain DNA, so it is commonly used to compare organisms. This is what the study of molecular biology is all about – investigating DNA, its code and the proteins it codes for. Molecular biology lets evolutionary scientists:

- trace ancestors of species
- estimate how long ago one species diverged into two
- discover how closely related two species are.

DNA analysis

DNA sequencing has become a powerful tool for understanding evolutionary relationships by allowing scientists to compare genetic material across different species. By analysing the sequences

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

DNA hybridisation a technique that measures genetic similarity between two organisms

of DNA bases, researchers can determine the degree of similarity between species at a genetic level. The more closely related two species are, the more similar their DNA sequences tend to be. **DNA hybridisation** is a technique to compare the DNA sequences of two species to find out how closely related they are. First, as shown in Figure 12.58, the DNA from each organism is extracted and heated so it forms two single strands. When the single strands from the two organisms are mixed together and allowed to cool, complementary nitrogenous bases will bind together (hybridise). The degree to which the single strands form a stable double-stranded DNA molecule is an indication of the relatedness of the species. For example, if there is a lot of hybridisation, there must be a lot of complementary bases, which means the organisms are similar and, therefore, have a recent common ancestor.

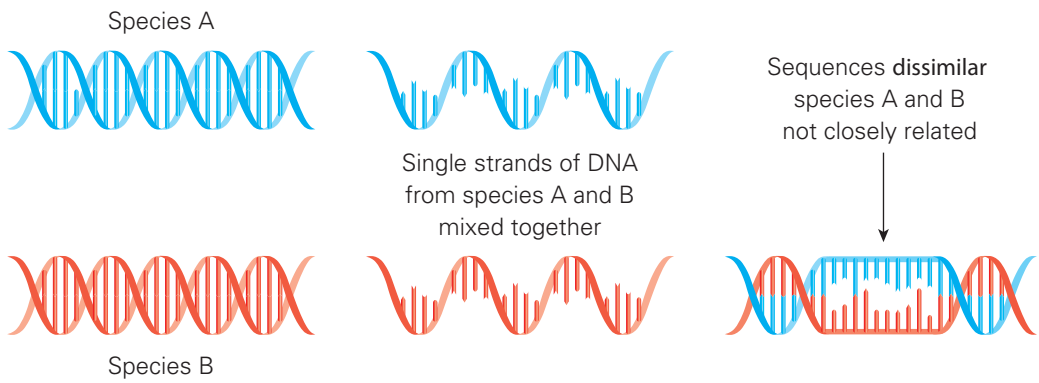


Figure 12.58 The process of DNA hybridisation allows scientists to determine the relatedness of two organisms by comparing their DNA.

Protein analysis

As we know, proteins are made up of building blocks called amino acids. Scientists can analyse the differences in the amino acid sequences, knowing that this relates to how similar proteins are in the different organisms. The number of different amino acid sequences in the proteins of different species is an indicator of the number of mutations and hence the degree of separation of species. In other words, a large difference in amino acid sequences between two organisms means they had a distant common ancestor, while a small difference in amino acid sequences mean they had a recent common ancestor. The cytochrome c protein is often studied as it is involved in cellular respiration and is found in most eukaryotic organisms. Table 12.6 shows the differences in the amino acid sequence for cytochrome c between humans and other organisms. Notice how the monkey has the lowest number of differences, suggesting they are more closely related to humans.

Note that it is also possible to predict amino acid sequences from the DNA code, and the latter also tells you about the relationship between organisms.

Organism	Number of differences in the amino acid sequence for cytochrome c compared to humans
Horse	12
Chicken	13
Dog	11
Moth	31
Tuna	21
Monkey	1

Table 12.6 The differences in the amino acid sequence for cytochrome c between humans and other organisms

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 12.8

Molecular clocks

The molecular clock concept says that mutations accumulate in biomolecules at a roughly constant rate because they occur by chance. We can use this mutation rate to deduce the time when life forms diverged. The biomolecular data that is normally used for calculations are DNA nucleotide sequences, including those found in mitochondrial DNA (mtDNA).

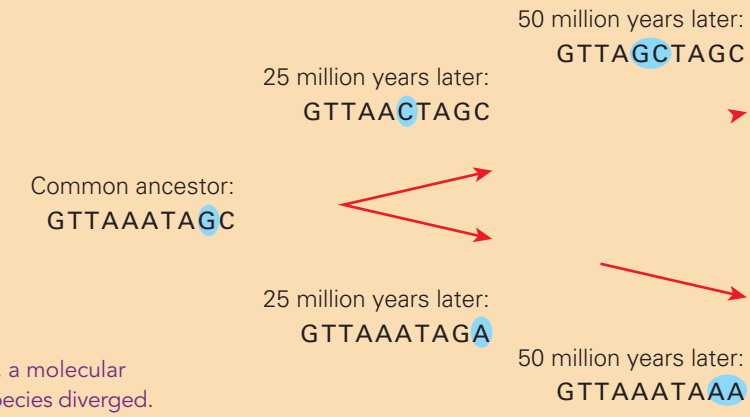


Figure 12.59 In the same way that a clock tells the time, a molecular clock allows scientists to determine how long ago two species diverged.

The importance of evidence for evolution from biochemistry and molecular biology

The combination of being able to find out how closely species are related, trace their ancestors, and estimate when new species appeared, makes molecular biology the most powerful tool in evolutionary biology today. It has changed how scientists understand evolution and its history. It also helps confirm or question evidence from other sources. Evidence from molecular biology is especially important because DNA is not only the genetic code for living things, but also the key to understanding how evolution happens through reproduction, mutation and genetic variation.

Quick check 12.12

1. **Describe** DNA hybridisation and how it provides evidence for evolution.
2. **Describe** how the number of differences in the amino acid sequence for cytochrome c can be used to establish the relationship in evolutionary terms between organisms.

Microbiology

Because natural selection and speciation happen so slowly, typically over millions of years, the emergence of a new species can't be observed in action. However, bacteria and viruses have such rapid life cycles that natural selection at least can be observed in action. This is what can happen in research to test and develop new antibiotics and anti-viral drugs. This principle was illustrated in **Try this 12.2** in Section 12.2.

INVESTIGATION

Explore! 12.8

Natural selection observed in bacteria

Research examples of natural selection being observed in bacteria. Search for any examples of researchers having observed bacteria in the laboratory evolve new traits, such as the ability to use a new food source, that could mark the beginning of a new species. Write a report on your findings and comment on the extent to which this is evidence for natural selection and speciation in action.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Biogeography

biogeography the study of the geographical distribution of plants and animals

Biogeography is the study of the distribution of organisms, both today and in the past. It provides us with additional evidence for evolution, such as when ancient fossils in one area resemble modern organisms in that same area and have a similar pattern of distribution (for example, fossil and modern platypuses are both found in Australia). The similarity of fossil and modern organisms suggests that the modern organisms have descended from ancestors living in same areas.

Remember that the continents were once joined in one big supercontinent, and ancestral organisms were distributed across more than one continent. When the continents split up and drifted apart, the separated populations evolved into different organisms due to reproductive isolation. However, in some cases, the selection pressures in each new area were so similar, that speciation created very similar looking organisms. For example, the emu of Australia, the ostrich of Africa, the cassowary of Papua New Guinea and northern Australia and the rhea of South America are all large, flightless birds. Despite being found on different continents with oceans between them, one possible explanation for their similarity is that they descended from a common ancestor that lived when these regions were part of the ancient Gondwana supercontinent (Figure 12.60). Gondwana had broken up by about 120 million years ago, so under this theory the common ancestor of these flightless birds would have lived before that.

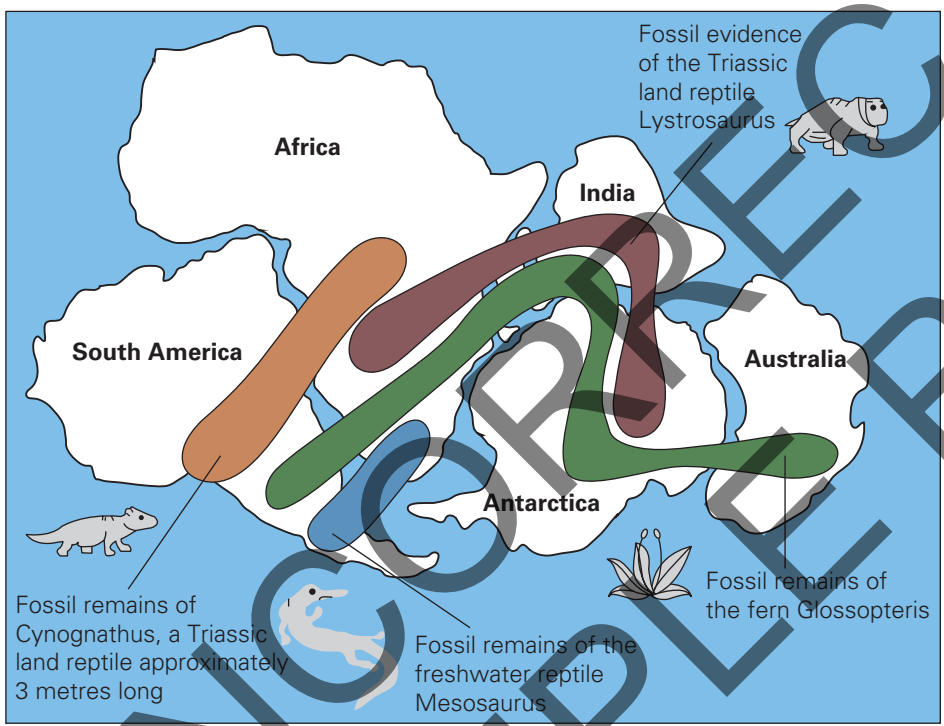


Figure 12.60 The ancient supercontinent Gondwana, which had broken up into seperate landmasses (as labelled) by 120 million years ago. The distribution of fossils of the species shown here provides strong evidence of continental drift, and supports the idea that pre-breakup species might evolve differently in the separated, isolated populations.

Figure 12.60 does not provide direct evidence of evolution, but it does provide indirect evidence for the idea that the break-up of supercontinents led to geographical isolation of ancestor species' populations, which then evolved into new species.

Figure 12.61 (Left to right) An emu and cassowary (Australia), a rhea (South America), and an ostrich (Africa)

UNCORRECTED SAMPLE PAGES

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Explore! 12.9

Biogeographic evidence for evolution

Research an example of evolution of a new species where populations become geographically isolated. Explain how the findings support the theory of evolution. The Southern Beech tree *Nothofagus* is an example where continental drift led to the isolation of populations, but there are more recent examples in the fossil record where a change in sea level or coastlines is the isolating factor.

Quick check 12.13

1. **Define** the term 'biogeography'.
2. **Explain** how biogeography provides evidence for evolution.

Evolution of humans: Bringing it all together

VIDEO Human evolution

In order to understand human origins, we need to first look at what humans are. Humans are in the animal kingdom, phylum Chordata, class Mammalia, order Primates, family Hominidae, genus *Homo* and species *Homo sapiens* (see Figure 12.62).

The primates living today gradually evolved over 65 million years from ancestral primates that were small tree-dwelling mammals. We did not evolve from apes and monkeys, but we share a common ancestor with them.

About six million years ago, the line that led to humans is thought to have diverged from the chimpanzee line due to different habitats and different selection pressures.

This divergence led to the evolution of the earliest members of the human family, the Australopithecines, which lived in Africa between about 4 and 2 million years ago. These early hominids were bipedal and had a small brain and teeth and jaws adapted to a diet that included tough plant materials. Over time, members of the human family continued to evolve and develop new adaptations, such as a larger brain and the ability to use more complex tools.

One of the most important periods of human evolution occurred around 2.5 million years ago with the emergence of the genus *Homo*. The first species in this genus, *Homo habilis*, was known for its ability to create stone tools; it had a slightly larger brain than the Australopithecines.

Over the next few million years, other species of *Homo* emerged, including *Homo erectus*, which was the first hominid to leave Africa and migrate into other parts of the world.

Homo neanderthalensis, commonly known as the Neanderthals, was a species of hominids that lived in Europe and parts of Asia from about 400 000 to 40 000 years ago. They were named after the Neander Valley in Germany, where the first Neanderthal fossils were discovered in the mid-19th century.

Neanderthals were well adapted to life in cold environments, with a stocky build and short limbs that helped to conserve body heat. They are also known to have used fire and create shelters, indicating a level of social and technological sophistication. Neanderthals produced art, made jewellery and performed burial rituals, indicating a degree of symbolic thought.

The most recent and only surviving species of the *Homo* genus is *Homo sapiens*, which emerged in Africa around 300 000 years ago. *Homo sapiens* is characterised by its large brain, complex culture, and use of language. Genetic studies have shown that Neanderthals interbred with modern humans, as evidence of their DNA has been found in the genomes of non-African humans. However, they eventually became extinct around 40 000 years ago for reasons that are not entirely clear, although

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

factors such as climate change, competition with modern humans, and disease have been suggested as possible contributing factors.

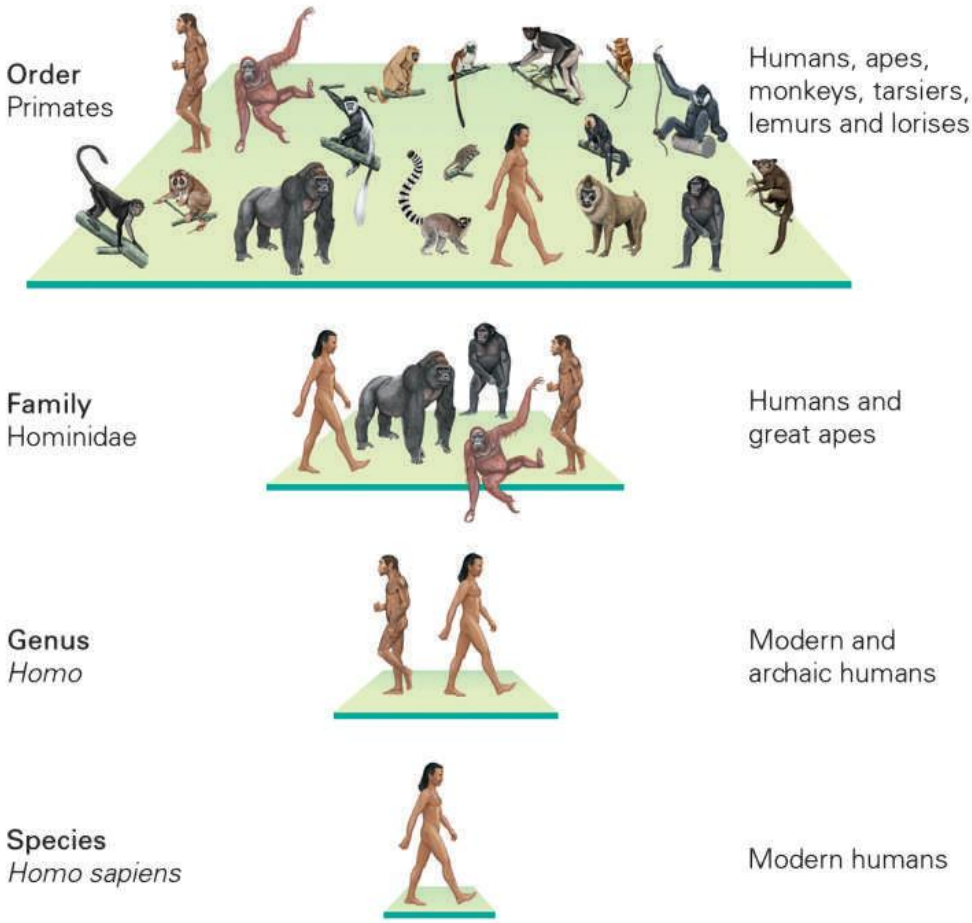


Figure 12.62 Classification of *Homo sapiens* within the order Primates

INVESTIGATION

Explore! 12.10

Evidence for human evolution

In this section you have learned about the different ways that we can gather evidence about evolution: palaeontology, comparative anatomy, embryology, molecular biology and biogeography. However, we have not investigated how they have informed us about human evolution.

Figure 12.63 A palaeontological reconstruction of the skull of *Australopithecus afarensis*, one of the earliest members of the human family, from 3–4 million-year-old fossils found in East Africa

1. Research the fossil evidence of human evolution. Summarise what fossils teach you about the evolution of humans and use pictures to illustrate what you find.
2. Research homologous and analogous structures related to human evolution. Summarise what comparative anatomy teaches you about the evolution of humans and use pictures to illustrate what you find.
3. Research the DNA evidence of human evolution. Summarise what DNA teaches you about the evolution of humans and use pictures to illustrate what you find.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Why understanding the origins of species is important

The study of different species in biology is centuries old, but for most of its history biology produced a bewildering and confusing collection of facts that scientists tried to classify using taxonomy. Biologists have always wondered about the strange assortment of similarities and differences they found – where did they come from? How did they arise?

The theory of evolution that explains the origin of species is the central organising principle to understanding life. "Nothing in biology makes sense except in the light of evolution" is a quote from a paper by evolutionary biologist Theodosius Dobzhansky in 1973. He added: "Because it is the only theory that can explain the relationships among all living things and the changes that have occurred in them over time."

From this organising principle we can compile a list of reasons why the theory of evolution is important. It is because it:

- helps us understand life and how all living things are related
- provides the background knowledge of connections that helps protect endangered species and conserve ecosystems by showing how everything is connected
- helps medical science by showing how pathogens and hosts change over time, and how humans compare to other animals, helping to develop better treatments
- shows us a method for developing useful bacteria, machines or technological solutions by mimicking evolution – using trial and error to see which solutions perform ('survive') best, often in a computer simulation, and selecting those for further development, and repeating
- helps us understand ourselves, in anatomy, physiology and behaviour, by comparison to other animals and our ancestors
- helps answer philosophical and cultural questions such as 'Where did we come from?'

Explore! 12.11

The importance of evolution

Refer to the list of reasons why evolution is important:

1. Select one of these reasons, research it in more detail and find examples of that reason in practice. Write a 500-word report on your findings.
2. Search for a reason for the importance of evolution that is not included in the list, such as one that relates to new discoveries or technologies. Justify why it is important.

Section 12.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 12.3 questions

Remembering

1. **Name** five sources of evidence for evolution.
2. **Recall** what is meant by the term 'fossil'.
3. **Recall** what the term 'biogeography' refers to.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

4. **Describe** analogous structures, providing an example.
5. **Explain** how the scales of reptiles and the feathers of birds are considered homologous structures.
6. **Explain** how DNA hybridisation can show that two organisms share a common ancestor.
7. **Summarise** why fossils of soft-bodied organisms are relatively rare.

Applying

8. Figure 12.64 represents the layers of rock found within a cave. **Identify** the layer (1 to 5) where you would expect to find the oldest group of fossils, giving reasons for your answer.

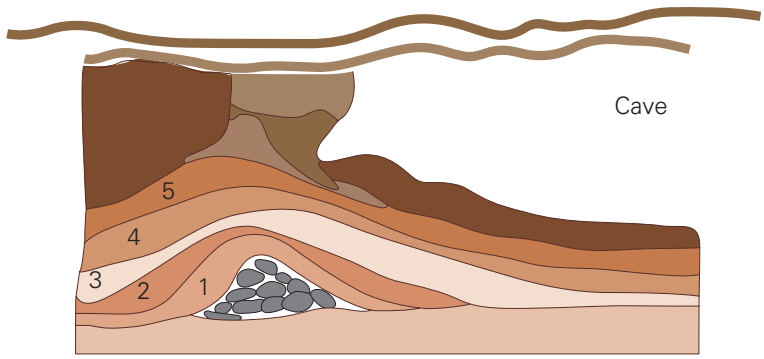


Figure 12.64 Layers of rock within a cave

9. Figure 12.65 shows a timeline for the evolution of some dinosaurs. The average mass of each dinosaur is shown in brackets under its name. **Identify** the appropriate dinosaur for each statement.
   - **a.** The dinosaur that lived the longest time ago is the _____.
   - **b.** The dinosaur/dinosaurs that evolved from *Agilisaurus* is/are the _____.
   - **c.** The dinosaur from which *Camarasaurus* evolved is the _____.
   - **d.** The dinosaur with the largest average mass is the _____.

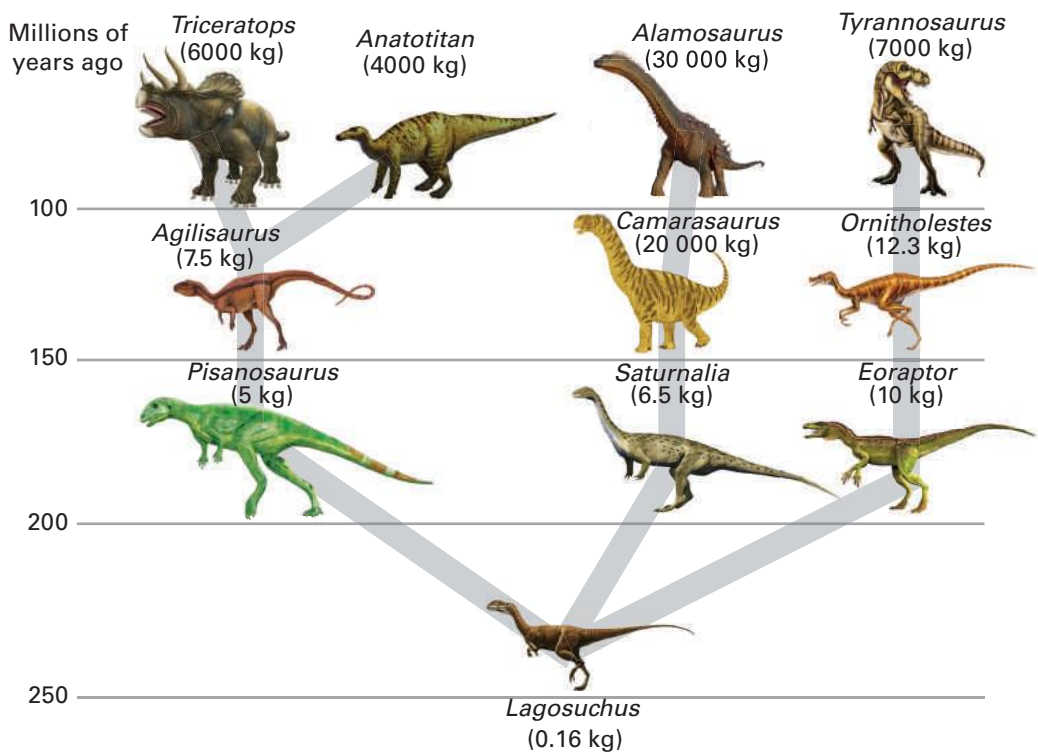


Figure 12.65 Timeline for the evolution of some dinosaurs

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

10. Figure 12.66 is a diagram like an evolutionary tree placed on its side, using geometric lines instead of curved lines for the branches. Each junction represents a common ancestor. In this way it shows the evolutionary relationship between some freshwater fish.

a. **Infer** which genus is most distantly related to *Poecilia*.

b. Between the genera *Cyprinodon* and *Fundulus*, **infer** which is more closely related to *Poecilia*.

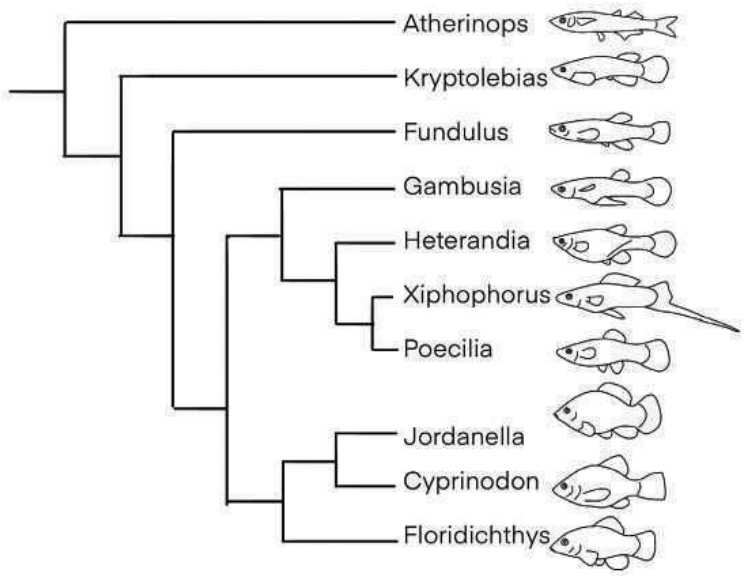


Figure 12.66 Chronogram showing evolutionary relationship between some freshwater fish

Analysing

11. **Distinguish** between absolute and relative dating techniques.

Evaluating

12. The table below shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees and a Neanderthal.

	Human 2	Chimpanzee 1	Chimpanzee 2	Neanderthal
Human 1	15	77	76	20
Human 2		79	80	27
Chimpanzee 1			23	72
Chimpanzee 2				71

a. Based on the table, **deduce** which organism is most closely related to the Neanderthal.

b. Based on the table, **deduce** which organism is the least closely related to the Neanderthal.

c. **Decide** which method could be used to estimate the absolute age of a Neanderthal fossil.

d. **Decide** which method could be used to estimate the relative age of a Neanderthal fossil.

Figure 12.67 A skull of *Homo neanderthalensis*

13. **Propose** how you would investigate whether birds are more closely related to mammals or reptiles. Include what evidence you would expect if the organisms were related or not related.

14. **Create** a concept map that shows the links between the different ways we can gain evidence for evolution. Include information on how each method sheds light on evolution.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

	Success criteria I am now able to…	Linked questions
12.1	describe the place of natural selection within an outline of the processes of evolution.	
12.1	outline how natural selection can lead to changes within and between species.	
12.1	outline how isolation (geographical or reproductive) following natural selection can lead to changes within and between species.	
12.1	using evidence, investigate and explain how the diversity of organisms has changed over time.	
12.1	describe how Aboriginal and/or Torres Strait Islander Peoples' artwork indicates changes in plants and animals, including megafauna.	
12.2	explain the process of natural selection in detailed steps.	
12.2	explain how isolation leads to speciation.	
12.3	discuss the evidence that drives the development of the theory of evolution.	
12.3	explain why an understanding of evolution is important.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Insert one full placeholder page for Review questions coming at 2pp.>

Data questions

Geospiza fortis is a ground finch that feeds on seeds on Daphne Major, one of the Galapágos Islands. From 1975 to 1977, the island experienced a severe drought. The graphs in Figure 12.68 show features of the *G. fortis* population and the island's seed supply during these years.

1. **Calculate** the percentage decrease in population size between July 1975 and December 1977.

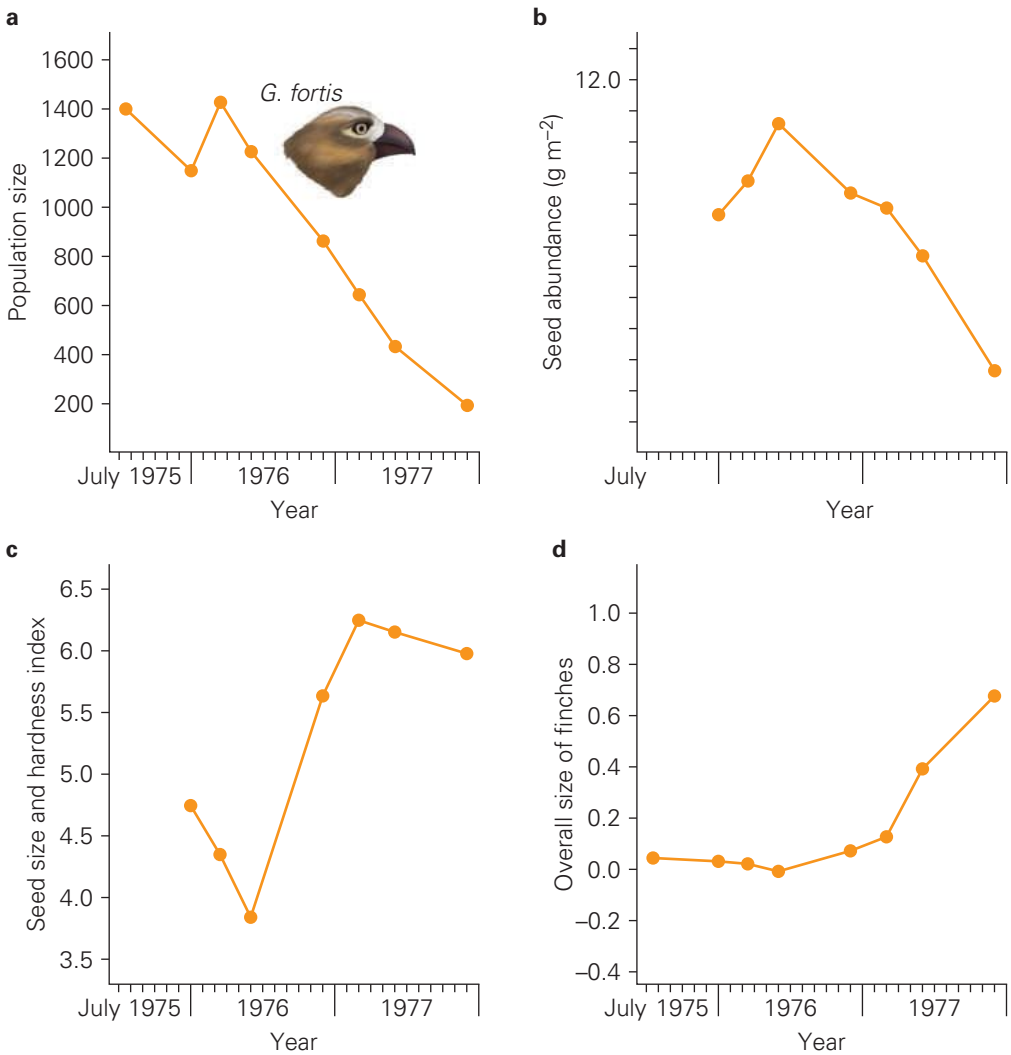


Figure 12.68 Features of the *Geospiza fortis* population and the seed supply on Daphne Major

2. **Identify** any relationships you can find in the graphs.
3. **Infer** why the size of the finches increased as the drought continued.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Designing a wheelchair to aid dogs with genetic problems

Background information

Individuals in a species become well adapted to their environment by the process of natural selection. In this process, individuals with characteristics that allow them to thrive in the environment are selected for, and they pass their suitable genes onto subsequent generations.

However, individuals within a species being too similar genetically can be detrimental to a species' survival. If the environment changes, genetic variation within a species gives it a better chance of survival because there are individuals that can cope better with the changed environment. A lack of genetic variation can result in extinction from an environmental change.

Inbreeding occurs when genetically similar individuals from a species breed with each other. There are many examples of inbreeding in humans and other species that are bred selectively, like dogs. In these cases, the problem is not that a population could be wiped out by an environmental change, but that genetic conditions that would be very rare in wider populations continue to be passed onto subsequent generations.

A famous example of this occurred with haemophilia, a condition resulting from a mutation on the X chromosome. In people with this condition, blood does not clot properly, so injury can cause excessive bleeding. Haemophilia spread throughout European royal families in the 19th and 20th centuries because of arranged marriages among the related royal families.

Humans have bred dogs for thousands of years, originally to serve a specific purpose or job like herding and hunting. All modern dog breeds exist because of human selective breeding.

Unfortunately, many pure-bred dogs suffer from genetic conditions because of inbreeding. For example, pure-bred dachshunds commonly suffer from knee problems because of their short legs and non-ideal angle for the knees. They also often have hip dysplasia and spinal problems because of their long bodies, and eye problems like cataracts.

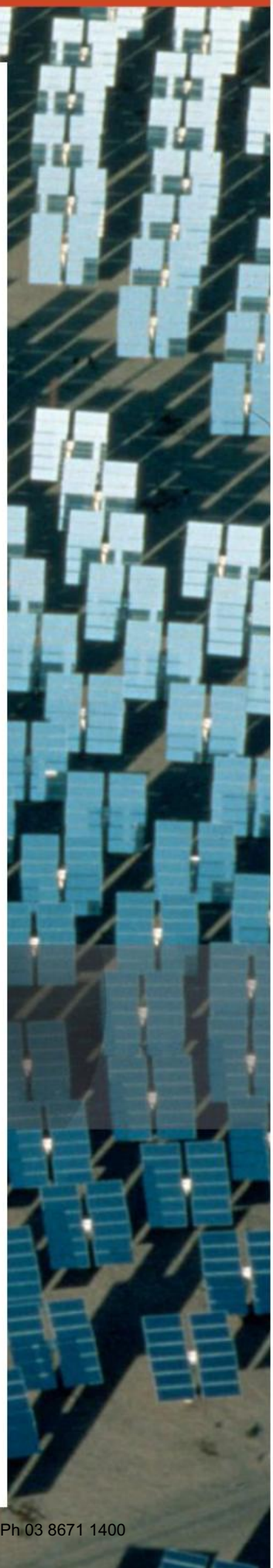
Figure 12.69 Left: Dachshunds are prone to numerous genetic diseases because their signature long bodies and tiny legs were developed by inbreeding. Right: Dachshunds are not the only dog breed that may need the aid of a wheelchair.

While dog owners can take preventive measures to reduce the effects of these disorders, often reactive treatment is the method used to give affected dogs a good quality of life. Wheelchairs are a potential solution to help with mobility for dachshunds that have hip and knee problems.

DESIGN BRIEF

Design a wheelchair to aid dachshunds with genetic knee and hip problems.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134



Activity instructions

In small groups, research the features of dog wheelchairs. You may like to put together a collection of different designs to help you decide which features you would like to include in your own design.

Draw your chosen design and label its features and the materials you intend to use. You will need to consider the method of attaching the wheelchair to the dog and whether the dog's legs will hang down or be supported on a platform.

You will also need to think about the best way to make it comfortable for the dog. Some research into the specific genetic problems occurring in dachshunds may be necessary to make sure you are catering for the dogs' needs.

Your wheelchair will need to be sturdy, so remember to use appropriate shapes and bracing to achieve the right strength for your design.

Suggested materials/presentation formats

- cardboard
- fabric/felt
- scissors
- wheels
- icy-pole craft sticks
- elastic bands
- straws
- sticky tape

Research and feasibility

1. Research and list all the features that make a wheelchair comfortable and functional.

Feature	Functionality
e.g. padded seat	Comfortable to use for long amounts of time

2. Research current dog wheelchairs available and how they are used for dogs with hip and knee problems. List all the problems that exist with current models and solutions that could be included.
3. Research the dachshund breed and make note of the size of the dogs and their common hip and knee problems.

Design and sustainability

4. Design a prototype of a wheelchair specifically for a dachshund. Annotate your diagram and include all design features and the functionality it provides.
5. Reflect on the sustainability of the materials used, and the life cycle of the wheelchair prototype regarding its durability.

Create

6. Construct the prototype using available materials.

Evaluate and modify

7. Describe any difficulties you came across when constructing your model. Explain how you overcame these difficulties.
8. Propose some improvements to the design of your wheelchair to improve comfort and functionality.
9. Depending on the size of your model, you may be able to test it by using your wrist or palm as the back of the dog and your index and middle fingers as the front legs to pull it along. Test it with different amount of downward pressure to represent different dog sizes and weights. Comment on how your wheelchair fared in your tests.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

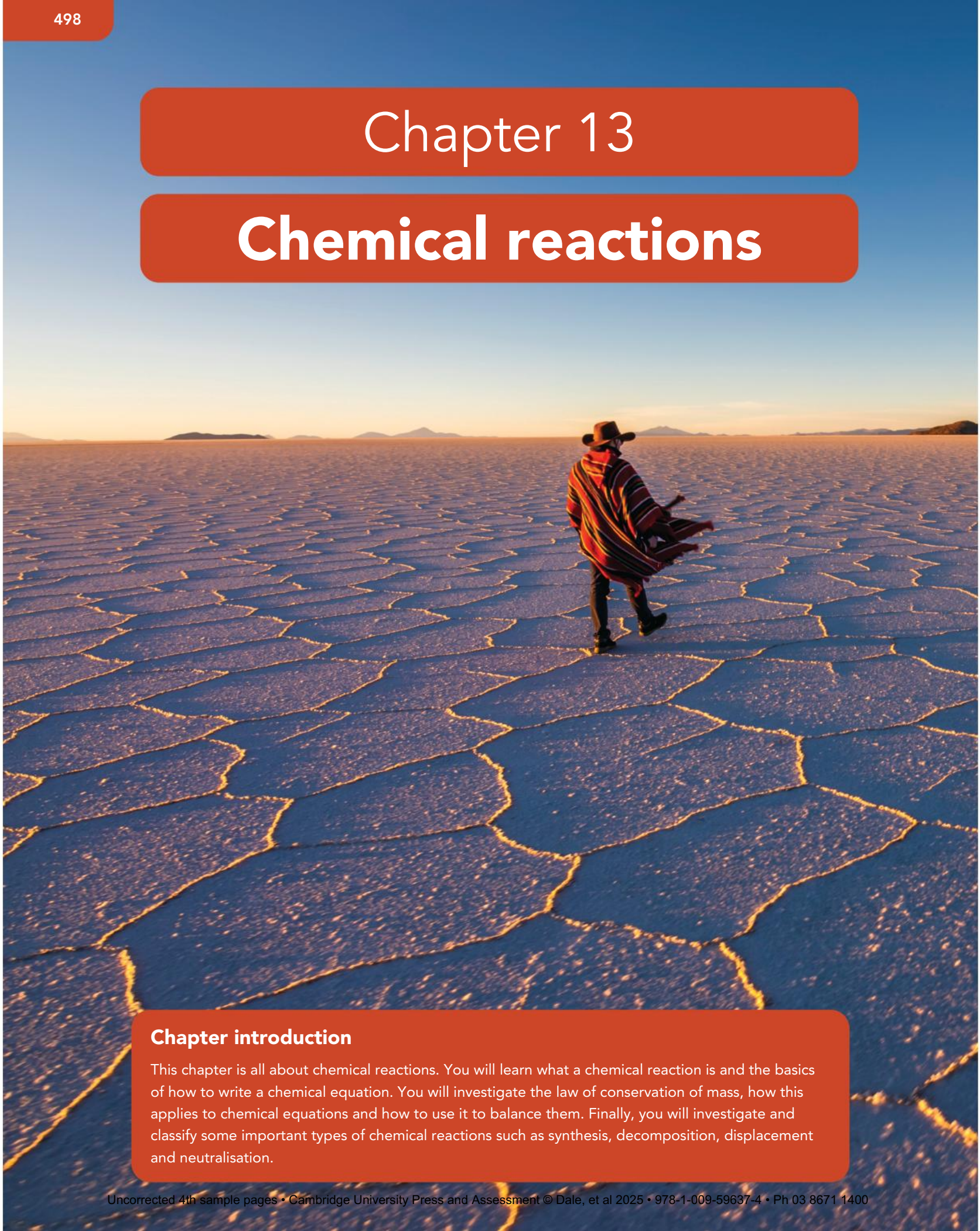
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 13

Chemical reactions

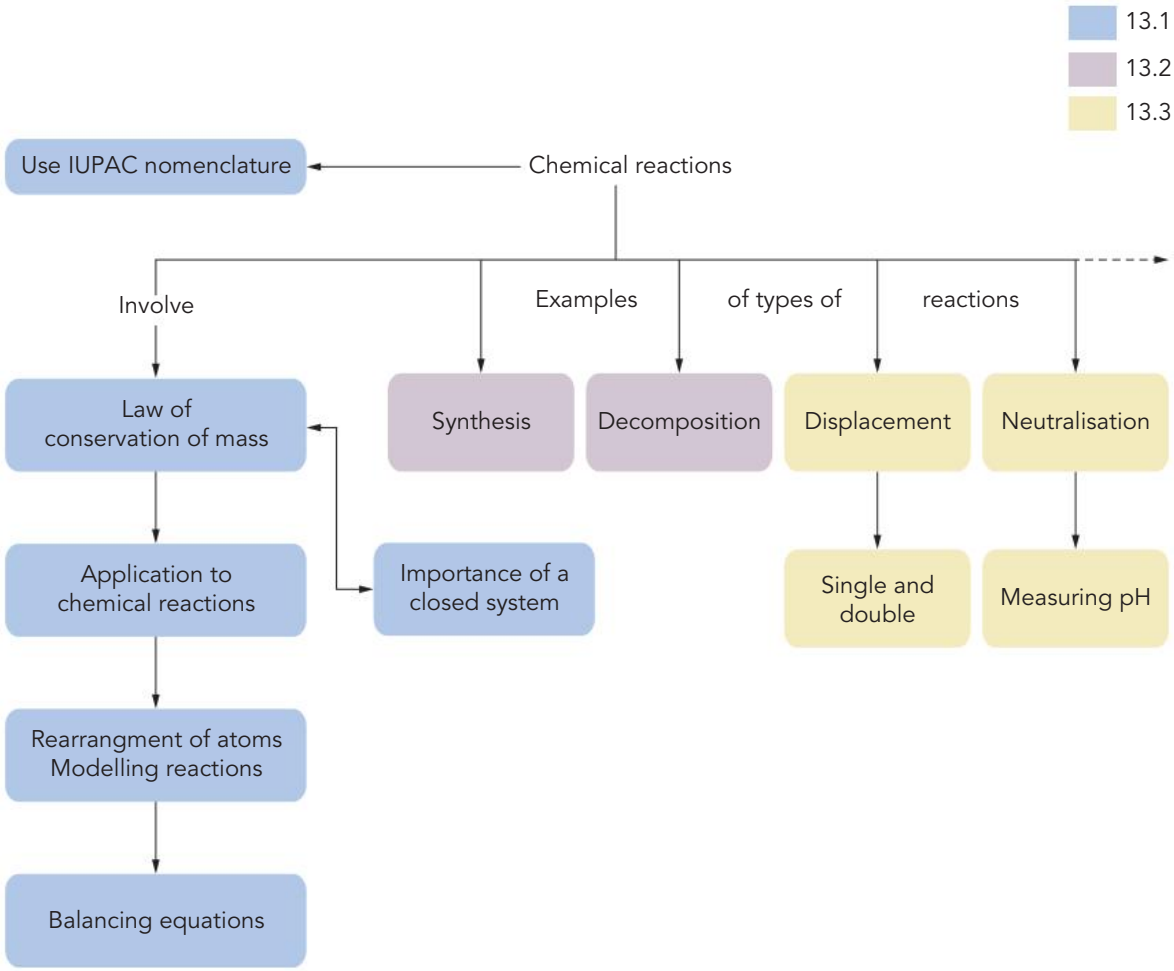


Chapter introduction

This chapter is all about chemical reactions. You will learn what a chemical reaction is and the basics of how to write a chemical equation. You will investigate the law of conservation of mass, how this applies to chemical equations and how to use it to balance them. Finally, you will investigate and classify some important types of chemical reactions such as synthesis, decomposition, displacement and neutralisation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

acid
aqueous
base
closed system
conservation of mass
decomposition
displacement reaction
neutralisation reaction
precipitate
reactivity series
salt
synthesis

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

13.1 Conservation of mass

WORKSHEETS
Writing chemical equations

VIDEO
Law of conservation of mass

Learning outcomes

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

1. explain the law of conservation of mass.
2. investigate the law of conservation of mass in action in a chemical reaction.
3. explain the importance of a closed system when measuring conservation of mass.
4. use IUPAC naming conventions for chemical compounds.
5. explain how the law of conservation of mass is applied in chemical equations.
6. model simple chemical reactions showing how atoms are rearranged and mass is conserved during a reaction.

The law of conservation of mass

conservation of mass
a law that states that matter can be neither created nor destroyed in chemical reactions

One of the fundamental laws of chemistry is the law of **conservation of mass**. This law states that matter can be neither created nor destroyed in chemical reactions. Of course, matter does change in chemical reactions, the reactants are rearranged into different chemicals, the products. While the combinations of atoms change in a chemical reaction, the number of atoms of each element present in the reactants will equal the number of atoms of each element present in the products.

Explore! 13.1

Mass and the universe

If the law of conservation of mass states that matter and energy can be neither created nor destroyed, how did the matter that is present today get here?

"We are made of star-stuff' is a famous statement by Carl Sagan, an American astronomer (although others had used the term 'star-stuff' before him). Use the internet to investigate how true the statement is and answer the following questions.

Figure 13.1 Carl Sagan said that "we are made of star-stuff".

1. What happened at the start of the universe? How did this cause matter to form?
2. How were elements heavier than hydrogen formed at the start of the universe?
3. When heavier elements are formed in this way, a large amount of energy is released. This does not seem to support the law of conservation of mass. How does Einstein's equation (energy = mass × speed of light^2 or $E = mc^2$) explain this?
4. How were heavier elements in the universe (for example, iron) made?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Putting the law of conservation of mass into practice

The law of conservation of mass means that matter and energy can be neither created nor destroyed – but what does this really mean?

A full glass of water left outside on a hot day will become less full if you leave it for long enough. The glass of water will now have a smaller mass. You may have thought that this mass has been lost, but you know now that this is not the case. The water heats up, forming water vapour, which leaves the glass and goes into the air. Water vapour has mass. The water vapour has left the glass, which is why the mass of the glass of water decreases. This example demonstrates why it is important to observe the conservation of mass in a **closed system** (one in which matter cannot escape) such as a bottle with a lid. In an open system, such as a bottle with no lid, reactions that produce gases will appear to lose mass.

closed system
a physical system that does not allow transfer of matter either in or out

Figure 13.2 Antoine Lavoisier proposed the law of conservation of mass.

Figure 13.3 Leave a glass of water outside on a hot day and it will appear to lose mass.

Try this 13.1

Investigating the law of conservation of mass

1. Place an unopened can of soda on a set of kitchen or lab scales and note its mass. Now open the can of soda. Re-weigh the can after a couple of minutes. Has it lost mass? How has this happened?
2. Place a glow stick on the scales and note it's mass. Turn off the lights and crack your glow stick, noting the chemiluminescence (light as a product) caused by the chemical reaction when you crack it. Turn the lights back on and re-weigh the glow stick. What has happened to its mass? How is this the case?

Figure 13.4 A chemical reaction that creates chemiluminescence takes place in glow sticks when they are cracked, breaking a small glass vial inside to mix the reactants. The sticks are a closed system, so mass is conserved, the products have the same mass as the reactants.

Quick check 13.1

1. **Recall** the definition of the law of conservation of mass.
2. If the mass of reactants in a chemical reaction is 30 g, **state** the mass of the products.
3. **Explain** why it is difficult to observe the law of conservation of mass in an open system.
4. **Explain** why the mass of a glass of water left out on a hot day decreases.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 13.1

Observing the law of conservation of mass (1)

Be careful

Do not stare directly at combusting magnesium.

Aim

To observe the law of conservation of mass by reacting magnesium and oxygen.

Materials

- small piece of magnesium ribbon
- tongs
- crucible
- safety glasses
- matches
- Bunsen burner
- clay triangle
- tripod
- heatproof mat

Procedure

1. Copy the results table in the Results section.
2. Set up a Bunsen burner on a heatproof mat. Place the clay triangle on top of the tripod.
3. Weigh the crucible with its lid.
4. Place a piece of magnesium ribbon in the crucible and weigh it again with the lid on.
5. The mass of magnesium can be calculated by subtracting the mass of the empty crucible.
6. Heat the crucible using the Bunsen burner on the blue flame, carefully lifting the lid using the tongs to allow sufficient air into the crucible.
7. Continue heating until the magnesium has fully reacted.
8. When the crucible has cooled sufficiently, weigh it and its contents again. Calculate the mass of the new compound by subtracting the mass of the empty crucible.

Results

Item	Mass (g)
Crucible + lid	
Crucible + lid + magnesium before heating	
Crucible + lid + compound after heating	
Magnesium	
Compound	

Discussion

1. Describe your observations when the magnesium reacted in the crucible. How did you know that a chemical change had occurred?
2. Explain why this reaction is a difficult example for showing the law of conservation of mass.
3. Propose how you could have made it easier to demonstrate the law of conservation of mass.
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

State if your results demonstrate the law of conservation of mass.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 13.2

Observing the law of conservation of mass (2)

Aim

To observe the law of conservation of mass by reacting acetic acid (also known as ethanoic acid, or vinegar) and sodium bicarbonate (baking soda).

Materials

- 100 millilitres (mL) of vinegar
- 10 g of baking soda
- balance
- measuring cylinder
- 250 mL conical flask
- balloon
- funnel

Procedure

1. Copy the results table in the Results section.
2. Measure 100 mL of vinegar using the measuring cylinder.
3. Weigh out 10 g of baking soda and carefully transfer it into the uninflated balloon.
4. Pour the vinegar into the conical flask.
5. Measure the mass of the measuring cylinder containing the vinegar and the balloon containing the baking soda. Record the combined mass of these items in your results table.
6. Carefully stretch the neck of the balloon over the mouth of the conical flask to attach it then lift the balloon to tip the baking soda into the vinegar as shown in Figure 13.5.

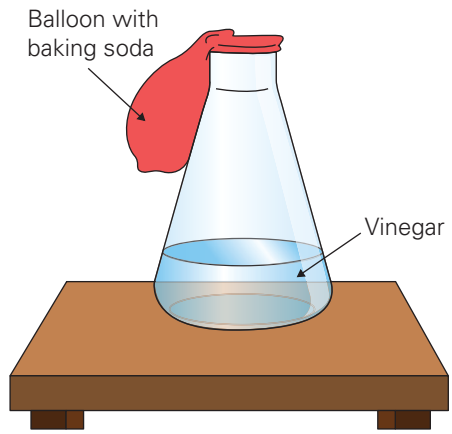


Figure 13.5 Conical flask containing vinegar and balloon containing baking soda

7. When you think the chemical reaction has finished, record the mass of the contents without removing the balloon. Record this in your results table.
8. Calculate the change in mass using the initial mass and final mass results. Record these in your results table.

Results

Initial mass (g)	Final mass (g)	Change in mass (g)

Discussion

1. Describe your observations when the vinegar and baking soda reacted. How did you know that a chemical change had occurred?
2. The gas produced in the reaction is the same as one of the gases we exhale (breathe out). What is the name and formula of this gas?
3. This experiment was carried out in a closed system. What does this mean? What would have happened if the balloon was not securely over the mouth of the conical flask?

Conclusion

State if your results demonstrate the law of conservation of mass.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 13.2

1. **Give** three examples of open systems and three examples of closed systems you might find in your home.
2. Two students were doing an experiment in the laboratory. They measured the mass of reactants as 50 grams (g). After the reaction was completed, the mass of the products was 34 g. They noticed that a gas was given off during the reaction, so they wanted to find out the mass of this gas. **Explain** to the students how they could calculate this.

WIDGET
Balancing formula equations

How does the law of conservation of mass relate to chemical equations?

As a scientist, you need to factor in the law of conservation of mass when you write chemical equations. Consider the reaction in Figure 13.6. Here, copper chloride ($CuCl_2$) is being broken down into its elements: copper (Cu) and chlorine (Cl_2).

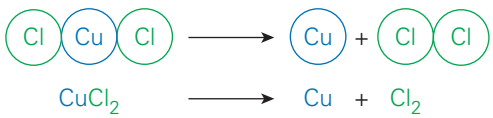


Figure 13.6 The diagram and symbol equations showing the breaking down of copper chloride into its elements.

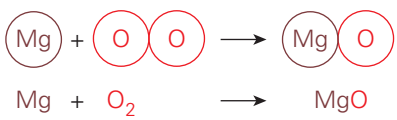


Figure 13.7 The reaction between magnesium and oxygen forms magnesium oxide.

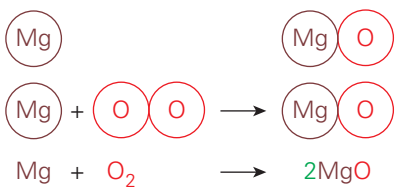


Figure 13.8 This equation now has the correct number of oxygen atoms, but it is still not observing the law of conservation of mass.

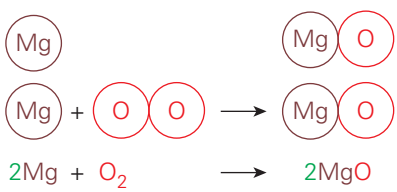


Figure 13.9 The correct balanced equation, which has the same number of each atom in the reactants and products and therefore observes the law of conservation of mass

For this reaction to obey the law of conservation of mass, there must be the same number of atoms of each element in the reactant and the products. In the reactant, there is one atom of copper and two atoms of chlorine. In the products, there is one atom of copper and two atoms of chlorine. Therefore, there is the same number of atoms on each side of the equation and therefore the same mass. The only difference is how the atoms are arranged. A chemical reaction is modelled as a rearrangement of atoms, with the same atoms and therefore the same mass at the start and the end.

Figure 13.7 shows the diagram and symbol equations for the reaction between magnesium (Mg) and oxygen (O_2) to form magnesium oxide (MgO).

What do you notice about the number of each type of atom in the reactants compared to the product? Hopefully you have realised that the number of each type of atom in the reactants and the product is different. This means that the equation in Figure 13.7 is not obeying the law of conservation of mass. There is one magnesium atom on each side of the arrow, but the left-hand side of the equation has two oxygen atoms while the right-hand side has only one. This shows the product as having less mass than the reactants, which does not happen. Therefore, the chemical equation must be altered (balanced) to show that the law of conservation of mass is observed.

Figure 13.8 shows the equation adjusted so that it has two oxygen atoms on the right-hand side. This was done by adding another unit of magnesium oxide to the products. Notice that the symbol equation also now shows two magnesium oxide units in the products.

However, adding the extra magnesium oxide unit to balance the oxygen atoms has also added another magnesium atom. The magnesium atoms are now unbalanced, with one on the left-hand side and two on the right-hand side of the equation. Adding one more magnesium atom to the left-hand side (reactants) will balance the equation (see Figure 13.9). Each side of the equation now has two magnesium atoms and two oxygen atoms. Again, notice that the symbol equation also reflects the addition of another magnesium atom.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Using IUPAC naming conventions

IUPAC naming conventions should be used to construct chemical formulas for ionic and covalent compounds as well as to name them. Access the linked worksheet in the Interactive Textbook to revise the IUPAC conventions, see examples, and practise writing formulas and names, and identifying formulas from names. For example, if you aren't sure what dihydrogen monoxide is, the worksheet will help you!

DOC
WORKSHEETS
IUPAC naming conventions for ionic and covalent compounds

Quick check 13.3

1. **Explain** why it is necessary to balance equations.
2. **Explain** what is wrong with the equation below and how it should be corrected.

$$Zn + O_2 \rightarrow ZnO$$

Try this 13.2

The combustion of methane

Methane is a gas that combusts in oxygen to form water and carbon dioxide. The simple (unbalanced) reaction is shown in Figure 13.10.

1. Use a molymod kit (lego or coloured modelling clay will also work) to build the reactants and products.
2. Does it follow the law of conservation of mass? If not, build additional molecules until the reaction does follow the law of conservation of mass.
3. Write the balanced equation for the reaction.

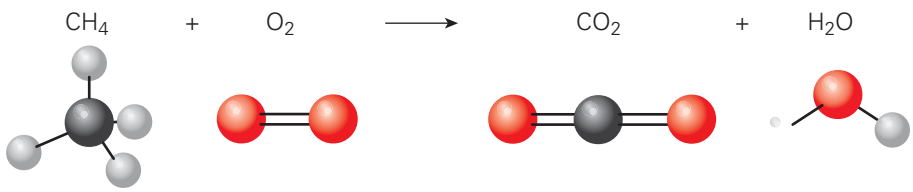


Figure 13.10 The unbalanced equation for combustion of methane, including models of the molecules involved

Section 13.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 13.1 questions

Remembering

1. **Recall** the law of conservation of mass.

Understanding

2. **Explain** how the law of conservation of mass is shown in chemical reactions.
3. Emma carried out an experiment by reacting different amounts of magnesium with oxygen. Her results are shown in the results table. **Explain** how her results support the law of conservation of mass.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Mass of magnesium (g)	Mass of oxygen (g)	Mass of product (g)
5.90	1.74	7.64
2.34	1.83	4.17
6.39	2.36	8.75

4. There are two reactants in a chemical equation, and one product. The mass of the product is 30 g. The mass of the first reactant is 17 g. **Show** that the mass of the second reactant must equal 13 g to observe the law of conservation of mass.

Applying

5. **Identify** the mass of the products in the following scenarios.
   - **a.** 35 g of reactants
   - **b.** 12 g of reactants
   - **c.** 2 g of one reactant added to 24 g of another reactant
   - **d.** 6 g of one reactant added to 3 g of another reactant

Analysing

6. **Distinguish** between an open and a closed system.
7. **Analyse** the following word equation and formula equation to answer the following:

$$\text{hydrochloric acid} + \text{magnesium} \rightarrow \text{magnesium chloride} + \text{hydrogen}$$

$$HCl + Mg \rightarrow MgCl_2 + H_2$$

   - **a.** **Identify** the reactants.
   - **b.** **Identify** the products.
   - **c.** **Decide** whether or not the equation observes the law of conservation of mass.
   - **d.** **Identify** the chemical formula of magnesium chloride.
   - **e.** **Balance** the equation to ensure it demonstrates conservation of mass.

Evaluating

8. **Decide** whether an open or a closed system is better to observe the law of conservation of mass. Justify your choice.
9. In a chemical reaction, the mass of the reactants was 15 g. The mass of the products was 12 g. **Decide** whether this reaction followed the law of conservation of mass. **Justify** your choice.
10. Joy and Paul leave a glass of water on their balcony. When they realise it has been left there, the volume of water in the glass has reduced. Joy says that the mass of water molecules has decreased. Paul says there is less water and therefore less mass in the glass because the water has evaporated, and this mass has been added to the mass of the air.
    - **a.** **Decide** who you think is correct and justify your reasoning.
    - **b.** **Design** an experiment to prove who was correct.
11. A 20 g sample of reactants were reacted together. Only 18 g of product was made. **Assess** what may have happened to the remaining 2 g of mass.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

13.2 Types of chemical reactions – synthesis and decomposition

Learning outcomes

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

1. describe synthesis and decomposition reactions and predict their products.
2. construct word equations for synthesis and decomposition reactions.
3. write balanced equations for synthesis and decomposition reactions.

WORKSHEET
The Haber process

VIDEO
Chemical reactions

Synthesis reactions

Synthesis reactions involve the combining of simple elements or compounds to create a more complex compound. In *Practical 13.1* you heated magnesium and saw it react with oxygen to produce magnesium oxide. This is a synthesis reaction.

synthesis
a chemical process where two or more simple elements or compounds combine to form a more complex product

Explore! 13.2

The hydrogen fuel cell

Hydrogen gas is considered a green or renewable fuel, and it can be combusted in oxygen gas to produce water and energy. The chemical equation for this reaction is:

$$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O + \text{energy}$$

This is a synthesis reaction as two reactants combine to form one product. The reaction vessel is called a 'fuel cell'. The energy released from a fuel cell can be used to power vehicles using hydrogen fuel as a green alternative to petroleum combustion engines.

Transit Systems, a bus operator in Sydney, have added two hydrogen powered buses to their Sydney fleet to help achieve net zero emissions. In Brisbane, Queensland, Transdev have also committed to manufacture two buses.

Low-res

Figure 13.11 A model Transdev hydrogen fuel cell bus which will use a synthesis reaction to release energy!

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Equations for synthesis reactions

Synthesis reactions can be represented like this:

$$A + B \rightarrow AB$$

A and B are reactants and AB is the product.

Another example of a synthesis reaction is the production of water from hydrogen and oxygen gas.

The word equation is:

$$\text{oxygen} + \text{hydrogen} \rightarrow \text{'dihydrogen monoxide' (water)}$$

The chemical equation is:

$$O_2(g) + 2H_2(g) \rightarrow 2H_2O(l)$$

You may have noticed that the chemical equation for the synthesis of water has small letters in brackets following each reactant and product. These are state symbols, showing the physical states of the substances in the chemical equation. They add information to the equation by categorising each substance as solid (*s*), liquid (*l*), gas (*g*) or **aqueous** (*aq*). Aqueous means that the substance (solid, liquid or gas) has been dissolved in water. For example, salt or sodium chloride (NaCl) is often dissolved in water, creating an aqueous solution.

aqueous
a physical state of matter that means dissolved in water

Did you know? 13.1

Salar de Uyuni salt flats in Bolivia

The Salar de Uyuni salt flats in Bolivia are the world's largest at 10 582 square kilometres in area. In addition to sodium chloride found in the brine (salt water) under the salt crust, there are also high concentrations of lithium, potassium and magnesium, all found in their chloride forms, dissolved within the brine. This makes the brine – an aqueous solution of sodium, lithium, potassium and magnesium chlorides – a valuable resource.

During the wet season the flats become a tourist attraction when a thin layer of water sits on top of the salt crust and the surface appears to be a huge mirror.

Figure 13.12 Sodium chloride (salt) crystals piled up on the Salar de Uyuni salt flats

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 13.4

1. **Write** a word equation for a synthesis reaction between sodium and chlorine.
2. **Explain** why sodium chloride dissolved in water is described as aqueous, not liquid?
3. **Identify** which of the following substances would be given the state symbol (s) at room temperature: iron, water, oxygen, magnesium oxide, copper sulfate solution

Decomposition reactions

Decomposition reactions are the opposite to synthesis reactions. They are reactions where a complex substance breaks down into two or more simpler compounds or elements.

decomposition a reaction where a substance breaks down into two or more simpler substances

Some compounds require heat to break down, in what is known as thermal decomposition reactions. When these compounds are heated, one product will form two or more products. Many metal carbonates take part in thermal decomposition. The word equation and the chemical equation below shows what happens when copper carbonate is heated:

$$\text{copper carbonate} \rightarrow \text{copper oxide} + \text{carbon dioxide}$$

$$CuCO_3(s) \rightarrow CuO(s) + CO_2(g)$$

When this reaction occurs, there are two signs that a reaction has taken place:

- a colour change (copper carbonate is green and copper oxide is black)
- the production of a gas (carbon dioxide).

Now you have learned how to balance synthesis and decomposition reactions, you can use this knowledge and your understanding of molecular formulas to step through creating a balanced equation from a word description of a reaction.

Lithium reacts with nitrogen gas to form lithium nitride in a synthesis reaction.

First, write the word equation for the reaction:

$$\text{lithium} + \text{nitrogen} \rightarrow \text{lithium nitride}$$

Next, write the equation using the chemical formulas. Remember that nitrogen is a diatomic gas, and that the chemical formula of lithium nitride depends on how many valence electrons lithium has (1) and nitrogen has (3):

$$Li + N_2 \rightarrow Li_3N$$

Finally, balance the equation to ensure the same number of atoms of each element on each side:

$$6Li + N_2 \rightarrow 2Li_3N$$

Figure 13.13 Hydrogen peroxide (H_2O_2) decomposes dramatically into water and oxygen gas. If soap and food colouring are used, this can be demonstrated dramatically as the oxygen is caught as coloured bubbles in an experiment known as 'elephants' toothpaste'.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 13.5

1. **Describe** how you would recognise a decomposition reaction from the word equation alone.
2. **Write** a word equation for the thermal decomposition of calcium carbonate.
3. **Write** a balanced chemical equation, including state symbols, for the decomposition of hydrogen peroxide solution (H_2O_2) into water and oxygen.

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. **Recall** the definition of a synthesis reaction.
2. **Recall** what type of reaction is the opposite of a synthesis reaction.
3. **State** the correct state symbol for each of the following substances at room temperature.
   - **a.** Water
   - **b.** Oxygen
   - **c.** Sodium chloride
   - **d.** Copper sulfate solution
   - **e.** Copper
   - **f.** Calcium carbonate

Understanding

4. **State** what type of reactions are shown in the following word equations.
   - **a.** $CuCO_3 \rightarrow CuO + CO_2$
   - **b.** $H_2 + O_2 \rightarrow H_2O_2$

Applying

5. **Use** your knowledge to balance the following equations.
   - **a.** $Mg + O_2 \rightarrow MgO$
   - **b.** $HCl \rightarrow H_2 + C_{l2}$
   - **c.** $KI \rightarrow K + I_2$
   - **d.** $Li + N_2 \rightarrow Li_3N$
6. **Determine** the chemical equations of the following reactions. Remember that most elemental gases exist as diatomic molecules.
   - **a.** Sodium chloride → sodium + chlorine
   - **b.** Calcium + oxygen → calcium oxide
   - **c.** Potassium + bromine → potassium bromide

Analysing

7. **Predict** the products of the following reactions. Include their chemical formula(s).
   - **a.** Synthesis reaction between hydrogen gas and bromine gas
   - **b.** Decomposition of sodium hydride

Evaluating

8. The Haber process is an industrial process to synthesise ammonia (NH_3) from hydrogen and nitrogen gases. **Evaluate** which gas would be needed in larger volumes for this reaction. **Justify** your answer using a balanced chemical equation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

13.3 Types of chemical reactions – displacement and neutralisation

Learning outcomes

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

1. describe displacement and neutralisation reactions and predict their products.
2. construct word equations for displacement and neutralisation reactions.
3. write balanced equations for displacement and neutralisation reactions.
4. identify pH as the measure of acidity and give examples
5. use pH indicators or meters to measure pH change.

WORKSHEET
The reactivity series

VIDEO
Green chemistry

reactivity series
a list of metals ordered by their reactivity from highest to lowest

displacement reaction
when a more reactive metal pushes out a less reactive metal from a compound

Displacement reactions

As you know, the majority of elements in the periodic table are metals and some of them, like sodium and potassium are very reactive, while others, like copper and gold, are much less reactive. Metals can be ranked in terms of their reactivity into a list called a **reactivity series**. Figure 13.14 shows a reactivity series of some common metals.

When a reactive metal encounters a solution containing a less reactive metal, it will usually react and displace (push out) the less reactive metal from the compound. This is called a **displacement reaction**.

Metal
Potassium (K)
Sodium (Na)
Calcium (Ca)
Magnesium (Mg)
Aluminium (Al)
Zinc (Zn)
Iron (Fe)
Nickel (Ni)
Tin (Sn)
Lead (Pb)
Copper (Cu)
Silver (Ag)
Gold (Au)

Figure 13.14 Reactivity series showing some common metals.

The reactivity series shows that magnesium is more reactive than copper. Therefore, we can predict that magnesium will displace copper from copper sulfate in a reaction. This is an example of a single displacement reaction as only one element is displaced:

Quick check 13.6

1. **Decide** whether the following statements are true or false. If they are false, **state** why.
   - **a.** Calcium is more reactive than potassium.
   - **b.** Nickel is less reactive than magnesium.
   - **c.** Group 1 metals are the most reactive metals in the reactivity series.
   - **d.** Tin would displace zinc from the compound zinc sulfate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 13.3

Metal displacement reactions

Be careful

Wear safety glasses, lab coat and gloves at all times to avoid contact with chemicals.

Aim

To determine the order of reactivity of metals using the outcome of single displacement reactions.

Materials

- 3 small pieces each of zinc, magnesium, iron and copper
- zinc nitrate solution
- magnesium nitrate solution
- copper(II) nitrate solution
- iron(III) nitrate solution
- pasteur pipettes or similar
- dimple or spotting tile

Note: for each metal, any available metal salt solution can be used if nitrate is not available

Procedure

1. Copy the results table to record your observations for each reaction.
2. Add 3–4 drops of each metal nitrate to five dimples in a row as shown in Figure 13.15.
3. Add a piece of the first test metal to each dimple in the second column. Watch the reaction and record your observations.
4. Repeat step **4** for each of the other three metals, using columns 3, 4 and 5.

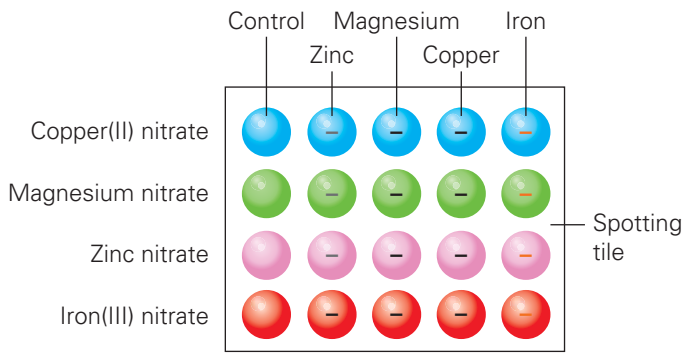


Figure 13.15 Arrangement of solutions and metals on dimple tile

Results

	Zinc nitrate	Magnesium nitrate	Copper(II) nitrate	Iron(III) nitrate
Zinc				
Magnesium				
Copper				
Iron				

Discussion

1. Describe the observations you used to determine if a displacement reaction had occurred.
2. What can you conclude from those reactions that did not show displacement?
3. Write the word equations for each of the successful displacement reactions.
4. Choose one successful displacement reaction and write a balanced chemical equation for it.

Conclusion

Draw a conclusion regarding the order of reactivity of the metals used in this investigation. Justify your order with data from the investigation.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Precipitation reactions: Double displacement with an insoluble product

When substances in a solution are mixed and an insoluble product is made, this can be described as a precipitation reaction. It is a type of displacement reaction with two displacements, so it is a double displacement reaction. A **precipitate** is a solid that is formed in a reaction mixture. Below is an example of a precipitation reaction:

precipitate
a solid formed in a solution

silver nitrate	+	sodium chloride	→	silver chloride	+	sodium nitrate
$AgNO_3(aq)$	+	$NaCl(aq)$	→	$AgCl(s)$	+	$NaNO_3(aq)$

Note the '*s*' next to the silver chloride tells us that this substance is a solid. This is the precipitate in the product and therefore informs us that this reaction is a precipitation reaction. The reaction shown above is also known as a double displacement reaction as two elements are displaced in the reaction.

Figure 13.16 The test tubes contain precipitates. The solid products are not soluble and therefore do not dissolve in the solutions. From left to right the precipitates are copper hydroxide (blue), iron(III) hydroxide (orange) and iron(II) hydroxide (green).

Quick check 13.7

1. For the following mixtures of metals and metal compounds, **state** whether a reaction will occur.
   - **a** Iron(II) chloride + nickel
   - **b** Sodium sulfate + silver
   - **c** Copper(II) nitrate + zinc
   - **d** Iron(II) sulfate + aluminium
2. **Recall** the meaning of the term precipitate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Using a solubility table

To determine if a precipitate will form in a double displacement reaction, we can use a solubility table, such as Table 13.1, containing information about the solubility of most compounds. For example, we can see in the fourth row down that magnesium chloride is soluble, but magnesium fluoride is insoluble. So, if magnesium chloride is the product of a reaction, it will not form a precipitate, but magnesium fluoride will.

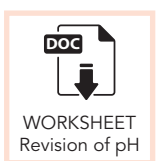
Key: s = soluble i = insoluble * = slightly soluble – = solubility data unavailable

	F^-	Cl^-	Br^-	I^-	NO_3^-	CH_3COO^-	OH^-	SO_4^{2-}	CO_3^{2-}
NH_4^+	s	s	s	s	s	s	s	s	s
Na^+	s	s	s	s	s	s	s	s	s
K^+	s	s	s	s	s	s	s	s	s
Mg^{2+}	i	s	s	s	s	s	i	s	i
Ca^{2+}	i	s	s	s	s	s	*	*	i
Ba^{2+}	*	s	s	s	s	s	s	i	i
Fe^{2+}	*	s	s	s	s	s	i	*	i
Fe^{3+}	*	s	s	-	s	i	i	*	*
Cu^{2+}	s	i	s	-	s	s	i	s	i
Ag^+	s	i	i	i	s	s	i	*	i
Zn^{2+}	s	s	s	s	s	s	i	s	i
Al^{3+}	*	s	s	s	s	-	i	s	-
Pb^{2+}	i	*	*	i	s	s	i	i	i

Table 13.1 This solubility table allows us to work out what compounds will form precipitates in solution.

Quick check 13.8

1. **Predict** the products of the following precipitation reactions and **state** which product will form a precipitate.
   - **a.** Iron(III) nitrate + sodium hydroxide ($Fe(NO_3)_3$ + NaOH)
   - **b.** Lead nitrate + sodium iodide ($Pb(NO_3)_2$ + NaI)
   - **c.** Potassium bromide + silver nitrate (KBr + $AgNO_3$)



WORKSHEET
Revision of pH

Acids and bases

In this subsection, you will learn about acid–base reactions, but before these reactions are discussed, you need to know what acids and bases are. A substance is classified as an **acid** when at 25°C it has a pH of less than 7: where pH stands for 'potential hydrogen' and is a measure of the concentration of hydrogen ions in a solution. The more hydrogen ions, the lower the pH. To revise the basics of pH, access the linked worksheet in the Interactive Textbook. Acids are sour and can sting or burn the skin. You can find some common acids in your kitchen, for example, lemon juice and vinegar, while some common bases are baking soda and milk. A **base**, in contrast to an acid, has a pH of more than 7.

acid
a substance that, when dissolved in water, has a pH of less than 7

base
a substance that has a pH greater than 7 and that can react with an acid to form a salt and water

The most common acids that you will come across in the science laboratory are hydrochloric, sulfuric and nitric acids. Hydrochloric acid (HCl) released by the stomach helps the digestion of food. The most common bases you will come across are sodium hydroxide (NaOH) and ammonia (NH_3).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 13.17 Lemon juice is a common household acid and washing-up liquid is an example of a household base.

Practical skills 13.4

Measuring pH with red cabbage indicator

Be careful

Ensure appropriate personal protective equipment is worn.
Do not eat or drink any of the materials used in this practical.

Aim

To measure the pH of some commonly found acids and bases using red cabbage indicator and universal indicator.

Materials

- red cabbage
- ziploc bag
- water
- 0.5 M hydrochloric acid
- 0.5 M sodium hydroxide
- 6 everyday substances to test, such as milk, apple juice, vinegar, lemon soda, diluted dish soap and baking soda dissolved in water
- 8 × 100 mL beakers
- dropping pipettes
- stirring rod
- universal indicator paper for checking pH and colour chart (full range)
- pH meter

Procedure

1. Tear 3–4 cabbage leaves into small pieces and place them in the bag with a cup of water.
2. Close the bag with as little air in as possible and squash the leaves around in the bag until the water turns dark blue. Note: to speed this process up, the torn leaves in water can be heated in a beaker before removing the blue liquid.
3. Pour the liquid into a beaker, this is your red cabbage indicator.
4. Copy the results table and add in your chosen substances.
5. Pour a small amount (10–20 mL) of each substance into a separate beaker.
6. Measure the pH of each substance using the pH meter and record your results.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

7. Measure the pH of each substance using the universal indicator and record your results.
8. Use the dropper pipette to add a few millilitres of the red cabbage indicator into each substance and measure the results. Red cabbage contains a chemical called anthocyanin, a natural indicator. It will remain blue for a neutral solution, turning pink and then red in acid or turning green and then yellow in a basic solution.

Results

Substance being tested	Colour using universal indicator paper	Colour using red cabbage indicator	pH using digital meter
Hydrochloric acid			
Sodium hydroxide			

Discussion

1. Did any of the results surprise you?
2. Compare the differences in the readings from the red cabbage indicator, the universal indicator and the pH meter. Which one is more accurate and why?

Neutralisation reactions

neutralisation reaction
a reaction between an acid and a base, forming a solution that has a pH of 7

salt
a compound produced by the neutralisation of an acid by a base

Acid–base reactions are also known as **neutralisation reactions**. They occur when any acid reacts with any base to produce a **salt** and water.

Acid–base reactions are called neutralisation reactions because when acids and bases with the same volume and concentration react, they may result in a neutral solution (pH = 7). (Note that this does not always occur as it depends on the strength of the acid and base; you will learn this if you study Chemistry in Stage 6.) Curing indigestion with an antacid and soothing a wasp sting with vinegar are examples of neutralisation reactions.

Figure 13.18 The pain from a wasp sting can be soothed by vinegar because of a neutralisation reaction.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The general word equation for any acid reacting with any base is shown in Figure 13.19.

acid + base → salt + water

Figure 13.19 The word equation for any acid reacting with any base

The name of a salt has two parts, the first coming from the metal and the second from the acid. For example, if sodium hydroxide (base) neutralises hydrochloric acid (acid), the salt produced will be named sodium chloride. The word equation and chemical equation are:

sodium hydroxide	+	hydrochloric acid	→	sodium chloride	+	water
$NaOH(aq)$	+	$HCl(aq)$	→	$NaCl(aq)$	+	$H_2O(l)$

You might also have noticed that in the reaction above, both the hydroxide ion (OH^-) and the chlorine ion (Cl^-) are displaced, so neutralisation reactions are also examples of double displacement reactions.

Quick check 13.9

1. **Write** the general word equation for when any base reacts with any acid.
2. **Identify** the name for a reaction between an acid and a base.
3. **Write** the word equation for a reaction between nitric acid and sodium hydroxide.

Practical skills 13.5

Reaction of acids with bases

Be careful

Ensure appropriate personal protective equipment is worn.

Aim

To observe what happens when acids react with bases.

Materials

- 0.5 M hydrochloric acid
- 0.5 M sodium hydroxide
- 250 mL beaker
- 25 mL measuring cylinder
- dropping pipette
- stirring rod
- universal indicator paper for checking pH and colour chart (full range)
- spotting tile
- pH meter

Procedure

1. Copy the results table.
2. Using a 25 mL measuring cylinder, measure 25 mL of hydrochloric acid and add to the 250 mL beaker.
3. Add a small piece of universal indicator paper to each of the six hollows on the spotting tile.
4. Using the dropping pipette, add a drop of the acid onto one of the pieces of universal indicator paper on the spotting tile and record the pH in your table.
5. Measure the pH of the acid in the beaker using the pH meter and record it in your table.
6. Using the 25 mL measuring cylinder, measure 5 mL of sodium hydroxide and add this to the beaker containing the acid.
7. Repeat steps **4–5**, recording your results in the results table.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

8. Now add a further 5 mL of sodium hydroxide and repeat steps **4–5**. Record the result against the total volume of sodium hydroxide added. Continue these steps until the table is complete.

Results

Volume of sodium hydroxide (mL)	pH using universal indicator paper	pH using digital meter
0		
5		
10		
15		
20		
25		
30		
35		
40		

Discussion

1. Describe what happened to the pH as you gradually added more and more base.
2. Identify the type of reaction that you carried out in this experiment.
3. Write a word equation for the reaction that you investigated.
4. Compare the differences in the readings from the universal indicator and the pH meter. Which one is more accurate and why?
5. To demonstrate this type of reaction, explain why it is important to use the same concentration and volume of the acid and base.

Go online to access the interactive section review and more!

Section 13.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 13.3 questions

Remembering

1. **Recall** how you would determine if a metal will displace another metal in a compound.
2. **Recall** the products of a neutralisation reaction.
3. **State** the pH range of an acid and a base.
4. **Recall** the two rules when naming a salt.
5. **Recall** the pH of a neutral solution.
6. **Identify** the missing words to complete the table:

Acid	Type of salt
Hydrochloric acid	
	Sulfate
	Nitrate

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

7. **Explain** why some metals will react in a displacement reaction while others will not.
8. **Explain** why a precipitate forms in some double displacement reactions.
9. During an experiment to show that when acids and bases react, a neutral solution is formed, Martin used equal volumes of sodium hydroxide (base) with equal volumes of hydrochloric acid. However, the solution after mixing was not neutral. **Explain** how this could have happened.
10. **Predict** the products of the following reactions.
    - **a.** Magnesium + silver nitrate
    - **b.** Silver + potassium nitrate
    - **c.** Hydrochloric acid + copper hydroxide
    - **d.** Nitric acid + potassium hydroxide
    - **e.** Calcium chloride + silver nitrate
11. **Classify** each of the following as more or less reactive than iron.
    - **a.** Potassium
    - **b.** Gold
    - **c.** Copper
    - **d.** Zinc

Applying

12. **Construct** word and chemical equations for the reactions in **10c** and **10e** (above).
13. **Identify** which of the following are salts.
    - Calcium oxide
    - Sodium chloride
    - Sodium carbonate
    - Copper chloride
    - Barium nitrate
14. For each of the following, **identify** the reaction type and balance the equations.
    - **a.** $Li + AlCl_3 \rightarrow Al + LiCl$
    - **b.** $P_4 + F_2 \rightarrow PF_3$
    - **c.** $NH_4OH + H_2CO_3 \rightarrow H_2O + (NH_4)2CO_3$
    - **d.** $Ni + HCl \rightarrow NiCl_2 + H_2$
    - **e.** $NH_3 \rightarrow N_2 + H_2$
    - **f.** $FeCl_3 + Na_2SO_3 \rightarrow NaCl + Fe_2(SO_3)_3$
    - **g.** $Ni + HCl \rightarrow NiCl_2 + H_2$

Analysing

15. **Categorise** the following as precipitation, decomposition or neutralisation.
    - **a.** A reaction that starts with one reactant and finishes with two products
    - **b.** A solid forms in a solution
    - **c.** The products are a salt and water
16. **Analyse** the following equations to find at least one mistake in each:
    - **a.** $HCl(aq) + NaOH(l) \rightarrow NaCl(aq) + H_2O(l)$
    - **b.** $KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + H_2O(l) + H_2(g)$
    - **c.** $NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(aq)$
    - **d.** $MgCl_2(aq) + Ca(s) \rightarrow Mg(s) + CaCl_2(aq)$

Evaluating

17. Heartburn is caused by acid from the stomach entering the oesophagus. **Justify** the use of antacids to alleviate the pain caused by heartburn.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
13.1	explain the law of conservation of mass.	
13.1	investigate the law of conservation of mass in action in a chemical reaction.	
13.1	explain the importance of a closed system when measuring conservation of mass.	
13.1	use IUPAC naming conventions for chemical compounds.	
13.1	explain how the law of conservation of mass is applied in chemical equations.	
13.1	model simple chemical reactions showing how atoms are rearranged and mass is conserved during a reaction.	
13.2	describe synthesis and decomposition reactions and predict their products.	
13.2	construct word equations for synthesis and decomposition reactions.	
13.2	write balanced equations for synthesis and decomposition reactions.	
13.3	describe displacement and neutralisation reactions and predict their products.	
13.3	construct word equations for displacement and neutralisation reactions.	
13.3	write balanced equations for displacement and neutralisation reactions.	
13.3	identify pH as the measure of acidity and give examples.	
13.3	use pH indicators or meters to measure pH change.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Data questions

A variety of fuel sources is shown in Table 13.2, with the number of carbon atoms per fuel molecule and the mass of CO_2 produced by burning 1 kilogram (kg) of each fuel.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

	Number of reactant carbon atoms per molecule	Mass of CO_2 produced (kg)
Natural gas	1	2.74
LPG	3	2.99
Butane	4	3.03
Petrol 91	8	3.08
Petrol 98	8	3.08
Diesel	10	3.09
Coal	Varies	3.66

Table 13.2 Number of carbon atoms per fuel molecule and the mass of CO_2 produced by burning 1 kg of fuel.

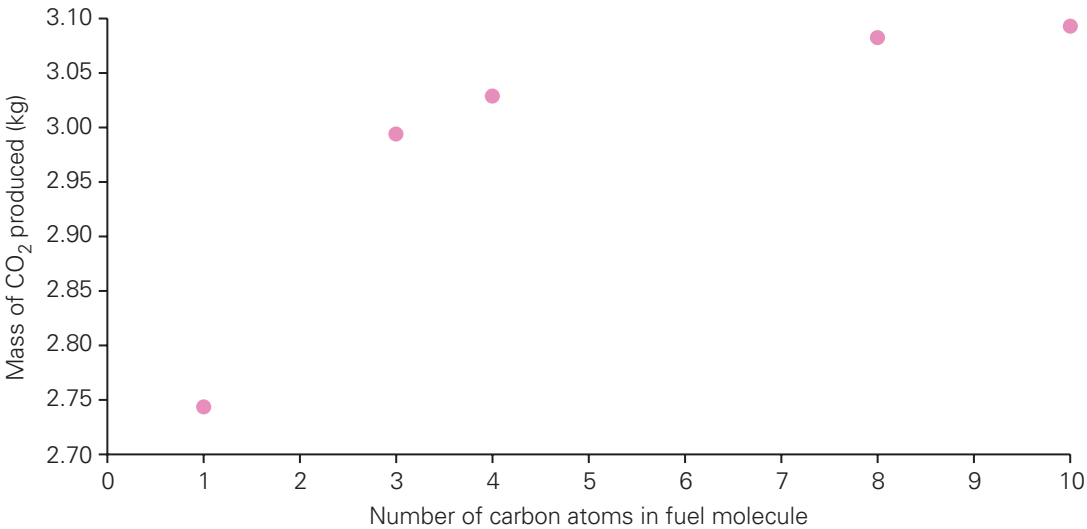


Figure 13.20 Number of carbon atoms per fuel molecule vs the mass of CO_2 produced by burning 1 kg of fuel

1. **Identify** the fuel that produces the lowest mass of carbon dioxide per kilogram burned.
2. A premium unleaded (petrol 98) brand has stated that their fuel produces less carbon dioxide emissions than a petrol 91 brand. **Determine** whether this statement is correct.
3. A coal mining company has argued that the mass of carbon dioxide produced by burning 1 kg of their fuel is under 1 kg more than that produced from natural gas. **Determine** whether the evidence from Table 13.2 supports this claim.
4. **Identify** the trend between the number of carbon atoms per reactant molecule and the mass of carbon dioxide produced.
5. At atmospheric temperature, generally fuel molecules with four carbons or less are gaseous fuels, while those with five or more carbons are liquid fuels. Coal is a solid fuel. **Classify** the fuels in Table 13.2 as gas, liquid or solid.
6. A fuel company is producing a new biofuel made primarily from ethanol, which is a molecule with two carbon atoms. **Predict** the mass of carbon dioxide that would be produced by burning 1 kg of this fuel.
7. Given the mass of carbon dioxide produced by burning coal, **deduce** the likely density of carbon atoms.
8. **Extrapolate** the data to predict the mass of carbon dioxide that would be produced by burning a fuel with a number of carbon atoms per molecule of 11.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM Baristas and the curdling milk problem

Background information

Curdling is the process of coagulation that occurs when the protein components in the milk clump together. Certain blends of coffee can be quite acidic, and acid causes the proteins in milk to unravel and clump together, similar to what happens when an egg is boiled and the yolk solidifies. Soy milk is particularly susceptible to curdling.

As with many chemical reactions, temperature can affect the rate at which the reaction occurs. If you add lemon juice or vinegar to hot milk, the milk will curdle almost immediately due to the acidity (low pH), but adding it to cold milk will not produce a reaction for quite some time.

DESIGN BRIEF

Create an infographic for baristas, based on your experimentation results, for best practice with milk. Use images from your experimentation process.

Activity instructions

You will propose the best pH, temperature and ratio of coffee to milk volume for a range of milk types in order to prevent curdling.

NOTE: an infographic is a visual representation of information, designed to make the data and information easy to understand at a glance.

Be careful

No food is to be consumed. Care is to be taken when handling boiling water.

Suggested materials

- white vinegar or fresh lemon juice (both have a pH of approximately 2)
- instant coffee
- a range of different milks, including normal milk and soy milk
- water
- beakers, measuring cylinders, pipettes
- spoons or stirring rods
- kettle
- paper towels
- thermometer
- data-logging pH meter or alternative method for measuring pH

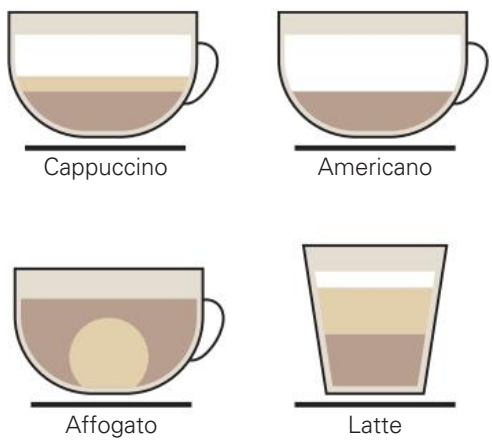


Figure 13.21 An infographic showing the various coffee, milk and froth ratios for different types of coffee drinks

Research and feasibility

1. Research the process of how milk curdles and list all the factors.
2. Research and list the ingredients that are used in barista-made coffee, and the ratios involved. Take note of any temperatures and pH values of the ingredients. Make sure you include research on all the suggested materials.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © [illegible] et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134

Design and sustainability

3. Design an experiment that demonstrates the conditions under which combining coffee and milk results in either curdling the milk or achieving a smooth texture. Think about how milk curdles and see if you can replicate this situation.

Create

4. Perform your experiment, ensuring you take photos and notes of all observations of the experiment along the way.
5. Create an A5 'cheat sheet' for baristas using infographics so they can easily identify the ratios possible for normal milk and soy milk with the most acidic coffee blends. You may do this by hand or search for free infographic design tools on the internet.

Evaluate and modify

6. Discuss your findings with your colleagues and present your infographic.
7. Propose the best ratio of coffee to milk for preventing the curdling of milk for acidic coffee blends with different milk products.
8. Identify possible sources of error in your testing procedure and suggest some ways to improve and modify your experiments in the future.
9. Predict how the temperature of the milk may have affected your findings.

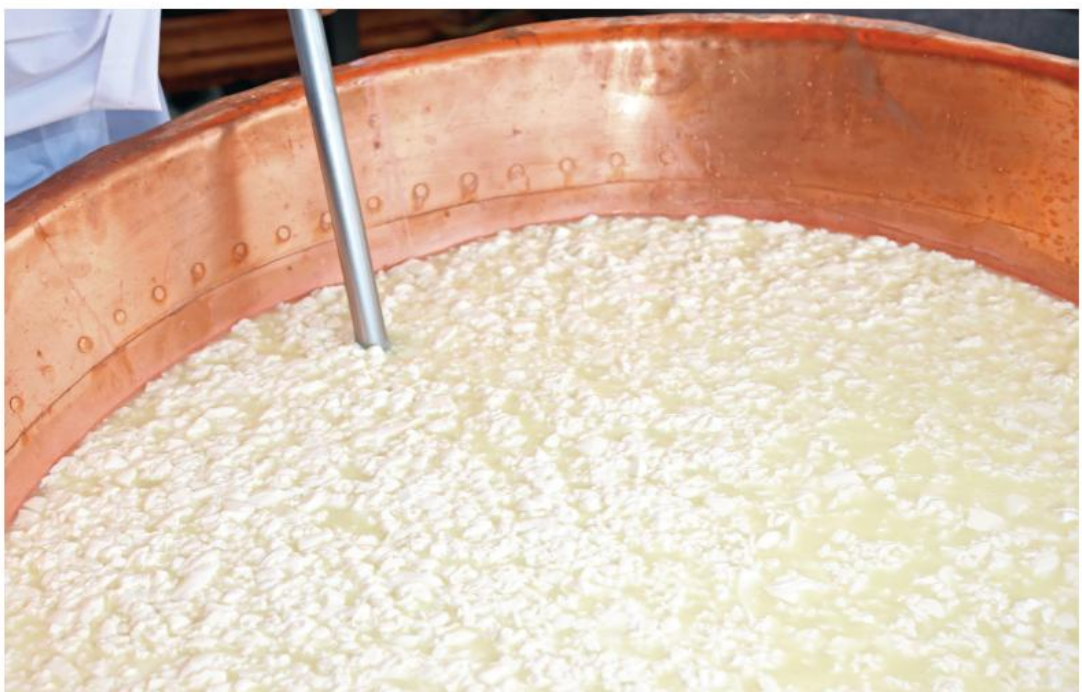


Figure 13.22 Australians drink nearly four billion cups of coffee each year, so it is important to know what situations cause milk to curdle in coffee.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 14

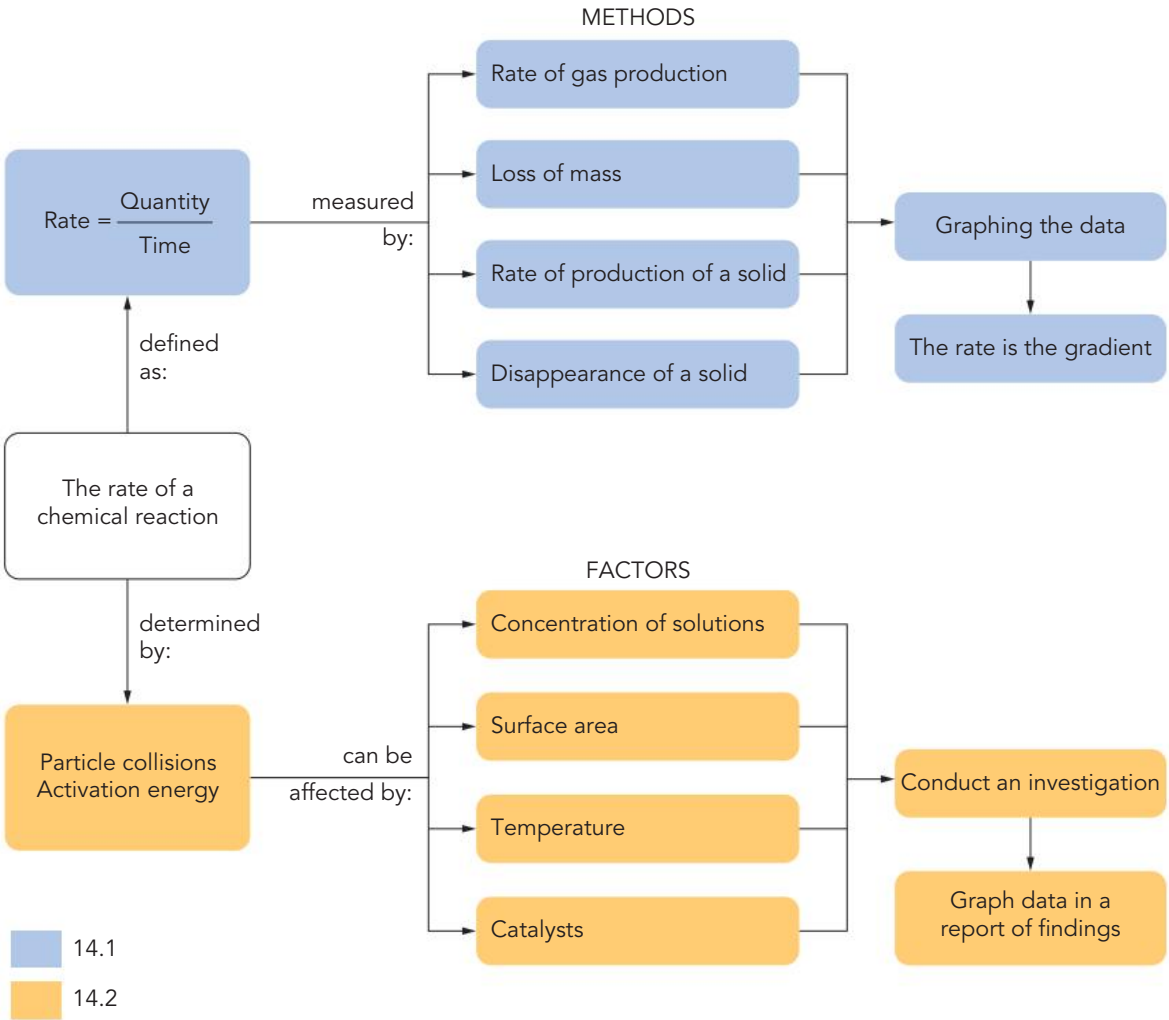
Rate of chemical reactions

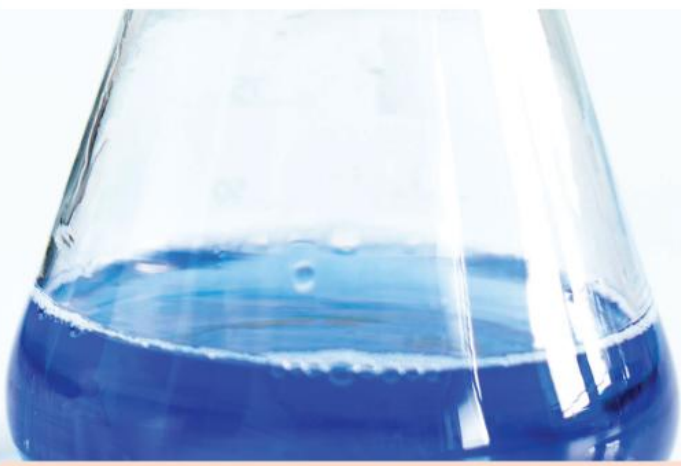
Chapter introduction

The chemical industry produces many useful substances in vast quantities, many of which we could not do without. Monitoring chemical reactions is a crucial part of determining the optimum reaction conditions required for the fast and efficient production of these substances. In this chapter, you will investigate factors that affect the rates of chemical reactions. To do this you will need first to learn how to measure rates of reaction, and the equipment and practical skills needed.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map





Glossary terms

activation energy
agitating
catalyst
collisions
concentrated solution
concentration
dilute solution
enzyme
reaction rate
surface area

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

14.1 Measuring reaction rates

WORKSHEET Monitoring the rate of a chemical reaction

Learning outcomes

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

1. describe how the rate of chemical reactions can be measured.
2. interpret the rate of chemical reactions graphically.

Reaction rate formulas

reaction rate the quantity of reactant or product used up or made per unit time; how fast the reaction goes

To understand how reactions can be sped up or slowed down, we first need to be able to measure their rates. The **reaction rate** of a chemical reaction can be found by measuring the quantity of a reactant used or the quantity of product formed over time. This gives an average rate of reaction over the measured time. The instantaneous rate at a point in time might vary.

$$\text{reaction rate} = \frac{\text{quantity of reactant used up}}{\text{time}}$$

or

$$\text{reaction rate} = \frac{\text{quantity of product formed}}{\text{time}}$$

The quantity of a reactant or product can be measured by its mass (in grams, g) or volume (in millilitres, mL). You will need to measure the quantity of reactants or products at the start or end of the reaction, and subtract the smaller amount from the larger. You will also need to measure the time the reaction takes with a stopwatch or other timer. Therefore, the units for rate of reaction may be given as g/s (g s^{-1}) or mL/s (mL s^{-1}). The quicker a product forms or a reactant is used up, the faster the rate of reaction.

Note that you don't necessarily have to make your measurements at the start or end of the reaction, as long as your method allows you to measure the quantity of the reactant or product at the moment you start the timer and at the moment you stop it.

Various methods can be used to measure the rate of a chemical reaction. It is important for you to be able to determine the method that would be most suitable for certain types of reactions.

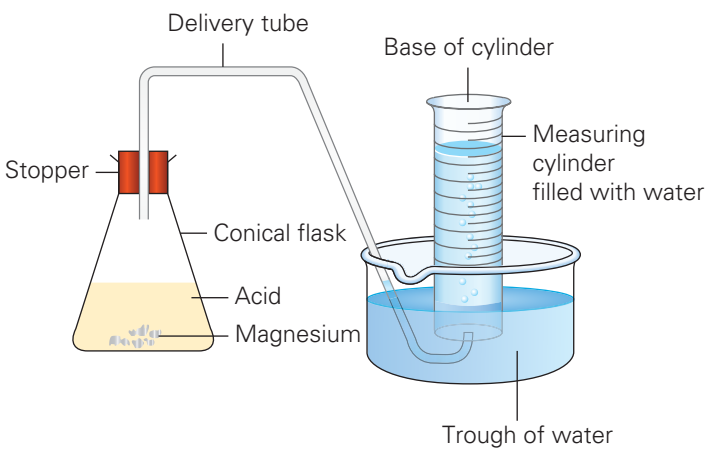


Figure 14.1 Diagram showing how to set up an upturned measuring cylinder to measure reaction rate

Measuring the rate of gas production

Upturned measuring cylinder

An upturned measuring cylinder, filled with water and placed in a trough of water, can be used to measure the volume of gas produced in a reaction over a set period of time. In this technique, the volume of displaced water is measure, as this is the same as the volume of gas produced. Figure 14.1 shows the set-up for this method of measuring reaction rates.

In this example, the magnesium reacts with the acid to produce hydrogen gas, which travels through the delivery tube and collects in the measuring cylinder,

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

displacing the same volume of water. This lets you measure the total volume of gas produced over a certain time. As volume is the dependent variable, the unit of rate will be mL/s.

Gas syringe

Gas syringes directly collect the volume of gas produced by a reaction. Figure 14.2 shows a gas syringe set-up. The increased pressure inside the syringe causes the plunger to move outwards. The volume of gas produced in a certain time can be recorded using the scale. Again, as volume is the dependent variable, the units of rate will be mL/s. Gas syringes are more accurate than measuring cylinders, but they may not be as practical depending on the amount and rate of gas produced.

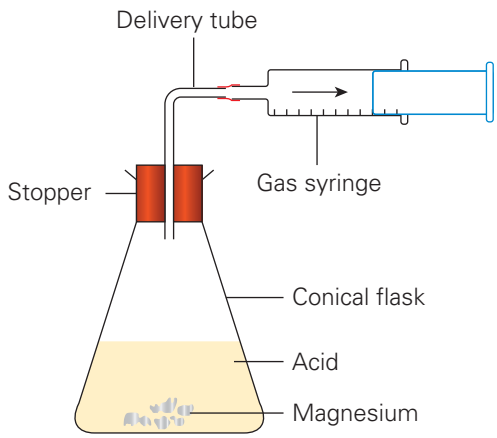


Figure 14.2 Diagram showing how to set up a gas syringe to monitor reaction rate

Quick check 14.1

1. **Determine** which of the following reactions can have their rate monitored using a gas syringe. **Give** reasons for your choice.
   - **a.** $Na_2CO_3(aq) + 2HNO_3(aq) \rightarrow 2NaNO_3(aq) + CO_2(g) + H_2O(l)$
   - **b.** $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
   - **c.** $Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq)$
   - **d.** $H_2O_2(aq) \rightarrow H_2O(l) + O_2(g)$
2. **Name** one reason why a gas syringe might be used rather than an upturned measuring cylinder for measuring reaction rates.
3. **State** the units of reaction rate when measuring the volume of gas produced.

Measuring the rate of mass loss

In this method, the reaction vessel is placed on top of an electronic balance. As gas is released into the atmosphere, the total mass of the reaction vessel decreases. The mass can be recorded at regular periods of time to determine the reaction rate. As mass is the dependent variable, the unit of rate is g/s. This method relies on gas loss into the atmosphere, so it can only be used for reactions that produce a gas.

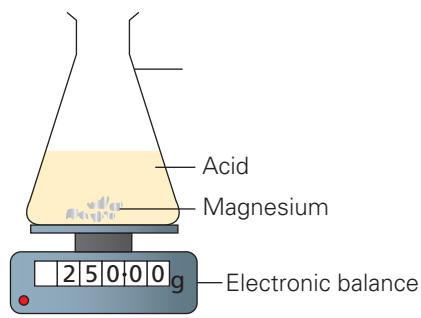


Figure 14.3 Diagram showing how reaction rate can be monitored by measuring loss of mass

Note that hydrogen gas can explosively ignite in the atmosphere, so the use of a fume hood is required (using or producing any hazardous substance should always be done under a fume hood to reduce exposure).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 14.2

1. **Determine** which of the following reactions can have their rate monitored by measuring the loss of mass. **Give** reasons for your choice.
   - **a.** $Na_2CO_3(aq) + 2HNO_3(aq) \rightarrow 2NaNO_3(aq) + CO_2(g) + H_2O(l)$
   - **b.** $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
   - **c.** $Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq)$
   - **d.** $H_2O_2(aq) \rightarrow H_2O(l) + O_2(g)$
2. **Explain** why using an electronic balance might be more accurate than using a gas syringe or upturned measuring cylinder.
3. **State** the units of rate when measuring the loss of mass in a reaction.

Measuring the rate of solid production

The rate of the production of a solid in a reaction can be used as a way of monitoring the reaction rate. This can be done by collecting the precipitate (solid produced in a reaction) and weighing it, and so producing a reaction rate in grams per second, g/s. However, in reality, it is not practical to collect a precipitate and weigh it as it is being formed because it forms in solution so the reaction would need to be interrupted for collection.

Another way for comparing relative reaction rates can be seen in the set-up in Figure 14.4. As the solid is produced, the cross beneath the conical flask will become more difficult to see. The time when the cross can no longer be seen is recorded and can be compared to the same reaction when variables are changed, such as concentration or temperature.

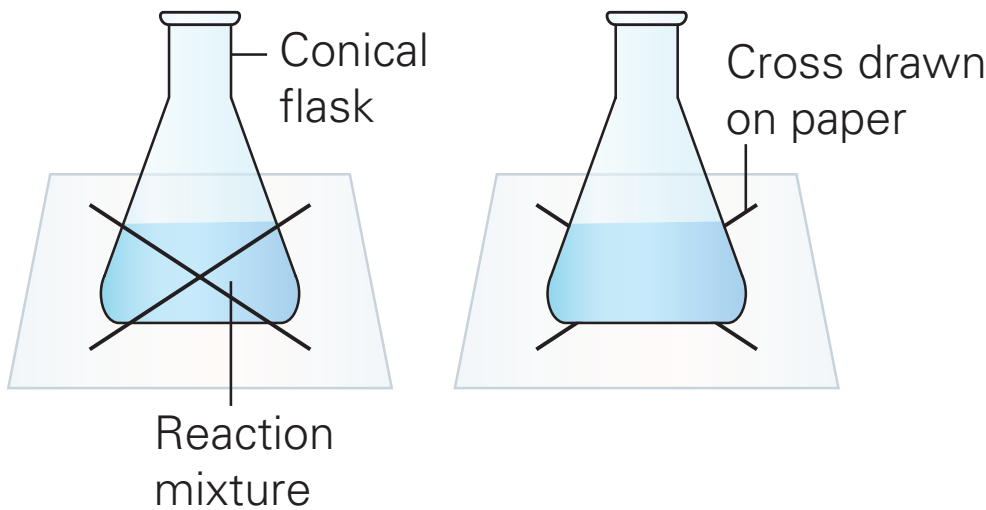


Figure 14.4 Diagram illustrating how to monitor the relative rate of a reaction in which a solid product is formed

Quick check 14.3

1. **Determine** which one or more of the following reactions can have their relative rate monitored using the time taken for a cross to disappear as shown in Figure 14.4. Give reasons for your choice.
   - **a.** $Na_2CO_3(aq) + 2HNO_3(aq) \rightarrow 2NaNO_3(aq) + CO_2(g) + H_2O(l)$
   - **b.** $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
   - **c.** $2HCl(aq) + Na_2S_2O_3(aq) \rightarrow S(s) + SO_2(g) + 2NaCl(aq) + H_2O(l)$
   - **d.** $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$
2. **State** the units of rate when measuring the production of a solid in a reaction.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Measuring rate of solid consumption

It is possible to record the time taken for a solid reactant to react with a liquid or solution. The mass of the solid is recorded at the start. Then the solid is placed into the liquid or solution. If the liquid is clear enough for the solid pieces to be observed, then the time taken for the solid to disappear can be recorded. The unit of rate for the consumption of solid is grams per second (g/s).

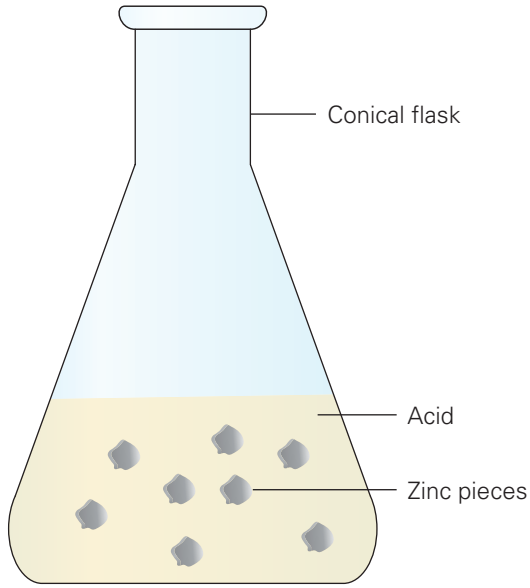


Figure 14.5 A reaction containing a solid and a liquid reactant can be monitored by eye if the solid pieces are large enough to be observed.

Graphing experimental data

A graph of a rate of reaction must have time on the horizontal axis and quantity of reactants or products on the vertical axis. Then the gradient of the plotline is the rate. Recall from mathematics that the gradient of a straight line is the vertical *rise* (change in reactant or product quantity) divided by the horizontal *run* (time in seconds). This has the same form as the reaction rate formula given at the beginning of the chapter.

To investigate the rate of reaction, a number of measurements of mass or volume need to be collected at regular time intervals during the course of the reaction. After collecting data, graphs can be plotted to provide more information on the rate of a chemical reaction. The steeper the gradient on a graph, the faster the rate.

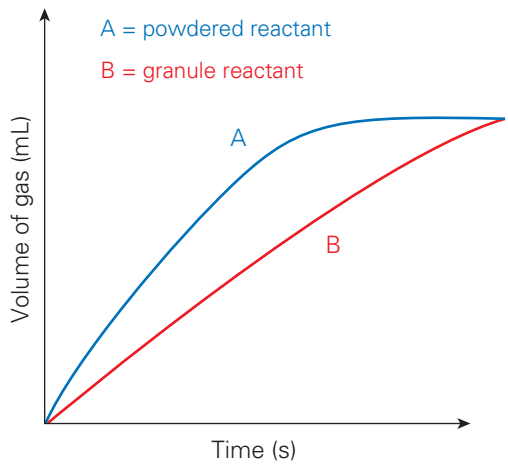


Figure 14.6 A graph showing the effect of surface area on the volume of gas produced over time

Consider the reaction between solid calcium carbonate and hydrochloric acid. The graph in Figure 14.6 shows that using powdered calcium carbonate produces a greater rate of reaction as it has a steeper gradient than when the calcium carbonate is in granule form. The reason for this is discussed in the next section.

Explore! 14.1

Using colorimetry to monitor reaction rates

Research the process of using a colorimeter to monitor the rate of a chemical reaction and then answer the following questions.

1. For what type of reactions would colorimetry be a suitable method to monitor the rate?
2. How does a colorimeter allow for reaction rates to be studied?
3. How does the concentration of the solution affect the amount of light absorbed by the sample?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

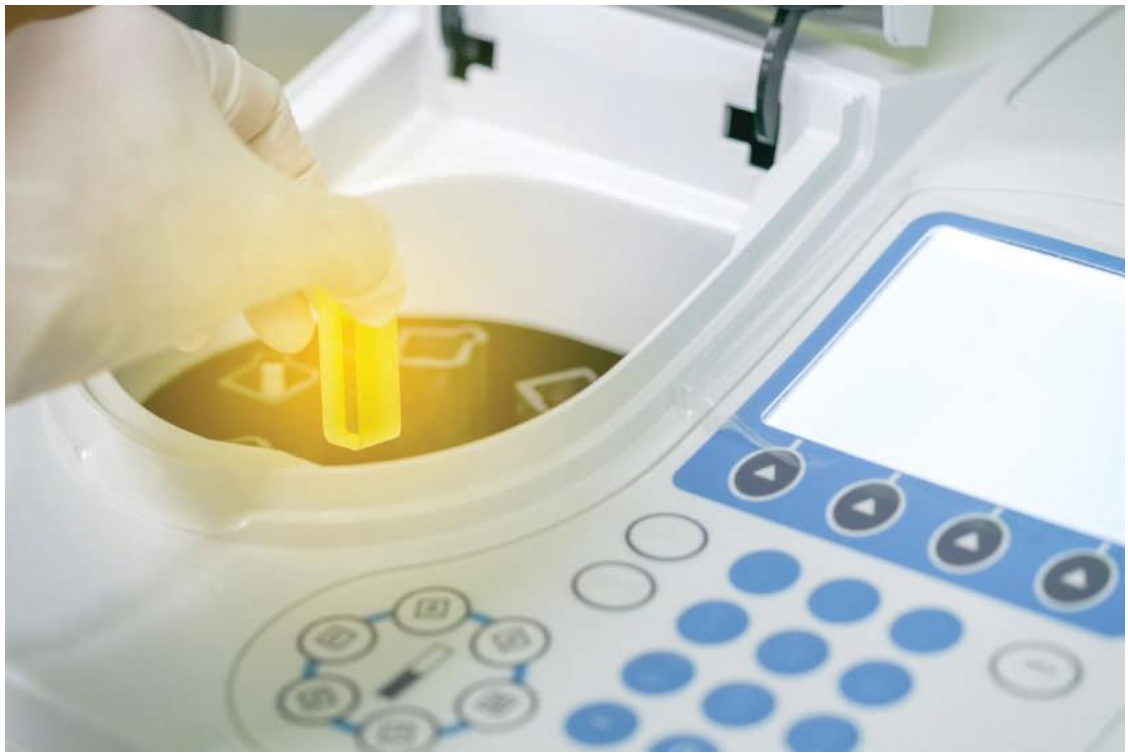


Figure 14.7 A scientist placing a sample for testing in a colorimeter

4. In the following reaction, the solution of iodine in propanone starts off brown. As the iodine is used up the solution turns orange, then yellow and eventually colourless.
   propanone + iodine → iodopropanone + hydrogen iodide
   a. Describe what you would expect the readings from the colorimeter to look like as the reaction progresses.
   b. Sketch a graph of the results you would expect (concentration of iodine on the horizontal axis and absorbance on the vertical axis).

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. **Name** two ways of monitoring the production of a gas from a chemical reaction.
2. **Identify** appropriate units of rate for the following methods of measuring reaction rates:
   a. loss of mass
   b. production of a solid
   c. gas syringe.
3. **Identify** the missing words to complete the following sentences:
   a. The greater the rate of reaction, the _____ the reactants are used up.
   b. The steeper the gradient on a volume versus time graph, the _____ the rate of reaction.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

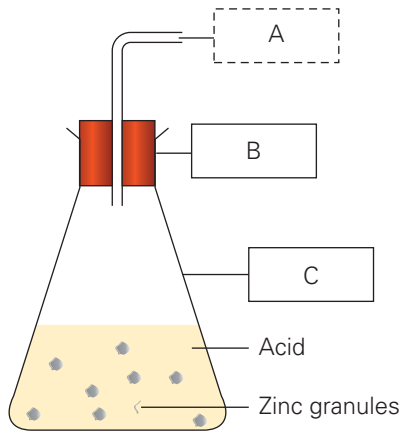
4. **Describe** what is meant by the term 'rate of reaction'.
5. **Explain** why the rate of reaction is greatest at the beginning of a chemical reaction.
6. **Demonstrate** by way of a labelled diagram how you could monitor the rate of a gas-producing chemical reaction using an upturned measuring cylinder.

Applying

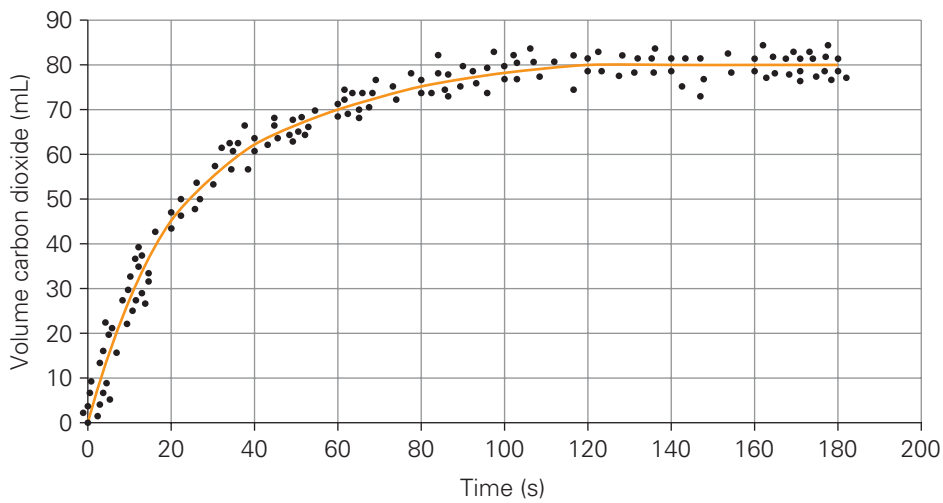
7. **Select** the most accurate technique to monitor the rate of the following chemical reaction. **Justify** your choice.

$$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$$

8. The following diagram shows how a gas can be collected, and therefore, the rate of reaction measured. **Draw** or **determine** the missing component A and **identify** the label for B and C.



9. **Identify** the time period during this experiment shown in the following graph which showed the fastest rate of reaction. **Justify** your choice.

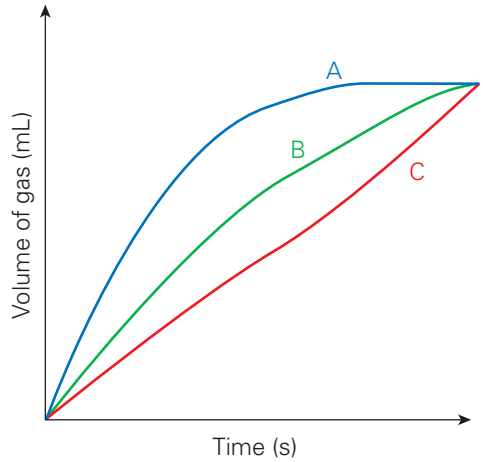


10. During an experiment, 45 mL of carbon dioxide was collected in 90 seconds. **Calculate** the average rate of reaction and give appropriate units. Show your working.
11. **Construct** a word equation for a reaction that can be monitored by timing the disappearance of a solid.

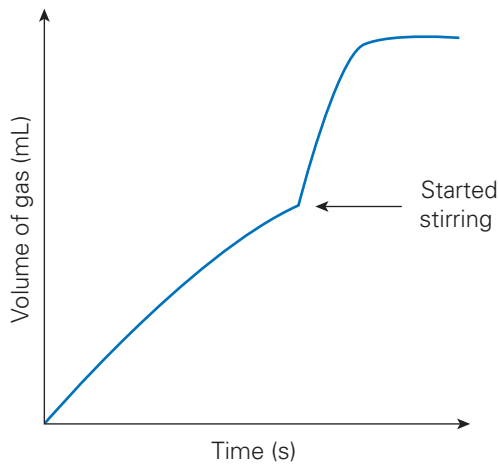
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Analysing

12. Contrast the rates of reaction for the three experiments shown in the following graph.



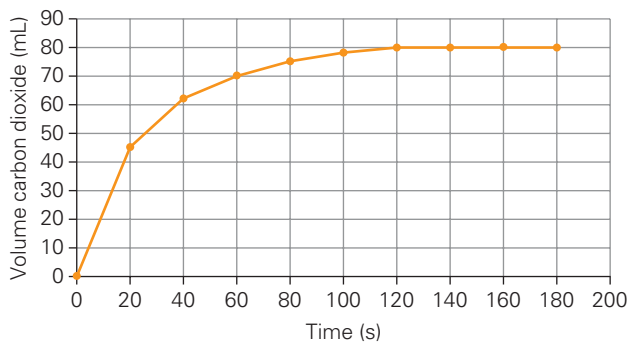
13. Analyse how stirring the reaction mixture affected the rate of this chemical reaction.



14. On a rate graph, **explain** how the start and end of a reaction can be distinguished.

Evaluating

15. Use the graph to answer the following questions.



a. **Explain**, using your knowledge of chemical reactions, why between 120 and 180 seconds the volume of carbon dioxide stays the same in this experiment.

b. **Deduce** the value for the rate of the reaction between 120 and 180 seconds.

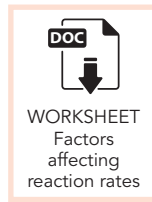
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

14.2 Factors affecting reaction rates

Learning outcomes

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

1. investigate and explain how concentration affects the rate of reactions.
2. investigate and explain how surface area affects the rate of reactions.
3. investigate and explain how temperature affects the rate of reactions.
4. investigate and explain how catalysts affect the rate of reactions.
5. conduct a practical investigation using a cause-and-effect hypothesis that predicts changes to the rate of a chemical reaction.
6. graph data that communicates the investigation findings in a scientific report.



WORKSHEET
Factors affecting reaction rates

Principles governing reaction rates

It is important to know how the rate of a chemical reaction can be increased, particularly in industry, where producing the maximum amount of product with the greatest efficiency is crucial to keeping manufacturing costs as low as possible.

For a chemical reaction to occur, reactant particles must collide with one another to form the products. However, not all **collisions** are successful ones. This is because reactant particles must also collide in the correct orientation and with at least a certain level of energy, unique to each chemical reaction, called the **activation energy**. The activation energy is the minimum energy required to break bonds in the reactants so they are able to form new bonds and make the products. If you can increase the frequency (number) of collisions and/or reduce the energy required for a successful collision (activation energy), you can increase the rate of reaction.

collisions
articles must collide for a chemical reaction to occur

activation energy
the minimum energy required for a successful collision and therefore to start a reaction

Quick check 14.4

1. **Recall** two requirements for a successful chemical reaction.
2. **Recall** the definition of the term 'activation energy'.

Figure 14.8 Industrial chemical plants rely on knowledge of reaction rates to produce maximum amounts of product in minimal amounts of time.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Concentration

concentration the amount of substance in a given volume

concentrated solution a solution which contains a large amount of solute compared to solvent

dilute solution a solution which contains a small amount of solute compared to solvent

The **concentration** of a solution is a measure of the number of particles per unit volume. A solution which contains a large number of solute particles within a given volume of solvent is called a **concentrated solution**. Likewise, a solution which contains a small number of solute particles within a given volume of solvent is called a **dilute solution**. Increasing the concentration of a solution means creating a solution with more particles of solute in the same volume.

If the concentration of a solution is increased, the particles are more likely to collide, and therefore, the reaction rate will increase. It is a bit like cramming lots of people onto a bus or train, it gets a bit tricky to avoid bumping into each other!

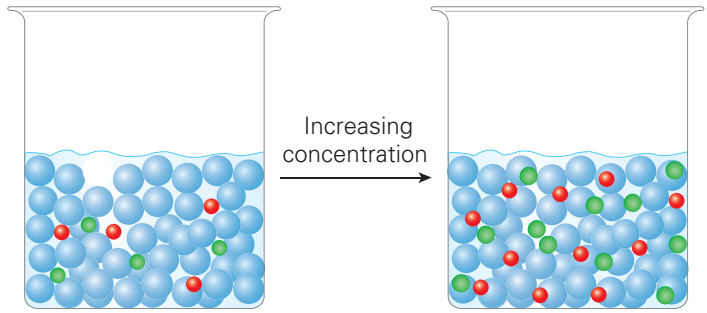
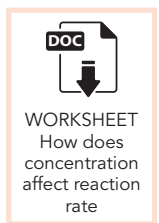


Figure 14.9 Increasing the concentration of the red and green particles in this solution increases the number of particles within the same volume and therefore the likelihood of successful collisions.



WORKSHEET
How does concentration affect reaction rate

Gaseous particles at a higher concentration are also more likely to collide as there are more molecules within a smaller volume. Therefore, decreasing the volume of the container holding the gas increases the rate of reaction as the same number of molecules are present in a smaller volume. This can only happen if one of the reactants is a gas, because solid and liquid particles are nearly impossible to compress.

Decreasing the volume of a container filled with gas, while keeping all other factors constant, increases the pressure.

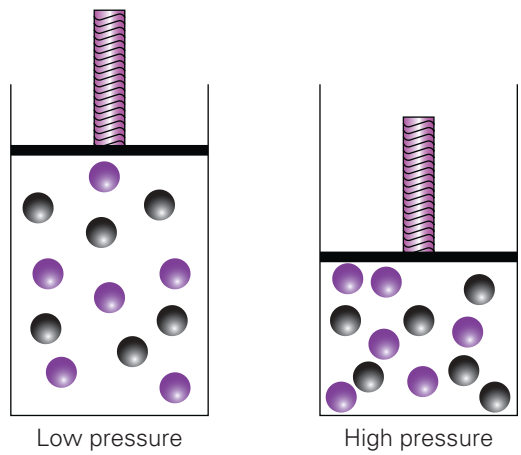


Figure 14.10 Reducing the volume of the container increases the concentration of gaseous molecules.

Although increasing the concentration of a mixture of gas increases the frequency of collisions, it does not affect the activation energy. Particles still need to collide with the same activation energy for collisions to be successful.

Quick check 14.5

1. **Decide** whether the following statements are true or false.
   - **a.** A dilute solution contains a large number of reactant particles in a given volume.
   - **b.** Increasing the concentration of a reactant only affects the frequency of collisions.
   - **c.** Concentration is a property of solutions and gases.
   - **d.** Increasing the pressure of solid and liquid reactants affects reaction rate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 14.1

Concentration and reaction rate

Aim

To determine how changing the concentration of sodium thiosulfate affects the rate of reaction with hydrochloric acid.

Be careful

Ensure appropriate personal protective equipment is worn. This experiment must be performed in a fume hood. Do not breathe in fumes when making observations.

Materials

- hydrochloric acid (2 M)
- sodium thiosulfate solution (0.15 M)
- 250 mL conical flask
- 10 mL measuring cylinder
- 50 mL measuring cylinder
- stirring rod
- 1 piece of white paper
- black marker pen
- stopwatch

Planning

Construct a hypothesis regarding how the sodium thiosulfate concentration will affect the reaction rate.

Procedure

1. Draw the table shown in the results section into your science journal.
2. Using the black marker, draw a large 'X' on the paper.
3. Using a 50 mL measuring cylinder, measure 50 mL of sodium thiosulfate and pour it into the 250 mL conical flask. In the fume hood, centre the conical flask on the black cross (Figure 14.11).
4. Using the 10 mL measuring cylinder, measure 5 mL of hydrochloric acid.
5. Pour the acid into the conical flask, stir with a stirring rod and start the stopwatch.
6. Stop timing when the cross is no longer visible and record the time in your results table.
7. If available, dispose of the reaction mixture in a fume cupboard, otherwise pour it down the sink, rinsing with lots of cold water (taking care not to splash).
8. Repeat the steps **3–7** for each concentration of sodium thiosulfate in the results table. The concentration of the sodium thiosulfate you add does not change (it is 0.15 M); however, adding water dilutes the solution.

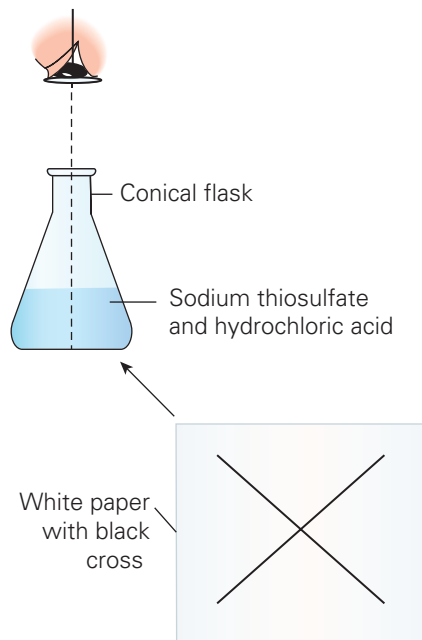


Figure 14.11 Diagram of centring the 'X' under the conical flask

Results

Concentration of sodium thiosulfate (M)	Volume of sodium thiosulfate (mL)	Volume of water (mL)	Time taken for cross to disappear (s)	Relative reaction rate $\frac{1}{\text{time}}$ (s)
0.15	50	0		
0.12	40	10		
0.09	30	20		
0.06	20	30		
0.03	10	40		

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

1. Work out the relative rate of the reaction by calculating: $\frac{1}{\text{reaction time}}$. Because it's the same reaction with the same substances, and only the concentration changes, this allows us to calculate relative reaction rates without needing to know that actual quantity of products or reactants.
2. Plot a graph of concentration (horizontal axis) versus rate (vertical axis).

Discussion

1. Using your graph, describe how increasing the concentration of sodium thiosulfate affects the rate of this chemical reaction.
2. Explain why increasing the concentration of a reactant normally increases the rate of reaction.
3. Explain why the disappearing cross method was suitable for this reaction, using the equation below:

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow S(s) + SO_2(g) + 2NaCl(aq) + H_2O(l)$$

Conclusion

1. State a conclusion regarding the concentration of sodium thiosulfate and the effect this has on the rate of reaction.
2. Support your statement by using the data you gathered.

Surface area

surface area
the area of the outer part or surface of an object

When solids react, it is only the particles on the surface, which are in contact with the other reactant, that are able to participate in the reaction. This is because they are the only particles available for the other reactants to collide with. If the solid reactant is made smaller, by cutting it into pieces or grinding it into a powder, then the **surface area** is increased, and more particles are exposed. Imagine a cake: when its surface area is increased by cutting into smaller pieces, there is a greater area of the cake exposed to the air, and therefore, it will dry out more quickly.

Figure 14.12 Cutting a cake into pieces increases its surface area.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

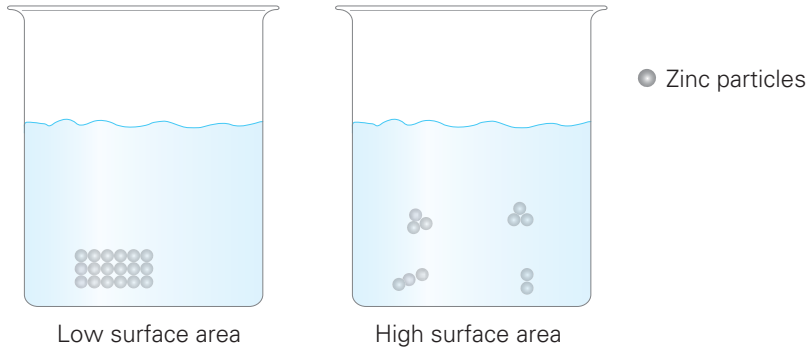


Figure 14.13 To increase the surface area of a solid reactant, such as this piece of zinc (left), it can be cut it into smaller pieces or ground into a powder (right).

Increasing the surface area of a solid will cause the reaction rate to increase. This is because there are more particles exposed to the reaction, increasing the frequency of collisions and therefore increasing the number of successful collisions. However, just like increasing the concentration, the energy with which the particles collide is not affected.

Did you know? 14.1

Swallow, don't crush

The pharmaceutical industry manufactures a wide variety of medicines through chemical reactions to produce a specific chemical that will help an immune response or reduce pain. Often pharmaceutical medicines are sold in tablet form and are meant to be swallowed in that form, not crushed! The chemicals in the tablet can react with stomach acid to release the active ingredients into the bloodstream in a controlled fashion. However, if the tablet is crushed, the surface area of the reactant is increased and this reaction in the stomach becomes much faster and less controlled. Therefore, there is a possibility of overdosing, or other side effects may occur, as the medicine will be released into the body too quickly. It might also make the medicine less effective. Pharmaceuticals in tablet form are designed not only to provide you relief from illness but also to provide the medicine over the right amount of time.

Figure 14.14 If swallowing tablets is difficult, it may be worthwhile asking a pharmacist whether the medicine comes in other forms rather than crushing them.

Quick check 14.6

1. **State** two ways that the surface area of a solid can be increased.
2. A chemical reaction contains two different gaseous reactants. Can increasing their surface area increase reaction rate? **Justify** your answer.
3. **Explain** how increasing the surface area of a solid reactant increases the reaction rate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 14.1

Reaction rates in everyday life

Make three cups of hot weak tea (so you can still see the bottom of the cup), filled to the same height. Place a sugar cube in cup 1, a level teaspoon of granulated sugar in cup 2 and a level teaspoon of icing sugar in cup 3. After reading this section, you should be able to make a prediction about surface area and the rate at which sugar dissolves. Make your prediction and the time how long it takes for the sugar in each cup to dissolve. Were you correct?

Figure 14.15 Sugar comes in various forms for different uses.

INVESTIGATION

Investigation 14.2

Surface area and reaction rate

Be careful

Potassium manganate(VII) is extremely toxic. Ensure appropriate personal protective equipment is worn. Wear safety glasses at all times. No food items are to be consumed.

Aim

To investigate how changing the surface area affects reaction rate.

Background information

Rhubarb contains oxalic acid (toxic in large doses), which will react with pink-coloured acidified potassium manganate (VII) to form colourless manganese(II) ions. This provides an ideal end point for measuring the rate of reaction.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Materials

- 2 measuring cylinders (250 mL and 50 mL)
- 3 × 50 mL beakers
- 500 mL conical flask
- potassium permanganate crystals
- 1 M sulfuric acid
- white tile
- rhubarb stalks with leaves removed (Note: there is variation in the oxalic acid found in different stalks. Check if the stalks produce a result with the concentration of acidified potassium permanganate. Radish could be used as a replacement.)
- cutting tile
- knife
- 30 cm ruler
- stopwatch
- tweezers

Planning

1. Identify the independent variable from the aim and describe the different reactions that will be set up for the experiment.
2. Define the dependent variables and how they will be measured.
3. Identify and list the controlled variables to be monitored. For each variable, you must define the property that will be measured (numerically if possible) to ensure they are not changing throughout the experiment, e.g. temperature (to be maintained at 25°C).
4. Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.
5. Write a risk assessment for this investigation.
6. Create a results table that will allow you to collect sufficient and relevant raw data, in addition to calculating the mean and uncertainty.

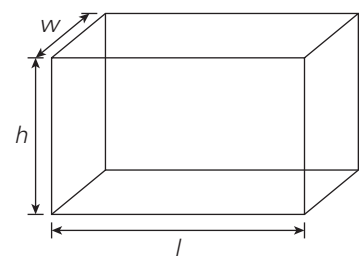
Procedure

Part 1: Prepare the potassium permanganate solution

Add two potassium permanganate crystals to 150 mL of 1 M sulfuric acid and stir well. Add another 150 mL of 1 M sulfuric acid to this solution, resulting in a light purple colour.

Part 2: Prepare the rhubarb

1. Cut nine identical pieces of rhubarb, ensuring they are as uniform as possible. You may need to use your knife to create straight edges and remove any excess.
2. Take three of the pieces and calculate the approximate surface area of one of these lengths by using the calculation shown in Figure 14.16. This will be your 'low' surface area rhubarb samples.
3. Take another three of the lengths and cut them each in half. Calculate the total surface area for the two halves. This will be your 'medium' surface area rhubarb.
4. Take another three of the lengths and cut them into four even pieces. Again, calculate the total surface area for the four quarters. This will be your 'high' surface area rhubarb and should be smallest in size compared to the other pieces from step **2** and **3**.



$SA = 2lw + 2lh + 2wh$

Figure 14.16 Calculating the surface area of a cuboid

Part 3: Measure the reaction time

1. Add 30 mL of acidified potassium permanganate to a beaker and place on a white tile. You may want to have a beaker of water next to the reaction beaker for a comparison.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

2. Using tweezers, add a piece of the low surface area rhubarb to the beaker. Be careful not to splash the solution.
3. Immediately start the stopwatch. Stir the solution until the purple colour disappears, then stop the timer. Record the time it takes for the colour to disappear.
4. Empty, wash and dry the reaction beaker.
5. Complete **Part 3** steps **1–3** twice more with another piece of low surface area rhubarb.
6. Repeat **Part 3** steps **1–4** with the other samples.

Results

1. Calculate the mean reaction time for each rhubarb sample.
2. Draw a scatter plot to analyse the relationship between the independent variable (surface area) and its dependent variable (reaction time).
3. Draw a graph and insert a copy below the results table into your science journal.

Discussion

1. Describe any trends, patterns or relationships that are found in your results.
2. Use your graph to predict the value of the dependent variable if you were given rhubarb pieces that were halfway between the sizes of the medium and high surface area group.
3. Extrapolate your data to predict the value of the dependent variable if you were given rhubarb pieces that had been cut into eight pieces.
4. How much variation was observed between the measurements between different student groups within the class?
5. Were other variables that could affect the validity of the results successfully controlled during the experiment?
6. Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

Conclusion

Propose a conclusion regarding the type of relationship between the surface area of the rhubarb and reaction rate. Justify your conclusion using data from your experiment.

agitating
stirring or shaking a mixture

Stirring the reaction mixture

Stirring or **agitating** a chemical reaction can keep the reaction rate more even as the reaction progresses. When a chemical reaction is left undisturbed (like the one in Figure 14.17), the product can form on the surface of the solid reactant, creating a barrier for any further reaction. Solid reactants can also settle to the bottom of a reaction or clump together, making them less available for collisions. Stirring a chemical reaction will prevent clumping or settling from happening and maintain the frequency of collisions.

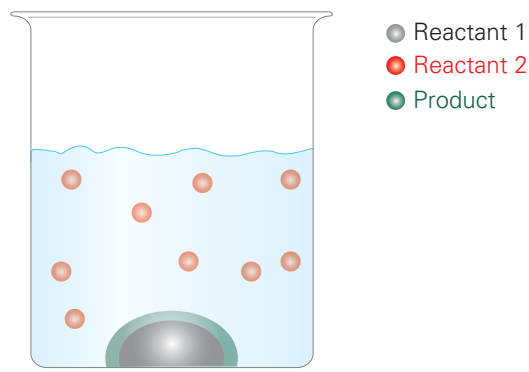


Figure 14.17 Stirring this reaction mixture would allow all of reactant 1 to come into contact with reactant 2.

Temperature

When you increase the temperature of a reaction, the rate of reaction also increases. The thermal energy added to the reaction is transformed into kinetic (movement) energy, so the particles move at greater speeds. Particles are therefore more likely to collide and, because they move at faster speeds, they are also more likely to collide at or above the reaction's activation energy.

Therefore, increasing the temperature of a reaction increases the number of successful collisions. It is a bit like running in a corridor: if you are moving fast, you are more likely to bump into someone *and* it is more likely to hurt!

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

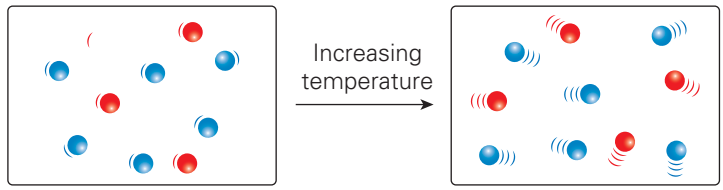


Figure 14.18 Increasing the temperature of a reaction increases kinetic (movement) energy of the reactant particles, increasing the number of successful collisions as shown for this mixture of gases.

Quick check 14.7

1. When heat is applied to a chemical reaction, **identify** the energy that it is converted to at the particle level.
2. **Explain** increasing the temperature of a chemical reaction increases the frequency of successful collisions.

Try this 14.2

Chemical reactions in glow sticks

Get three glasses and fill one with ice cold water, one with room temperature water and one with hot water. Crack three glow sticks and add one to each glass. Observe which one glows the brightest. Can you explain why this is the case?

Figure 14.19 A chemical reaction causes glow sticks to release light.

Practical skills 14.3

Temperature and reaction rate

Be careful

Hydrochloric acid is corrosive.

Heat the hydrochloric acid using a water bath only. Do not heat the acid directly with the Bunsen burner or hotplate.

Do not seal the boiling tube while reacting the acid and magnesium.

Wear safety glasses.

Work under a fume hood.

Aim

To determine the effect of temperature on reaction rate.

Materials

- 3 pieces of cleaned magnesium ribbon (3 cm in length)
- 2 M hydrochloric acid, initially at room temperature
- 10 mL measuring cylinder
- beaker
- 3 boiling tubes

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

- ice
- stopwatch
- thermometer
- Bunsen burner
- gauze
- tripod
- bench mat
- matches

Note that water baths or a hotplate may be used if available.

Planning

1. Create a research question that can be easily and safely investigated.
2. Write a hypothesis for your investigation regarding the effect of temperature on reaction rates.
3. Identify the independent and dependent variables in this investigation.
4. Give two controlled variables and why they needed to be controlled.

Procedure

1. Draw the table shown in the results section into your science journal.
2. Using the 10 mL measuring cylinder, measure 10 mL of the room temperature 2 M hydrochloric acid and pour it into the boiling tube.
3. Add one piece of magnesium ribbon to the acid and start timing immediately.
4. Time how long it takes for the magnesium to disappear and record this time in the results table.
5. Repeat another two times.
6. Using either a Bunsen burner, water bath or hotplate, heat a beaker of water to 40°C. This will be your water bath.
7. Once your water bath has reached 40°C, reduce the heat to maintain the temperature, but not allow it to increase.
8. Measure another 10 mL of 2 M hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your water bath and wait for it to reach the same temperature as the water. Switch off the hotplate or Bunsen.
9. Repeat steps **3–5**.
10. Finally, create a cold ice bath by placing ice in a beaker of water.
11. Measure another 10 mL of 2 M hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your cold ice bath and wait for it to reach the same temperature as the water.
12. Repeat steps **3–5**.

Results

Temperature (°C)	Time taken for magnesium to disappear (s)				Uncertainty
	Trial 1	Trial 2	Trial 3	Mean	

1. Calculate the mean time taken for the magnesium to disappear at each temperature.
2. Calculate the uncertainty for each set of trials at each temperature.
3. Plot a graph of your results, including a line of best fit.
4. Extrapolate your graph to predict the time it would take for the magnesium to disappear at 50°C and 60°C.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Discussion

1. Identify any patterns, trends or relationships in your results.
2. Write a balanced chemical equation for the reaction of magnesium (Mg) with hydrochloric acid (HCl) to form magnesium chloride ($MgCl_2$) and hydrogen gas (H_2).

Conclusion

1. Write a conclusion regarding the effect of temperature on reaction rate based on this experiment.
2. Support your statement by using the data you gathered.

Catalysts

A **catalyst** is a substance that can be added to a chemical reaction to make a reaction take place or increase the reaction rate. During the reaction the catalyst is not used up and therefore it is not part of the reaction. That is why the catalyst is not included in the chemical reaction, but it is often written above the reaction arrow between the reactants and products as in the equation below.

catalyst speeds up a chemical reaction by lowering the activation energy; does not get used up in the process

enzyme a substance produced by a living organism that acts as a catalyst

$$\text{starch} + \text{water} \xrightarrow{\text{amylase}} \text{glucose}$$

When you eat carbohydrate-rich foods, the starch molecules react with water to form glucose. The **enzyme** amylase, which is found in your saliva, acts to catalyse (speed up) this reaction. Catalysts increase the reaction rate by providing an alternative route, which has a lower activation energy, for the reaction.

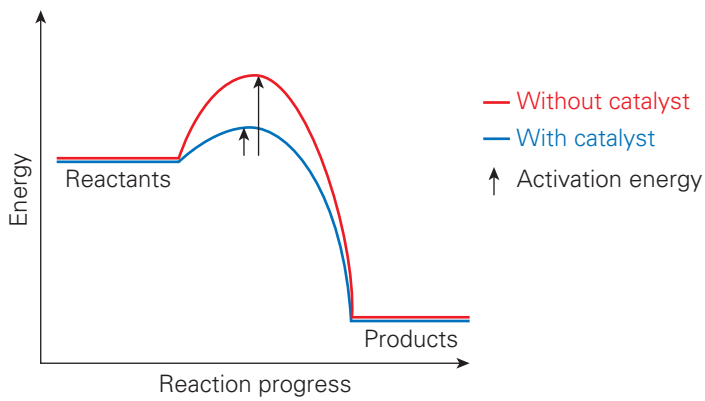


Figure 14.20 Adding a catalyst to a chemical reaction decreases the activation energy. This increases the number of molecules with the required energy and therefore increases the number of successful collisions which in turn increases the reaction rate.

It can be likened to sheep jumping over a fence. The sheep are the reactant particles, and the fence is the activation energy. If the fence (activation energy) is high, fewer sheep (particles) will reach the other side (there will be fewer successful collisions) On the other hand, if the fence is lowered by adding a catalyst, more sheep will be able to jump the fence (there will be a greater number of successful collisions).

Quick check 14.8

1. **Define** 'catalyst'.
2. **Describe** how a catalyst speeds up a chemical reaction.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 14.4

Catalysts and reaction rate

Be careful

Hydrogen peroxide is corrosive to the eyes. Ensure appropriate personal protective equipment is worn.

Aim

To determine the most effective catalyst to decompose hydrogen peroxide.

Materials

- 0.5 g manganese(IV) oxide
- 0.5 g iron(III) oxide
- 50 vol hydrogen peroxide solution
- 1 cm^3 piece of potato
- 1 cm^3 piece of liver
- 1 cm^3 piece of celery
- dishwashing detergent
- 5 × 250 mL measuring cylinders
- 1 dropping pipette
- 25 mL measuring cylinder
- plastic tray

Note: Potato, liver and celery each contain a number of enzymes (biological catalysts) including catalase which breaks down hydrogen peroxide.

Procedure

1. Draw the table shown in the results section into your science journal.
2. Line up the five measuring cylinders into the tray and add about 1 mL of dishwashing detergent to each measuring cylinder.
3. Add 25 mL of the 50 vol hydrogen peroxide to each measuring cylinder.
4. Add the manganese oxide to one of the measuring cylinders and start the stopwatch.
5. Measure the height of the foam when it stops rising and record this height in the results table.
6. Repeat in a clean measuring cylinder for two more trials.
7. Repeat for each of the catalysts.

Results

Catalyst	Height of foam (cm)				Uncertainty of foam height max − min/2
	Trial 1	Trial 2	Trial 3	Mean	
Manganese oxide					
Iron oxide					
Potato					
Liver					
Celery					

1. Calculate the mean height of foam for each catalyst.
2. Calculate the uncertainty in your results.

Discussion

1. Identify the catalyst that was the most effective at decomposing the hydrogen peroxide. Use data to support your answer.
2. Identify the catalyst that was the least effective at decomposing the hydrogen peroxide. How did you know?
3. One of the products formed in this reaction relights a glowing splint. Identify this product.
4. Identify any limitations to your experiment.
5. Describe any improvements you could make that would improve the reliability of your results.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Explore! 14.2

Catalytic converters

Catalytic converters have been a key component of car exhaust systems in Australia since 1986. Their outer body is made of stainless steel and their inside comprises a honeycombed ceramic block containing transition metals such as platinum and palladium. The role of a catalytic convertor is to speed up a chemical reaction which converts harmful emissions produced by burning petrol and diesel into less harmful emissions. Catalytic converters play such an important part in reducing harmful exhaust emissions that you can be given a heavy fine if your car does not have one.

Figure 14.21 A catalytic converter used in a car's exhaust system

1. Research and give the name of some harmful gases produced by burning petrol and diesel and describe how they could affect the environment.
2. State the name of the gases produced by the catalytic converter and describe how they affect the environment.
3. Write the chemical equation for the conversion of nitrogen monoxide (NO) into nitrogen (N_2) and oxygen (O_2) which occurs in a catalytic converter.
4. Give the chemical equation for the oxidation of carbon monoxide (CO) into carbon dioxide (CO_2) by reacting it with oxygen (O_2) that occurs in a catalytic converter.
5. Explain the advantage of a catalytic converter having a honeycomb structure.
6. Explain why catalytic converters are less efficient when you start your car cold than when it has warmed up.

A summary of changing reaction rates

Table 14.1 summarises how each factor discussed in this section influences the rate of a chemical reaction.

Factor affecting reaction rate	Effect on the frequency of collisions	Effect on the proportion of successful collisions	Effect on rate
Increasing concentration of reactants	Increases	Not affected	Increased
Decreasing volume (increasing concentration) of gaseous reactants			
Increasing surface area of solid reactants			
Increasing temperature		Increased	
Adding a catalyst	Not affected		

Table 14.1 A summary of how each factor discussed affects reaction rate

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Investigation 14.5

INVESTIGATION

Investigation into reaction rates

Aim

To investigate how either concentration, temperature or surface area affect the rate of reaction of sodium bicarbonate with ethanoic acid.

Be careful

Ensure appropriate personal protective equipment is worn.

Materials

- sodium bicarbonate tablets
- sodium bicarbonate powder
- ethanoic acid (2 M)
- variety of measuring cylinders
- variety of beakers
- 250 mL conical flasks
- water basin
- 1 stopper and delivery tube
- weighing boat
- bosshead and clamp
- electronic balance
- thermometer/temperature probe
- heating block
- water bath
- stopwatch
- other equipment as determined by your teacher

Planning and procedure

Complete the following steps to create a full scientific report detailing your investigation.

1. Choose a variable (concentration, temperature or surface area) to investigate.
2. Write a hypothesis for your investigation regarding the effect (a cause-and-effect relationship) that changing your chosen variable will have on the rate of the reaction.
3. Write a clear step-by-step method for your investigation.
4. Carry out your investigation and record your results in an appropriate table.
5. Choose an appropriate graph to display your results.
6. Write a detailed discussion of your investigation and results, including any errors identified or improvements that could be made.
7. Form a conclusion stating whether your data supports the hypothesis.

Go online to access the interactive section review and more!

Section 14.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 14.2 questions

Remembering

1. **Name** three factors that can affect the rate of a chemical reaction.
2. **Decide** whether the following statements are true or false.
   a. Decreasing the volume of a gas chamber has no effect on the rate of reaction.
   b. Changing the surface area of liquid reactants will increase the reaction rate.
   c. Changing the concentration of a reaction mixture will only affect reactions containing gaseous reactants.
   d. Increasing the temperature of a reaction increases the frequency and energy of collisions.
3. **Define** the term 'activation energy' in your own words.
4. **Identify** the name given to chemicals that are added to a reaction to reduce the activation energy.
5. **Recall** one factor which speeds up the rate of a chemical reaction solely by affecting the number of collisions.

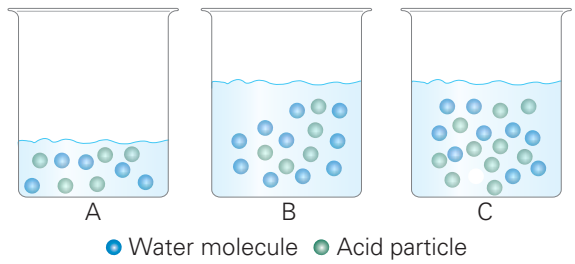
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

6. **Outline** the requirements for a chemical reaction.
7. **Summarise** the relationship between temperature and reaction rate.
8. Custard powder can explode when launched into the air and ignited, but not when it is tightly packed in a container. **Explain** why.
9. **Describe** what is meant by the term 'successful collision'.

Applying

10. Children are advised to take fewer tablets than adults. **Determine** the factor affecting reaction rate that is influencing this advice.
11. Your pie is not cooking quickly enough, so you make a change to the conditions. **Identify** which factor you should change to increase the reaction rate.
12. The chemical reaction that occurs when you bake a cake mixture requires a large amount of heat for it to be successful. What can you **deduce** about the activation energy of this reaction?
13. Use the following figure to answer the questions.
    a. **Determine** which two solutions have the same concentration.
    b. Is the solution in the other beaker more concentrated or more dilute? **Justify** your choice.



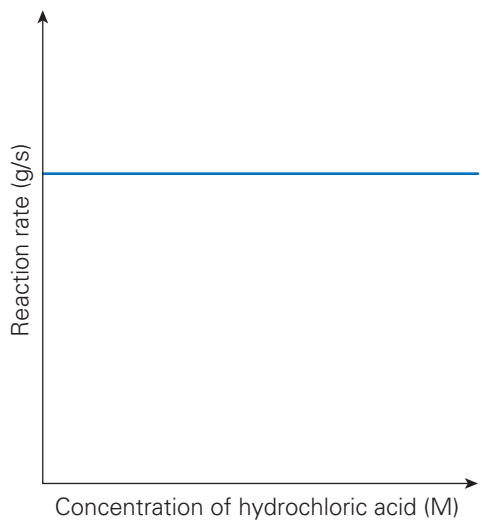
14. **Construct** a graph to show how surface area could affect reaction rate.

Analysing

15. **Contrast** a dilute and concentrated solution.
16. **Describe** the relationship between surface area and reaction rate.

Evaluating

17. Scientists often use magnetic stirrers to stir chemical reactions. **Explain** why this continuous stirring is important for the rate of reaction.
18. A student conducted an experiment to determine how changing the concentration of hydrochloric acid affected the rate of reaction with sodium thiosulfate. They plotted the a graph (right) of their results. What can you conclude about the effect of increasing the concentration of acid in this reaction?
    Deduce why this may be the case and provide reasoning.



19. Your sugar cube is dissolving too slowly in your tea. **Propose** what you could do to make it dissolve faster and explain why this would work.
20. You have two beakers of the same solution. They are both of the same concentration. To increase the concentration of the solution, you pour them into the same beaker.
    Decide whether you have changed the concentration or not. **Justify** your choice.
21. **Discuss** the importance of our understanding of reaction rates on the chemical industry. How do advances in technology affect our lives?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

	Success criteria I am now able to…	Linked questions
14.1	describe how the rate of chemical reactions can be measured.	
14.1	interpret the rate of chemical reactions graphically.	
14.2	investigate and explain how concentration affects the rate of reactions.	
14.2	investigate and explain how surface area affects the rate of reactions.	
14.2	investigate and explain how temperature affects the rate of reactions.	
14.2	investigate and explain how catalysts affect the rate of reactions.	
14.2	conduct a practical investigation using a cause-and-effect hypothesis that predicts changes to the rate of a chemical reaction.	
14.2	graph data that communicates the investigation findings in a scientific report.	

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Insert one full placeholder page for Review questions coming at 2pp.>

Data questions

A group of Chemistry students is measuring the rate of a reaction of magnesium metal and hydrochloric acid under different conditions. In three separate test tubes, the students added a strip of magnesium to 1M HCl, powdered magnesium to 1M HCl, and powdered magnesium in 2M HCl (M is a unit of concentration; 2M HCl is twice as concentrated as 1M). The data points are presented in Figure 14.22. Note that the mass of magnesium used was the same for each reaction.

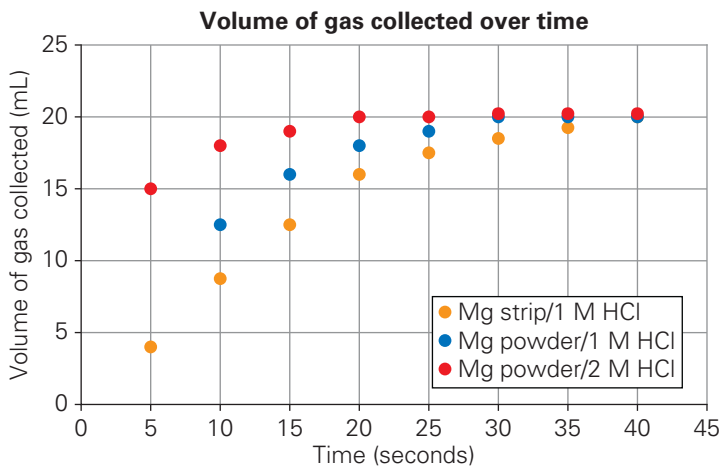


Figure 14.22 Volume of gas collected over time from reactions of magnesium metal and hydrochloric acid

1. **Identify** the conditions in which the reaction went to completion fastest.
2. **Calculate** the rate of the reaction (in mL/s) for magnesium strip/1 M HCl from the time 0 to 40 seconds.
3. Use your answers to Questions 1 and 2 to **determine** which reaction has the slowest reaction rate.
4. **Identify** the trend in the plot which is similar for all three experiments.
5. **Compare** the effect of the magnesium surface area on the volume of gas produced and the rate of the reaction.
6. **Analyse** the data presented in Figure 14.22 for the three experiments. What would be the volume of gas collected for each experiment at 0 seconds (before reactants were mixed)?
7. A student has stated that when all magnesium has reacted, the volume of gas produced will be 20 mL. **Justify** this conclusion with reference to the data in Figure 14.22.
8. **Extrapolate** the data for the Mg strip/1 M HCl experiment and estimate the volume of gas produced after 120 seconds.
9. The students would like to run another experiment with the same mass of magnesium powder and 5 M HCl. **Predict** (using Figure 14.22 as a template) how the data might be different in this experiment.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

activity: Designing airbags

Background information

Airbags work on the principle of increasing the time of impact between two objects. In a car this could be the difference between life and death. A sensor is connected to an electrical circuit and once activated will send a signal that ignites the extremely toxic chemical sodium azide (NaN_3), releasing nitrogen at high speed.

Airbags are not without risk and have failed, causing burns and injury due to the chemical reaction and projectile velocity of the bag itself, which can reach velocities up to 330 km/h. Sodium azide undergoes an initial reaction where it produces nitrogen gas and sodium metal. Sodium metal is highly reactive and if left would explode with the surrounding oxygen. Potassium nitrate is then used to react with the sodium, and after this reaction, silicon dioxide is used to produce the final product, a silicate, which is both harmless and stable.

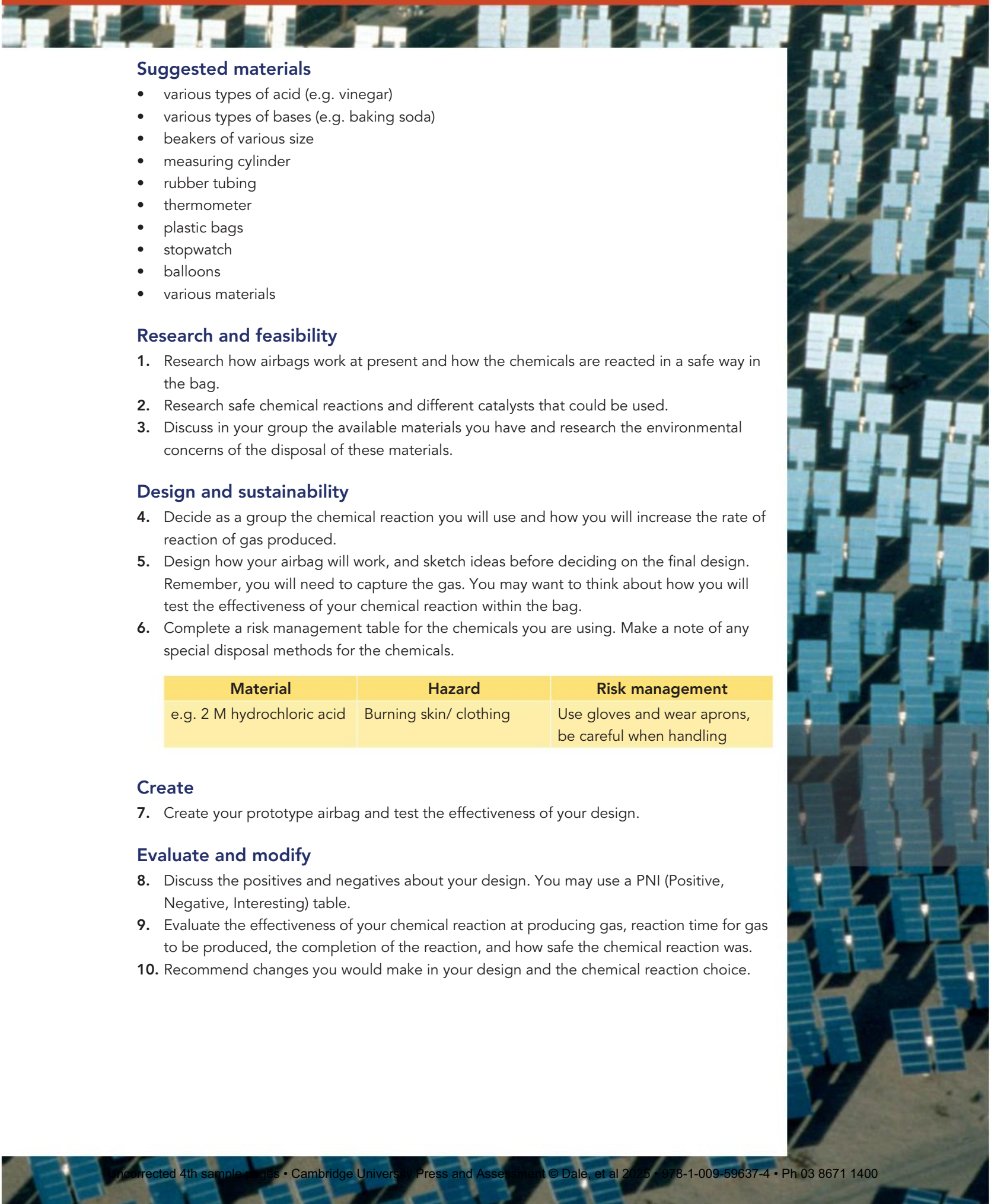
DESIGN BRIEF

Design and create an airbag prototype that uses environmentally friendly chemicals and materials of manufacture. The airbag will need to create gas rapidly to work effectively.

Activity instructions

Figure 14.23 An airbag that has been activated

Low-res
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134



Suggested materials

- various types of acid (e.g. vinegar)
- various types of bases (e.g. baking soda)
- beakers of various size
- measuring cylinder
- rubber tubing
- thermometer
- plastic bags
- stopwatch
- balloons
- various materials

Research and feasibility

1. Research how airbags work at present and how the chemicals are reacted in a safe way in the bag.
2. Research safe chemical reactions and different catalysts that could be used.
3. Discuss in your group the available materials you have and research the environmental concerns of the disposal of these materials.

Design and sustainability

4. Decide as a group the chemical reaction you will use and how you will increase the rate of reaction of gas produced.
5. Design how your airbag will work, and sketch ideas before deciding on the final design. Remember, you will need to capture the gas. You may want to think about how you will test the effectiveness of your chemical reaction within the bag.
6. Complete a risk management table for the chemicals you are using. Make a note of any special disposal methods for the chemicals.

Material	Hazard	Risk management
e.g. 2 M hydrochloric acid	Burning skin/ clothing	Use gloves and wear aprons, be careful when handling

Create

7. Create your prototype airbag and test the effectiveness of your design.

Evaluate and modify

8. Discuss the positives and negatives about your design. You may use a PNI (Positive, Negative, Interesting) table.
9. Evaluate the effectiveness of your chemical reaction at producing gas, reaction time for gas to be produced, the completion of the reaction, and how safe the chemical reaction was.
10. Recommend changes you would make in your design and the chemical reaction choice.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 15

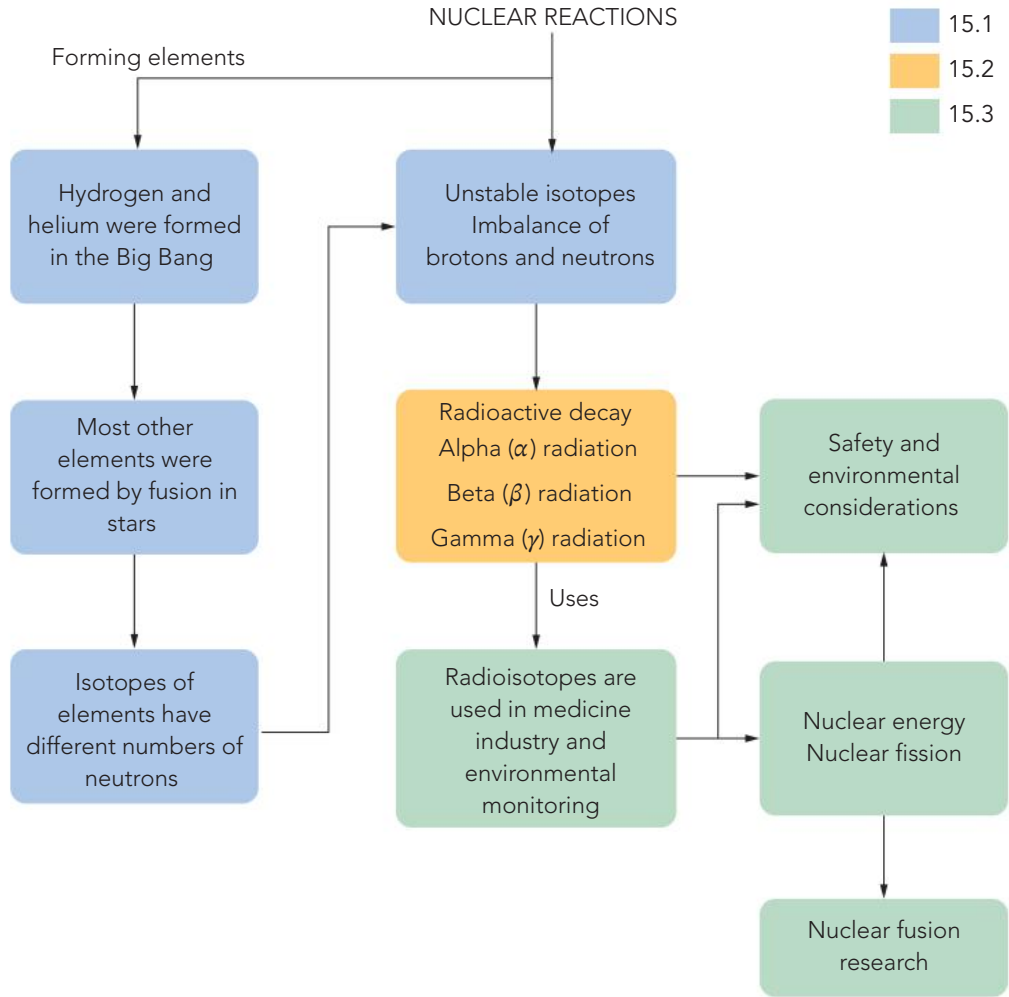
Nuclear reactions

Chapter introduction

This chapter is all about nuclear reactions. Now that you know about atoms and the subatomic particles they contain, you will learn what happens when they collide or even split. These reactions cause changes in the nucleus of an atom, which is why they are called nuclear reactions. Changes to the nucleus of an atom change its characteristics and behaviour. You will explore the different types of nuclear reaction and discover their uses. First, you will learn about the reactions that took place at the very beginning of the universe, creating the first elements in the Big Bang around 14 billion years ago!

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

alpha particle
beta particle
gamma ray
half-life
ionising
isotopes
mass number
negligible
nuclear fission
nuclear fusion
quark
radioactive decay
radioisotopes
singularity

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

15.1 The Big Bang and the first elements

WORKSHEET
Isotopes

VIDEO
Forms of carbon

Learning outcomes

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

1. recall the Big Bang theory.
2. describe how the first elements were formed after the Big Bang.
3. describe what causes a nucleus to be unstable.

The Big Bang

Figure 15.1 Georges Lemaître was also a professor of physics at the Catholic University of Louvain in Belgium.

Scientists had been developing theories about the universe for many years when in 1927, Georges Lemaître, a Belgian astronomer, mathematician and cosmologist, proposed that the universe was expanding, and therefore, at some time in the past, it must have originated from an initial point. He suggested that it had begun from the explosion and rapid expansion of what he called the 'Primaeval atom'. This was radically different to what the scientific community believed at that time, but his idea went on to achieve support as scientists found evidence to support what we now know as the Big Bang theory.

The term 'big bang' was first used by steady state astronomer Fred Hoyle while he was on a radio talk show for the British Broadcasting Corporation (BBC) in 1949. The term stuck. However, it took another thirty years for the concept of the expanding universe to be generally accepted. It was the discovery of cosmic microwave background radiation, radiation left over from the early stages of the universe, by Arno Penzias and Robert Wilson in 1964, that provided the conclusive evidence.

singularity
a point at which infinitely dense matter occupies an infinitely small space

quark
an elementary type of subatomic particle, fundamental component of matter

The Big Bang theory suggests that the universe was created 13.8 billion years ago from a very small, yet exceptionally dense **singularity**. In the immediate moments after the Big Bang, the universe was extraordinarily hot and dense, but it then cooled just enough to provide the right conditions for electrons then **quarks**, the building blocks of atoms, to form.

In an extremely short time frame after that, just a few millionths of a second, quarks joined to build protons and neutrons, completing the formation of the three subatomic particles you are now familiar with. In the next few minutes, protons combined with neutrons, creating what we now know are nuclei of hydrogen, helium and a small amount of lithium. This finished after just 20 minutes, things happened quickly after the Big Bang!

However, as the universe continued to spread out and cool, events slowed down considerably. It took another 370 000 years for the universe to cool enough for electrons to combine with hydrogen nuclei to form hydrogen atoms. These were the very first atoms! Essentially all of the hydrogen in the universe – in water, in our bodies – was made in the Big Bang.

Quick check 15.1

1. **Describe** what happened at the Big Bang in your own words.
2. **Recall** which atoms were the first to be formed.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Advances in science 15.1

Quarks and gluons!

While the word for atom comes from the Greek meaning 'indivisible', scientists discovered atoms were formed from subatomic particles: neutrons, protons and electrons. For a long time, these were believed to be indivisible themselves, until the proposal of particles called quarks in the 1960s. Quarks join together to form protons and neutrons, and gluons are the 'glue' that holds them together.

Since their discovery, scientists have been trying to create a better model of the atomic nucleus to study. This has presented a considerable challenge as at low energies the nucleus seems to be the neutrons and protons that we are familiar with, while at high energies, it is a sea of quarks and gluons. However, in October 2024 a team of physicists from around the world, including the University of Sydney, finally developed a model combining traditional nuclear physics and quarks and gluons. The model is complex and comprises mathematical formulations, data, diagrams and computer simulations.

This is a great leap forward for science and will help advance our understanding of fundamental forces. It also has the potential to benefit practical applications like nuclear energy.

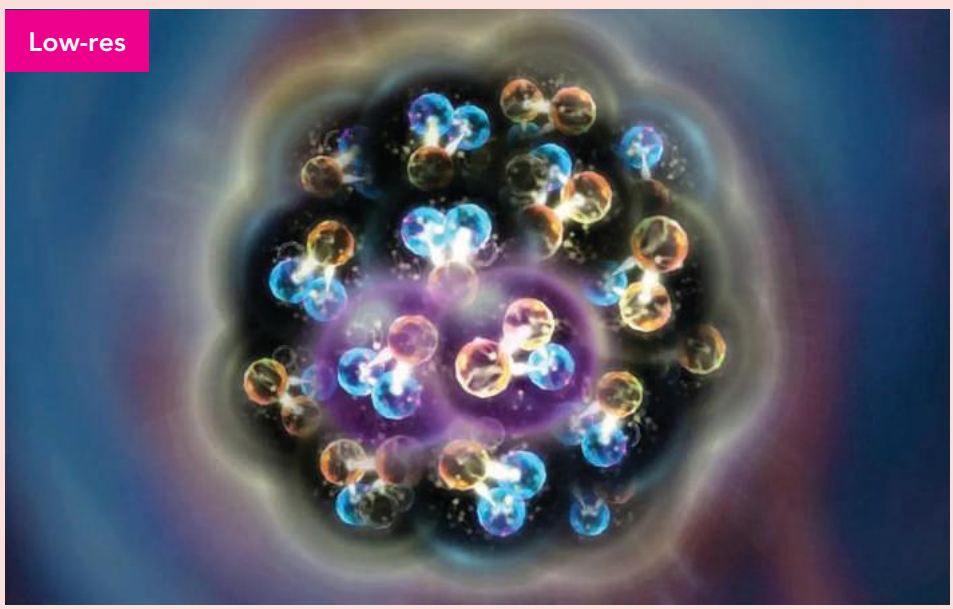


Figure 15.2 For the first time, quarks and gluons can be modelled accurately alongside protons and neutrons in an atomic nucleus. The quarks are represented here by the blue and yellow spheres arranged in groups of three connected by the white rods, which are the gluons. Each set of three quarks forms a proton or neutron, represented by surrounding ghostly shells.

How did the other elements form?

Cosmologists have calculated that the universe started with 75% hydrogen, 25% helium and just a tiny scatter of the next most massive element, lithium. So how did the other elements that make up our universe form?

Nuclear fusion

The next stage of element creation didn't take place for hundreds of millions of years as it was dependent on the first set of stars. Stars power themselves through a process called **nuclear fusion**, initially creating helium from hydrogen (Figure 15.3). Because it is so hot inside the cores of stars, hydrogen nuclei have enough energy to overcome the electrostatic repulsion between their protons. They fuse together to form helium, and an enormous amount of energy is released in the process.

nuclear fusion a nuclear reaction where the nuclei of two small atoms fuse to create an atom with a higher atomic mass, releasing a large amount of energy

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

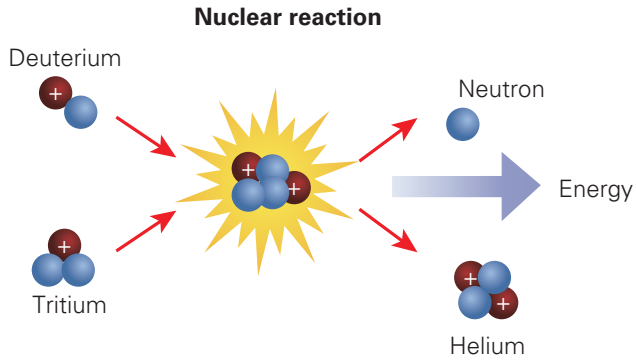


Figure 15.3 One step in the fusion of hydrogen happens when two different forms of hydrogen, deuterium (one proton and one neutron) and tritium (one proton and two neutrons) fuse together. A neutron is released, and a helium nucleus is formed (two protons and two neutrons).

When stars are coming to the end of their lives, they start creating oxygen and nitrogen from the fusion of helium. This explains why oxygen and nitrogen are such abundant elements in our universe and on Earth. Other elements like nitrogen, sulfur, magnesium and iron are made by fusion in the core of massive stars as they come to the end of their lives.

Elements heavier than iron are very rarely made through fusion during the life of the star, so the rest of the elements are created through the death of stars. Stars die in a range of dramatic ways, each creating an enormous amount of energy, which then allow fusion to create the heavier elements we find in our universe.

It is amazing to think that all the atoms that make up all the molecules in every cell in your body were formed in distant stars, well before Earth, the Sun and our solar system even existed.

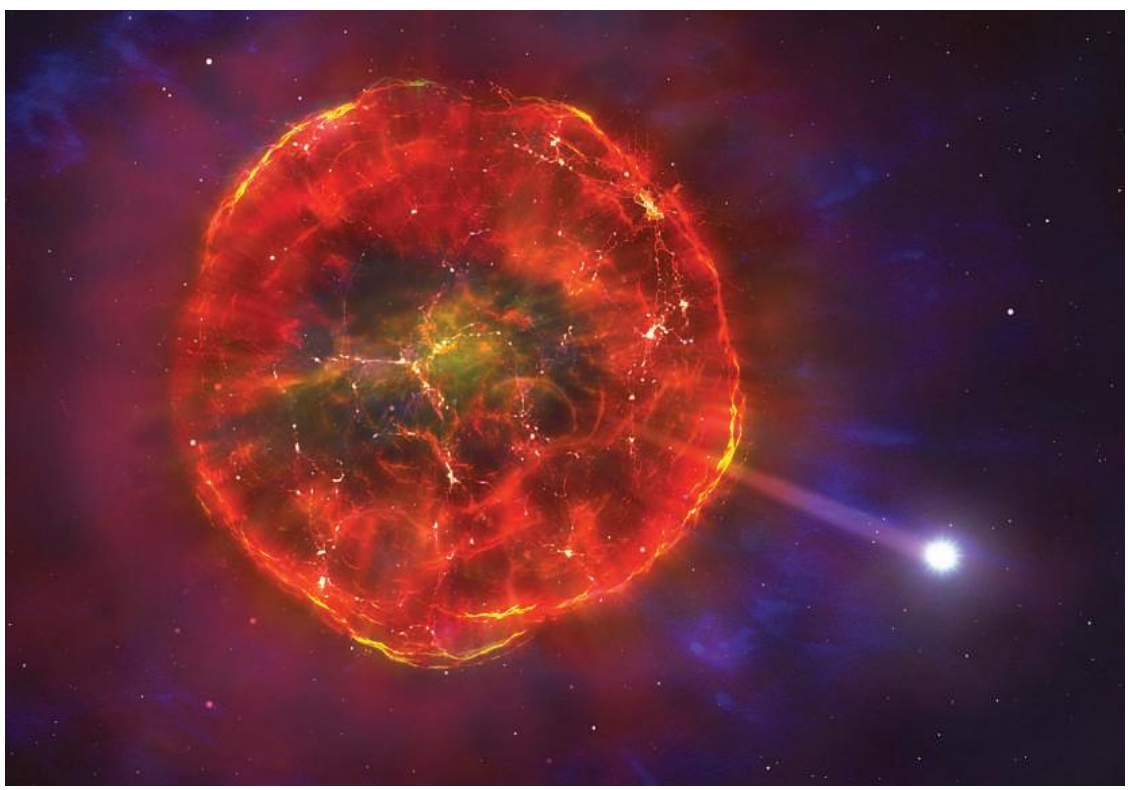


Figure 15.4 An illustration of a supernova, one form of star death. Enough energy is created to fuse elements including some of the precious metals found on Earth like silver and gold.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 15.2

1. **Recall** what nuclear fusion is.
2. **Recall** how elements heavier than iron are formed.

Explore! 15.1

Creation of elements

Pick an element that can be found somewhere in your home and research its origin in or after the Big Bang. How was it created and how did it find its way from the star that created it to Earth? Where is it found now and how is it recycled on Earth?

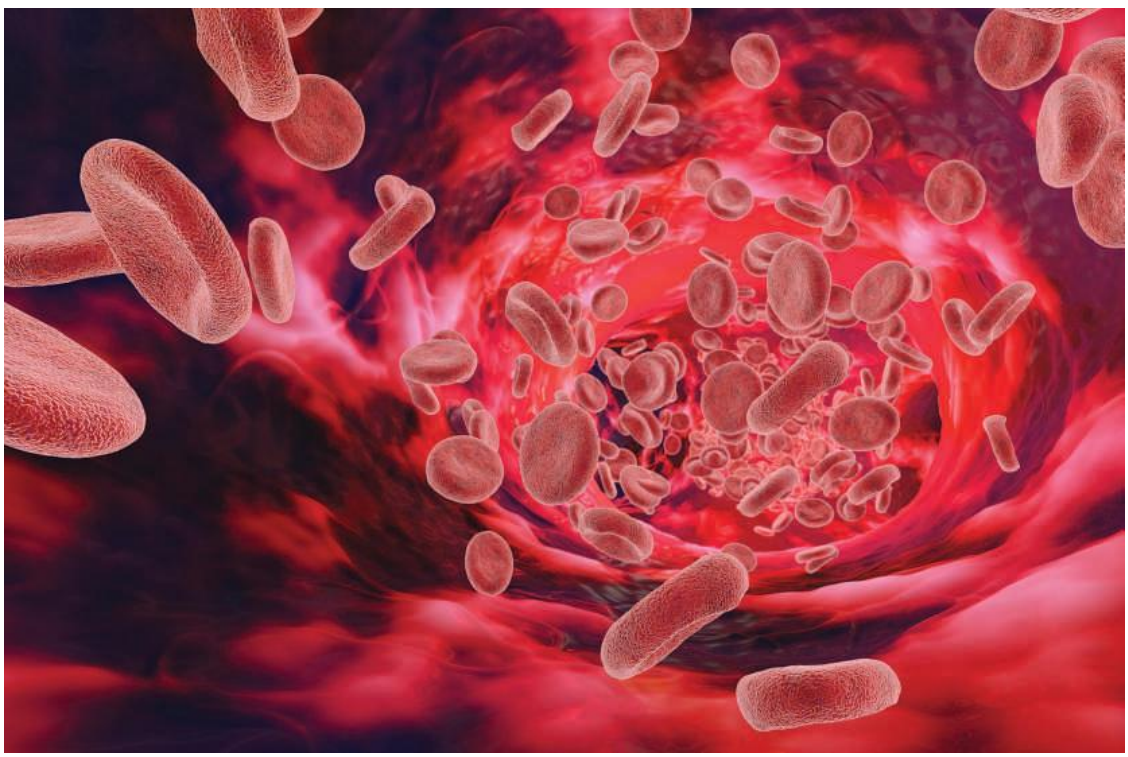


Figure 15.5 The iron found in your red blood cells was made in massive stars.

What are isotopes?

You have previously learned how changing the number of protons in an atom results in a totally different element. You also know how changing the number of electrons results in a charged atom called an ion. In nuclear fusion you came across two versions of hydrogen (deuterium and tritium) that have different numbers of neutrons in the nucleus to the more common hydrogen (protium). Now you will learn what happens when the number of neutrons in an atom is altered.

Figure 15.6 Frederick Soddy discovered isotopes in 1913 in his work on uranium.

Two atoms that have the same atomic number, but different mass numbers are called **isotopes**. This means that they have the same number of protons as each other (same atomic number, therefore the same element), so their differing mass numbers must be explained by having a different number of neutrons.

isotopes atoms of the same element with the same number of protons but a different number of neutrons

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Let's look at an example. Carbon exists naturally in three forms (see Figure 15.7). All three of these forms are the element carbon as they all have an atomic number of 6 (6 protons).

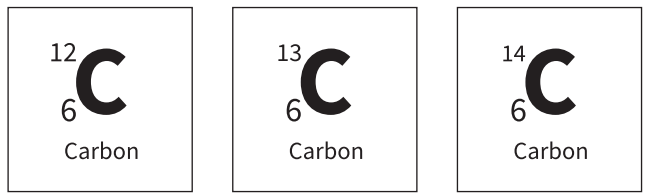


Figure 15.7 The three naturally occurring isotopes of carbon. Each shows the mass number (superscripted) and atomic number (subscripted) of the isotope.

mass number total number of protons and neutrons in the nucleus of an atom

negligible so small that it can safely be ignored without significantly altering results

Notice that the three forms of carbon have different **mass numbers**. The mass number of an atom comes from the sum of its protons and neutrons. As the mass of electrons is so small that it has a **negligible** effect, they are not included. This difference in mass number of the carbon isotopes is because they have different numbers of neutrons.

The number of neutrons in an atom can be calculated by taking away the atomic number from the mass number. Therefore, the first form of carbon has six neutrons, the second has seven and the third has eight. As they have different numbers of neutrons but the same atomic number, they are called isotopes of carbon.

WORKSHEET

VIDEO Too many neutrons!

Naming isotopes

When writing the symbols for isotopes, the convention is to write the mass number on the top left-hand side of the element symbol and the atomic number on the bottom, as this time it is the mass number that defines the isotope (see Figure 15.8). Another way of representing an isotope is to write the name of the element followed by the mass number. For example, you have already come across the three isotopes of hydrogen. They are hydrogen-1 (H-1), also known as protium, hydrogen-2 (H-2), known as deuterium, and hydrogen-3 (H-3), known as tritium.

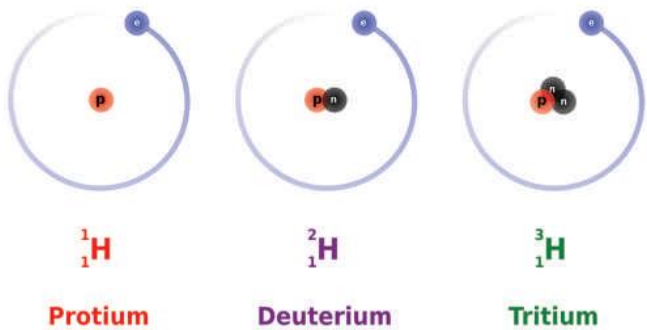


Figure 15.8 The three isotopes of hydrogen. Each has a single proton and a single electron, but a different number of neutrons and therefore a different mass.

Explore! 15.2

Unusual mass numbers

The relative atomic mass of chlorine on the periodic table is 35.5. If you were to use this number to work out the number of neutrons, then it would have 18.5 neutrons. This is clearly incorrect as half a neutron does not exist. Conduct some research to answer the following questions.

1. Why is the relative atomic mass of chlorine recorded as 35.5 on the periodic table?
2. Chlorine has two naturally occurring stable isotopes, chlorine-35 and chlorine-37. What is the difference between an atom of chlorine-35 and chlorine-37?
3. Which isotope of chlorine do you think is the most abundant form in nature?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Stable and unstable isotopes

The stability of an isotope is based on whether it is likely to break down or decay into other elements. Isotopes that have too many or too few neutrons for their number of protons are unstable. As the number of protons increases, the greater the number of neutrons a stable nucleus can hold, but also the greater the number of unstable nuclei. Unstable isotopes, such as the isotopes of the element uranium, are often called **radioisotopes**. In these types of isotopes, **radioactive decay** (splitting of the nucleus) occurs to try to achieve a stable nucleus (as discussed in the next section). On the other hand, stable isotopes are not radioactive as their nucleus is stable and therefore not prone to radioactive decay. Some elements can have more than one stable isotope, such as carbon-12 and carbon-13. Table 15.1 summarises the differences between stable and unstable isotopes.

radioisotopes unstable isotopes that are likely to break down or decay into other elements to try to achieve a stable nucleus

radioactive decay when an unstable nucleus emits radiation and breaks down to form another element

Stable isotopes	Unstable isotopes
Have a stable nucleus	Have an unstable nucleus
Not radioactive	Radioactive

Table 15.1 A comparison between stable and unstable isotopes

Quick check 15.3

1. **Define** the term 'isotope' in your own words.
2. **Recall** the characteristics of unstable isotopes.

Did you know? 15.1

No relative atomic mass?

Look at francium (Fr) on the bottom left of the periodic table. The relative atomic mass is not listed. In some periodic tables, you may see the relative atomic mass listed as '(223)' with brackets around it. Elements written like this are radioactive, they are very unstable. Most of their isotopes decay into other elements relatively quickly. The relative atomic mass in parentheses represents the most stable isotope of that element: the one that exists the longest.

Can you find other radioactive elements on the periodic table?

Section 15.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 15.1 questions

Remembering

1. **Recall** the first subatomic particles to be formed in the Big Bang.
2. **Recall** the three isotopes of hydrogen.
3. **State** the difference between a carbon-12 and a carbon-13 atom.

Understanding

4. **Summarise** how the hydrogen and helium found in our universe were formed.
5. An element has an atomic number of 15 and an atomic mass of 31. **Deduce** how many neutrons it has.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6. **Compare** and **contrast** these isotopes of sodium: Na-23 and Na-24.
7. **Deduce** the mass number of an isotope of iodine with 74 neutrons and 53 protons.
8. **Copy** and **complete** the following table to summarise the three main isotopes of neon.

Isotope	Mass number	Number of protons	Number of neutrons	Number of electrons
$^{20}_{10}Ne$				
$^{21}_{10}Ne$				
$^{22}_{10}Ne$				

Applying

9. **Deduce** the relationship between the mass of an element and how stable it is.
10. **List** two different notations, representing an isotope of oxygen with eight neutrons.
11. **Explain** why lighter elements were formed earlier in the birth of the universe than heavy elements like iron.
12. **Describe** the three isotopes of hydrogen: protium, deuterium and tritium. How do their atomic structures differ, and what was their role in nuclear fusion shortly after the Big Bang?

Analysing

13. The atomic structure of atoms A, B, C, D and E are shown in the table below. **Determine** which two are isotopes and **explain** your decision.

Atom	Atomic number	Number of electrons	Mass number
A	6	6	13
B	8	8	16
C	7	7	14
D	6	6	12
E	7	7	15

14. Using your knowledge of atomic structure and reactivity, **explain** why two different isotopes of the element bromine have the same chemical properties.

Evaluating

15. The element silicon has twenty-three known isotopes with mass numbers between 22 and 44. In the periodic table, its mass number is stated as 28.0855. **Deduce** how many neutrons are found in the most common isotope of silicon.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

15.2 Radioactive decay

Learning outcomes

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

1. represent alpha and beta decay as nuclear reactions.
2. understand the process of radioactive decay in terms of isotope half-lives.

WORKSHEET Radioactive decay

Alpha decay

Emissions from radioactive decay are commonly alpha (α), beta (β) or gamma (γ) radiation. First, you will learn about alpha decay. When an isotope decays in this way, the unstable nucleus emits an **alpha particle** which consists of two protons and two neutrons. This is the same as the nucleus of a helium atom. Therefore, when an atom undergoes alpha decay, the atomic number decreases by 2 and the mass number decreases by 4 (the number of protons and neutrons combined). You know that when the atomic number changes, a new element is formed, so alpha decay results in the formation of a different element. The equation in Figure 15.9 shows what happens when an atom of uranium undergoes alpha decay.

alpha particle a particle, identical to the nucleus of a helium atom, consisting of two protons and two neutrons

$$^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + \underbrace{{}^{4}_{2}\text{He}}_{\text{alpha particle}}$$

Figure 15.9 When a uranium-238 nucleus undergoes alpha decay, it becomes a thorium-234 atom. By emitting an alpha particle, the atom of uranium has changed into an atom of thorium.

Beta decay

Beta decay is the most common form of radioactive decay. **Beta particles** are simply fast-moving electrons emitted from the nucleus. During beta decay, a neutron is converted into a proton and an electron. Consequently, the atomic number will increase by one, which changes the identity of the element altogether. The mass number of the remaining atom will not be affected as it has lost a neutron but gained a proton. The equation in Figure 15.10 shows what happens during beta decay.

beta particle a high energy electron (β^-) or positron (β^+) that is emitted from the nucleus of a radioactive element during beta decay of an unstable atom

$$^{42}_{19}\text{K} \rightarrow {}^{42}_{20}\text{Ca} + \underbrace{{}^{0}_{-1}\text{e}}_{\text{beta particle}}$$

Figure 15.10 When a potassium-42 nucleus undergoes beta decay, it becomes a calcium-42 atom and emits a beta particle (a high-speed electron).

Gamma decay

Gamma decay is different from alpha and beta decay in that the atom undergoing gamma decay is not changed; that is, the mass and atomic numbers are not altered. This is because gamma decay involves a nucleus in an excited state emitting a high-energy wave called a **gamma ray**, rather than a particle. The equation in Figure 15.11 shows gamma decay of radioactive barium.

gamma ray a high energy wave emitted from the nucleus of radioactive elements during radioactive decay

$$^{137}_{56}\text{Ba}^{*} \rightarrow {}^{137}_{56}\text{Ba} + \underbrace{\gamma}_{\text{gamma ray}}$$

Figure 15.11 When radioactive barium decays, a gamma ray is emitted. The asterisk indicates that barium is initially in an excited and therefore unstable state.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 15.4

1. If an atom emits alpha radiation, **name** the particle it gives off and **describe** how the atom is changed as a result.
2. If an atom emits beta radiation, **name** the particle it gives off and **describe** how the atom is changed as a result.
3. **Describe** how gamma radiation differs from alpha and beta radiation.

Half-lives of radioactive isotopes

While individual atoms decay at random time intervals, when you consider an amount of a certain isotope, it will decay at a consistent rate over time. Radioactive decay is described using the term **half-life**, which gives the amount of time it takes for half of the atoms in a sample to decay.

half-life
the time taken for half of the nuclei in a radioactive sample to decay

The half-life stays constant regardless of the number of radioactive nuclei present. For example, if you start with 100 atoms of an isotope with a half-life of an hour, 50 nuclei will decay in the first hour, followed by 25 in the second hour and so on. In mathematical terms, radioactive decay occurs at an exponential rate.

The radioactive atoms are called the parent atoms, and the atoms present following radioactive decay are called daughter atoms.

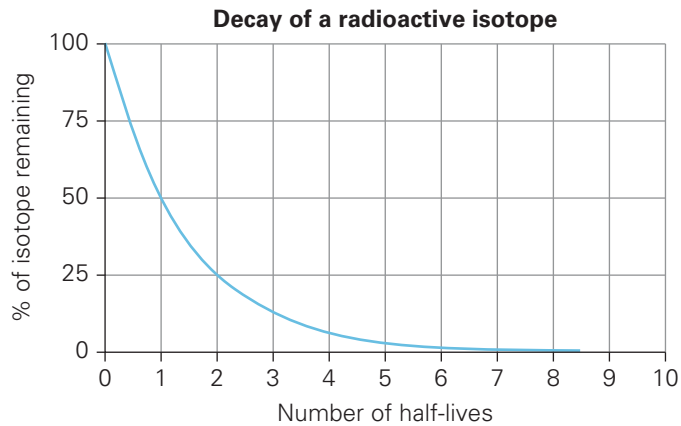


Figure 15.12 When an isotope decays, the time taken for 50% of the nuclei to decay is known as the half-life.

Practical skills 15.1

Modelling radioactive decay with lollies

Aim

To model the exponential decay of a radioactive isotope.

Materials

- 100 pieces of candy with a letter printed on one side (skittles or similar)
- paper cup with lid
- paper towel or plate

Procedure

1. Copy the table in Results into your journal.
2. Place the candy in the cup and shake it around briefly.
3. Gently pour the candy onto the paper towel or plate.

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

4. Count the number of candies that have settled with the lettered side facing up (daughter atoms) and record the number in your results table.
5. Discard the lettered candies and then place the blank (parent) atoms back in the cup.
6. Repeat steps **2–5** until no candies remain.

Results

1 Complete the table below.

Trial / half-life number	Radioactive isotope / parent remaining	Daughter atoms produced in this half-life (letter side up)	Total percentage parent atoms remaining
0	100	0	100
1			
2			
3			
4			
5			
6			
7			
8			

2. Draw a graph with number of half-lives on the horizontal axis and percentage of parent atoms remaining on the vertical axis.

Discussion

1. What percentage of parent nuclei remained after one half-life?
2. How many trials (half-lives) did it take for all the atoms to decay?
3. Did your results support the theory of radioactive decay that you have learned?
4. Can you think of any reasons it is useful to know the half-lives of different radioactive isotopes?

Quick check 15.5

1. **Recall** the definition of radioactive half-life.
2. If a radioactive sample of 200 atoms has a half-life of 30 minutes, **calculate** the number of radioactive atoms that will remain after 90 minutes.
3. If a sample contains 80 grams (g) of a radioactive isotope and has a half-life of 4 years, **calculate** how much of the isotope will remain after 12 years.

The importance of radioactive half-lives

Different radioactive isotopes have different half-lives. For example, the half-life for uranium-238 is 4.5 billion years, but the half-life for technetium-99m is just 6 hours. In the next section you will learn that some radioactive isotopes are useful and some are dangerous. It is important to know the half-life of different radioactive isotopes and therefore, critically, how long they remain radioactive.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive section review and more!

Section 15.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 15.2 questions

Remembering

1. **Recall** the three types of radioactive decay.
2. **Recall** what happens to an unstable nucleus when it undergoes radioactive decay.
3. **Name** the particle that is released during alpha decay.

Understanding

4. **Summarise** what happens to the nucleus of an element during alpha decay.
5. **Complete** the equation to show the particle released during alpha decay.

$$^{226}_{88}\text{Ra} \rightarrow {}^{222}_{\square}\text{Rn} + {}^{\square}_{2}\square$$

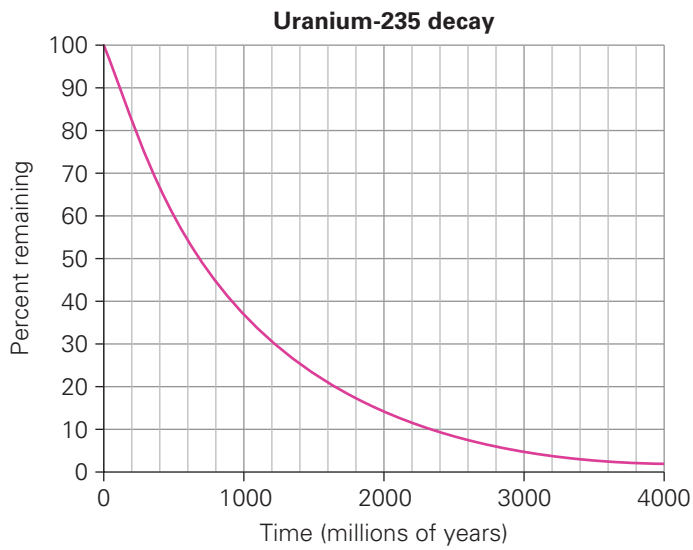
6. If you start with 200 g of a radioactive isotope with a half-life of 10 years, **determine** how much will remain after 40 years.
7. **Determine** the half-life of a radioactive isotope that has 25% of the parent atoms remaining after 48 hours.
8. **Explain** how an additional proton is gained in beta decay, yet the mass of the atom formed remains the same as the atom that decayed.

Applying

9. **Construct** an equation to show the alpha decay of uranium-235 to thorium-231.
10. **Construct** an equation to show the beta decay of carbon-14.
11. **Sketch** a graph showing radioactive decay of a radioactive isotope with a half-life of 150 years.

Analysing

12. **List** the main differences between stable isotopes and radioisotopes.
13. Using the following graph, **deduce** the half-life of the radioisotope it represents.



14. An element undergoes radioactive decay; its atomic number and mass number are not affected. **Deduce** the type of decay. Give a reason for your answer.
15. During the radioactive decay of an isotope a high-energy electron is released. **Deduce** the type of decay. Give a reason for your answer.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

15.3 Uses of radioisotopes

Learning outcomes

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

1. evaluate the benefits and risks of using radioisotopes in medicine, industry and environmental monitoring.
2. describe nuclear fission and nuclear fusion.
3. outline the impacts on the environment of nuclear reactions including materials, production and waste.
4. investigate a chemical or nuclear reaction used in industry to produce an important product (STEM activity at end of chapter).

Ionising and penetrating powers

Radioisotopes are useful in many fields including medicine, industry and environmental monitoring. Radiation is also very dangerous, so it is important to understand the considerations of using different types of radioisotopes. How dangerous a type of radiation is depends on its ability to penetrate materials and how much damage it can do (how **ionising** it is). Ionising radiation can seriously disrupt normal biological functions of living things, damaging their cells including their DNA. Table 15.2 and Figure 15.13 summarise the properties of the three types of radiation.

ionising having enough energy to knock electrons off atoms, turning them into ions and changing their properties

Type of radiation	Penetrating power	Ionisation power
Alpha	Least penetrating. It can be stopped by a sheet of paper.	Very strongly ionising; can cause the most damage, especially if alpha particles are inside the body
Beta	It can penetrate paper but is stopped by a thin aluminium sheet.	Not as ionising as alpha particles but more than gamma rays
Gamma	The most penetrating. It can only be stopped by thick pieces of lead or concrete.	Not very ionising so causes the least damage; can penetrate the body, and high-energy gamma rays are used to kill cancer cells

Table 15.2 Properties of the three different types of radiation

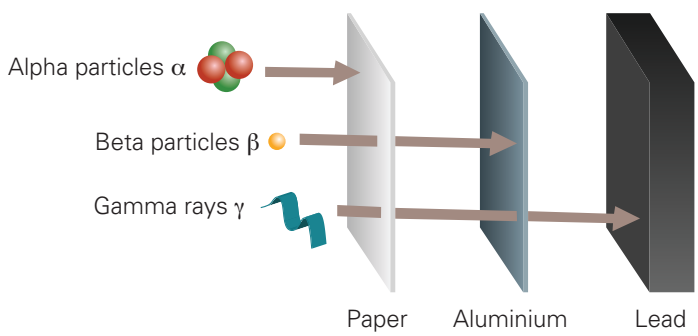


Figure 15.13 The penetrating powers of alpha, beta and gamma radiation

What are isotopes used for?

There are around 90 naturally occurring elements with around 250 stable isotopes and about 3200 unstable radioisotopes. Both stable isotopes and radioisotopes have important uses, dependent on their penetrating ability and half-life.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Use in medicine

Perhaps the most well-known use for radioisotopes is in medicine to diagnose and treat illnesses: technetium-99m is widely used to scan body tissues; cobalt-60 (Co-60) is used in radiotherapy to kill cancer cells; strontium-90 (Sr-90) is used in the treatment of skin cancer in pets; and caesium-137 (Cs-137) produces gamma rays that sterilise medical equipment through a process called gamma irradiation.

Figure 15.14 A patient undergoing radiotherapy for cancer

Use in nuclear power generation

Energy produced from radioactive decay is used as an energy source. It can be used:

- in power stations to produce electricity (uranium-235, plutonium 239)
- as fuel on space missions (uranium-235, plutonium-238)
- as a weapon in war (uranium-235, plutonium 239, deuterium, tritium, lithium-6).

Table 15.3 summarises the benefits and issues of radioisotopes in nuclear energy for use in medical and industrial environments.

	Medical	Industrial
Benefits	• Provides us with information about the functionality of the body • Scans are produced in lots of detail • Can kill cancerous cells and tumours with finely-targeted, precise doses • Amount of radiation given to the patient is minimal	• Fuel can be re-used • Large amount of energy produced per gram of fuel • Reduces greenhouse gas emissions compared with using fossil fuels
Issues	• May adversely affect women who are pregnant or breastfeeding • Threat of severe allergic reactions • Exposure to radioisotopes can damage DNA, causing short-term and long-term issues including cancer • Expensive and therapeutic machines may only be available in larger urban centres	• Expensive to store fuel and dispose of waste • Waste remains highly radioactive posing a threat to the environment • Threat of an accident when working with nuclear energy and of radiation poisoning • Expensive to build nuclear power stations

Table 15.3 Benefits and issues with using radioisotopes and nuclear energy in medicine and industry

WORKSHEET
Radioisotopes used in environmental monitoring

Radioisotope use in environmental monitoring

Radioisotopes are also used as easily-detected markers that help scientists understand environmental changes, pollution and natural cycles.

For example, isotopes used in environmental monitoring include sodium-24 (Na-24), which is used in detecting leakages in pipes that are difficult to access; carbon-14 (C-14), which is used in dating archaeological artefacts; and americium-241 (Am-241), which is used in smoke detectors.

Access the linked worksheet in the Interactive Textbook for examples and questions on the use of radioisotopes in environmental monitoring.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 15.6

1. **Recall** which types of radiation are least and most penetrating.
2. **Recall** two benefits and two issues of using radioisotopes in medicine.
3.

Advances in science 15.2

Radiocarbon dating rock art

Carbon-14 is an isotope of carbon that primarily decays via beta radiation to nitrogen-14 on a consistent time scale. Scientists can predict the age of a fossil by examining the relative amounts of carbon-14 and carbon-12 (which does not decay) in an organic fossil, in a technique known as radiocarbon dating. Carbon dating techniques are continuously improving, allowing for more accurate dating.

Figure 15.15 An example of rock art from Quinkan country

In late 2019, a $1.34 million grant from the Australian Research Council funded a team of researchers, including rock art researchers from Griffith University. The purpose of the 5-year project is to investigate and catalogue Quinkan art, which can be found in Queensland. Many paintings have been dated to 6000 years ago, but there are some that date up to 30 000 years ago.

Explore! 15.3

Marie Curie

Marie Curie was an exceptional scientist and is the only person to date to have been awarded two Nobel Prizes in different scientific fields: Physics in 1903 (with her husband, Pierre Curie, and Henri Becquerel) and Chemistry in 1911. Research the work of Marie and Pierre Curie that led to their scientific discoveries in radiation.

Figure 15.16 Marie Curie (right) and Pierre Curie's eldest daughter, Irène Joliot-Curie (left), won the Nobel Prize in Chemistry in 1935 with her husband, Frédéric Joliot-Curie, for their synthesis of new radioactive isotopes; this was the first time radioactivity was created artificially.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation 15.2: Self-design and teacher demonstration

Investigating the penetration of alpha, beta and gamma radiation

You have been provided with the materials listed below. Suggest an experiment that could be carried out using this equipment to show the penetrating properties of alpha, beta and gamma radiation. You may wish to draw a diagram or write a method to demonstrate that you have completed this task.

Aim

To investigate the penetrative strengths of ionising radiation.

Materials

- alpha radiation source
- beta radiation source
- gamma radiation source
- Geiger–Müller tube (detects radiation)
- absorbing materials: sheet of paper, aluminium sheet, lead sheet

Procedure

Your teacher will demonstrate the experiment. Due to the dangerous radiation that is emitted, this experiment can only be performed by a teacher and under strictly controlled conditions.

Results

Copy and complete the table below.

Radiation	Material that stops most of the radiation from passing through	Penetrating power
Alpha		
Beta		
Gamma		

Discussion

1. Identify the most penetrating radiation and justify your choice.
2. Propose which type of radiation you think could cause the most damage if it gets into our bodies.
3. Research the effects that radiation can have on the body to explain why it is so damaging.
4. Discuss how the experiment could be modified to show the effectiveness of the radiation over different ranges and thickness of absorbing materials.

Nuclear power

Nuclear fission

nuclear fission a reaction where the nucleus splits into two or more smaller nuclei, releasing energy

Nuclear power is a form of energy that is generated through nuclear reactions, most commonly by splitting atoms in a process called **nuclear fission**. In nuclear power plants, uranium-235 or plutonium-239 isotopes are used as fuel. When these atoms are split, they release a large amount of energy in the form of heat, which is then used to produce steam that drives turbines, generating electricity.

The process of nuclear fission was first discovered in 1938, by bombarding elements with neutrons, causing nuclei to split. The radioisotopes you have just learned about are naturally unstable and decay (undergo fission) naturally. However, bombing neutrons is a method of inducing, or forcing, fission to capture the energy released. When uranium-235 is bombarded with neutrons, the additional neutron in its nucleus causes it to become very unstable and initiates a fission reaction as shown in Figure 15.18.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 15.17 Nuclear power plants carry out and contain nuclear fission reactions, using the heat to produce steam and power turbines, generating large amounts of electricity. The nuclear reactors are inside the concrete dome-shaped containment buildings designed to prevent possible leakage of radioactive material.

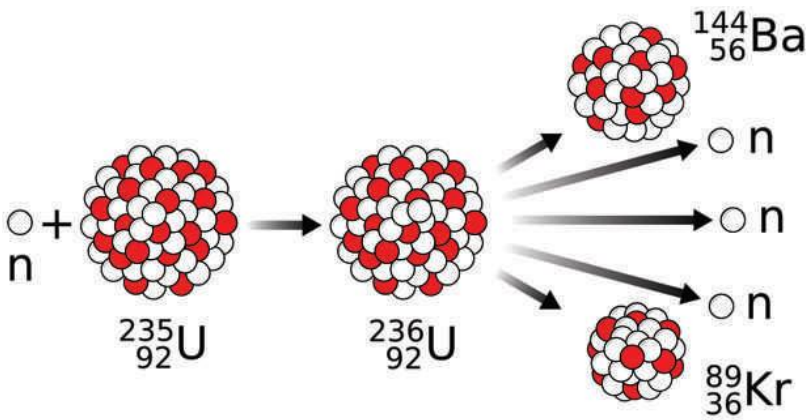


Figure 15.18 Fission of uranium-235 by bombardment with neutrons, forming barium-144 and krypton-89, and releasing more neutrons, which go on to split more uranium-235 nuclei in a chain reaction.

While Australia has around a third of the world's uranium deposits, it has never had a nuclear plant for the generation of power. Two uranium mines operate today, Four Mile and Olympic Dam, both in South Australia. Uranium mining in Australia raises several environmental concerns for local ecosystems and communities. Uranium ore emits a radioactive gas, radon-22, usually in small amounts but which must be monitored and not allowed to build up. The extraction process often destroys habitats and causes soil erosion, impacting biodiversity. Chemicals used in mining can contaminate nearby water sources, posing risks to both aquatic life and drinking water quality. Additionally, the waste materials, known as tailings, can remain radioactive and hazardous for thousands of years, making waste management challenging. These issues highlight the need for careful regulations and management practices to reduce the environmental impact of uranium mining.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Figure 15.19 A tailing pond at the Olympic Dam uranium mine in South Australia

Additional environmental factors must be considered when evaluating the use of nuclear power plants for energy generation. The uranium ore must be concentrated and processed into 'yellowcake' (uranium oxides), and then enriched, finishing up as uranium dioxide, which is processed into fuel rods. At every stage its radioactivity increases and stringent precautions must be taken to avoid leakage and contamination and release of radiation. Workers need to be protected at all times. Handling and transporting the material is hazardous.

The power plants produce radioactive waste, which can remain hazardous for thousands of years. Nuclear plants also require large amounts of water for cooling, which can lead to thermal pollution, where heated water is released back into natural bodies, potentially harming aquatic ecosystems and altering local habitats. Finally, although they are rare, accidents at nuclear power plants can have catastrophic and long-lasting environmental impacts, as seen in incidents like Chernobyl and Fukushima.

Nuclear fission generates huge amounts of power: a uranium pellet the size of an egg can generate around the same amount of energy as 88 tonnes of coal! It is also a low carbon source of energy: nuclear power plants do not produce any carbon dioxide. However, the safety and environmental considerations mean scientists have been searching for an alternative.

Nuclear fusion

Nuclear fusion, the process that powers stars, was described in Section 15.1 and illustrated in Figure 15.3. It is a promising energy source as it generates enormous amounts of energy in stars. It has the potential to provide abundant, clean energy with minimal environmental impact. The challenges surrounding it are the ability to create, sustain and contain temperatures hot enough to cause fusion. The massive gravitational fields of stars enable them to do this, but we can't create such high gravitational fields on Earth. Efforts to develop nuclear fusion as an energy source are ongoing, with scientists working towards making it a viable option in the coming decades.

Quick check 15.7

1. **Recall** the definition of nuclear fission.
2. **Recall** the conditions required for nuclear fission.
3. **Explain** briefly why nuclear fusion is a promising energy source.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Advances in science 15.3

Nuclear fusion in Sydney

A nuclear fusion tokamak device in Sydney, known as the ITER-like Tokamak Experiment (ILWT), is part of ongoing research into harnessing fusion energy. A tokamak is a type of device that uses powerful magnetic fields to confine hot plasma in a doughnut-shaped chamber, where fusion reactions can occur. The ILWT aims to replicate conditions similar to those found in stars, allowing researchers to study plasma behaviour and improve the efficiency of fusion reactions.

The device has been designed, built and operated by students in the Department of Physics at the University of New South Wales (UNSW). By exploring these advanced fusion technologies, the project contributes to the global effort to make nuclear fusion a viable and sustainable energy source for the future, potentially reducing reliance on fossil fuels and minimising environmental impact.

Low-res

Figure 15.20 The inside of the doughnut-shaped vacuum chamber of a tokomak, similar to the device operated at UNSW.

Section 15.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 15.3 questions

Remembering

1. **Name** three important uses of radioisotopes.
2. **Recall** some of the safety concerns associated with the use of radioisotopes.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Understanding

3. **Describe** nuclear fission and explain its use in nuclear power plants.
4. **Explain** why wearing thick gloves, a face shield and a lab coat should be sufficient safety measures if you are working with beta radiation.
5. **Explain** why it is important that industries using nuclear power ensure appropriate waste disposal procedures.
6. **Explain** why the half-life of a radioisotope is an important consideration in its use.

Applying

7. Iodine-131 is a radioisotope with a half-life of 8 days that undergoes beta decay. **Explain** why these properties make it a good candidate for the treatment of thyroid cancer.
8. Xenon-133 is a radioactive gas that is inhaled and used to diagnose lung issues by taking a picture of its presence in the lungs from outside of the body with a gamma camera. **Suggest** two reasons why it is important that xenon-133 emits gamma not alpha radiation.
9. **Explain** why radioactive sources in schools must be stored in lead-lined boxes.

Analysing

10. Sandy is given his grandfather's watch which has radioactive paint on its dial. **Suggest** how he would go about determining what type of radiation it is emitting.
11. Ionising radiation is used in smoke detectors. **Determine** the type of radiation you would choose for smoke detectors and **explain** why.
12. **Analyse** the benefits and problems of the use of nuclear energy in medicine and in industry.

Evaluating

13. **Compare** the use of nuclear power plants with coal-fired power stations for the generation of electricity.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
15.1	recall the Big Bang theory.	
15.1	describe how the first elements were formed after the Big Bang.	
15.1	describe what causes a nucleus to be unstable.	
15.2	describe alpha and beta decay as nuclear reactions.	
15.2	understand the process of radioactive decay in terms of isotope half-lives.	
15.3	evaluate the benefits and risks of using radioisotopes in medicine, industry and environmental monitoring.	
15.3	describe nuclear fission and nuclear fusion.	
15.3	outline the impacts on the environment of nuclear reactions including materials, production and waste.	
15.3	investigate a chemical or nuclear reaction used in industry to produce an important product (STEM activity at end of chapter).	

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

<Insert one full placeholder page for Review questions coming at 2pp.>

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

<Insert one full placeholder page for Review questions coming at 2pp.>

Data questions

The isotope carbon-14 decays via beta radiation to form nitrogen-14 atoms, following the decay curves presented in Figure 15.21. Scientists can predict the age of a fossil using analytical techniques that measure the relative abundances of carbon-14 and nitrogen-14 in the fossil and comparing these with the decay curves.

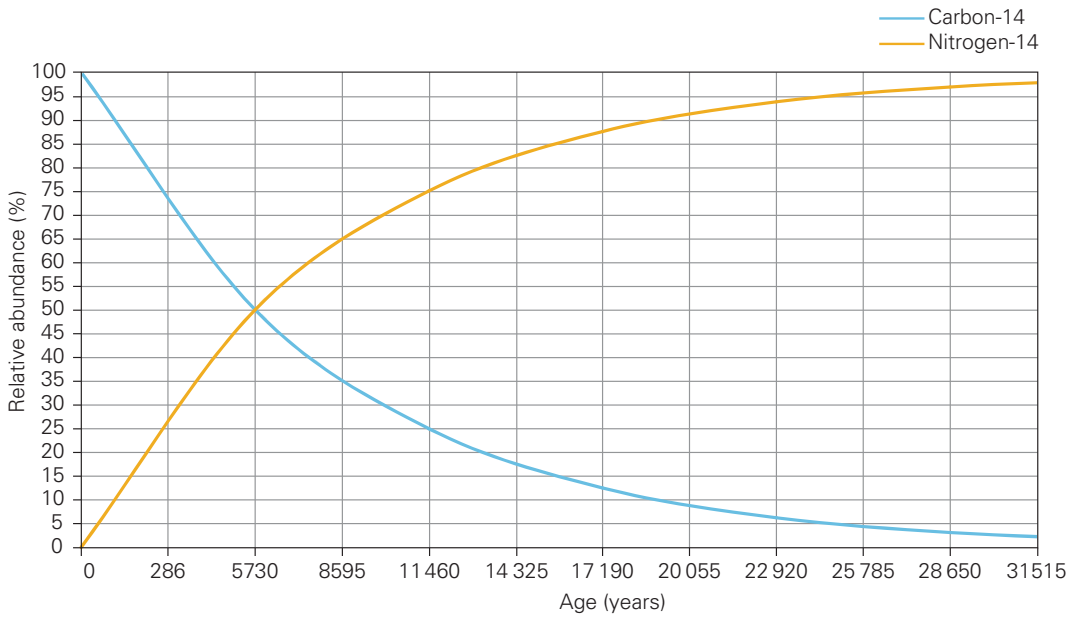


Figure 15.21 Relative abundance of carbon-14 (blue line) and nitrogen-14 (orange line) in an initial sample of carbon-14 over 31 515 years

1. A scientist has measured the relative abundance of carbon-14 in a sample of ancient kangaroo fossil at 25% compared to nitrogen-14. **Determine** the age of the fossil.
2. The relative abundance of nitrogen-14 in a kangaroo fossil sample is 40%. **Calculate** the relative abundance of carbon-14.
3. **Identify** the relative abundance of nitrogen-14 in a fossil dated at 8595 years old.
4. **Contrast** the two curves and comment on the relative rate of decay of carbon-14 and growth of nitrogen-14.
5. **Deduce** the half-life (time taken for half of the carbon-14 to decay to nitrogen-14) of carbon-14.
6. After 28 650 years, the relative abundance of carbon-14 is 3.125%. **Predict** the relative abundance of nitrogen-14 after another 5730 years (34 380 years total).
7. **Predict** and **explain** whether it would be possible to find a fossil with a relative abundance of carbon-14 of 0%.
8. The use of radiocarbon dating is most efficient with fossils less than 20 000 years old. **Compare** the carbon-14 decay curve before and after 20 000 years and elaborate on this comment.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Investigation of a chemical or nuclear reaction used in industry

Background information

A range of chemical and nuclear reactions are fundamental to different industries. For instance, the chloralkali process involves the electrolysis of saltwater to produce chlorine and sodium hydroxide, vital for the manufacture of disinfectants, plastics and various chemicals. Similarly, methanol synthesis converts natural gas into methanol, a versatile compound used as a fuel, solvent and feedstock for producing other chemicals. In addition to these chemical processes, nuclear reactions play a crucial role in applications such as wastewater treatment, where radioactive isotopes can be used for sterilisation and pathogen reduction.

Understanding these processes and their importance to society is essential for assessing their efficiency, environmental impact and sustainability.

DESIGN BRIEF

This investigation aims to explore a chemical or nuclear reaction utilised in industry, analysing the reactions involved, the application of the reaction, importance to society and environmental and safety considerations.

Activity instructions

1.

Conduct research into the industrial process.

3. Produce a report in a format of your choice (scientific report, article, presentation) including the following elements:
   - detailed description of the chemical or nuclear reaction involved
   - reaction conditions for the industrial process and considerations for optimisation of these conditions
   - descriptions of the product(s) and an explanation of their importance to society
   - environmental considerations
   - safety considerations.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 16

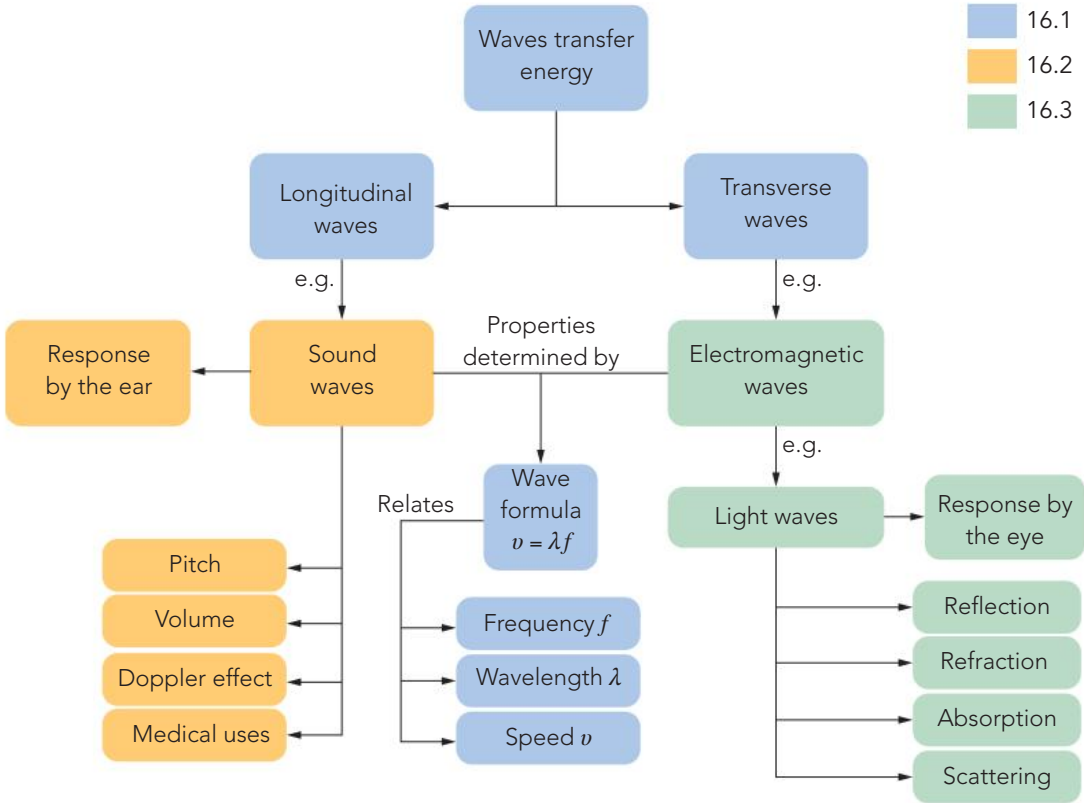
Waves

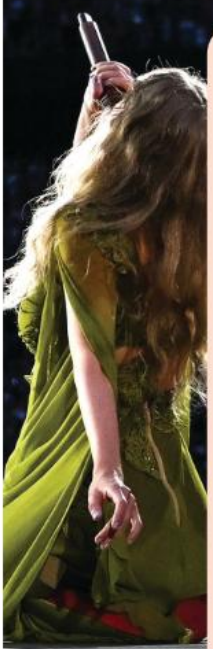
Chapter introduction

Waves aren't just for surfing! Waves underpin many effects and phenomena in our lives, including the light we see and the sound we hear. In this chapter, you will learn about how waves transfer energy without transferring particles, how frequency and wavelength are related, and how sounds waves affect our hearing and light waves affect our eyes. Finally, you will learn how the properties of waves can reveal the secrets of distant stars.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map





Glossary terms

absorb
amplitude
angle of incidence
angle of reflection
auditory nerve
blue shift
cochlea
compression
concave
convex
crest
cycle
displacement
Doppler effect
ear canal
eardrum
echolocation
electromagnetic radiation
electromagnetic wave
fovea
frequency
gamma ray
hertz
incident ray
infrared radiation
ionising radiation
lens (eye)
longitudinal wave
mechanical wave
medium
microwaves
normal
opaque
optic nerve
optical density
oscillating
oscillation
period
periodic motion
pitch
radio waves
rarefaction
red shift
reflect
reflected ray
refraction
refractive index
retina
seismic waves
SONAR
translucent
transparent
transverse wave
trough
ultraviolet light
vacuum
visible light
wave
wavelength
X-rays

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

16.1 Properties of waves

VIDEO
Light and sound waves

Learning outcomes

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

1. explain how energy is transferred without the net transfer of particles, using the wave model.
2. use models to compare and describe the features of transverse and longitudinal waves.
3. compare the different wave forms of the electromagnetic spectrum.
4. investigate the features of waves, including amplitude, frequency, speed and wavelength by exploring a range of wave types.
5. use the formula $v = \lambda f$ to explain the relationship between a wave's frequency, speed and wavelength.
6. analyse data from secondary sources to compare the uses of different EM waves based on their properties.

During a lightning storm, both light and sound energy are transferred by waves to your eyes and ears respectively. When you see the lightning, your eyes are detecting light waves, and when you hear the thunder, your ears are detecting sound waves. We see the lightning before we hear the thunder because light waves travel faster than sound waves.

Figure 16.1 Lightning and thunder are forms of light and sound energy that travel as waves.

wave
carrier of energy from one place to another without any matter accompanying it

mechanical wave
a disturbance in a medium that transfers energy through that medium

medium
the matter through which a mechanical wave travels

oscillation
a type of motion back and forth about a central point, repeating regularly

periodic motion
a movement of a particle or object that returns to its starting position and repeats in the same time interval, like a swing; oscillation is an example

The wave model

A **wave** transfers energy from one place to another without any matter accompanying it. **Mechanical waves** transfer energy from the source of a wave (a force that starts the disturbance in the medium). The matter through which the wave travels is called the **medium**. In mechanical waves, a disturbance in a medium results in the transfer of energy by the **oscillation** or **periodic motion** of particles.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Mechanical waves, therefore, require particles to allow the energy to travel through matter. These particles don't move along the wave, they only pass on the energy of the disturbance to the particles next to them. For example, a duck will bob up and down as a ripple passes, revealing the periodic motion of the water particles, but it and the water particles return to their original positions – they do not travel with the wave. Another kind of wave, called an **electromagnetic wave**, doesn't require a medium and can travel through a **vacuum**. Light and radiant heat are examples of electromagnetic waves.

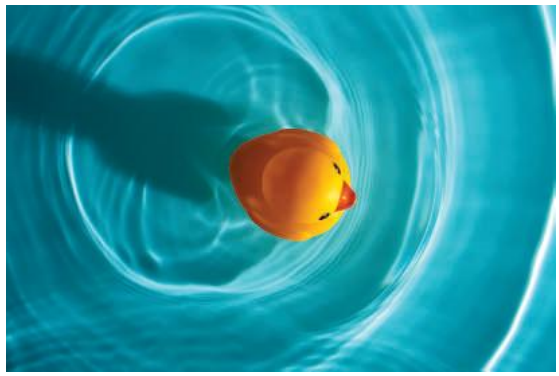


Figure 16.2 As a ripple passes through the medium (water), the duck is temporarily displaced as it bobs up and down, before returning to its original position.

Depending on the direction of oscillations of particles relative to the direction of energy transfer, a mechanical wave can be classified as a **transverse** or **longitudinal wave**.

Transverse waves

A transverse wave is a wave in which the disturbance of the medium is perpendicular to the direction of energy transfer. In mechanical transverse waves, the particles vibrate up and down, about their rest position, creating a series of **crests** and **troughs**. Crests and troughs represent the maximum **displacement** of a particle in the medium at the top and bottom of the wave respectively.

The number of **cycles** every second is called the **frequency**, symbol f and is measured in **hertz** (Hz). The time it takes for one cycle is called the **period** of the wave, symbol T and is measured in seconds. The distance between two consecutive points on the waves is called the **wavelength**, **symbol** λ and is measured in metres. The **amplitude** of a wave is how far the wave displaces from its middle position (centre line or equilibrium position) illustrated in Figure 16.3.

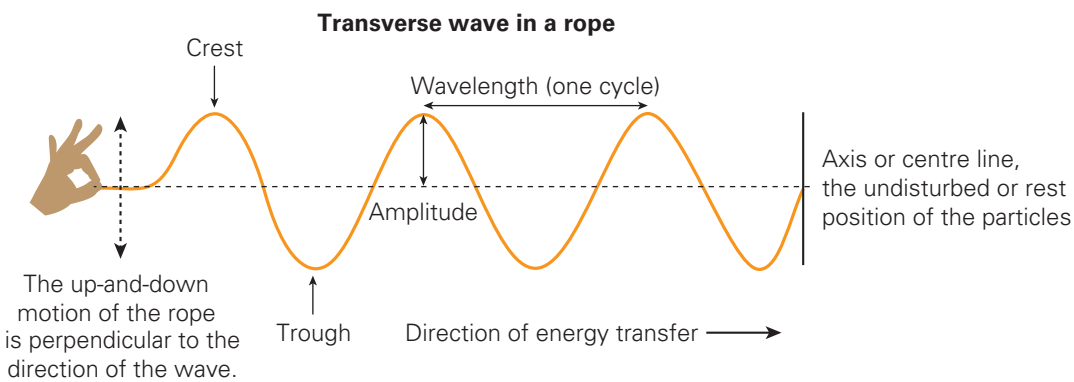


Figure 16.3 In a transverse wave the particles move perpendicular (at right angles) to the direction of energy transfer.

To show the relationship between frequency, f, and period, T, consider the definitions:

$$\text{frequency} = \frac{\text{cycles}}{\text{second}}$$

$$\text{period} = \frac{\text{seconds}}{\text{cycle}}$$

Notice that they are the inverse of each other, therefore:

$$f = \frac{1}{T}$$

and

$$T = \frac{1}{f}$$

electromagnetic wave
a wave made of oscillating electric and magnetic fields that can travel through matter or a vacuum

vacuum
a space totally devoid of matter

transverse wave
a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

longitudinal wave
particles oscillate parallel to direction of energy transfer

crest
the maximum displacement of a particle at the top of the wave

trough
the maximum displacement of a particle at the bottom of the wave

displacement
the distance of a particle from its rest position on the centre line of the wave

cycle
one complete vibration or periodic movement of a particle through the crest and trough and back to its starting position; the length of a cycle is the wavelength

frequency
the number of cycles per second

hertz
a unit for measuring the number of cycles that happen every second (frequency); abbreviation is Hz

period
time in seconds for one cycle

wavelength
the distance from one wave crest to the next

amplitude
the distance (height) of a wave crest or the depth of a wave trough from the centre line of the wave

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 16.1

Looking at wavelength and amplitude

Copy Figure 16.4, using a ruler to make the sides of the grid squares exactly 1 cm long. On your copy, label the wavelength and amplitude of the waves. Use a ruler to measure these features.

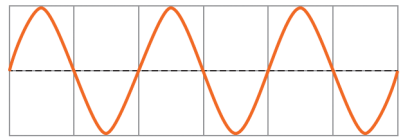


Figure 16.4 A transverse wave

Quick check 16.1

1. **Explain** what the word 'transverse' means in relation to waves.
2. **Recall** the three measurements of waves that give their dimensions.

Examples of transverse waves

seismic waves waves that travel through the Earth and over its surface which when large enough cause earthquakes

The strings in musical instruments, deep ocean waves, some **seismic waves** (S waves) and electromagnetic waves including visible light are all examples of transverse waves.

Figure 16.5 When the strings of a guitar are plucked, they vibrate up and down while waves travel along the string to its ends.

Longitudinal waves

compression the part of a longitudinal wave where the particles are close together

rarefaction the part of a longitudinal wave where the particles are spread apart

A longitudinal wave (or compression wave) is a wave in which the particles of the medium oscillate (that is, vibrate) parallel to the energy transfer. The particles vibrate back and forth creating a series of **compressions** and **rarefactions**. As can be seen in Figure 16.6, longitudinal waves have areas where the particles (coils in this case) crowd close together and areas where they are spread apart. Places where the particles in a medium are closer together are called compressions, and places where the particles in the medium are further apart from each other are called rarefactions.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

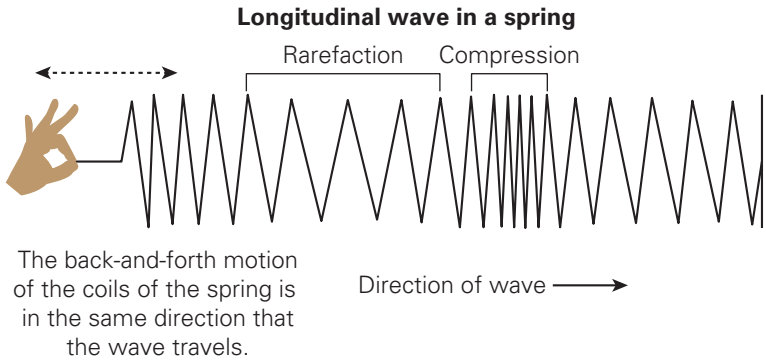


Figure 16.6 In a longitudinal wave, the particles move parallel to the direction of the wave.

Examples of longitudinal waves

Sound is a longitudinal wave because the air particles vibrate backwards and forwards in the same direction as the travelling sound wave. The motion of sound through the air is similar to when you move the end of a slinky forwards and backwards quickly to send a series of pulses through the spring. When a sound wave passes through air, the movement of the molecules is in a pattern that consists of regions of high pressure (compression) and regions of low pressure (rarefaction). Sound is a mechanical wave and therefore needs a medium to travel through, but the medium does not have to be air – it can also be a solid or a liquid. In fact, because sound needs particles to vibrate in order for it to travel, sound travels faster through solids, where the particles are close together and can therefore transfer energy faster. It can't travel at all through a vacuum (where there are no particles).

Some seismic waves are also longitudinal waves (P waves).

Try this 16.2

Visualising longitudinal waves

Grab a slinky and stretch it out along the floor until it is a couple of metres in length. Create vibrations in the slinky by moving the coils back and forth. Observe the areas of compression and rarefaction that move back and forth along the length of the slinky.

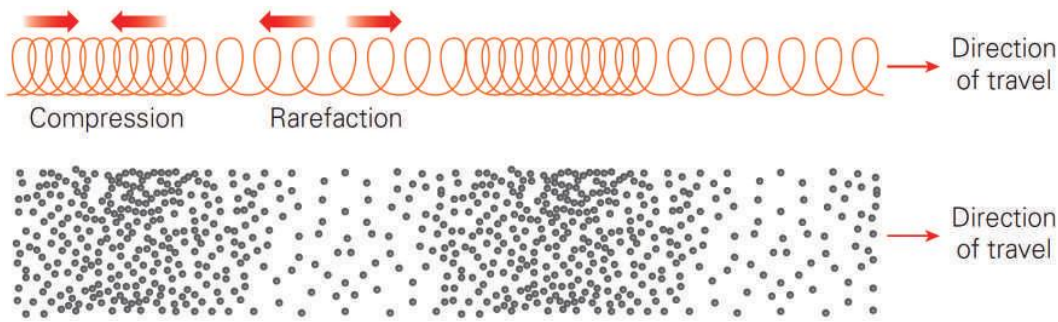


Figure 16.7 Longitudinal waves in a slinky can model longitudinal sound waves.

Properties of longitudinal waves

The properties of the longitudinal waves can also be described using the terms 'wavelength', 'frequency' and 'amplitude' where:

- Wavelength (metre, m) is the distance between two consecutive points (such as compressions or rarefactions) of a wave. The greater the distance between two points of maximum compression, the longer the wavelength.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

- Frequency (Hz) is the number of cycles (complete waves or vibrations) that pass a point each second. The more cycles or wavelengths that pass in a second, the higher the frequency.
- Amplitude (m) is the maximum displacement of air particles from their undisturbed position. This is the displacement amplitude. In a sound wave, which has regions of high and low pressure, the amplitude is the difference between the maximum pressure in a compression and atmospheric pressure.

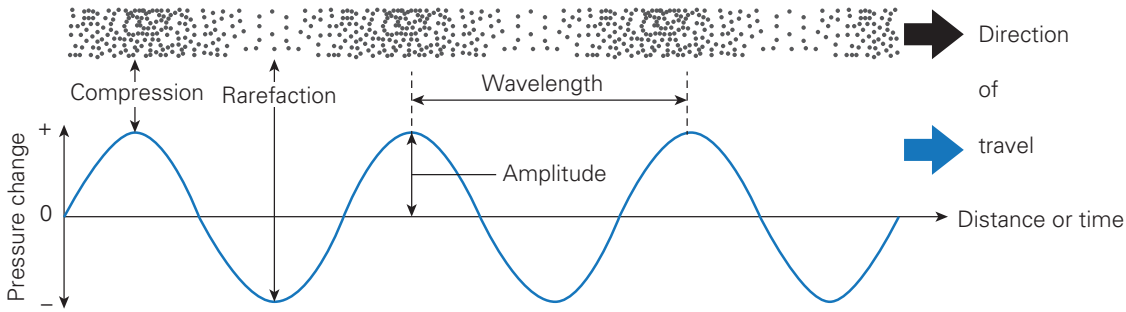


Figure 16.8 A sound wave represented as a graph of change in air pressure over distance or time. The air pressure change with no sound is 0, and +/– represents increase / decrease in pressure. Above the graph is a diagram showing the space between the air molecules and the regions of compression and rarefaction. Amplitude and wavelength now appear like they do for a transverse wave. Note that the graph is the same shape whether air pressure or air pressure change is plotted, or whether time or distance is the horizontal axis.

Speed of a wave

Let's get back to the lightning and thunder. How do you know how close that thunderstorm is? You may be familiar with counting "one one-thousand, two one-thousand, three one-thousand…" you start counting as soon as you see the lightning and stop when you hear the thunder. If you get to three one thousand you know the storm is one kilometre away. Sound takes about 3 seconds to travel a distance of one kilometre, so the number of seconds between the thunder and the lightning divided by 3 will give you the distance travelled in kilometres. The speed of light is very fast, in fact is travels at 300 000 000 metres per second (m/s), and we are assuming you see it the instant it appears. However, sound is much slower, it travels at approximately 330 m/s. The equation to calculate speed is:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Sound is a wave, and since the distance travelled by one cycle is the wavelength, and the time taken for one cycle is the period, therefore the speed of the wave must be wavelength divided by the period. We use the symbol v for speed (velocity).

$$\text{speed (or velocity)} = \frac{\text{wavelength}}{\text{period}}$$
$$v = \frac{\lambda}{T}$$

This is the same as:

$$v = \lambda \times \frac{1}{T}$$

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

and

$$\frac{1}{T} = f$$

so substituting for $1/T$ we get:

$$v = \lambda f$$

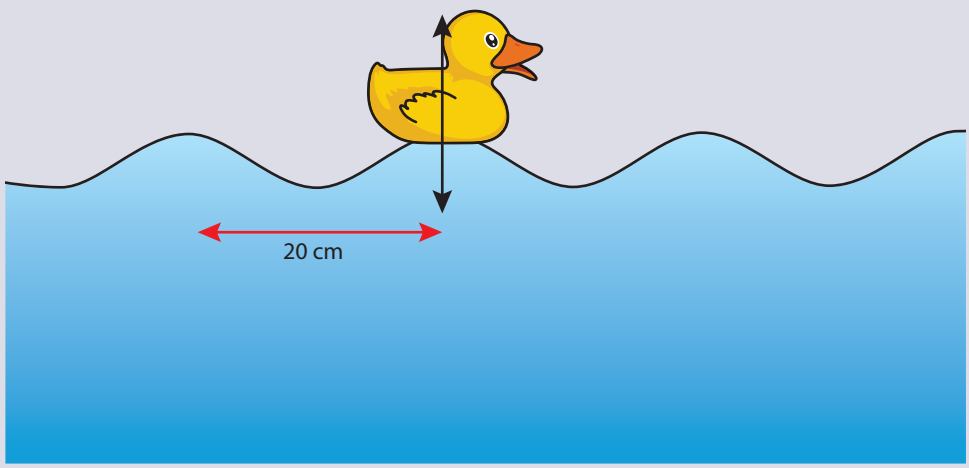
This is the wave speed equation, or just wave equation.

Worked example 16.1

You are sitting by the side of the pool, and you notice a rubber duck is bobbing up and down twice every second, you happen to have a 20 cm ruler next to you and notice the wavelength matches this.

a. What is the frequency?

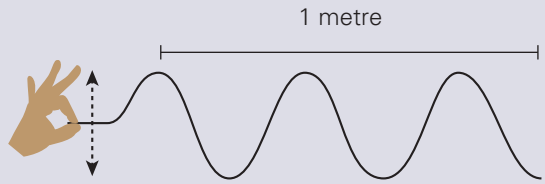
b. What is the speed of the wave?



Working	Explanation
a. Frequency	
frequency = cycles per second	Recall the definition of frequency.
frequency = 2 Hz	The duck completes two cycles every second given in the question.
b. Speed	
$v = f\lambda$	Identify the equation needed to answer the question.
$v = 2 \times 0.2$ $= 0.4$ m/s	Substitute the relevant values into the equation and give the answer with correct units.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 16.2



Your friend is distracting you by flicking a rope and as you watch, you count the number of wavelengths in a distance of 1 m.

a. What is the wavelength?

b. Find the period of the wave if it takes 0.2 seconds for the first peak to reach the end of the rope.

c. Find the speed of the wave using the equation: speed = $\frac{\text{distance}}{\text{time}}$

d. Find the speed of the wave using the wave equation: $v = f\lambda$

e. Compare your answers.

Working	Explanation
a. Wavelength	
$\lambda = \frac{1}{2.5} = 0.4$ m	From the diagram, count the number of wavelengths. There are 2.5 wavelengths per metre.
frequency = $\frac{2.5}{0.2} = 12.5$ Hz	Frequency is cycle per second, there are 2.5 cycles in 0.2 seconds
b. Period	
period = $\frac{1}{\text{frequency}}$	Identify the values given in the question.
period = $\frac{1}{12.5} = 0.08$ s	Substitute the relevant values into the equation and give the answer with correct units.
c. Speed of the wave using the equation: speed = $\frac{\text{distance}}{\text{time}}$	
speed = $\frac{\text{distance}}{\text{time}}$ = $\frac{1}{0.2}$ = 5 m/s	Substitute the relevant values into the equation and give the answer with correct units.
d. Speed of the wave using the wave equation: $v = f\lambda$	
$v = f\lambda$ = 12.5 × 0.4 = 5 m/s	Substitute the relevant values into the equation and give the answer with correct units.
e. Compare answers	
They are the same.	Conclude by answering the question in words.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 16.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 16.1 questions

Remembering

1. **Recall** the difference between a mechanical wave and an electromagnetic wave.
2. **Identify** the unit of frequency.
3. **Define** the following terms in your own words: wave, periodic motion, medium.

Understanding

4. **Explain** the direction of particle motion in relation to the direction of wave propagation in transverse and longitudinal waves.
5. **Outline** the difference between amplitude and wavelength.
6. **Sketch** four cycles of a wave of amplitude 2 m and wavelength 3 m.

Applying

7. **Calculate** the speed of a wave that repeat 10 cycles every 2 seconds, and has a wavelength 0.5 m.
8. A sound wave travelling at 340 m/s is emitted from a trumpet, playing middle C. Middle C has a frequency of 261.63 Hz. **Calculate** the wavelength of the wave.

Analysing

9. Students place block of chocolate in the microwave and observed that after 2 minutes some patches are more melted than others. By collecting quantitative data, they calculate the wavelength to be 15 cm. They know microwaves travel at the same speed as the speed of light, which is 300 000 000 m/s. **Calculate** the frequency of the microwaves.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

16.2 Sound waves

WORKSHEET
Wavelength, frequency and amplitude of sound waves

Learning outcomes

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

1. explain how energy is transferred by sound waves, without the net transfer of particles, using the wave model.
2. model sound waves as waves of compressions and rarefactions of particles.
3. understand and describe how amplitude and frequency affect the pitch and volume of sound.
4. understand the Doppler effect of waves.
5. describe how the ear responds to sound waves.
6. investigate and outline the use of sound in Aboriginal and/or Torres Strait Islander Peoples' traditional musical and communication instruments.
7. describe how sound waves are used in medical diagnosis.

Longitudinal sound waves displayed as transverse pressure vs time or distance graphs

Sound waves are longitudinal waves, as shown in Figure 16.7. This means the vibration of the particles is parallel to the direction of propagation of the wave. Sound waves are mechanical waves meaning they need a medium to travel through, there must be particles present to bump into each other so that sound can travel. This is how energy is is transferred in a sound wave, through collisions of particles, without the particles travelling with the wave.

As Figure 16.8 shows, sound waves are usually measured as a graph of air pressure (amplitude) changing against time or distance, which gives a shape like a transverse wave. This is what you see on an oscilloscope and related devices that measure and display sound waves. The displays of sound waves in the this section are of this type.

Explore! 16.1

Sound in a bell jar

Consider the following experiment (or find a video demonstration of it online). A bell jar is simply a jar in the shape of a bell that is attached to a vacuum pump. The bell jar is completely sealed so no air can enter; the vacuum pump is used to suck all the air out of the space. Additionally, an old-fashioned electric bell is placed inside the jar and switched on so you can see the hammer hit the bell and hear the sound. While the bell is on, the bell jar is sealed, and the air is removed (evacuated). Once the air is evacuated, can you still hear the bell? Why or why not?

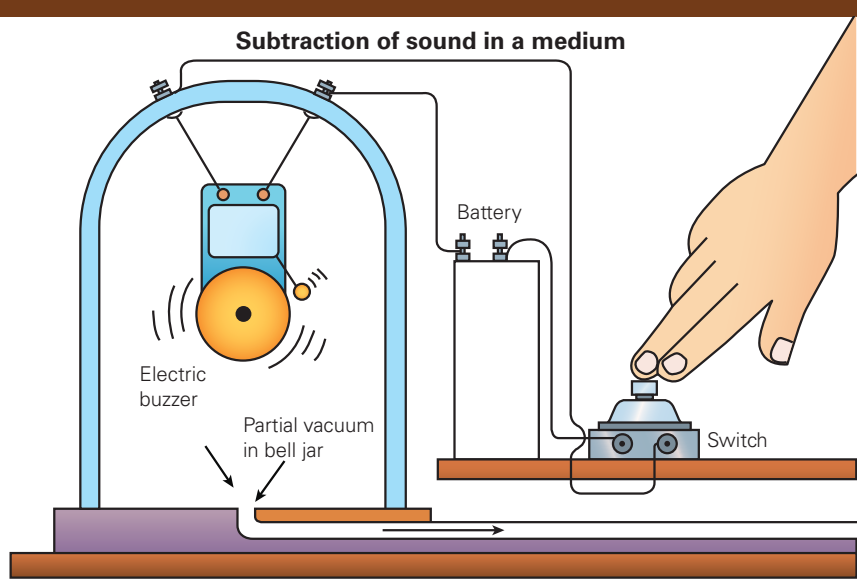


Figure 16.9 Sound waves must have a medium such as air to carry them. In the diagram, a buzzer is hooked up in a bell jar. As the air is pumped out, the sound of the buzzer grows fainter and finally dies away.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 16.1

Measuring the speed of sound in air

Aim

To measure the speed of sound in air.

Materials

- stopwatches
- trundle wheel
- blocks of wood or cymbals

Background information

Sound travels at a measurable speed, which is why you often see something in the distance before you hear it.

Procedure

1. A sound maker and assistants should stand at the far end of an oval.
2. Use the trundle wheel to measure the length of the oval.
3. Stand at the end of the oval with a stopwatch paying attention to the sound maker.
4. Start the stopwatch when you SEE the blocks of wood strike and stop as soon as you HEAR it.
5. Record the time.
6. Repeat as many times as you can.
7. Calculate an average and hence calculate the speed using the formula below.

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

Repeats	Time (s)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	

Questions

Light travels about 900 000 times faster than sound.

1. What is the speed of sound in air?
2. How close was you value?
3. What are some difficulties or limitations with this method?
4. Explain why you see the lightning before you hear the thunder.
5. What can you conclude if you see the lightning and hear the thunder at the same time?
6. If sound travels 330 m/s (this is its speed), how could you use an echo to work out the distance across a valley. Draw a diagram to show this.
7. It takes 3 seconds for an echo to return from a lookout across a valley. What is the distance across the valley?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Explore! 16.2

Sound waves and the didjeridu

Aboriginal and Torres Strait Islander Peoples developed various technologies and processes involving the transfer of sound. Some instruments were used for playing music such as clapsticks, others were used for communicating or hunting such as an emu caller. One example of an instrument for creating music is the didjeridu. Note that in traditional culture this instrument is generally played by men. Conduct some research on the didjeridu to answer the following questions.

Figure 16.10 The didjeridu is made of bamboo or tree trunks that have been hollowed out by termites or other insects.

1. Where is it believed that the didjeridu got its name from?
2. Find out the tribes that used a didjeridu, what it was used for and who played it.
3. How old is the didjeridu thought to be?
4. Describe the construction of a didjeridu. What material is it made of?
5. How does the length and flare end of a didjeridu affect its acoustic behaviour?
6. Outline how a didjeridu produces its unique sound, including all components that play a role.
7. Conduct research on the clapsticks and the emu caller. Compare your findings.

Figure 16.11 Aboriginal clapsticks presented at the Swearing-In Ceremony for the 39th Governor Of New South Wales, Margaret Beazley

Figure 16.12 Aboriginal emu caller on exhibit at the Australian Museum in Sydney, New South Wales

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 16.2

Making sound

Aim

To hear and observe vibrations in the air.

Materials

- tuning fork
- rubber stopper
- 100 mL beaker, half filled with water
- pith ball
- string
- retort stand

Procedure

1. Strike the tuning fork on a soft surface, such as the rubber stopper.
2. Bring the tuning fork to your ear and see if you can hear anything. You can use a sounding board to hear the sound clearly.
3. Repeat step **1** and lightly touch the vibrating ends of the tuning fork to the surface of the water.
4. Observe what happens to the water.
5. Repeat step **1** and lightly touch the vibrating ends of the tuning fork to the pith ball (suspended by a string from a retort stand).

Results

Record your observations.

Discussion

1. Explain what you heard when you held the tuning fork to your ear. How does this work?
2. Describe what happened when you submerged the ends of the tuning fork in water and when you touched the pith ball. Explain why this happened.

Pitch

We all know about a high-pitched scream, or a low-pitched rumble, but what does this mean? The **pitch** of a sound is how high or low the note is on a music scale. The pitch of a sound wave is determined by its frequency, the higher the frequency, the higher the pitch. Pitch is related to wavelength as well. Shortening the wavelength increases how many wavelengths pass each second (frequency), and this increases the pitch of the sound. Low-pitched sounds have a low frequency and long wavelength, whereas high-pitched sounds have a high frequency and short wavelength (shown in Figure 16.13).

pitch
how high or low a sound seems to our ears on a music scale

Try this 16.3

Test your hearing range

The hearing range for humans is typically between 20 and 20 000 Hz. The range decreases with age, particularly for high-pitched sound. Try testing your hearing range and compare to your peers and to adults such as your teacher. There are many free hearing tests available online.

Observe Figure 16.13. What do you notice about the differences in sounds that can be made compared to the sounds that can be heard? Using the values given, write a numerical conclusion about a particular creature, or about two different creatures.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

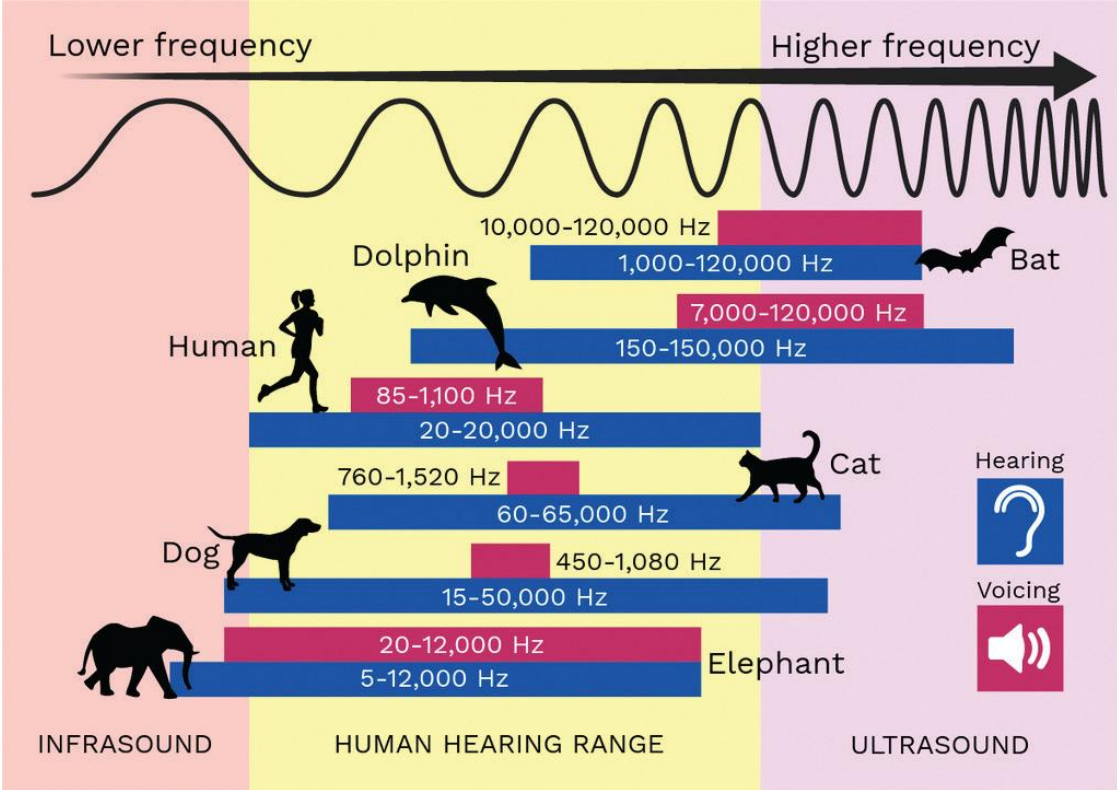


Figure 16.13 The hearing and voicing ranges of various creatures

Volume

The amplitude of a sound waves dictates the volume of the sound. A louder sound will have a larger amplitude, while a soft sound has a low amplitude. The energy of a wave depends on its amplitude as well as its frequency. A higher frequency means that the energy of the wave arrives more often in a given time period. If you look at water waves, you might notice that some waves are bigger than others. Amplitude is the maximum height of a wave from its resting position. If you were able to see sound waves, you would notice that loud sounds have a higher amplitude than soft sounds – that is, compressions are even closer together and rarefactions are even more spread apart. The volume (loudness), thus amplitude, of the sound is a measure of the amount of sound energy. This is shown in Figure 16.14.

Short wavelength means many wavelengths per second; high frequency, high pitch

Long wavelength means fewer waves; low frequency, low pitch

Figure 16.14 Which of the two waves do you think would be a whistle and which would be a bass guitar?

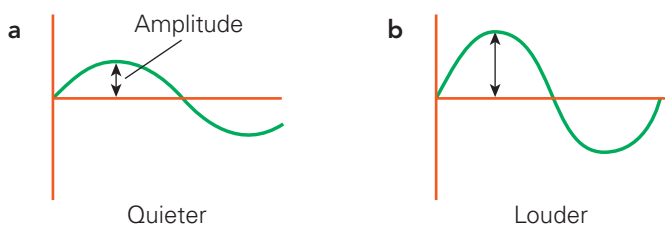
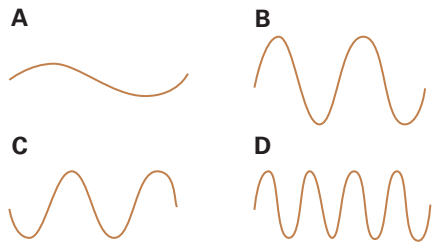


Figure 16.15 The amplitude of a sound wave is an indication of the loudness of the sound.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 16.2

1. **Define** the term 'sound' in your own words.
2. **Define** the terms 'compression' and 'rarefaction' in your own words.
3. **Explain** why sound travels faster in solids.
4. **Explain** how sound is an example of a longitudinal wave.
5. **Define** the terms 'frequency', 'wavelength' and 'amplitude' in your own words. Include the units.
6. Look at these sound waves, shown as pressure against time, and **determine** the answers to the questions below.



   a. Which wave has the highest frequency?
   b. Which wave has the longest wavelength?
   c. Which wave do you expect to have the highest pitch?
   d. Which wave is the loudest?
   e. Which two waves would you choose to illustrate the hearing range of a dolphin? Justify your answer.

Ears and sounds

When we hear something, sound waves travel through the air, into the **ear canal** and reach the **eardrum**. These vibrating air particles cause the eardrum to vibrate. The vibrations are passed on to three tiny bones called the hammer, anvil and stirrup – also known as the malleus, incus, and stapes, respectively. These three bones together are part of the middle ear. The eardrum causes these three bones to vibrate, and in turn this causes the vibration of fluids in the cochlea. This part of the ear is the inner ear. Finally, in the **cochlea**, the vibrations are converted into electrical impulses, which travel along the **auditory nerve** to the brain, where they are interpreted as sound. You have already learned that the loudness of a sound depends on the amplitude of the sound wave. The unit of measurement for loudness of sound is the decibel (dB). Carrying on a normal conversation with someone is usually around 60 dB. A rock concert is around 105 dB. Humans can hear sounds as low as 0 dB – this limit is called the threshold of hearing. Meanwhile, anything at around 85 dB can start to damage your hearing. Sounds louder than 120 dB can quickly cause irreversible damage.

ear canal
a tube that connects the outer ear and the middle ear

eardrum
a thin piece of membrane inside the ear that moves backwards and forwards very quickly (vibrates) when sound waves reach it

cochlea
a spiral tube inside the inner ear that is the main organ of hearing

auditory nerve
the nerve which connects the ear with the brain

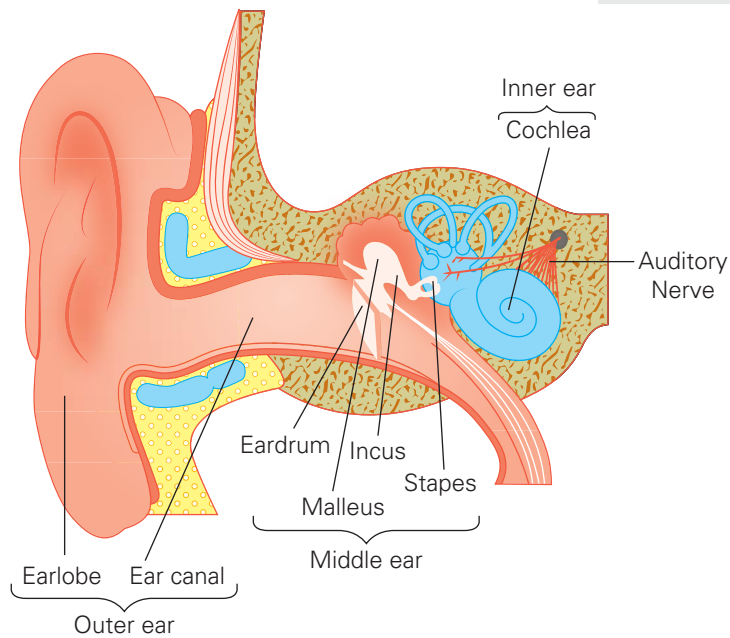


Figure 16.16 The structure of the human ear

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Did you know? 16.1

Protecting our hearing

Excessive noise can damage the delicate hearing cells in the inner ear. People who work with noisy machinery can be exposed to sounds above 85 dB, which can damage their hearing over time. If the delicate hair cells that detect sound in the inner ear are damaged, they cannot be replaced. This can cause hearing loss or a disorder called tinnitus, where a person permanently hears a ringing noise in their ears. To prevent this from occurring, people who are constantly exposed to loud sounds wear ear defenders to protect their hearing.

Figure 16.17 People who work with aircraft can be exposed to sounds above 140 dB, so they wear ear defenders.

The Doppler effect

When you hear an ambulance travelling past you, the pitch of the siren changes as it passes. When the ambulance is travelling towards you, the sound wave is compressed, shortening the wavelength, and results in a higher frequency wave. You hear it as a higher pitch. When the ambulance is travelling away from you, the sound wave is stretched and results in a lower frequency wave. You hear it as a lower pitch. This phenomenon is called the **Doppler effect**.

Doppler effect a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

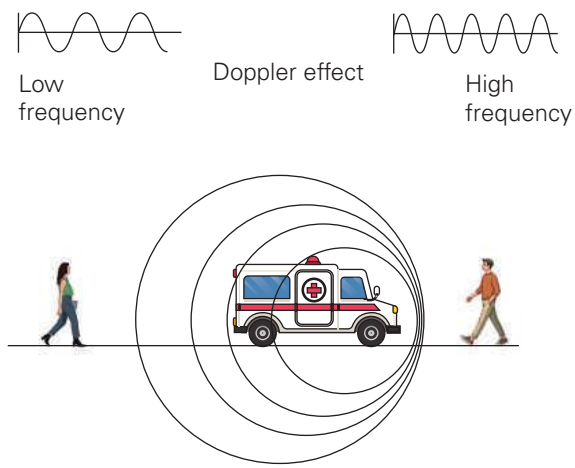


Figure 16.18 Sound waves are squashed together as the ambulance travels into them, so we hear a higher pitch. Sound waves are spread out as the ambulance moves away from them, so we hear a lower pitch.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applications of sound

Doppler ultrasound

Doppler ultrasound is used to assess blood flow and detect vascular issues by measuring changes in the frequency of sound waves reflected from moving blood cells. Since the blood is moving, the change in frequency as it moves towards the detector (which acts as the observer) can be used to calculate the speed of the flow. This is useful to monitor varicose veins, and diagnose blood clots, narrowed arteries and other problems that affect the heart and blood vessels.

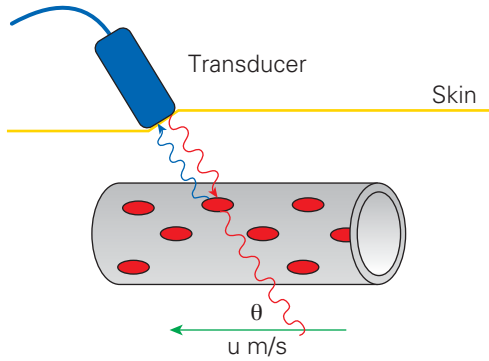


Figure 16.19 Detecting blood flow using the Doppler effect

Ultrasound medical imaging

Ultrasound is used in medical diagnosis to visualise internal structures and monitor foetal development using high-frequency sound waves. This is also called sonography. Sound waves are sent towards the target, reflected back and are detected by the same device. The time for waves to return are converted to distances and used by a computer to create an image of the tissue or object reflecting the waves. Echolocation and sonar are based on similar principle.

Figure 16.20 Left: a pre-natal ultrasound showing a baby in the mother's womb. Right: a three-dimensional sonograph, which gives even greater detail.

Echolocation

Animals such as bats and dolphins use **echolocation** to navigate and locate prey. To do this, they utilise the ability of sound waves to reflect off hard surfaces. These animals emit high frequency sound (ultrasound) waves, which hit surrounding objects and produce an echo. They then listen for the echoes that return and use them to identify objects in close proximity that they cannot see.

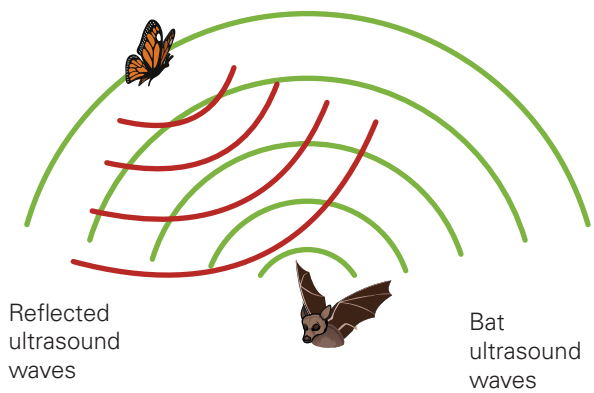


Figure 16.21 A bat using the reflected sound waves produced in echolocation to locate prey

echolocation the location of objects using reflected sound (echo)

Interestingly, some humans have developed through practice the ability to echolocate. By making short high-pitched clicks they are able to find their way around by listening to echoes bouncing off surrounding objects.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

SONAR

SONAR
a mode of navigation used by ships to locate underwater objects using reflected sound

SONAR (an acronym of SOund NAvigation and Ranging) uses ultrasound waves, in the same way as animals use echolocation, to navigate and locate underwater objects such as land mass, submarines and schools of fish. Ships send out an ultrasound wave and a receiver detects the echo. Based on the time delay of the echo, and the speed of sound in water, the distance to underwater objects can be calculated.

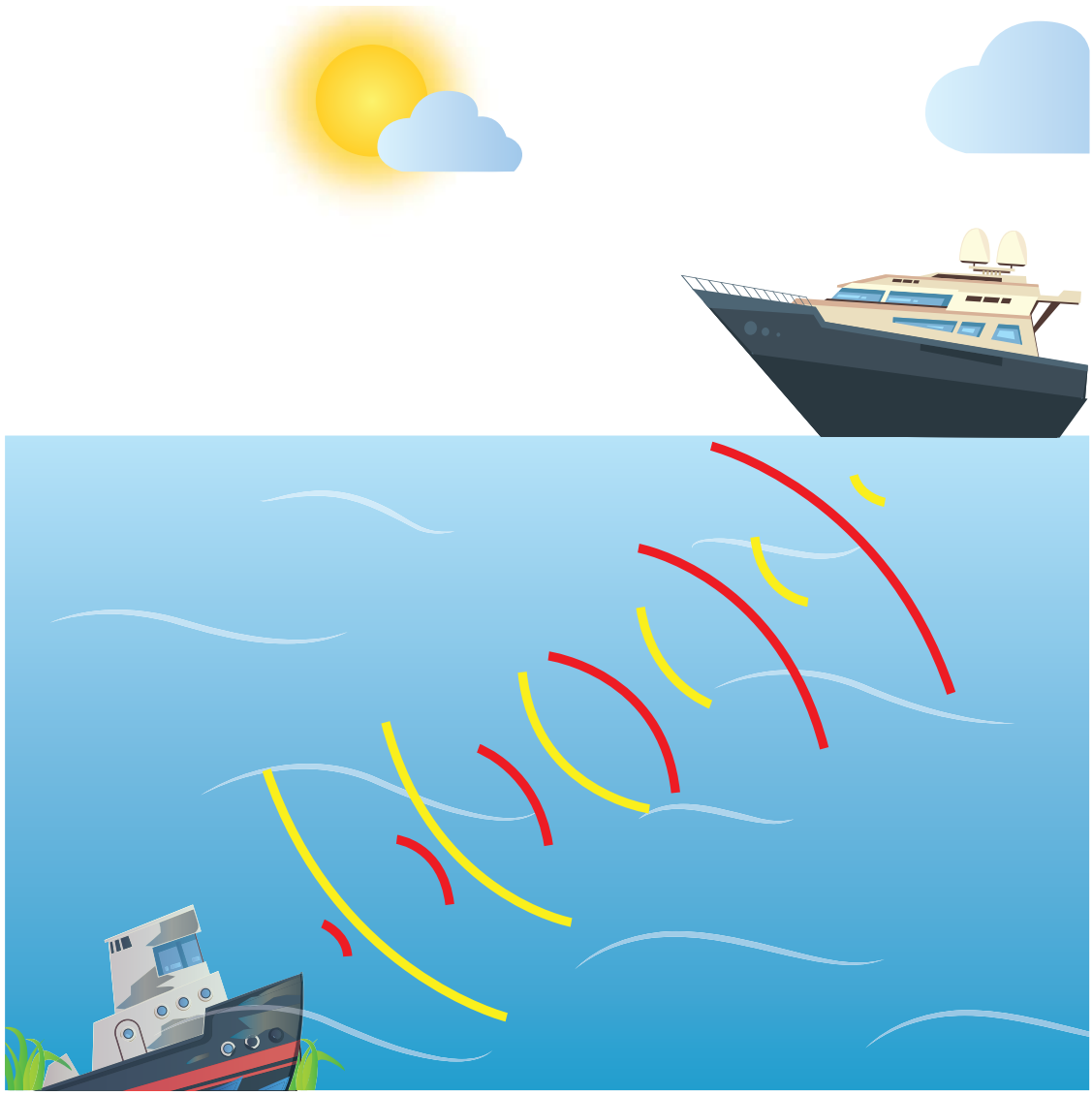


Figure 16.22 A ship using SONAR to locate underwater objects

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Section 16.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 16.2 questions

Remembering

1. **Recall** the terms for the high-pressure and low-pressure areas of a sound wave.
2. **Identify** the correct words to complete the following sentences.
   a. Pitch is determined by the _____ of a wave.
   b. Volume is determined by the _____ of a wave.
3. **Define** the following terms in your own words: rarefaction, amplitude, pitch.
4. **Recall** the names of the three small bones in the middle ear.

Understanding

5. **Explain** what is meant by the term 'longitudinal wave'.
6. **Explain** why sound cannot travel through the vacuum of space.
7. **Explain** why you see the flash of lightning first before you hear the thunder.
8. **Explain** why the pitch you hear changes when an ambulance passes you as you stand on the side of the road.

Applying

9. A sound wave has a frequency of 5 Hz and a wavelength of 3 m. **Interpret** what this means.
10. **Sketch** a sound wave to compare the sounds produces by a mouse and by an elephant.

Analysing

11. Use the image below to **determine** why the loudness of a sound decreases as you move away from the source of the sound.

12. The Doppler effect is very useful. Choose one application and explain how the Doppler effect is used to enable this technology. **Discuss** the importance of this application.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

16.3 Light waves

WORKSHEET
Refraction and reflection

Learning outcomes

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

1. describe how the eye responds to light.
2. investigate the properties of light, including absorption, reflection, refraction and scattering.
3. explain how the electromagnetic spectrum is used to learn about stars.
5. analyse data from secondary sources to compare the uses of different electromagnetic waves based on their properties.

Light waves are transverse waves. This means oscillations are perpendicular to the direction of propagation of the wave. Light does not need a medium to travel through. This is because light is an electromagnetic wave.

Electromagnetic waves

oscillating moving back and forth with periodic motion somewhat like vibration

electromagnetic radiation transfer of energy by electromagnetic waves

Electromagnetic waves consist of **oscillating** electric and magnetic fields, and since an oscillating electric field induces a magnetic field, and an oscillating magnetic field induces an electric field then no medium is needed as the wave propagates itself. The energy is carried in the oscillation of the fields, and it does work when the wave hits matter and is absorbed, such as heating up the matter. There are no particles of matter travelling with the wave. **Electromagnetic radiation** is the term for the transfer of energy by electromagnetic waves.

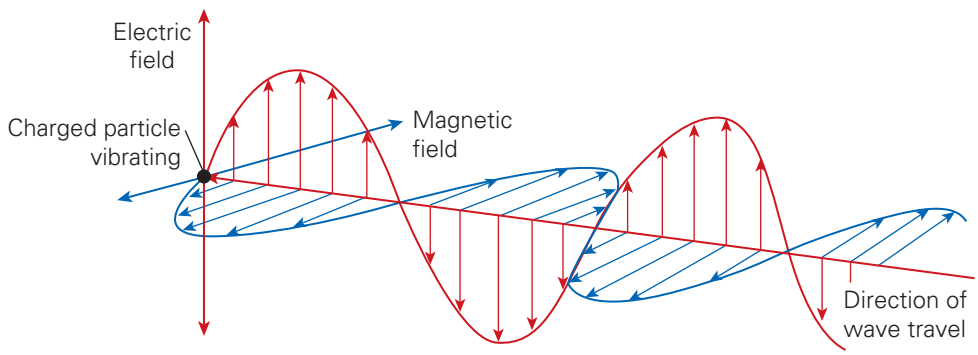


Figure 16.23 A vibrating charged particle generates oscillating electric and magnetic fields. These fields are perpendicular to each other and to the direction of the wave.

Electromagnetic waves all travel at the same speed through a vacuum (the speed of light), this speed is 3×10^8 m/s. That's 300 000 000 m/s! That's very fast, in fact it is the fastest known speed, nothing has ever gone faster than the speed of light. Theories exist that if speeds greater than the speed of light could be achieved, then time travel would be possible. Remember the speed of sound? It is approximately 330 m/s. No wonder we could use the counting method to estimate how far a thunderstorm is!

Like all waves, the wave speed equation, $v = f\lambda$, still applies and since the speed of light is constant for all electromagnetic radiation, there is a simple proportional relationship between the frequency and wavelength of a wave. Either of these two variables determines a wave's position on the electromagnetic spectrum (Figure 16.24). As speed remains constant, the frequency of an electromagnetic wave can easily be calculated from its wavelength and vice versa.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

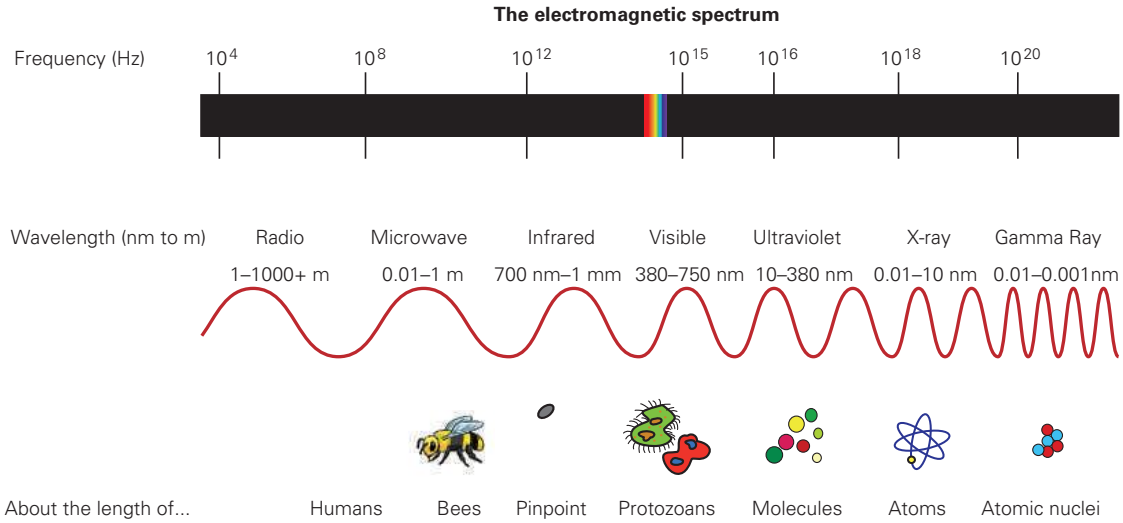


Figure 16.24 The electromagnetic spectrum extends far beyond the visible spectrum (light waves) as shown at the top.

The different types of electromagnetic waves and their uses are listed below.

- **Radio waves** are useful for communications and signals over long distances (including for radar). Radio waves were originally used for communication with ships at sea, then broadcasts by radio and television stations, and are now also used to send communications around the world via satellites. Radio waves have very long wavelengths (some of them are several kilometres long), but their energy and frequency are very low.
- **Microwaves** are used for cooking, Wi-Fi communications and mobile phone technology. In a microwave oven, any water molecules present in food will vibrate at the same frequency as the microwaves and convert this energy into heat, cooking the food quickly. Microwaves are also used in mobile phone networks. When a mobile phone is switched on, it produces microwave signals that are picked up by receivers in mobile phone towers. The towers then transmit signals back to the phone for incoming calls, to connect to the internet and to download files, images and video.
- **Infrared radiation** is the radiation you feel immediately when you stand near a fire or when you feel heated by the Sun. It is also used in home remote controls. Objects at a higher temperature release more infrared radiation than similar objects at a lower temperature (as you learned in your previous studies). Infrared cameras can be used to detect infrared waves being emitted by an object. The signals are then processed to produce a false-colour image showing the relative temperatures of parts of the object.
- **Visible light** is the section of the electromagnetic spectrum that is visible to the human eye. The various colours have different wavelengths (and hence different frequencies). For example, red light has wavelength from 620 to 750 nanometres while purple light has wavelength of 380 to 450 nanometres.
- **Ultraviolet light** is invisible radiation that can cause sunburn and skin cancer. Not all ultraviolet is bad though: skin cells use low-frequency ultraviolet light to make vitamin D.
- **X-rays** are high-energy electromagnetic waves that are used to create images of bones. Bone absorbs most of the radiation whereas X-rays will pass through soft tissue such as fat and muscle. This results in bones appearing white, soft tissue appearing grey and air appearing black in X-ray images. The development of imaging technologies has contributed greatly to our understanding of the functions and interactions of body systems. X-rays can cause cancer, although the radiation dose from medical scans is small.
- **Gamma rays** are high-energy, high-frequency waves with a short wavelength. They are released when atomic nuclei decay, and although they can cause cancer, they can also be used in its treatment.

radio waves electromagnetic radiation that has the longest wavelength

microwaves electromagnetic radiation used for cooking, communications and Wi-Fi; lies between radio waves and infrared radiation

infrared radiation electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

visible light the part of the electromagnetic spectrum that we can see

ultraviolet light radiation that lies between visible light and X-rays; is needed by our bodies to make vitamin D; short wavelength UV can cause sunburn and cancer

X-rays short wavelength electromagnetic radiation that can pass through flesh to give images of bones; hazardous and can cause cancer

gamma ray high-energy ray with a very short wavelength produced when radioactive atoms decay

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

The higher the frequency of an electromagnetic wave, the more energy it carries. Higher frequency ultraviolet rays, X-rays and gamma rays have enough energy to knock electrons off atoms, so they become ions. This is referred to as **ionising radiation**, and it damages living cells.

ionising radiation higher frequency ultraviolet rays, X- and gamma rays which can turn atoms and molecules into ions; can potentially damage living cells

Try this 16.4

Electromagnetic radiation applications

In small groups, choose one of the types of electromagnetic radiation listed above and research an application of electromagnetic radiation. This could be a technology in medicine, such as the gamma knife, antiseptic uses of ultraviolet radiation in sanitation, or radio waves to transmit information in communication. Make sure you follow the skill of using secondary sources covered in Chapter 1. Make a PowerPoint with at least four slides, ensure there is not too much text, be sure to include quality visual information. When you present your findings to the class, be sure you can explain without reading the slides! Allow time for questions too.

Figure 16.25 Gamma knife radiosurgery

Figure 16.26 Sydney water sewage treatment plants include a process of ultraviolet wastewater treatment, which involves exposing wastewater to UV light to inactivate bacteria, viruses and parasites in the water.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 16.3

1. **State** which forms of radiation can be harmful to humans.
2. **State** two uses of radio waves.
3. **State** the approximate wavelength of microwaves.
4. **Compare** radio waves and microwaves.
5. **State** what property an object should have to emit a large amount of infrared radiation.

Properties of light

All electromagnetic radiation behaves in the same way. Each type exhibits the same properties of reflection, refraction, absorption and scattering. But since we can see light with our eyes, let's have a look at these properties for visible light.

Opaque surfaces are able to **reflect** or **absorb** light. The colour we see an object as depends on the colour of light reflected off its surface. White objects reflect all the colours in the visible spectrum and absorb none compared to black objects, which absorb all the colours and reflect none. Absorbing light cause the object the become warm, light energy is transformed to thermal energy. You may have notice that wearing a black t-shirt or sitting in a black car in summer causes more heating than wearing a white t-shirt or sitting in a white car in summer. An object that appears red has a pigment in its surface that absorbs all wavelengths except red, which is reflected into our eyes and seen as the colour red.

Light rays reflecting off a smooth surface bounce off at the same angle allowing a clear image to be seen.

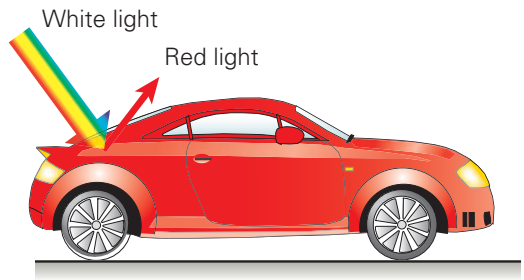


Figure 16.27 A red car reflects all red wavelengths of light and absorbs all the other colours of the visible spectrum.

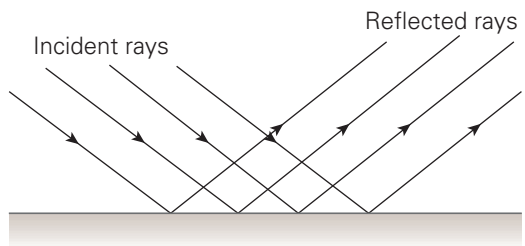


Figure 16.28 Light rays hitting a smooth surface are all reflected at the same angle, and an image can be formed.

Refraction

Law of reflection of light

To understand the law of reflection of light, you first need to learn some definitions.

- The incoming ray of light that hits the reflecting surface is called the **incident ray**.
- The outgoing ray of light that is reflected off the surface is called the **reflected ray**.
- The **normal** is an imaginary line that is at right angles to the surface.
- The angle between the incident ray and the normal is the **angle of incidence** (i).
- The angle between the reflected ray and the normal is the **angle of reflection** (r).

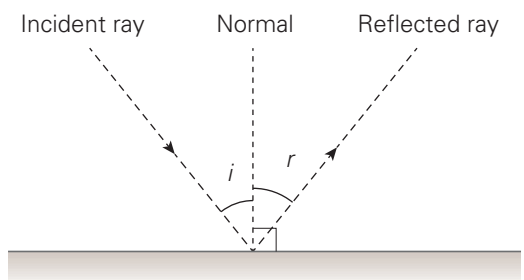


Figure 16.29 The law of reflection of light states that the angle of incidence (i) is always equal to the angle of reflection (r).

The law of reflection of light states that the angle of incidence is equal to the angle of reflection.

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

opaque
a substance that blocks the transmission of light completely

reflect
to bounce back the energy of a wave (e.g. heat, light, sound) without absorbing it

absorb
to take up the energy of a wave (e.g. absorb light)

incident ray
a ray of light arriving at a surface

reflected ray
a ray of light that is reflected off a surface

normal
an imaginary line that is at right angles to a surface

angle of incidence
the angle between an incident light ray and the normal when the ray arrives at a surface

angle of reflection
the angle between a reflected light ray and the normal, when the ray leaves a surface

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 16.4

1. **State** the law of reflection.
2. **Explain** what the law of reflection means.

Concave mirror

concave
a mirror that is curved inwards, like a cave

A **concave** mirror curves inwards, like a cave. Concave mirrors can be used to magnify images and are commonly used for shaving or applying make-up.

When parallel rays are reflected from a concave mirror, they converge at a *focal point*. The focal point is where an image forms. Alternatively, if you place a light at the focal point, you direct all the rays of light in the same direction, this is how a car headlight or a torch works.

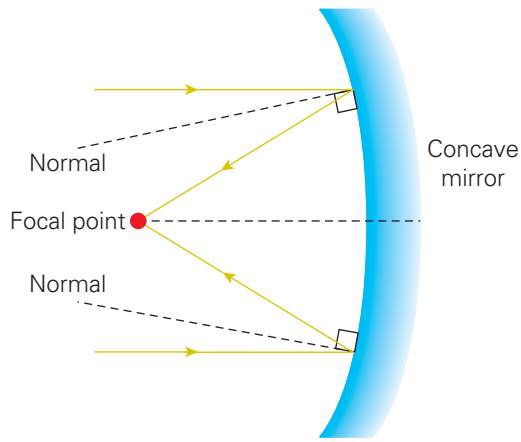


Figure 16.31 The reflected light rays converge (this means they meet).

Figure 16.30 If you hold a concave mirror close, it will magnify your image, as shown here. But if you moved a long distance away from the mirror, it would turn your image upside down.

Convex mirror

convex
a mirror that bulges outwards

Convex mirrors bulge outwards and give a wider field of view. They are used in car rear view mirrors to allow drivers greater visibility. You may also see large convex mirrors at intersections that have limited visibility, or in the hallways of hospitals to provide a view of what is around the corner.

When light rays are reflected from a convex mirror, the light rays diverge. This means they spread out as illustrated in Figure 16.33.

Figure 16.32 A car's side view mirror is often a convex mirror. It gives a wider field of view, but also makes objects appear smaller and further away than they actually are.

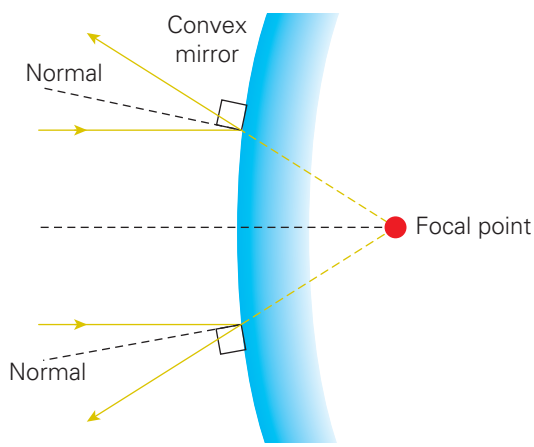


Figure 16.33 Reflected light rays diverge from a convex mirror.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

INVESTIGATION

Investigation **16.3**

Investigating ray diagrams with concave and convex mirrors

Be careful

Take care as the light box can become hot with prolonged use.

Aim

To observe and record the way in which light rays are reflected from curved mirrors.

Materials

- light box
- clear ruler
- pencil
- concave mirror
- convex mirror
- white A4 paper

Procedure

1. Plug in the light box and position it at the edge of a piece of A4 white paper.
2. Place the triple ray-forming plate into the slot and turn on the light box. Adjust the position of the bulb until you see three parallel rays of light on the paper.
3. Place the concave mirror about 10 cm in front of the rays and align it so that the middle ray reflects back on itself.
4. Use a pencil to outline the mirror and use a clear plastic ruler to trace the incident and reflected rays.
5. Label the point at which they meet the 'focal point'.
6. Get a new piece of paper and repeat steps **3** and **4** with a convex mirror.
7. Trace the reflected rays back behind the outline of the mirror with dotted lines.
8. Label the point at which the dotted lines meet the 'virtual focal point'.

Results

On your ray tracing diagrams, measure how far the focal point or virtual focal point is from the mirrors. Include this in your diagrams.

Discussion

1. Do the focal lengths for the convex and concave mirrors differ?
2. Where id the focal point of a convex mirror? How do you know?

Conclusion

1. Make a claim regarding light rays reflected from curved mirrors. Start your sentence with: 'This experiment suggests that with curved mirrors … '.
2. Support your claim by using what you observed when you used convex and concave mirrors. Start your sentence with: 'It was observed that … '.
3. Explain how the data supports your claim. Start your sentence with: 'This means that … '.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

translucent allowing some light to pass through, but no clear image can be seen through them

transparent allowing light to pass through and a clear image can be seen through the substance

refraction the bending of light as it passes from one medium to another

optical density an indicator of the refractive power of the substance, which is measured by comparing the amount incident light to the amount of transmitted light

refractive index a measure of how much the speed of light changes as it passes from a vacuum into a particular substance

Scattering

Some materials are **translucent**. This means they allow some light to pass through, but no clear image can be seen as the light transmitted through them is **scattered** in many directions and thus doesn't reach the eye as a coherent image. This can be very useful – for example, a shower screen offers privacy while still allowing light through.

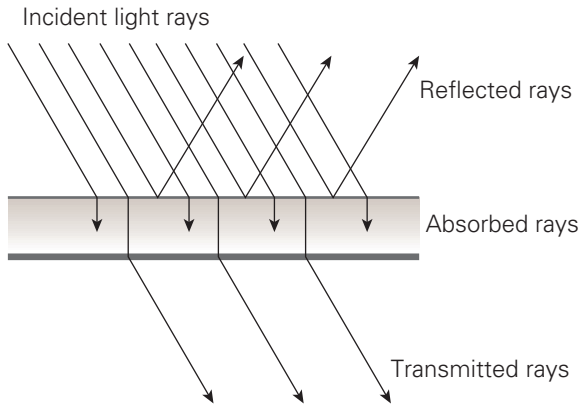


Figure 16.34 In a translucent material some of the incident rays are scattered, while other are transmitted. A percentage are absorbed.

Refraction

Transparent materials, such as diamond, glass and water, allow light to pass through them with little or no alteration, allowing clear images to be seen through them. Coloured transparent materials such as cellophane will absorb some wavelengths and transmit others. For example, red cellophane contains a red pigment which absorbs all wavelengths of light except for red, which is then transmitted through the cellophane.

When light travels from one substance into a different substance it bends. That's why objects that are half submerged look like they are bent like the straw in your drink. This bending of light is called **refraction** and is the result of light slowing down or speeding up when it enters a substance of different **optical density**. Each material has a **refractive index**, which is a measure of the change in the speed of light as it moves from a vacuum into that material. When light travels from a material with a lower refractive index into a material with a higher index (for example, from air into water), it slows down and bends *towards* the normal. The normal is the line perpendicular to the surface (Figure 16.36, left). Conversely, when light travels from a material with a higher refractive index into a material with a lower refractive index (for example, from water into air), it speeds up and bends *away* from the normal (Figure 16.36, right).

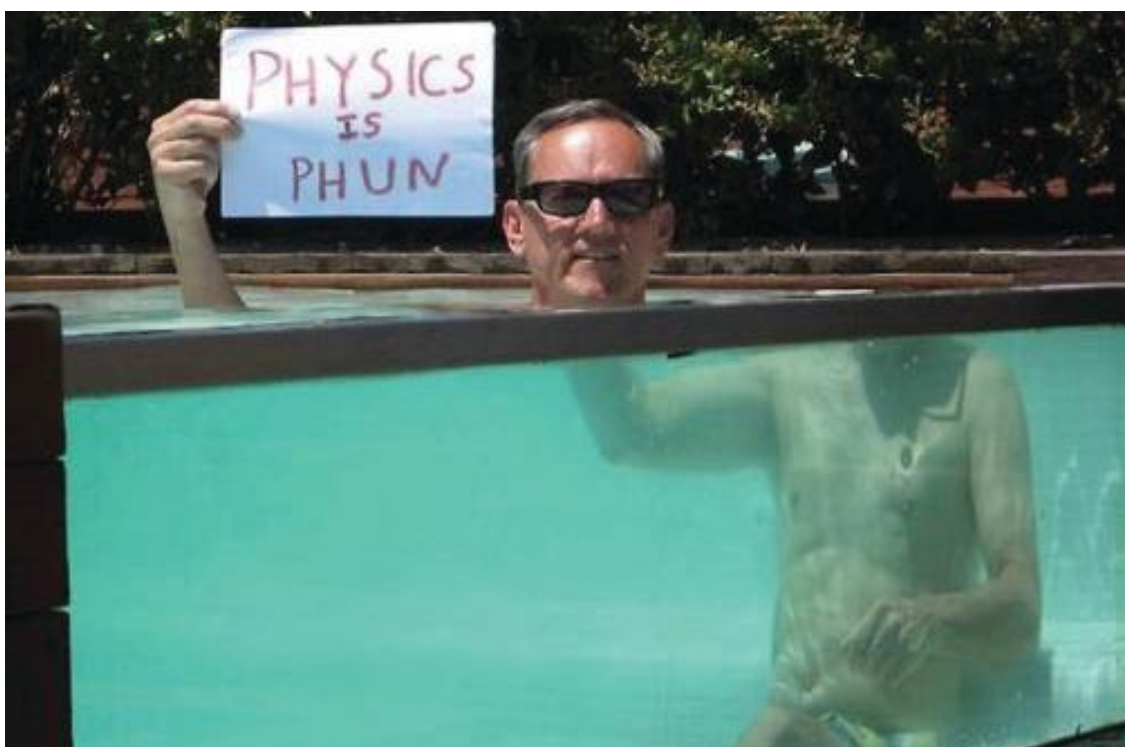


Figure 16.35 Partially submerged objects look distorted due to refraction. This occurs because light travels at different speed in different mediums.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

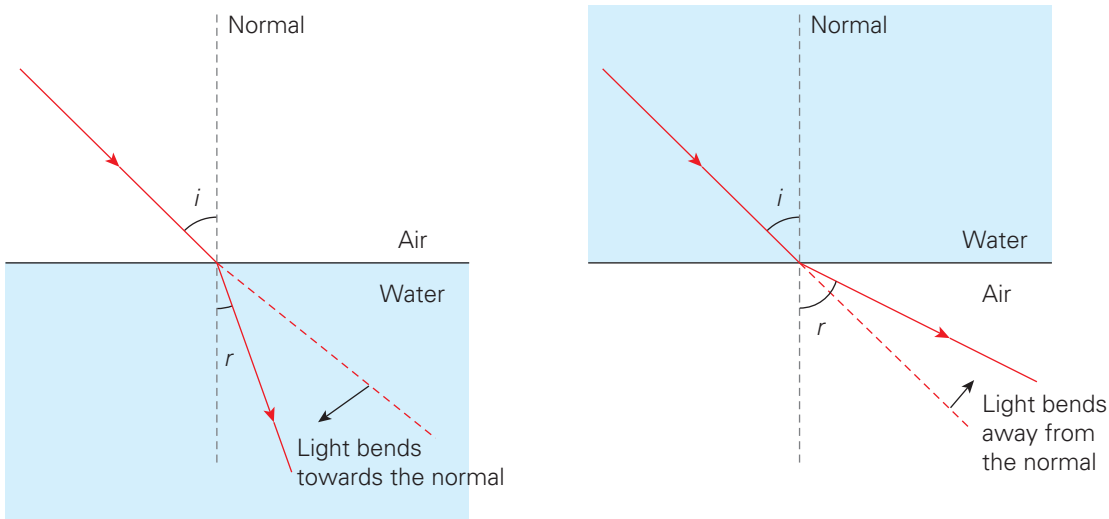


Figure 16.36 The direction light bends is dependent on the refractive index of the materials it enters and leaves from. Water has a higher refractive index than air.

Try this 16.5

Bending light

Look up the 'Bending light' simulation on the University of Colorado Boulder's PhET Interactive Simulations website. Using the simulation, examine what happens as the angle of incidence changes for a given refractive index.

Quick check 16.5

1. **Define** the term 'refraction' in your own words.
2. **Explain** how refraction differs from reflection.
3. **State** whether light will bend towards or away from the normal when it is travelling from a material with a refractive index of 1.02 into a material with a refractive index of 1.4.

INVESTIGATION

Investigation 16.4

Refracting light

Be careful

Take care as the light box can become hot with prolonged use.

Aim

To investigate refraction of light through a glass block.

Materials

- glass rectangular block
- light box
- sheet of A4 white paper
- protractor
- clear plastic ruler
- pencil

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1. Connect the light box to a power source and insert a single-ray forming plate.
2. Place the light box on its side on the piece of white paper and switch it on.
3. Direct the single ray towards the glass block, as shown in Figure 16.37.

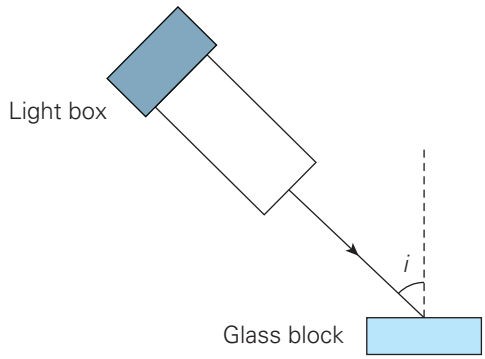


Figure 16.37 Experimental set-up

4. Trace the outline of the glass block onto the white paper. Use the clear ruler to trace the path of the incident ray and the refracted ray.
5. Remove the glass block and connect the two lines to visualise the path of the light through the glass.
6. Use the protractor to make measurements of the angles and record your results in the results table.

Results

	Angle of incidence	Angle of refraction
Light entering glass		
Light leaving glass		

Discussion

1. Does light bend towards or away from the normal when:
   a. entering glass
   b. leaving glass?
2. What do you notice about the beam of light that is entering the glass and the beam of light that is leaving the glass?
3. Does all the light travel through the glass and emerge from the other side?

Conclusion

1. Make a claim regarding light refraction through materials. Start your sentence with: 'This experiment suggests that light … '.
2. Support your claim by using what you observed. Start your sentence with: 'It was observed that … ' and include potential measurement uncertainties and experimental faults.
3. Explain how the data supports your claim. Start your sentence with: 'This means that … '.

WORKSHEET Applications of reflection, refraction and absorption

Applications of reflection, refraction and absorption

The principal applications of light are in the wide field of optics, while absorption has applications in solar energy, photosynthesis, colour pigments and many others. Access the linked worksheet in the Interactive Textbook to learn about some examples.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Eyes and light

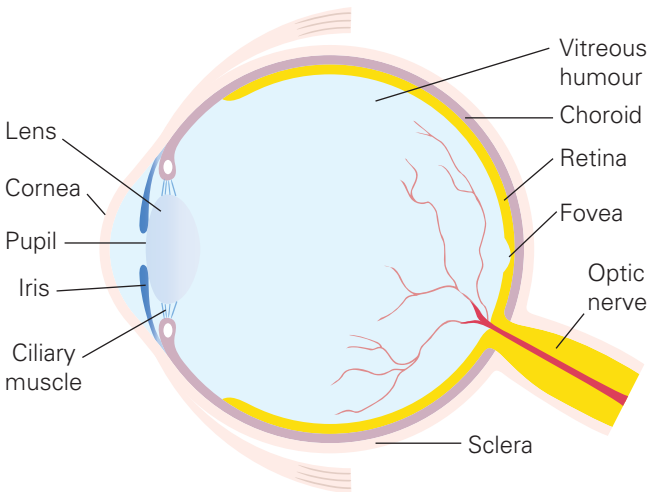
Our eyes function using a multi-part system to focus light on to receptors, which produce a signal our brain interprets. Light enters the human eye through the cornea and then through the small hole at the front called the pupil. The size of the pupil is controlled by the iris muscles, which form the coloured part of the eye. If you are somewhere dark, the pupil's size will increase to let in as much light as possible. On a bright sunny day, the pupil's size will reduce to limit the amount of light that enters in order to protect the eye. Just behind the iris is the **lens**, which focuses the light on to the **fovea**, a small area on the **retina** at the back of the eye. The retina is covered in a thin layer of specialised light-receptor cells that send impulses to the brain about the light they receive via the **optic nerve**. The image we see on the retina is upside down. Our brain turns the image the correct way up.

lens (eye)
a small disc of transparent tissue behind the pupil that allows near and far objects to be focused on

fovea
a small part of the retina that contains the most light-sensitive cells

retina
an area of tissue at the back of the eye that contains cells that detect light and colour

optic nerve
the nerve that connects the eye with the brain



Cornea: clear protective covering in front of the iris

Pupil: a gap in the front of the eye where light enters

Iris: muscles that change the size of the pupil to control the amount of light entering the eye

Lens: a convex shape that is flexible and helps to focus light on the retina

Ciliary muscles: muscles that control the focus of the lens by changing its shape

Vitreous humour: clear jelly-like substance in the eyeball through which light passes

Choroid: contains the blood vessels that supply the retina

Retina: light-sensitive lining at the back of the eye that converts light into electrical signals

Fovea: the most sensitive part of the retina where the lens aims to focus the vision

Optic nerve: carries the information from the retina to the brain

Sclera: the white outer layer of the eyeball of the eye

Figure 16.38 The structure of the human eye, side-on cross-section view

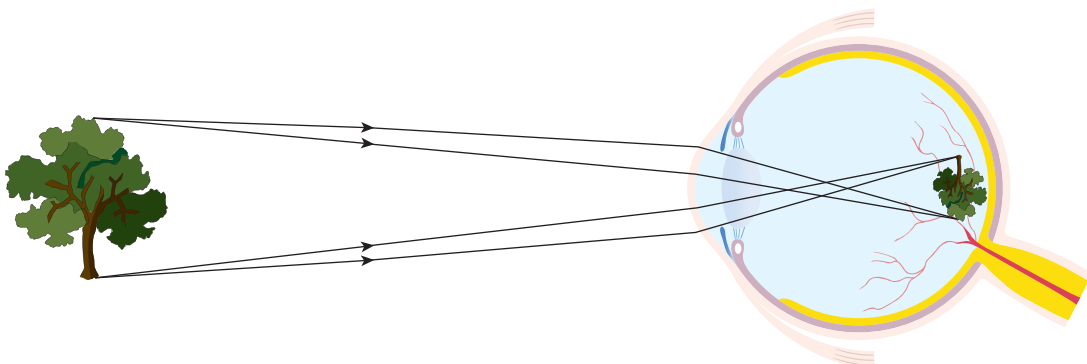


Figure 16.39 The light coming from the tree passes through the pupil and the lens to form an image on the retina.

Stars

What we see of stars is their light. We may not have visited the stars, yet we know a lot about them. From the colour of their light, we can tell the temperature of a star, and using the Doppler effect, we can tell the movement of a star.

The Doppler effect we learned about earlier in sound waves also occurs for light waves, and the shift is measurable if it is travelling fast enough. When the object is travelling towards you, the light received is of a higher frequency, which translates to the light appearing more blue. This is called **blue shift**. When the object is travelling away from you, the light received is of a lower frequency, which translates to the light appearing more red. This is called **red shift**.

blue shift
a spectrum shifted towards shorter wavelengths

red shift
a spectrum shifted towards longer wavelengths

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

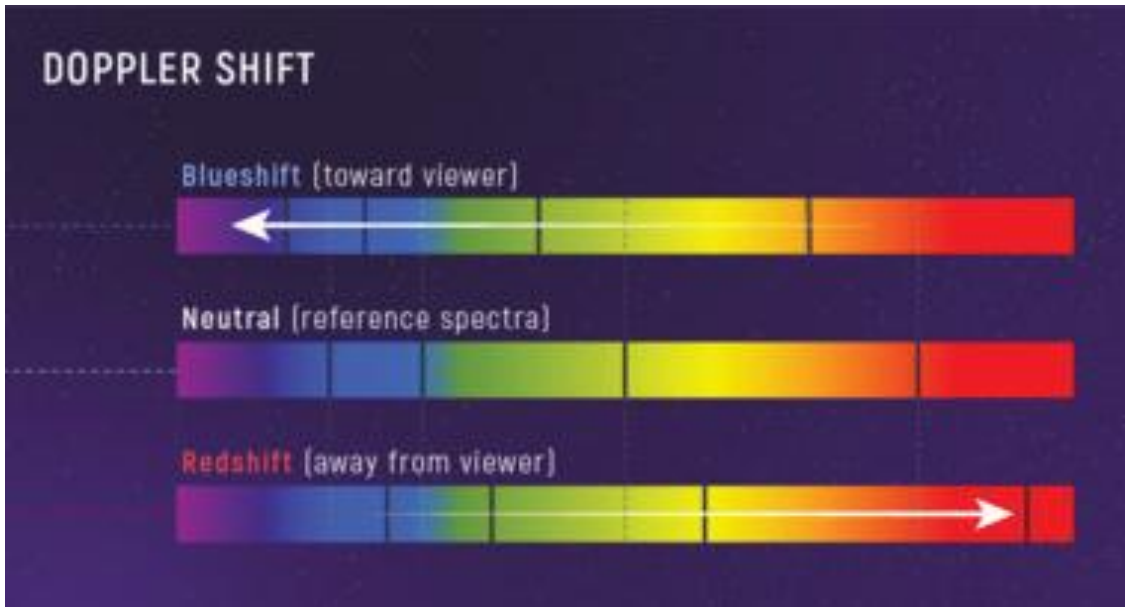


Figure 16.40 The spectrum (or fingerprint) of the star is shifted towards the red end for stars moving away from us compared to neutral, not moving away or moving towards us.

However, what is shifted is the entire spectrum of the star. It is not the colour of the star that we observe. The spectrum is similar to a fingerprint, where a pattern of lines defines the composition of the star. This whole spectrum is shifted towards the red end of the spectrum for stars moving away from us.

In 1929, Edwin Hubble, by processing a lot of data, observed that all stars are redshifted. This means that they are moving away from us. This led to an understanding of an expanding universe.

The actual colour of a star we see gives us an indication of its temperature. Iron is black at room temperature, but when heated it becomes red hot, and if you keep heating, it will glow yellow, then white. Similarly, a star's colour provides a direct measurement of its surface temperature.

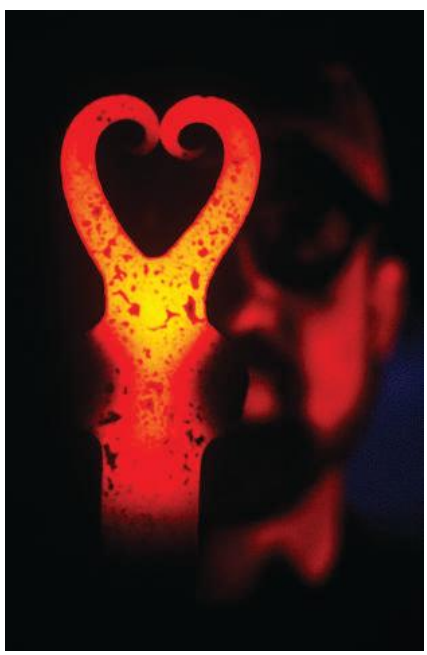


Figure 16.41 The colour of the iron indicates its temperature.

Figure 16.42 Stellar cluster NGC 2093 in the Large Magellanic Cloud, a comparatively rich aggregate of young stars, a few tens of millions of years old. The hot temperature of the most massive of such young stars is responsible for its predominantly blue colour.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 16.6

Temperature of the Sun

Use Table 16.1 to estimate the temperature of the Sun, then research the Sun to compare your answer to the accurate value.

Surface temperatures (°C)	Colour of the star	
30 000–60 000	Blue	
10 000–30 000	Blue white	
7500–10 000	White	
6000–7500	Yellow white	
5000–6000	Yellow	
3500–5000	Orange	
<3500	Red	

Table 16.1 Surface temperatures of stars

Section 16.3 review

Online quiz

Section questions

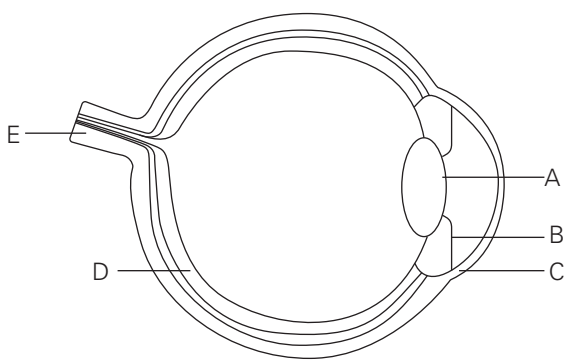
Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 16.3 questions

Remembering

1. **State** the types of electromagnetic radiation that are outside the visible spectrum.
2. **Recall** the wavelength range of radio waves.
3. **Define** the following terms in your own words: reflection, refraction.
4. **Label** the diagram of the eye.



5. **State** the information the colour of a star gives us.

Understanding

6. Using the wave speed equation, **explain** the relationship between frequency and wavelength in the electromagnetic spectrum.
7. **Explain** how microwaves heat up food.
8. **Explain** why you see the flash of lightning first before you hear the thunder.

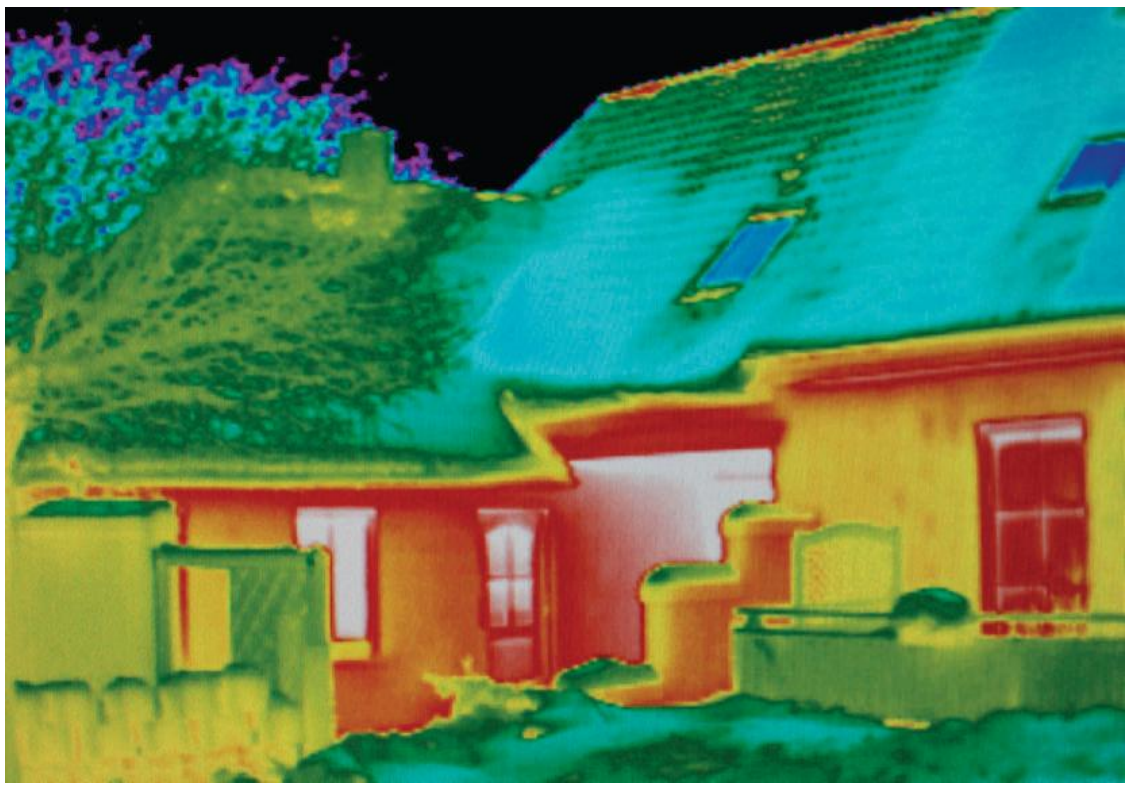
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Applying

9. Imagine you found a worn, cloudy green piece of glass on the beach. **Explain** how light interacts with this object creating this effect using the appropriate terminology.
10. **Compare** the Doppler effect for sound and light waves. Describe an application of each.

Analysing

11. The following figure shows a thermal image of a house, which has been produced by an infrared camera. **Decide** what the different colours mean.



12. **Explain** with the help of a labelled diagram how the law of reflection applies to concave and convex mirrors.
13. A fisherman standing in shallow water sees a fish and wants the catch it with a net. **Explain** what the fisherman needs to know about the apparent position of the fish to aim accurately.

Evaluating

14. **Discuss** the advantages and disadvantages of a human with a limited range of sound and light perception.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		**Linked questions**
16.1	explain how energy is transferred without the net transfer of particles, using the wave model.	
16.1	use models to compare and describe the features of transverse and longitudinal waves.	
16.1	compare the different wave forms of the electromagnetic spectrum.	
16.1	investigate the features of waves, including amplitude, frequency, speed and wavelength by exploring a range of wave types.	
16.1	use the formula $v = \lambda f$ to explain the relationship between a wave's frequency, speed and wavelength.	
16.1	analyse data from secondary sources to compare the uses of different EM waves based on their properties.	
16.2	explain how energy is transferred by sound waves, without the net transfer of particles, using the wave model.	
16.2	model sound waves as waves of compressions and rarefactions of particles.	
16.2	understand and describe how amplitude and frequency affect the pitch and volume of sound.	
16.2	understand the Doppler effect of waves.	
16.2	describe how the ear responds to sound waves.	
16.2	investigate and outline the use of sound in Aboriginal and/or Torres Strait Islander Peoples' traditional musical and communication instruments.	
16.2	describe how sound waves are used in medical diagnosis.	
16.3	describe how the eye responds to light.	
16.3	investigate the properties of light, including absorption, reflection, refraction and scattering.	
16.3	investigate applications of absorption, reflection and refraction in everyday life.	
16.3	explain how the electromagnetic spectrum is used to learn about stars.	
16.3	analyse data from secondary sources to compare the uses of different electromagnetic waves based on their properties.	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive chapter review!

Scorcher competition | Review questions | Data questions

Data questions

A 20-year-old took their 80-year-old grandparent for a hearing loss evaluation and decided to take the auditory test as well. An audiogram shows the lowest volume at which a person can hear a sound at a particular frequency. (Note that the values on the vertical axis are in decreasing order.)

The audiogram results for the 20-year-old and the 80-year-old are illustrated in Figure 16.43. Hearing is considered normal if you can hear sound volumes over 30 dB at a particular frequency. Hearing loss is considered moderate if you require volumes of 30 dB to 60 dB, and is severe if you can only hear sound volumes over 60 dB.

An audiogram showing the lowest volume at which a person can hear a sound at a particular frequency

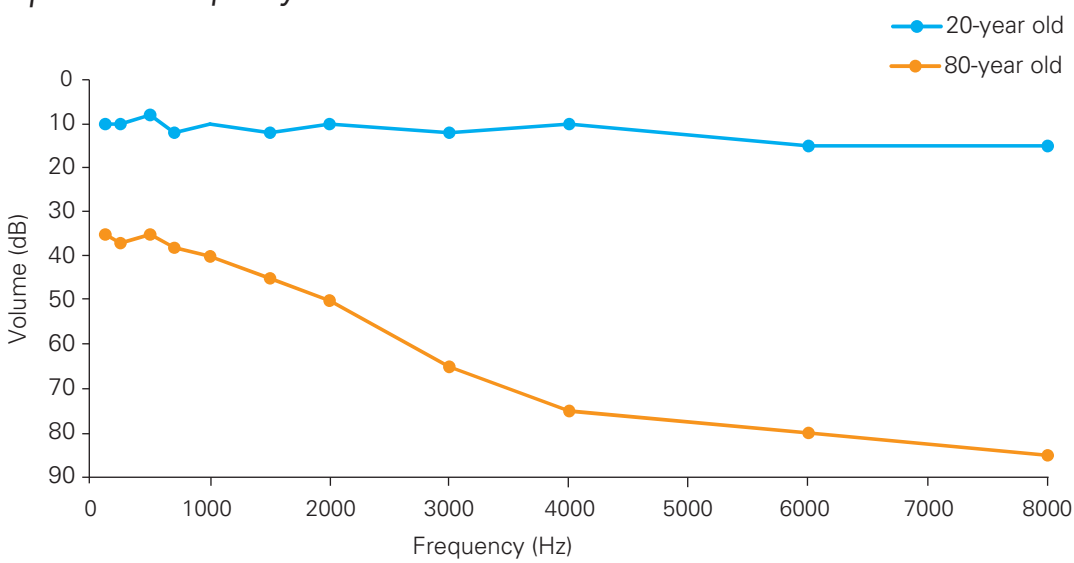


Figure 16.43 Audiogram for a 20-year-old and 80-year-old

1. **Identify** which person required a louder sound to hear at a sound wave frequency of 2000 Hz.
2. **Determine** the volume of the 1000 Hz sound wave that is the lowest volume that can be heard by the 20-year-old based on the test.
3. **Recognise** which person displays hearing loss.
4. **Identify** a trend in volume and frequency for both the 20-year-old and 80-year-old.
5. **Analyse** the plot for the 80-year-old and find any frequencies where the person suffers from severe hearing loss.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

6. **Contrast** the two data sets between the frequencies of 1000 Hz and 2000 Hz.
7. Following the trend in the data, **deduce** the lowest volume at which the 20-year-old can hear a frequency of 9000 Hz.
8. **Predict** whether the 80-year-old would more easily hear a person talking or a higher pitch bird whistle of the same volume.
9. The outcome of the test was that the 80-year-old suffers from 'moderate low-pitch hearing loss and severe high-pitch hearing loss'. **Justify** whether this statement is accurate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Musical instruments

Background information

Music is part of most people's lives. Whether you listen to music, play an instrument or even create your own music, it is something that most people encounter every day.

DESIGN BRIEF

Design and build a musical instrument from recycled materials.

Activity instructions

In small groups your task is to design and build a musical instrument. The first step will be to research the main components of musical instruments as well as ways to alter the pitch of a note played.

Figure 16.44 In musical instruments, vibration produces sound, and this sound is often amplified in the body of the instrument.

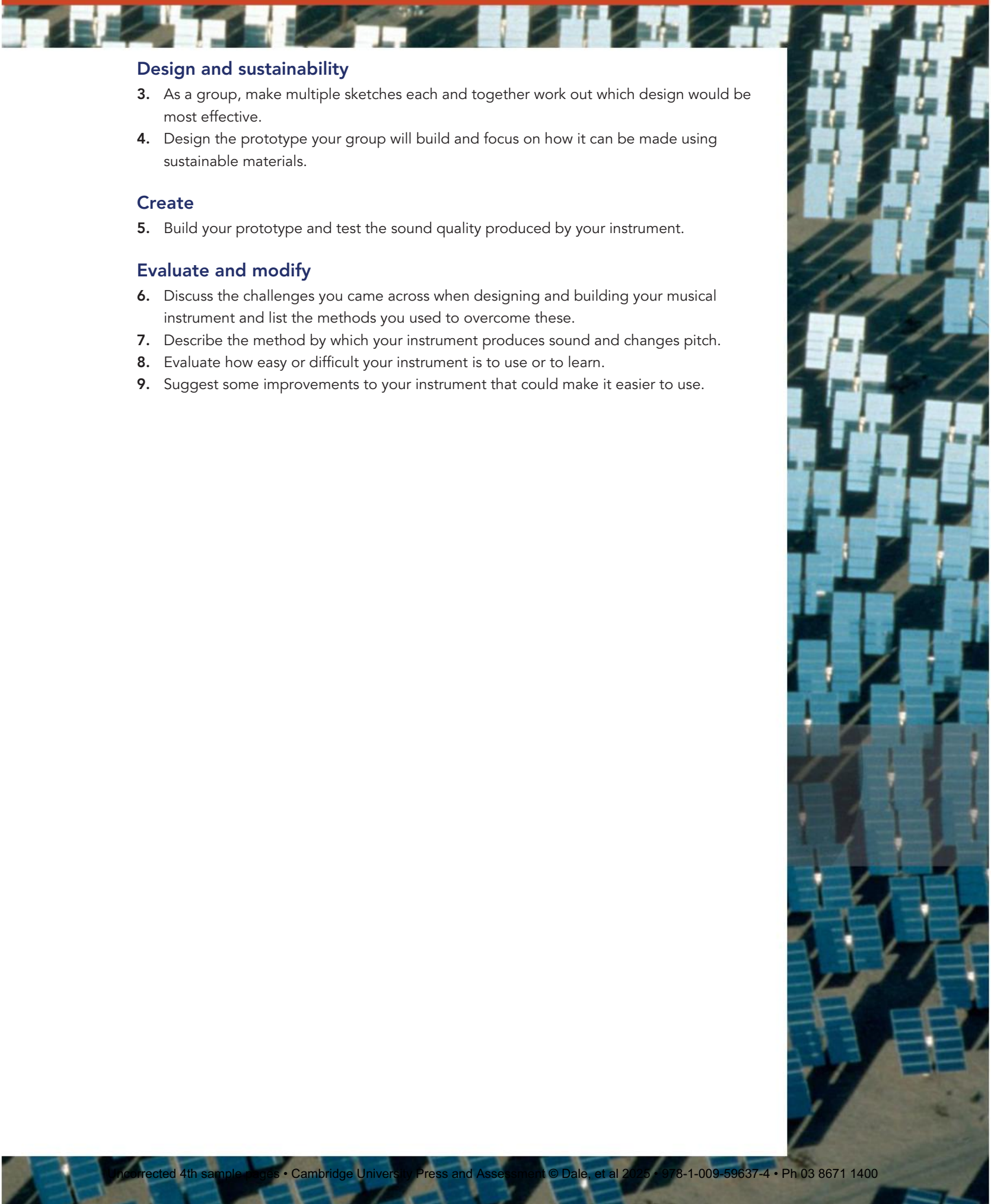
Suggested materials

- plastic containers
- elastic bands
- bottles
- icy-pole sticks
- scissors
- cardboard

Research and feasibility

1. Discuss in your group which type of instrument you will focus on – will you build an instrument that is a woodwind, string or percussion instrument? (It might be difficult to find the resources to build a brass instrument.)
2. Research all the components required for the instrument you are going to build, and list all the ways you can change pitch and/or volume of sound. For inspiration, search for the 'Landfill Harmonic Orchestra' on YouTube.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134



Design and sustainability

3. As a group, make multiple sketches each and together work out which design would be most effective.
4. Design the prototype your group will build and focus on how it can be made using sustainable materials.

Create

5. Build your prototype and test the sound quality produced by your instrument.

Evaluate and modify

6. Discuss the challenges you came across when designing and building your musical instrument and list the methods you used to overcome these.
7. Describe the method by which your instrument produces sound and changes pitch.
8. Evaluate how easy or difficult your instrument is to use or to learn.
9. Suggest some improvements to your instrument that could make it easier to use.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter 17

Motion

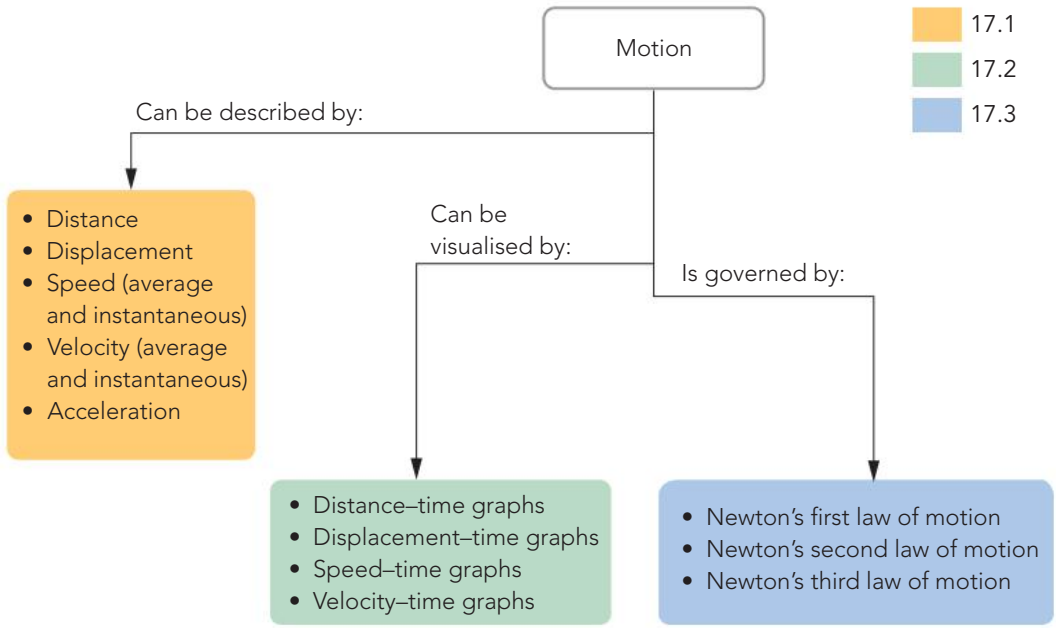
Chapter introduction

Motion is something we all deal with every day. To get from A to B you need to move. To get somewhere on time you need to know how long it will take to get there. To find that out you need to know how far it is between A and B and how quickly you can travel. The force required to make an object speed up or slow down needs to be carefully calculated to achieve the motion you desire.

Understanding motion helps engineers design safer vehicles. By analysing how cars accelerate, brake and behave in a collision we can improve features like anti-lock braking systems and airbags. Motion analysis is crucial for all kinds of transport including air travel and launching rockets for space exploration. In sports, athletes and coaches study motion to enhance performance. For example, analysing a sprinter's acceleration can lead to better training techniques, helping them achieve faster times.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter map



Glossary terms

acceleration
displacement
distance
force
gradient
inertia
instantaneous speed
net force
Newton's first law of motion
Newton's second law of motion
Newton's third law of motion
origin
speed
velocity

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

17.1 Analysing and describing motion

WORKSHEET Describing motion

Learning outcomes

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

1. explain and quantitatively relate the relationships between distance, time, speed, displacement and velocity using mathematical representations and the algebraic formulas.
2. explain acceleration as rate of change of velocity.
3. conduct an investigation to analyse motion of a trolley on a ramp.

distance total distance travelled; measured in metres

speed distance travelled per unit time, calculated by distance divided by time; this is the rate of change of distance with time

How fast an object travels is determined by the time it take to travel a certain **distance**. For example, if you could run 100 metres in 10 seconds, then you travelled at a **speed** of 10 metres every second. This is given by the formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

This is actually the *average* speed over the stated distance. Speed is commonly measured in units of metres per second (m/s), or kilometres per hour (km/h). However, depending on the motion, speed may sometimes be measured in m/min, cm/h, or even km/s.

But what if instead of running in a straight line, you ran in a zig zag to the finish line? To get there in the same amount of time, you would have to run faster because you are covering a greater distance. Consider Figure 17.1.

To distinguish between these paths, we need to discuss vector and scalar quantities.

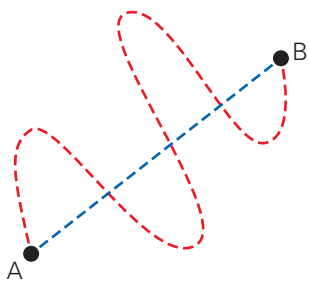


Figure 17.1 To get from A to B in the same time, you would need to travel faster in a path that is not direct.

WORKSHEET Scalar and vector

Vectors and scalars

A **scalar** quantity has magnitude but no direction. Examples of scalar quantities are time, temperature, mass and volume. Distance and speed are also scalar quantities.

A **vector** quantity has magnitude and direction. To indicate that it's a vector, the symbols for displacement, velocity, force and acceleration have an arrow on top, but at this level it is OK to omit it. However, it should be used if the direction is being discussed or is relevant, and to distinguish displacement from distance, or velocity from speed, since these often use the same letter symbols.

Scalar quantity	Vector quantity
Time t	
Distance d or s	Displacement $\vec{s}$
Mass m	
Speed v	Velocity $\vec{v}$ (or $\vec{u}$ for initial velocity)
Area A	
Volume V	
Work W	
Energy, E	
	Force $\vec{F}$
	Acceleration $\vec{a}$

Table 17.1 Comparing vector and scalar quantities, showing which quantities fall into which category

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Displacement

In Figure 17.1, the **displacement** is the distance-in-a-straight-line between A and B. So, the displacement of both paths is the same, but the distance of the curvy path is more than the straight path. If both paths go from A to B in 10 seconds, then the average **velocity** on both these paths is the same because they moved the same displacement in the same amount of time. However, the curvy path would have a greater speed.

displacement how far you are from where you started and what direction you are from where you started

velocity displacement travelled per unit time, calculated by displacement divided by time; this is rate of change of displacement with time

VIDEO Distance versus displacement

Try this 17.1

Compare the distance travelled and displacement of the soccer ball in Figure 17.2.

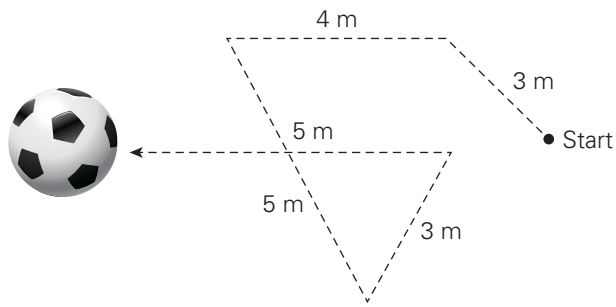


Figure 17.2 Distance travelled by a soccer ball and its displacement from the start.

Displacement compares the initial position with the final position of an object in motion. The symbol for displacement is *s*, often denoted with a little arrow on top because it is a vector. Do not confuse it with speed! If the final position is the same as the initial position, then the displacement is zero. Consider a person who walks six metres forwards from point A to point B, and then two metres backwards to point C (Figure 17.3). The distance that they have travelled is eight metres. However, since they have only ended up four metres from the starting position, the displacement from their starting point, A, is four metres forwards.

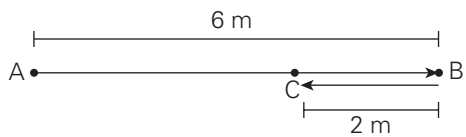


Figure 17.3 The walk described can be represented using arrows, where the length of the arrow symbolises the magnitude, and the direction of the arrow shows the direction of motion.

The total distance travelled from A to C is $s = 6 + 2 = 8$ m.

The displacement from A to C is $\vec{s} = 6 - 2 = 4$ m to the right.

Worked example 17.1

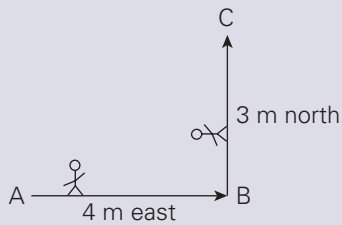
Distance and displacement

A person walks 4 metres east and then 3 metres north.

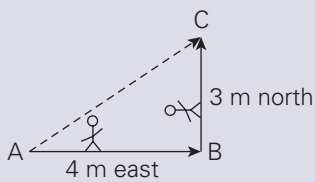
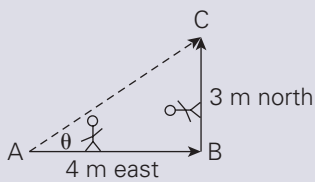
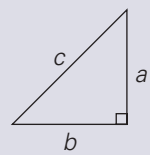
This can be represented in a simple diagram as follows.

a. What is the distance travelled by the person?

b. What is the displacement?



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Working	Explanation
a. Distance	
$s = 3\text{ m} + 4\text{ m} = 7\text{ m}$	Add the two distances travelled to find the total distance that the person has travelled.
b. Displacement	
Using Pythagoras's theorem, find the distance from A to C. $AC = \sqrt{4^2 + 3^2}$ $= \sqrt{16 + 9}$ $= \sqrt{25}$ $= 5\text{ m}$  To determine the direction requires trigonometry.  $\tan\theta = \frac{3}{4}$ $\theta = 36.9°$ north of east Therefore, the displacement $\vec{s}$ is 5 m 36.9° north of east.	Use Pythagoras's theorem to find the distance from A (the starting point) to C (the end point). $a^2 + b^2 = c^2$  $c = \sqrt{a^2 + b^2}$ Remember that you also need the direction travelled from the starting position to the final position.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Try this 17.2

Map vectors

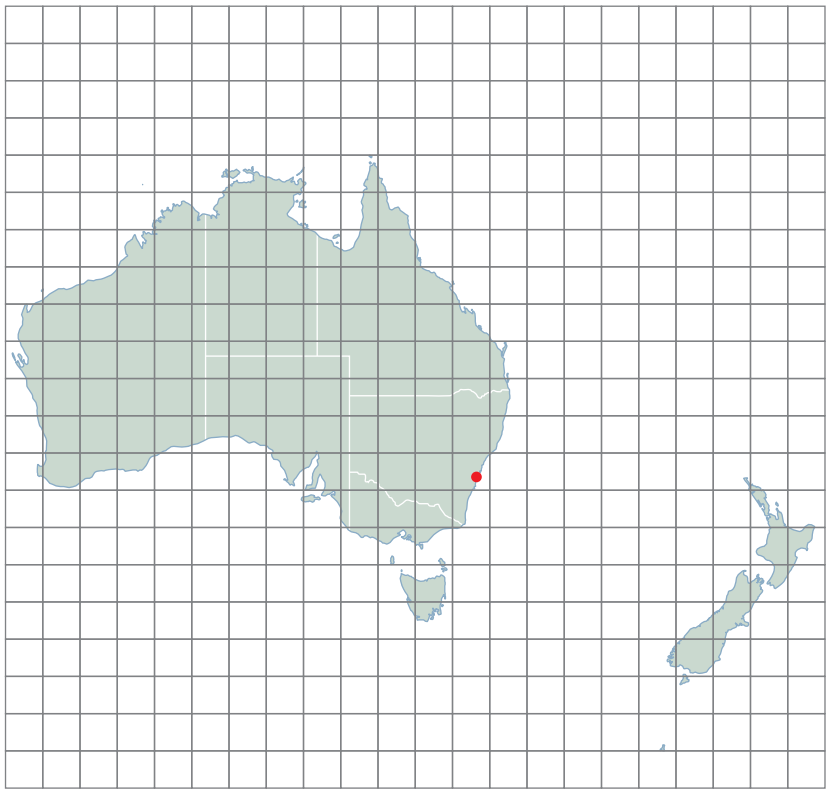


Figure 17.4 Vector map

Start at Sydney (the red dot).

1. Set sail! Draw a vector for each stage of your journey. Travel 5 squares east, then 5 squares north, 9 squares east, 10 squares south and finally 3 squares west. Where did you end up?
2. What is the distance travelled? What was your displacement?
3. Now imagine you did the same journey but there was a steady breeze of 2 squares north. Repeat the journey but add the wind vector for each stage. Now where do you land?

Quick check 17.1

1. **Define** the terms 'distance' and 'displacement' in your own words.
2. A classmate travels between classrooms. From their initial classroom, they travel west 100 m and then north 50 m, where they arrive at the intended classroom.
   a. **Represent** this journey in a diagram.
   b. **Calculate** the distance travelled by the student.
   c. **Calculate** the displacement of the student, to the nearest metre. Remember to also give an angle in your answer.
   d. The student then travels back to the initial classroom. **Determine** their displacement.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 17.2

Average speed

Consider two runners who are competing in a 100 m hurdles event. Runner 1 finishes in a time of 12.5 s. Runner 2 runs the race with an average speed of 7 m/s.

a. Who wins the race?

b. How long does it take Runner 2 to cross the finish line? Round your answer to one decimal place.

Working	Explanation
a. Who wins?	
$s = 100$ m $t = 12.5$ s speed = ?	List the relevant information for runner 1. Note that as they run in a straight line, we can use speed rather than velocity.
$\text{speed} = \frac{s}{t} = \frac{100 \text{ m}}{12.5 \text{ s}}$ $= 8$ m/s	Calculate the average speed using the formula for average speed.
Runner 1: speed = 8 m/s Runner 2: speed = 7 m/s Since runner 1 has a higher average speed, they finish before runner 2 does. Therefore, runner 1 wins the race.	Compare the average speed of each runner.
b. Runner 2 time	
t = ? speed = 7 m/s $s = 100$ m	List the information that you have for runner 2.
$t = \frac{s}{\text{speed}} = \frac{100 \text{ m}}{7 \text{ m/s}}$ $= 14.3$ s	Calculate the time taken for runner 2 to complete the race using a rearranged average speed formula.
It takes 14.3 s for runner 2 to complete the 100 m hurdles race.	Interpret the solution, ensuring that you have correct units and decimal places.

Converting units

So far, we have only used m/s for speed, but another common unit for speed is kilometres per hour (km/h), which is what most people use in cars. Here is a quick guide for converting units.

$$1 \text{ km} = 1000 \text{ m}$$

$$1 \text{ h} = 3600 \text{ s}$$

$$1 \frac{\text{km}}{\text{h}} = \frac{1000 \text{ m}}{3600 \text{ s}} = \frac{1}{3.6} \frac{\text{m}}{\text{s}}$$

Multiplying both sides by 3.6 and swapping the sides to make 1 m/s the subject gives:

$$1 \text{ m/s} = 3.6 \text{ km/h}$$

To convert m/s to km/h, multiply by 3.6.

To convert km/h to m/s, divide by 3.6.

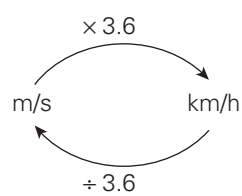


Figure 17.5 Converting m/s into km/h

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Velocity

Velocity, introduced and defined earlier in the section with displacement, is a term used to describe how fast something travels in a particular direction. Like speed, the common units associated with velocity are m/s or km/h. Calculating velocity is similar to using the formula for speed, except distance travelled is replaced by change in displacement. As with the speed formula, this gives average velocity over the change in displacement. The main difference between calculating speed and velocity is that direction is important with the velocity, so displacement is used instead of distance.

Mathematically, velocity can be described in the following ways:

$$\text{average velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

$$\vec{v}_{av} = \frac{\Delta\vec{s}}{t}$$

The triangle symbol means 'change in'.

Worked example 17.3

Average speed versus average velocity

Consider the triangle in Figure 17.6 between Adelaide, Brisbane and Alice Springs. Imagine two aeroplanes that need to get from Alice Springs to Brisbane. Plane 1 travels directly to Brisbane. Plane 2 must stop in Adelaide before flying to Brisbane. It takes both planes 4.00 hours to reach Brisbane. The true bearing of Brisbane from Alice Springs is 106° clockwise from north.

a. What is the average speed of each plane?

b. What is the average velocity of each plane?

c. Which plane travels faster over the ground?

Figure 17.6 Travelling between Adelaide, Brisbane and Alice Springs

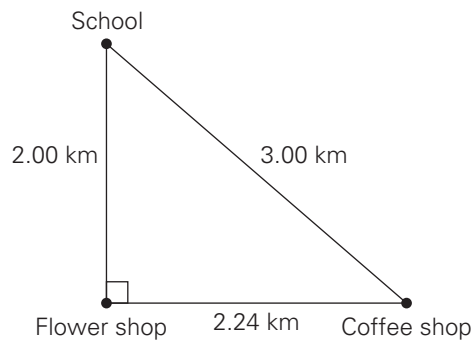
continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Working	Explanation
a. Average speed	
Plane 1: speed = $\frac{1965}{4.00}$ = 491 km/h Plane 2: speed = $\frac{(1330 + 1603)}{4.00}$ = 733 km/h	For average speed, use this formula: speed = $\frac{s}{t}$
b. Average velocity	
Plane 1: $\vec{v}_{av} = \frac{1965}{4.00}$ = 491 km/h 106° clockwise from north Plane 2: $\vec{v}_{av} = \frac{1965}{4.00}$ = 491 km/h 106° clockwise from north	For average velocity, use this formula: $\vec{v}_{av} = \frac{\Delta\vec{s}}{t}$
c. Comparing speed over the ground	
From the answer to part **a**, Plane 1's average speed is 491 km/h compared to 733 km/h for Plane 2. Plane 2 is faster over the ground.	The plane with the greater average speed travels faster as it covers more ground in the same amount of time.

Quick check 17.2

Two students, Mia and Peter, leave school to meet at the local coffee shop. Peter decides to jog to the coffee shop but also stops at a flower shop along the way. Mia decides to walk from school directly to the coffee shop. They arrive at the coffee shop at the same time, 30 minutes after they leave school. Use the diagram to answer the following questions.



1. **Calculate** how much further Peter travels than Mia.
2. If it takes them both half an hour to reach the coffee shop, **calculate**:
   - **a.** Mia's average speed
   - **b.** Peter's average speed
   - **c.** their average velocities.

Acceleration

acceleration
the rate of change in velocity of an object

Acceleration can be thought of as a change in velocity, usually 'speeding up' or 'slowing down'. It is a rate of change in velocity. Consider a car at a set of traffic lights. Initially it is stationary; we would say that it has an initial velocity, represented by u, of 0 km/h. Imagine that when the light turns green the car speeds up to 40 km/h in the next five seconds. This change in velocity means that the

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

car has an acceleration. And since it took five seconds to change velocity from 0 to 40 km/h, the acceleration is 40 divided by 5, so the car speed increased by 8 metres per second every second.

Acceleration ($\vec{a}$) is therefore represented by the equation:

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

Where a is acceleration in units of metres per second per second (m/s/s) or metres per second squared (m/s^2), v is the final velocity, and u is the initial velocity. The arrow on top of a can be omitted if direction isn't included in the discussion.

Worked example 17.4

Acceleration

Consider the motion of a dirt bike.

a. If it speeds up from rest to 54 km/h in a straight line in 3 seconds, calculate the acceleration.

b. If that same bike travelling at 54 km/h comes to a stop in a straight line within 5 seconds, what is the acceleration? What does this mean?

c. If better brakes were installed on the bike, it could decelerate at a quicker rate of 10 m/s^2. Calculate how long it would take to stop if it was initially travelling at a speed of 72 km/h.

Figure 17.7 A dirt bike in motion

Working	Explanation
a. Acceleration	
u = 0 m/s v = 54 km/h = $\frac{54}{3.6}$ = 15 m/s t = 3 s a = ?	List the information that you have. Since the bike begins at rest, the initial speed is zero. Convert km/h to m/s by dividing km/h by the conversion factor 3.6.
$a = \frac{v - u}{t} = \frac{(15 - 0)}{3}$ = 5 m/s^2 forward	Calculate using the acceleration formula by substituting in all of the known values. Remember to include units and a direction.
The bike accelerates at a rate of 5 m/s^2 (5 metres per second, every second).	Interpret the answer.

continued

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

b. Negative acceleration	
u = 54 km/h = 15 m/s v = 0 m/s t = 5 s a = ?	List the information. In this example, the bike has an initial speed of 54 km/h, and a final velocity of 0 km/h. The initial speed is the same as before so we can use the same conversion to m/s.
$a = \frac{v - u}{t} = \frac{(0 - 15)}{5} = -3$ m/s^2 forward	Substitute the known values.
Since there is a negative acceleration, the bike is decelerating (slowing down) at a rate of 3 m/s^2 forward.	Interpret the solution and remember to include correct units and direction. The bike is still travelling forward (in the positive direction) and so its displacement remains forward despite it slowing down.
c. Faster stopping	
a = −10 m/s^2 v = 0 m/s u = 72 km/h = $\frac{72}{3.6}$ = 20 m/s t = ?	List the known information. The minus sign in –10 means it is decelerating. We can divide the speed in km/h by the same conversion factor to get m/s.
$-10 = \frac{(0 - 20)}{t}$	Substitute the values into the acceleration formula.
$t = \frac{-20}{-10} = 2s$	Rearrange so that the unknown is the subject of the equation.
It takes the bike 2 seconds to brake (decelerate) from 72 km/h to rest.	Interpret the solution.

Quick check 17.3

1. **Define** the terms 'acceleration', 'deceleration' and 'constant speed' in your own words.
2. An object increases its speed from 5.2 m/s to 7.7 m/s in four seconds.
   - **a.** **Calculate** the acceleration of the object.
   - **b.** Assume that the object could decelerate at a rate of 1.5 m/s^2 (a = –1.5 m/s^2).
     Calculate the time it would take for the object to stop if it was initially travelling at 10 m/s (u = 10 m/s). Give your answer to two decimal places.

INVESTIGATION

Investigation 17.1

Ramps and cars

Aim

To investigate the effect of ramp height on the average speed of a crash trolley or model car.

Materials

- ramp at least 90 cm long
- stopwatch
- metre ruler
- books or blocks that can be used to make a ramp
- crash trolley or model car

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Planning

1. Develop a hypothesis by predicting how a change to the height of the ramp will affect the average speed of a model car.
2. Identify as many controlled variables as possible and describe how these will be managed to prevent them from affecting the measurements.

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 independent variables in the table and its units.
3. Identify and label the dependent variable in the table and its units.

Part 2: Collect the data

Set up the ramp as shown in Figure 17.8.

1. Measure the height of the ramp.
2. Measure the distance that the trolley will roll from the release point to the point at which the stopwatch is stopped.
3. Use the stopwatch to measure how long it takes for a crash trolley or model car to roll down the ramp. Record the results in the results table.
4. Repeat steps **1–3** three times so you can take the mean of the results.
5. Repeat steps **1–4** using some different heights and record your results in the table.

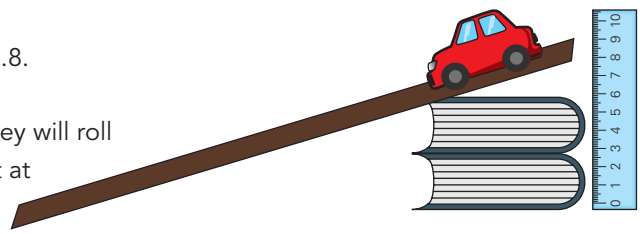


Figure 17.8 Experimental set-up

Results

1. Calculate the average time taken for the car to roll down the ramp.
2. For each ramp height, calculate the average speed for the rolls and draw a table of values for height of ramp and average speed. Draw a scatter plot to analyse the relationship between the height and the average speed.
3. Format the graph and insert a copy into your science journal, below the results table.

Independent variable: _____ **Units:**_____	**Dependent variable:** _____ **Units:** _____			
	Trial 1	**Trial 2**	**Trial 3**	**Mean**

Discussion

1. Describe the effect of different ramp heights on the mean speed of a model car.
2. Describe any limitations to your investigation and how these may have affected your results.
3. 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. State a conclusion as to how increasing the height can affect average speed.
2. Justify this conclusion using data from your results.
3. Describe the change in speed during the roll. What kind of motion is observed?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Go online to access the interactive section review and more!

Section 17.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 17.1 questions

Remembering

1. **Recall** the unit or units normally used for distance.
2. **List** the unit or units normally used for speed.
3. **State** the formula and unit for average acceleration in a straight line.

Understanding

4. **Distinguish** between distance and displacement.
5. **Distinguish** between speed and velocity.

Applying

6. The average speed of a galloping horse is 40 km/h. If a horse is already travelling at that speed, **calculate** how far it will travel in 2.3 hours.
7. If a person walks at an average speed of 4 km/h, **calculate** how long it will take them to travel 50 m. Round your answer to the nearest second. Hint: First convert 4 km/h into m/s.
8. **Determine** the acceleration of a car travelling at a constant speed of 50 km/h.
9. A sprinter starts from rest. In the first three seconds they reach a speed of 2 m/s. After the next 10 seconds they reach a speed of 6.5 m/s.
   a. **Calculate** the average acceleration in the first three seconds, and round to two decimal places.
   b. **Calculate** the average acceleration in the last 10 seconds.
   c. **Determine** when the sprinter's acceleration was the greatest: over the first three seconds or the last 10 seconds.
10. A car starts from rest and accelerates at a constant rate of 5 m/s^2 for five seconds.
    a. **Calculate** the final speed.
    b. **Calculate** the average speed. Because the speed increases at a constant rate, you can do this by using $\frac{v_1 + v_2}{2}$ to find the average speed.
    c. **Calculate** the displacement of the car after five seconds.
11. Consider the times of one of Usain Bolt's record 100 m sprints.

Distance (m)	0	20	40	60	80	100
Time (s)	0	2.87	4.65	6.32	7.96	9.69

    a. **Calculate** the average speed of Usain Bolt for the entire 100 m. That is, from $t = 0$ to $t = 9.69$.
    b. Does he travel quicker in the first 40 m or the last 40 m? **Give** a reason why.

Analysing

12. **Categorise** the following as either acceleration, deceleration or constant speed.
    a. A bike rider slowing down
    b. A textbook sitting on a desk
    c. A sprinter taking off at the start of a race
    d. A dog running at 5 m/s forwards
    e. A car crashing into a brick wall
    f. A car rolling down a hill and gaining speed

Evaluating

13. Imagine you are trying to figure out how efficiently your car uses petrol. **Propose** whether you would use distance travelled or displacement covered with one tank full. **Explain** your reasoning.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

17.2 Graphing motion

Learning outcomes

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

1. investigate the motion of objects and represent them using motion diagrams.
2. describe and calculate the speed of an object from a distance–time graph and displacement–time graph.
3. draw distance–time and displacement–time graphs to show the movement of an object.
4. describe and calculate the speed of an object from a speed–time graph and velocity from a velocity–time graph.
5. draw velocity–time graphs to show the movement of an object.
6. calculate acceleration from a velocity–time graph.
7. conduct an investigation to analyse the relationship between distance, time and speed, and draw and analyse a line graph of the results.

DOC WORKSHEET Graphing motion

Distance–time graphs

Distance–time graphs show how far an object moves as time progresses. Distance travelled is on the vertical axis (also called the *y*-axis) and time is on the horizontal axis (also called the *x*-axis). The **gradient** of the line indicates the speed of the object. Recall that:

gradient the gradient of a graph is its slope calculated as the rise over the run

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{rise}}{\text{run}}$$

Table 17.2 shows two features (shapes) that you may see on a distance–time graph.

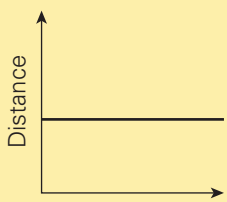
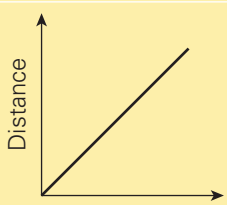
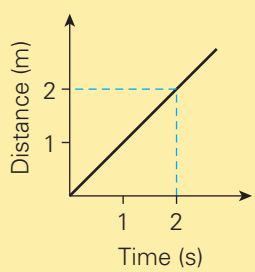
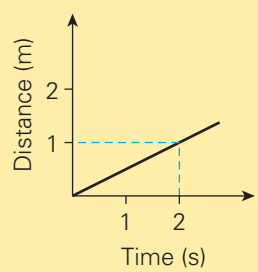
Feature/shape	Explanation	Example
 Flat line	Horizontal lines indicate that an object is stationary.	The $\frac{\text{rise}}{\text{run}}$ of horizontal lines is zero because the rise is 0 m. So, the distance doesn't change, gradient is zero, the speed is 0 m/s.
 Straight diagonal	A straight line with a gradient indicates that the object is moving at a constant speed.	The distance increases at a constant rate, which can be calculated as shown below for two different slopes.  $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{2\text{ m}}{2\text{ s}} = 1\text{ m/s}$  $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{1\text{ m}}{2\text{ s}} = 0.5\text{ m/s}$ The gradient of the first graph is steeper, which shows that object has a greater speed.

Table 17.2 Two features (shapes) that may be seen in distance–time graphs

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 17.5

Distance–time graph

Look at the distance–time graph that shows Lin's walk in a straight line for six seconds in Figure 17.9.

a. Calculate her speed at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

b. During which time interval is Lin travelling the fastest?

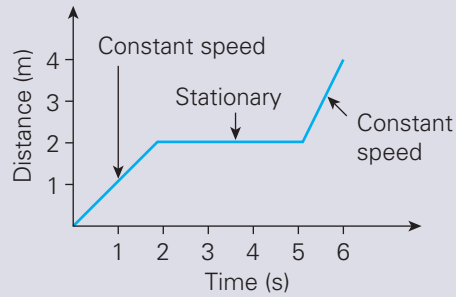


Figure 17.9 Distance–time graph of Lin's walk

Working	Explanation
a. Speed	
0 to 2 seconds: speed $= \frac{\text{rise}}{\text{run}} = \frac{(2-0)\text{ m}}{(2-0)\text{ s}} = \frac{1\text{ m}}{1\text{ s}} = 1$ m/s 2 to 5 seconds: A horizontal line indicates she is stationary. 5 to 6 seconds: speed $= \frac{\text{rise}}{\text{run}} = \frac{(4-2)\text{ m}}{(6-5)\text{ s}} = \frac{2\text{ m}}{1\text{ s}} = 2$ m/s	Select two points from each time interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the speed.
b. Fastest interval	
She travels the fastest from the 5th to the 6th second.	The steeper line indicates a faster speed.

Quick check 17.4

1. Look at the distance–time graph of a moving object in Figure 17.10.

a. **Calculate** the average speed for each of the sections A, B and C.

b. **Describe** the motion of the object in the graph.

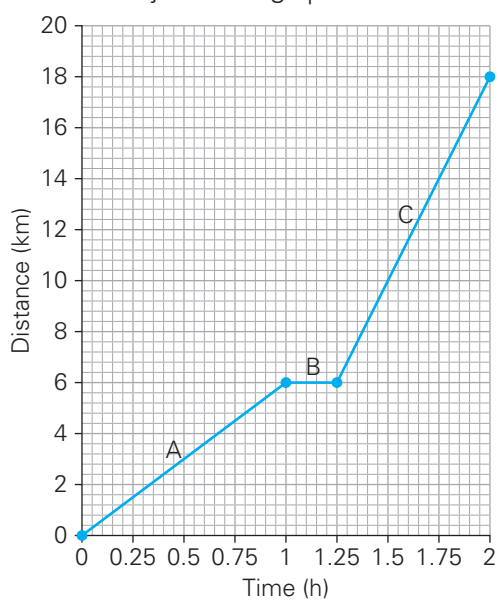


Figure 17.10 Distance–time graph of a moving object

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Calculating distance travelled

Distance can be calculated from the area under the distance–time graph. This is shown in *Worked example 17.6*.

Calculating displacement from a velocity–time graph

Displacement can be calculated from the area under the velocity–time graph, just as distance can be calculated from the are under a speed–time graph *Worked example 17.6*). Since displacement has direction, the area above the horizontal axis gives the displacement in the positive direction while the area below the horizontal axis gives displacement in the negative direction. To calculate area, it is simpler to split the graph into smaller sections.

If calculating the area under a speed–time graph, the distance travelled can be calculated, but since speed is not a vector, this is not displacement. However, if velocity is always positive, the displacement will be equal to the distance travelled, this occurs when the object has not changed direction.

Worked example 17.6

Calculating the distance

Consider the graph shown in Figure 17.11 of an object in motion.

a. Calculate the distance travelled in the first 5 seconds

b. Calculate the distance travelled from $t = 5$ to $t = 8$.

c. Calculate the distance covered in the final 2 seconds.

d. What is the total distance covered by the object, over the entire 10 seconds?

Area under speed–time graph is the distance travelled

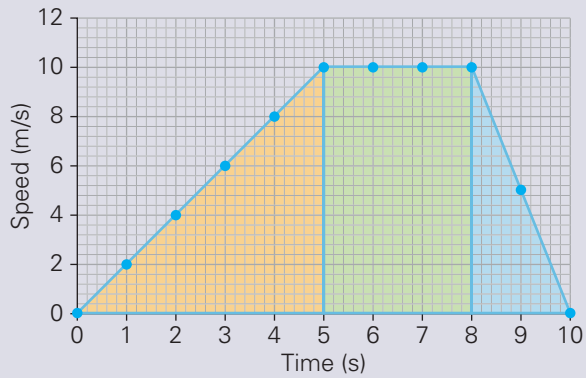
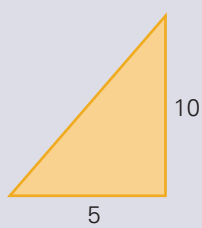
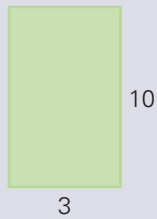
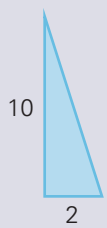


Figure 17.11 Speed–time graph

Working	Explanation
a.	
 $A_1 = \frac{1}{2}(5)(10) = 25$ This means that in the first 5 seconds the object travels 25 metres.	Redraw the shape and label the known sides. The area of a triangle is given by the formula $A_1 = \frac{1}{2}bh$ Interpret the area, and check that units are correct.

continued ...

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

b. Distance from $t = 5$ to $t = 8$	
The area under the graph between $t = 5$ and $t = 8$ can be described by the following rectangle. $A_2 = 3 \times 10 = 30$ This means that the distance travelled over this period is 30 metres.  	Redraw the shape and label the known sides. Calculate the area of the rectangle given by the formula $A_2 = l \times w$. Interpret the solution with correct units.
c. Distance in final 2 seconds	
The area under the graphs in the final 2 seconds is represented by the following triangle.  $A_3 = \frac{1}{2}(2)(10) = 10$ In the final 2 seconds the object travels 10 metres.	Redraw and label the shape. Calculate the area. Interpret solution with correct units.
d. Total distance covered	
Sum each of the areas for the total distance covered. $A_T = A_1 + A_2 + A_3$ $= 25 + 30 + 10$ $= 65$ Therefore, the total distance covered by the object over the 10 seconds is 65 metres.	Add up all of the area sections under the graph to get the total distance travelled.

Try this 17.3

Following directions

Have you ever been lost? Maybe you followed your smartphone map directions, and it took you the long way around! The distance you travelled was far more than the displacement from your starting point to your goal.

Figure 17.12 Have you ever been lost?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

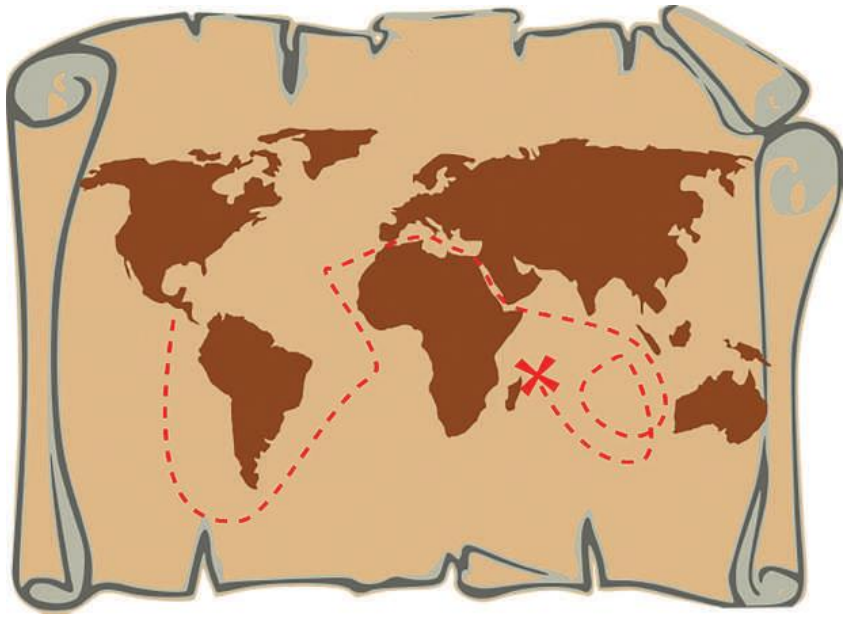


Figure 17.13 Treasure maps often take you a convoluted route to make it more difficult to find.

Many discoveries are made by accident just by getting the navigation wrong and arriving somewhere you did not intend! Similarly, treasure maps often take you a convoluted route to make it more difficult to find. Working in groups, each group hides an item (the treasure) and make a treasure map. Once completed, exchange map between groups. Follow the map to find the treasure, and on your way record the distance travelled. Compare the distance and displacement from your starting point to the treasure.

Displacement–time graphs

Displacement–time graphs are similar to distance–time graphs, but they also show the object's location with respect to a starting point. In other words, they can show whether an object is moving away from, or back towards, its initial position over a period of time. The starting position is always located on the graph at the coordinate (0, 0) and is referred to as the **origin**. There the displacement is 0 m and the time is 0 s. The gradient of a displacement–time graph gives the velocity for specific time periods.

origin
the point on a graph where the horizontal axis and vertical axis intercept (0, 0)

Recall the formula for velocity:

$$\text{average velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

$$\vec{v}_{av} = \frac{\Delta\vec{s}}{t}$$

In addition to the worked example below, the linked worksheet in the Interactive Textbook gives examples of features and shapes of displacement–time graphs, with questions for practice.

WORKSHEET
Features of displacement–time graphs

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 17.7

Displacement–time graph

Remember the distance–time graph for Lin's walk in Figure 17.9 in *Worked example 17.5*. Figure 17.13 shows her displacement–time graph for the same motion.

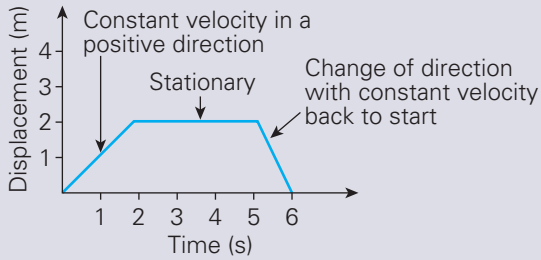


Figure 17.14 Displacement–time graph of Lin's walk

a. Describe her movements in relation to her starting point.

b. Calculate her velocity at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

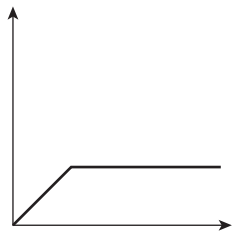
Working	Explanation
a. Describing movements	
For the first two seconds, Lin moves away from her starting position by 2 metres. For the next three seconds, she is stationary. In the final second, she increases her velocity, moving back to the origin (her starting position).	The displacement on the vertical axis indicates how far from the start she is. In the distance–time graph, you could not tell which direction she was travelling, only that she was moving.
b. Velocity	
0 to 2 seconds: $\bar{v} = \frac{\text{rise}}{\text{run}} = \frac{(2-0)\text{ m}}{(2-0)\text{ s}} = \frac{2\text{ m}}{2\text{ s}} = 1\text{ m/s}$	Select two points from each interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the velocity.
2 to 5 seconds: A horizontal line indicates she is stationary, in other words, $\bar{v} = 0$ m/s.	
5 to 6 seconds: $\bar{v} = \frac{\text{rise}}{\text{run}} = \frac{(0-2)\text{ m}}{(6-5)\text{ s}} = \frac{-2\text{ m}}{1\text{ s}} = -2\text{ m/s}$	A negative velocity means that she has changed directions and is travelling the opposite direction, in this case, back to the start. She is travelling faster towards her original position (5 to 6 seconds) compared to when she was travelling away from it (0 to 2 seconds).

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

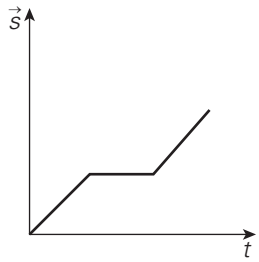
Quick check 17.5

1. **Describe** the motion of an object according to the following displacement–time graph shapes.

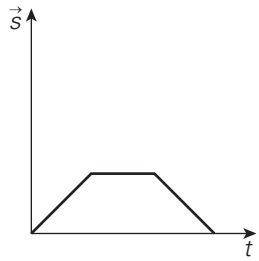
a.



b.



c.



2. **Compare** the displacement–time graph in Worked example 17.7 with the distance–time graph in Worked example 17.5. Explain the difference in the shape of the graphs.

Did you know? 17.1

Figure 17.15 Anything that is moving faster than the shutter speed of a camera will be blurred. The camera in this photo must be moving with the runners!

Speed–time graphs

Speed–time graphs show the speed of a travelling object as time passes. They are quite useful because they can be used to determine the distance travelled, the **instantaneous speed** and the acceleration of a moving object. Speed–time graphs have three important features.

instantaneous speed
the speed at any particular instant

- Instantaneous speed can be read directly from the graph at any point in time.
- The gradient between two points on a speed–time graph represents the average acceleration over that time interval of the object in motion.
- The area under a speed–time graph represents the distance that the object has travelled.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

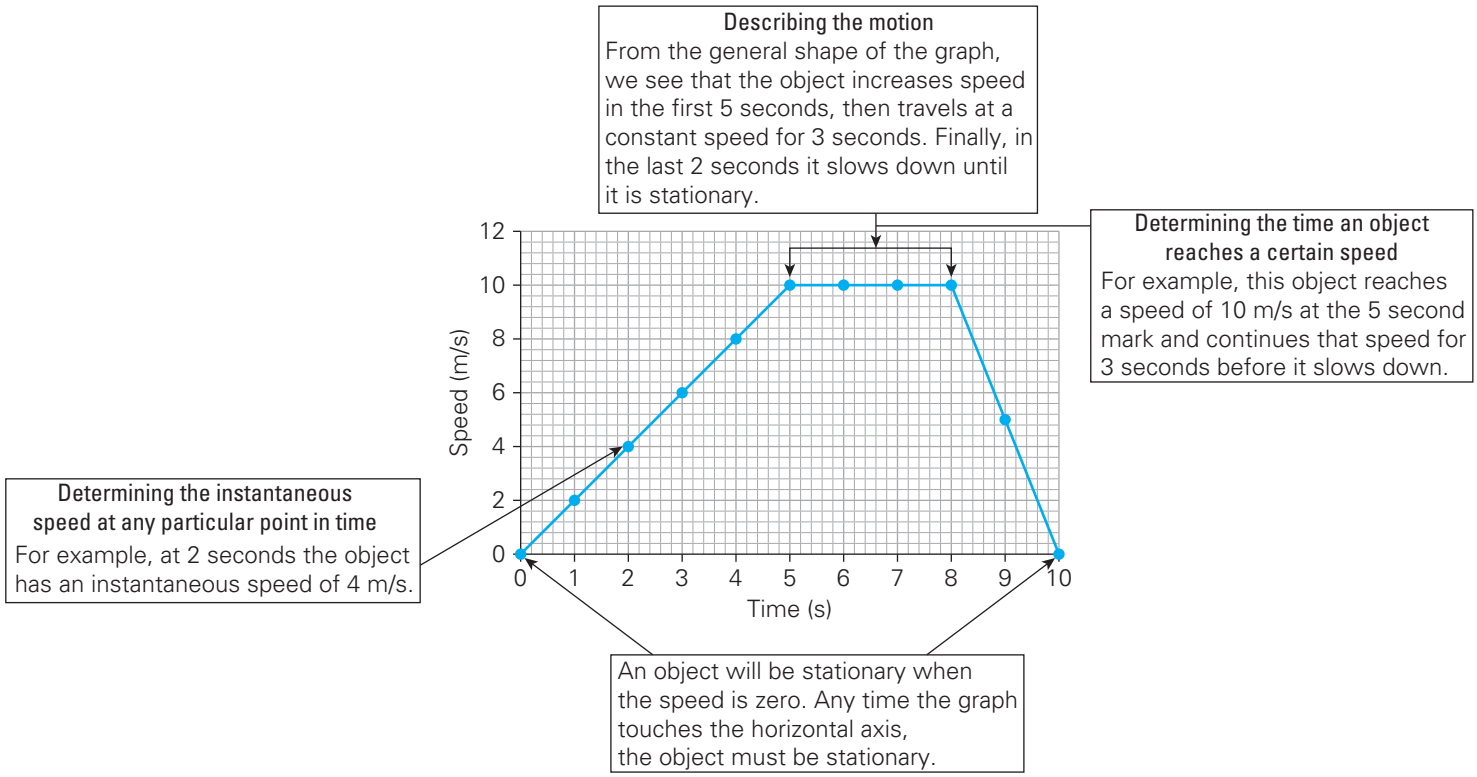


Figure 17.16 A speed–time graph tells you a lot about an object's motion.

Try this 17.4

Sketching a speed–time graph

Traffic is indicated in the directions on the map in Figure 17.17. What do the yellow and red zone indicate? Notice how there are several different options? What is the difference between them? Sketch a speed–time graph of the fastest route.

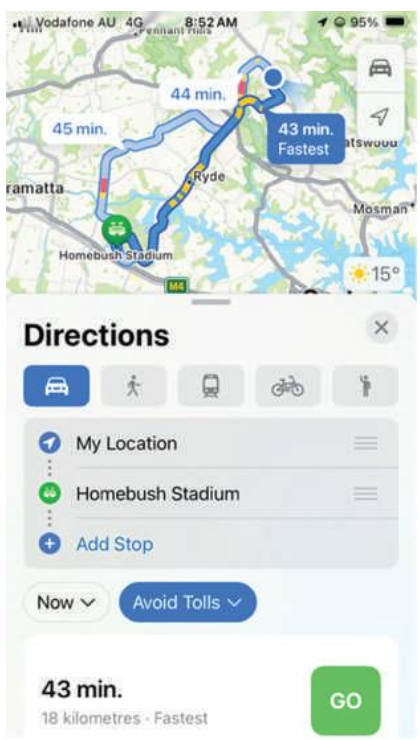


Figure 17.17 Directions on a smartphone map

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Velocity–time graphs

Velocity–time graphs are similar to speed–time graphs, but they also show the object's location with respect to a starting point. The gradient of a velocity–time graph gives the acceleration, which is also a vector. Remember, the negative sign refers to a direction opposite to the positive sign.

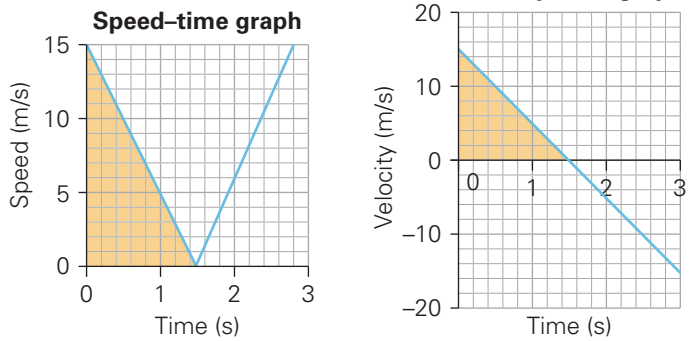


Figure 17.18 The negative and positive velocities show movement in opposite directions. Here, positive is up, and negative is down.

Consider the motion of a ball thrown upwards (Figure 17.18). The speed–time graph shows that the speed of the ball is initially 15 m/s when it leaves the boy's hand and decreases at a constant rate until it stays still momentarily at the top of its trajectory with a velocity of 0 m/s. The velocity then increases again as the ball falls back down. The velocity–time graph also shows the change in direction of the ball as the velocity changes from positive to negative. It is now increasing speed in the negative direction.

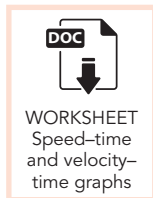
The velocity–time graph clearly shows the acceleration on the ball is constant throughout the whole time in the air regardless of the direction of the velocity. This can be seen as the gradient of the line is constant. The acceleration on the ball is the acceleration due to gravity, which acts in the same downwards direction regardless of the direction of the velocity of the ball. Hence the acceleration due to gravity is always negative.

The area under a velocity–time graph represents the displacement of the moving object. Since the ball returns to the boy's hand, the displacement is zero. In the graph, the area above the line is subtracted from the area below the line. The total area from the distance–time graph would give you the distance travelled by the ball, not it's displacement.

Ask yourself, is the velocity reasonable in this situation? Could the ball the boy throwing upward be going at 15 m/s? Why?

Finding acceleration from the gradient

The gradient of speed–time and velocity–time graphs represent acceleration. Calculating the gradient allows you to calculate the rate at which the object is changing speed or velocity. Remember, acceleration is a vector, and the negative or positive sign tells you whether the acceleration is in the same direction as the motion (speeding up and hence velocity and acceleration are both positive or both negative) or opposite to the direction of motion (slowing down and hence velocity had the opposite sign to acceleration).



Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Recall the formula for acceleration:

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

In addition to the worked examples that follow, the linked worksheet in the Interactive Textbook gives examples of features and shapes of speed–time and velocity–time graphs, with questions for practice.

Worked example 17.8

Finding acceleration from the gradient

A new electric car company is boasting that the acceleration on their latest model can go from 0 to 100 km/h in 2 seconds. An experiment to test this claim displayed their results in the following graph.

a. Identify the section of the graph that tests this claim.

b. Describe the motion in the first 10 seconds.

c. Is the claim true?

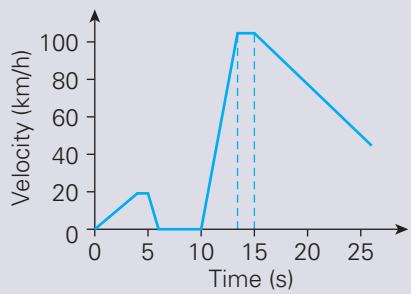


Figure 17.19 Velocity–time graph

Working	Explanation
a. Identify the section of the graph that tests this claim.	
This is the section from 10 seconds as the car is stationary at this point and suddenly increases speed.	The claim is the change in speed from 0 to 100 km/h.
b. Describe the motion in the first 10 seconds.	
From the start the car accelerates for 4 seconds, then travels at a constant velocity of 20 km/h for 1 second, then brakes for 1 second and comes to a stop for the next 4 seconds. Perhaps the driver is moving the car to the start line to start the test then stops to ensure the test begins at 0 km/h.	A line sloping up on a velocity–time graph indicates acceleration, a horizontal line indicates a constant speed and a line sloping down indicates slowing down (decelerating or negative acceleration). A line along the horizontal axis indicates the object is stopped.
c. Is the claim true?	
The graph shows the change in speed from 0 to 100 occurs in 3 seconds, not 2, therefore the claim in not true.	Conclude by answering the question in words.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 17.6

Figure 17.20 shows a speed–time graph of an object travelling in a straight line of motion.

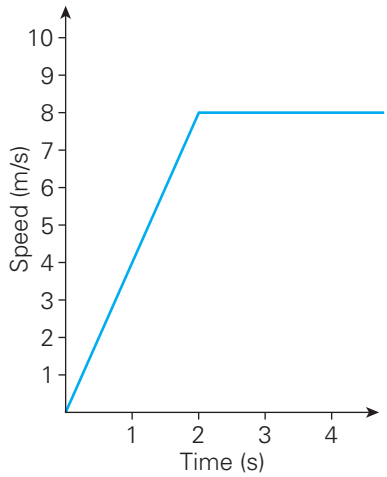


Figure 17.20 A speed–time graph

1. **Describe** the motion of the object shown in the graph.
2. **Calculate** the acceleration over the first 2 seconds.
3. **Determine** the acceleration between $t = 2$ and $t = 4$.
4. **Calculate** the distance travelled after the first 2 seconds.
5. **Determine** how far the object travels in 4 seconds.

Try this 17.5

Read the fable, *The Tortoise and the Hare* (many versions are available in the library or online). Draw a pair of speed–time graphs to represent the movement of the tortoise and the hare (use arbitrary units for time). Compare your graph with your peers.

DOC
WORKSHEET
Distance–time, speed–time and acceleration–time graphs

Figure 17.21 A modern tortoise and hare race!

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Worked example 17.9

Calculating the displacement

Consider the graph shown in Figure 17.22 of an object in motion. The positive direction is east.

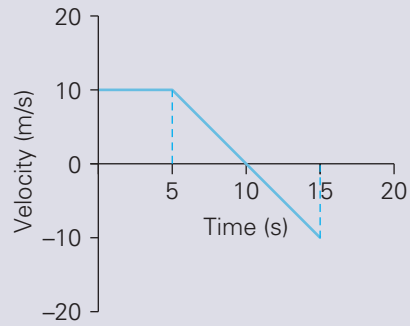
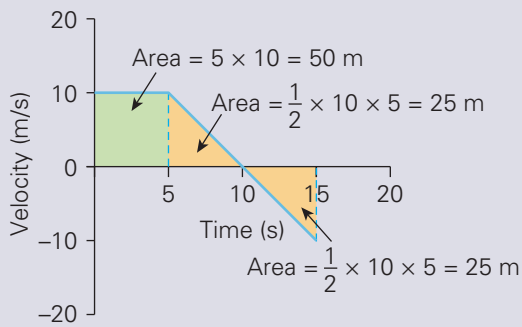


Figure 17.22 Velocity–time graph of an object in motion

a. Calculate the displacement in the first 5 seconds.
b. Calculate the displacement from $t = 5$ to $t = 10$.
c. Calculate the displacement from $t = 10$ to $t = 15$.
d. What is the total displacement by the object, over the entire 10 seconds?

Working	Explanation
a.–c. Calculating the displacement of each section	
	Calculate the area of each section using the graph.
d. Calculating the total displacement	
Displacement east is 50 + 25 =75 m Displacement west is 25 m	Calculate the total displacement using your answers from parts **a–c**.
Therefore, total displacement is 75 – 25 = 50 m east. The object is 50 m east of its stating position.	Conclude by answering the question in words.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Practical skills 17.2

Investigating the motion of students over 100 m

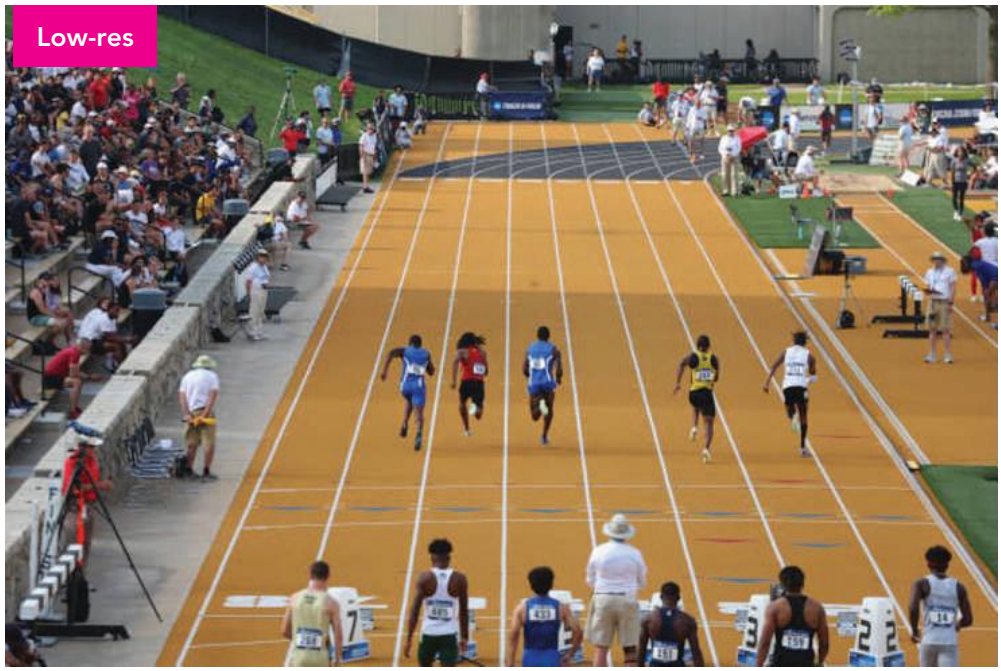


Figure 17.23 A 100 m sprint

Procedure

1. Copy the results tables below.
2. Choose at most five classmates to sprint 100 m.
3. Line up the remainder of your classmates at 20 m intervals along the 100 m track. Start the first sprinter.
4. Use stopwatches to capture the time from when a sprinter begins, to when they pass each 20 m interval. Ideally, there will be at least two classmates at each interval so that an average of the times can be calculated. Record these results in a table.

Results

1. Calculate the difference in elapsed time for each 20 m interval.

Results of sprint times at each 20 m interval					
Student name	**20 m**	**40 m**	**60 m**	**80 m**	**100 m**

2. Calculate the average speed for each interval and complete the table of average speed versus time.

Student name	20 m	40 m	60 m	80 m	100 m

continued …

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

3. Plot the distance–time and average speed–time graphs by drawing smooth trend lines.
4. Repeat the experiment using a circular running track where the student returns to the start line to finish. Plot a displacement–time graph and a velocity–time graph.

Discussion

1. Are the shapes of the graphs generally similar?
2. Describe what is happening at each 20 m interval in terms of speed.
3. Propose why it was important to gather data from various classmates instead of just from one.
4. Identify some potential sources of error (uncertainties or experimental method faults).
5. Imagine if your classmates walked, hopped or crawled. Predict what the graphs would look like.
6. Compare the graph of the straight-line race and the circular track. Justify your reasoning.

Go online to access the interactive section review and more!

Section 17.2 review

Online quiz | Section questions | Teachers can assign tasks and track results

Section 17.2 questions

Remembering

1. **Recall** what the gradient of a distance–time graph tells us.
2. **Recall** what the gradient of a speed–time graph tells us.
3. **Recall** what the area under a speed–time graph tells us.

Understanding

4. **Describe** what the shape of a displacement–time graph can reveal about an object's movements.
5. **Describe** what the shape of a speed–time graph can reveal about an object's movements.

Applying

6. The path of a caveman as he makes the trek to a nearby river, then back to his cave, is shown on the displacement–time graph in Figure 17.24.

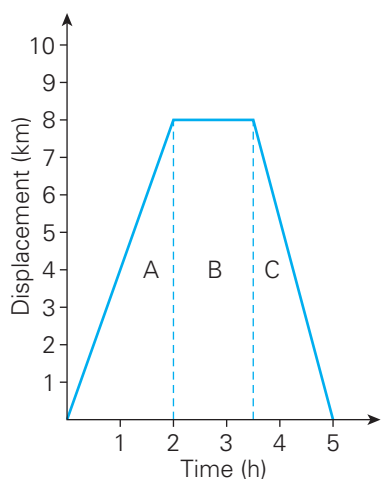


Figure 17.24 Displacement–time graph

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

a. **Determine** how far the river is from the cave.
b. **Determine** the velocity of the caveman as he walks from his cave to the river (section A).
c. **Determine** how long the caveman stops at the river (section B).
d. **Calculate** how quickly the caveman returns to his cave once he leaves the river (section C).

7. Consider the speed–time graph in Figure 17.25.

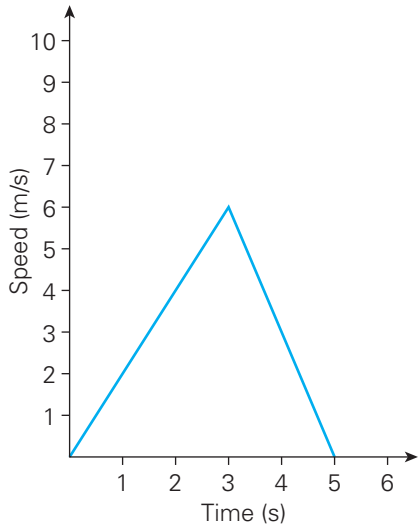


Figure 17.25 Speed–time graph

a. **Describe** the motion of the object.
b. **Calculate** the acceleration in the first three seconds.
c. **Calculate** the acceleration for the next two seconds.
d. **Calculate** the distance the object has travelled after five seconds.

Analysing

8. Hundreds and thousands of animals in Australia are killed every year by vehicles.

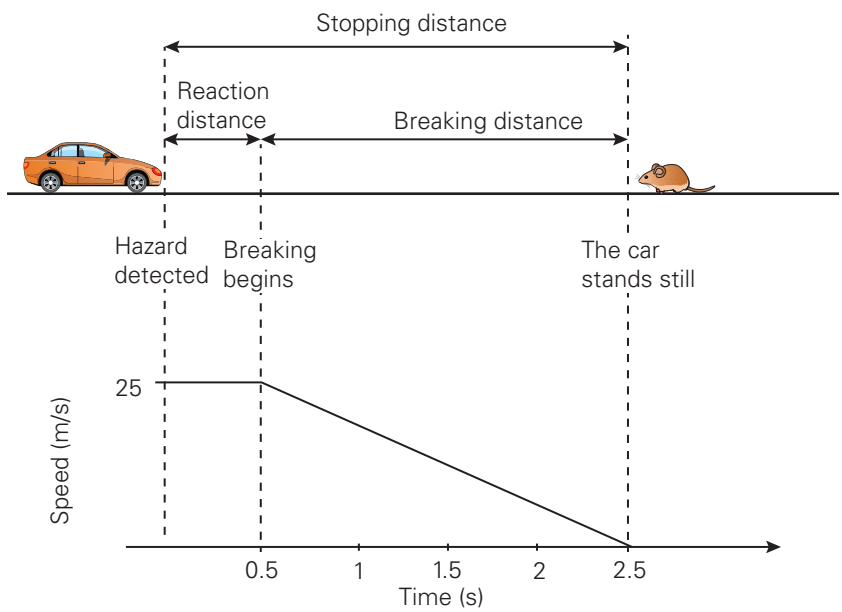


Figure 17.26 Speed–time graph for car travelling along a road

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

a. If a driver travelling at 90 km/h (25 m/s) takes 0.5 seconds to react, and they come to a stop according to the speed–time graph in Figure 17.26, **calculate** the total stopping distance.
b. If the reaction time was increased by 0.5 seconds, in other words the reaction time was one second, **calculate** what the stopping distance would be.
c. What can you **infer** about reaction times? What things can affect reaction time?

Evaluating

9. Use the following table to draw the distance–time graph of an object. Based on the shape of the graph, what conclusions can we make about the object's movements? **Evaluate** whether we can tell in which direction the object went and **justify** your response.

Time (s)	Distance (m)
0	0
2	2
5	3
7	3
9	4
10	5

10. A car starts from rest and accelerates at a constant rate of 3 m/s^2 in a straight line for five seconds.
a. **Calculate** the final speed.
b. **Calculate** the average speed. Because the speed increases at a constant rate, you can do this by using $\frac{v + u}{2}$ to find the average speed.
c. **Calculate** the distance the car had moved after five seconds.
d. **Construct** the speed–time graph for this scenario and use it to calculate the distance using the area under the graph.
e. What can you **conclude** from you answers to part **c** and **d**?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

17.3 Newton's laws of motion

Learning outcomes

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

1. conduct an investigation to analyse the relationships between force, mass and acceleration.
2. determine the net force acting on an object in one dimension using vector analysis.
3. predict the movement of an object based on the net force acting on it.
4. relate acceleration to a change in speed and/or direction as a result of a net force.
5. analyse everyday situations involving motion in terms of Newton's laws.
6. use mathematical representations, including graphs and the algebraic formulas to quantitatively relate force, distance, time, speed, displacement, acceleration, velocity and mass.
7. use waves and motion in context – structure an argument to analyse how waves and motion have changed society (STEM activity at end of chapter).

VIDEO
Newton's first law

Figure 17.27 Are the forces balanced? Or not? What happens when one team lets go?

WORKSHEET
Forces and Newton's laws of motion

Sir Isaac Newton's three laws of motion

Isaac Newton developed laws of motion through a combination of observation, experimentation and mathematical analysis. His findings were published in 1687 in *Philosophiæ Naturalis Principia Mathematica*, a significant contribution to scientific advancement. His laws were very useful in making predictions of motion and are still used today.

Access the linked worksheet in the Interactive Textbook for examples and questions on the laws.

Newton's first law of motion

Newton's first law of motion, also known as the law of **inertia**, states:

An object will remain at rest or in constant motion in the same direction unless it is acted upon by an external unbalanced force.

As you might remember from previous studies, a force is a push or pull acting on an object. Put simply, a **force** is any interaction with an object that, if left unopposed, will cause a change in the motion of the object. At any given time, multiple forces may act on any single object. These forces determine if the object will accelerate, continue to travel at a constant speed or remain at rest. Force is a vector, it has both magnitude and direction; it can be represented using the symbol $\vec{F}$, but at this

Newton's first law of motion
an object will remain at rest or in constant motion in the same direction unless acted upon by an external unbalanced force

inertia
a property of matter that keeps something in the same position or moving in the same direction unless acted upon by an external force

force
any interaction that, when unopposed, will change the motion of an object

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

level it is fine to use just F without the arrow. It is measured in newtons (N). Recall that a newton is the force required to accelerate a 1 kilogram mass at 1 metre per second per second.

If the forces acting on an object are balanced, meaning they are equal in magnitude (size) and in opposite directions, then the object will not change its motion. That is, if the object is at rest, it will stay at rest, and if an object is travelling at a constant speed, it will continue at a constant speed in the same direction. The term **net force** is used to describe the sum of all forces acting on an object. When the net force is zero ($F_{net} = 0$), it means that the forces are balanced, and the motion of the object will not change. However, if the forces applied to an object are unbalanced ($F_{net} \neq 0$), then the object will either accelerate or decelerate or change direction.

net force
the sum of all the forces acting on an object

$F_{net} = 0$	$F_{net} \neq 0$
The forces acting on an object are balanced and sum to zero. The motion of the object is not changed in speed or direction.	The forces acting on the object are unbalanced and sum to either a positive or negative number. The motion of the object changes. It either speeds up or slows down or changes direction depending on the direction of the net force.

Table 17.3 The effect of balanced and unbalanced forces

Inertia is responsible for the feeling that you get when you suddenly change motion in a car, train, aeroplane or on a bike. At times when we travel at a constant speed, we hardly even recognise that we are moving. But when the vehicle that we are travelling in suddenly stops, turns a sharp corner or accelerates, we notice that our body moves unexpectedly. This is inertia. It is the tendency for objects to either stay at rest or continue travelling at a constant speed in the same direction.

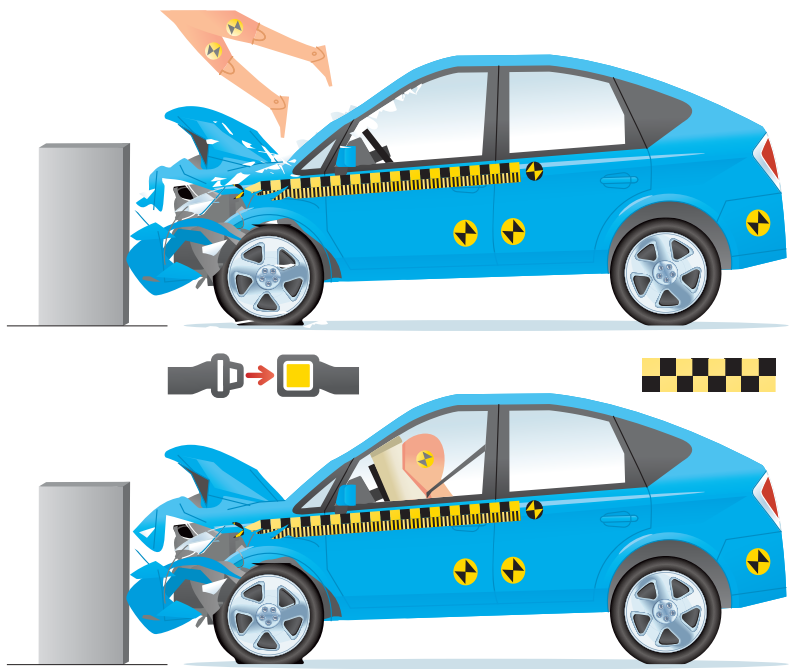


Figure 17.28 Consider travelling in a car at a constant speed. If the car crashes into an object, the car stops, but our body continues to move forwards at the original speed. (top) If it were not for seatbelts (bottom), we would continue our motion towards and through the windscreen of the car.

Quick check 17.7

1. **Explain** Newton's first law in your own words with an example.
2. **Explain** why wearing seatbelts is compulsory when travelling in a car.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Newton's second law of motion

Newton's second law of motion states that the force (F) required to change an object's motion (rate of change in velocity) is proportional to its mass (m). This relationship between net force, mass and acceleration is described by a mathematical formula. Newton's second law states:

> The net force acting on an object equals the mass of the object multiplied by the acceleration.

Newton's second law of motion describes the force (F) required to change an object's acceleration (a) for a particular mass (m)

It can also be written as:

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

$$F_{\text{net}} = ma$$

From this equation, the following four statements can be generated:

1. The more massive the object, the greater the force needed to accelerate it.
2. The greater the force applied to an object, the quicker it will accelerate.
3. If the same force is applied to a more massive object, the acceleration will be less.
4. If there is an acceleration, then there is a net force.

VIDEO Newton's second law

Imagine hitting a baseball with a bat as in Figure 17.29. When a net force is applied to the ball, it will accelerate. Consider what would happen if we were to swap the baseball with a larger baseball with twice the mass. Newton's second law tells us that if the same force were applied to a larger baseball with twice the mass, it would not accelerate as much as the smaller baseball because of the difference in mass. Lastly, if we were to apply a greater force on the baseball, it would increase the acceleration.

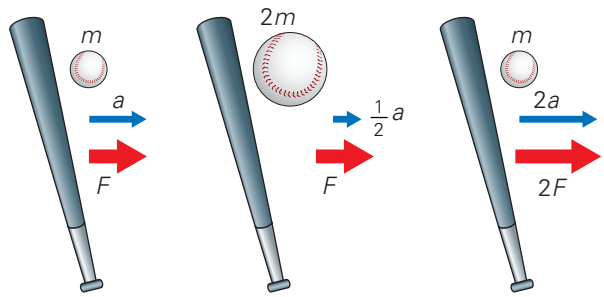


Figure 17.29 A baseball hit by a bat follows Newton's second law of motion.

WIDGET Newton's second law

Worked example 17.10

Newton's second law

Calculate the:

a. force required to accelerate an object with mass 6 kg at 3 m/s^2

b. acceleration resulting from a force of 60 N applied to a mass of 50 g

c. mass of an object accelerated by 4 m/s^2 by a force of 80 N.

Working	Explanation
a. Force required	
mass = 6 kg acceleration 3 m/s^2 force = ?	List the relevant information.
$F = ma$ $= 6 \times 3$ $= 18$ N	Use the formula for Newton's second law. Substitute the relevant values into the formula and calculate.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

b. Acceleration replied	
force = 60 N mass = 50 g = 0.050 kg acceleration = ? $F = ma$ $a = \frac{F}{m}$ $= \frac{60\,\text{N}}{0.05\,\text{kg}}$ $= 1200\ \text{m/s}^2$	List the relevant information. Convert grams to kilograms. Use the formula for Newton's second law and rearrange for a. Substitute the relevant values into the formula and calculate.
c. Mass of an object	
force = 80 N acceleration = 4 m/s^2 mass = ? $F = ma$ $m = \frac{F}{a}$ $= \frac{80\,\text{N}}{4\ \text{m/s}^2}$ $= 20\ \text{kg}$	List the relevant information. Use the formula for Newton's second law and rearrange for *m*. Substitute the relevant values into the formula and calculate.

INVESTIGATION

Investigation **17.3**

Force and mass

Aim

To investigate the effects of force and mass on acceleration.

Materials

- crash trolley
- trolley track or table top
- elastic bands of equal size and elasticity
- anchor points for elastic bands
- weights
- masking tape to mark start and finish lines
- stopwatch

Procedure

Design an experiment that investigates the effects of force and mass on acceleration. You can use increasing numbers of elastic bands to demonstrate increased force applied on the trolley.

Results

Record your data in a table.

FPO

Discussion

1. As you increase force, what happens to acceleration?
2. As you increase mass, what happens to acceleration?
3. How can your experimental design be improved?
4. Identify any sources of error (experimental uncertainty or experimental faults).

Conclusion

1. Make a claim about force, mass and acceleration based on this experiment.
2. Support the statement by using the data you gathered and include potential sources of error (experimental uncertainty or experimental faults).
3. Explain how the data supports the statement.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 17.8

1. **Explain** Newton's second law in your own words with an example.
2. A force of 10 N is applied to an object with a mass of 5 kg. **Calculate** the acceleration experienced by the object.

Newton's third law of motion

Whenever two objects interact the apply a force on each other. **Newton's third law of motion** states that all forces come in pairs. For example, if you were to push on a wall, the wall pushes back just as hard – if it did not, you would fall through (Figure 17.31)! Newton's third law states:

> For every action, there is an equal and opposite reaction.

Newton's third law of motion
for every action, there is an equal and opposite reaction

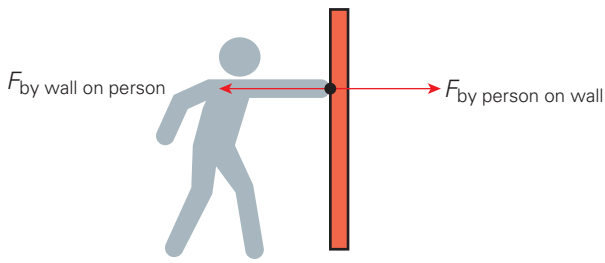


Figure 17.31 The action of pushing against a wall has a reaction force that pushes back on the person with the same magnitude.

There are many examples of action–reaction pairs. Action–reaction pairs always act on different objects. For example, in Figure 17.32 the action force acts on the wall and the reaction force acts on the person. If the action force is the force the person's feet exerts on the ground (a direct force) then the reaction force is the direct force that the ground pushes up on the person's feet (or vice versa). The action–reaction forces always act on different objects, in opposite directions and have the same magnitude. This means that an apple pulls Earth up with exactly the same force that Earth pulls the apple down!

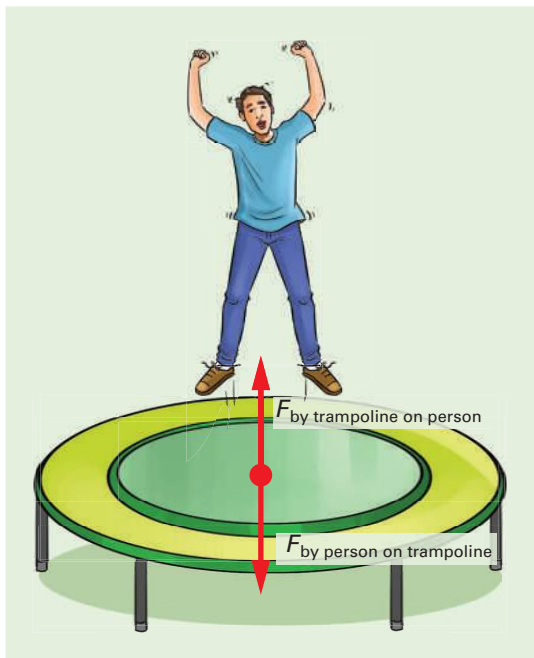


Figure 17.32 As a person jumps down on a trampoline, they exert a force downwards on the mat when in contact with the mat. The mat then pushes back up with an equal but opposite force. This can cause the person to bounce back into the air.

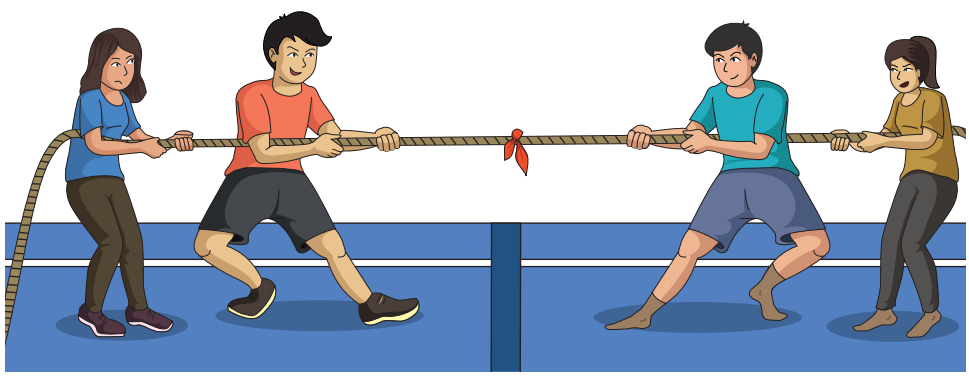


Figure 17.33 In a game of tug-of-war, who wins? Is it the team that pulls the rope with the greater force? No, it isn't! The team that pushes harder on the ground towards the other team will win, because the ground will exert an equal force back – as long there is sufficient friction to stop them slipping. Here, one team is wearing socks. Do you think they will win?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Quick check 17.9

1. **Explain** Newton's third law in your own words with an example.
2. A football player applies a force of 250 N to the ball in a kick. **Calculate** the force applied by the ball to the player's foot.

Explore! 17.1

Projectiles and throwing devices

Aboriginal and Torres Strait Islander Peoples have used spears, spear-throwers, and bows and arrows for thousands of years prior to European settlement They recognised patterns in the data and had an understanding of the relationship between the mass of the projectile (spear/arrow), the force that the throwing device (spear-thrower/bow) applied to it, and the effect on its acceleration. Use your preferred search engine to investigate how Aboriginal and Torres Strait Islander Peoples achieved an increase in velocity and subsequent impact force by using spear-throwers and bows.

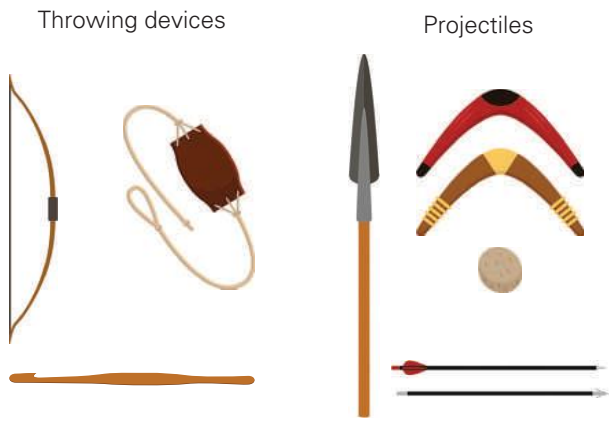


Figure 17.34 What is the throwing device of the boomerang?

Practical skills 17.4

Crash-test eggs

Be careful

No food items are to be consumed.

A risk assessment should be performed to check for any students that are allergic to eggs.

Aim

To design and build a car with safety features that will protect an egg from breaking during a collision.

Materials

As chosen by students but may include:

- rubber bands
- wheels
- icy-pole craft sticks
- dowels
- plastic cups
- straws
- rubber bands
- string
- springs
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- plastic bottles
- flat cardboard
- sticky tape

continued

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Procedure

1. Research information on vehicle collisions, safety features of cars and the forces involved during a collision.
2. Based on your research, design and build a vehicle or device that has safety features to protect an egg during a collision.
3. Test your design by competing as a class to see whose crash-test egg survives.

Results

Take a high-speed video of your collision and slow it down to see the forces in effect.

Discussion

1. Compare your safety device to a safety feature in a car.
2. Draw the forces acting on the egg during the collision.
3. What difficulties or errors did you encounter during this experiment? How could you improve the experiment to avoid these in the future?

Conclusion

1. Make a claim about safety based on this activity.
2. Support the statement by using your observations and include potential sources of error.
3. Explain how your observations support the statement.

Section 17.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 17.3 questions

Remembering

1. **Describe** what is meant by the term 'inertia'.
2. **Describe** the term 'net force'.

Understanding

3. If there is zero net force applied to an object that is travelling at a constant speed in a straight line, **outline** what happens to the object. Which of Newton's laws applies to the situation?

Applying

4. A 50 kg person sits on a chair with feet dangling above the ground. **Construct** a diagram to represent the action–reaction pair of forces acting on the scenario and include labels to indicate the force quantities. (Remember that acceleration due to gravity is $g = 9.8\ m/s^2$.)

Analysing

5. Consider the action–reaction forces in the scenario in Figure 17.35. Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass and Student 2 exerts a force of 220 N. Ignore frictional forces.
   a. **Determine** the net force acting on the mass.
   b. **Determine** the direction the mass will move.

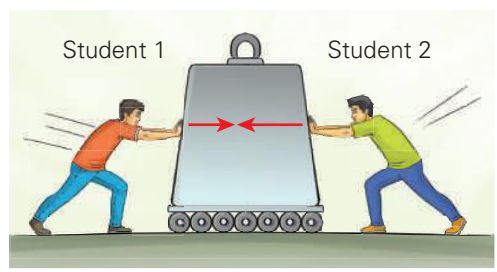


Figure 17.35 Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass and Student 2 exerts a force of 220 N.

Evaluating

6. **Evaluate** whether there are other action–reaction pairs in the system from Question 5. Can you quantify the forces?

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Chapter review

Chapter checklist

Success criteria I am now able to…		Linked questions
17.1	explain and quantitatively relate the relationships between distance, time, speed, displacement and velocity using mathematical representations and the algebraic formulas.	
17.1	explain acceleration as rate of change of velocity.	
17.1	conduct an investigation to analyse motion of a trolley on a ramp.	
17.2	investigate the motion of objects and represent them using motion diagrams.	
17.2	describe and calculate the speed of an object from a distance–time graph and displacement–time graph.	
17.2	draw distance–time and displacement–time graphs to show the movement of an object.	
17.2	describe and calculate the speed of an object from a speed–time graph and velocity from a velocity–time graph.	
17.2	draw velocity–time graphs to show the movement of an object.	
17.2	calculate acceleration from a velocity–time graph.	
17.2	conduct an investigation to analyse the relationship between distance, time and speed, and draw and analyse a line graph of the results.	
17.3	conduct an investigation to analyse the relationships between force, mass and acceleration.	
17.3	determine the net force acting on an object in one dimension using vector analysis.	
17.3	predict the movement of an object based on the net force acting on it.	
17.3	relate acceleration to a change in speed and/or direction as a result of a net force.	
17.3	analyse everyday situations involving motion in terms of Newton's laws.	
17.3	use mathematical representations, including graphs and the algebraic formulas to quantitatively relate force, distance, time, speed, displacement, acceleration, velocity and mass.	
17.3	use waves and motion in context – structure an argument to analyse how waves and motion have changed society (STEM activity at end of chapter).	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

<Insert one full placeholder page for Review questions coming at 2pp.>

Data questions

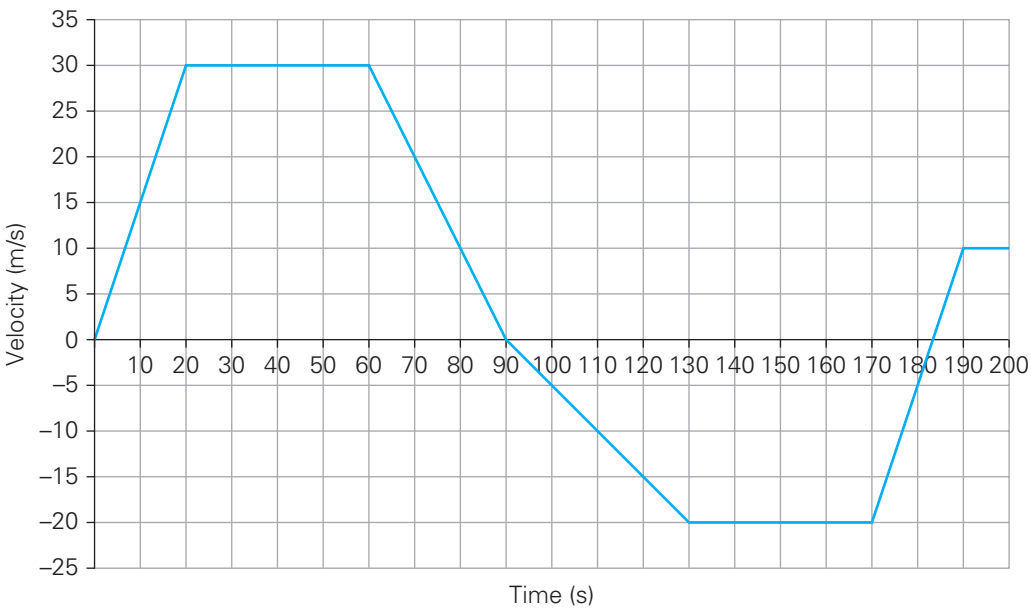


Figure 17.36 Velocity–time graph of unknown object

1. Using the velocity–time graph in Figure 17.36, **identify** the instantaneous velocity of the object at the 10, 40, 90 and 140 second marks.
2. **Calculate** the acceleration of the object at the 10, 40, 80 and 110 seconds.
3. **Calculate** the displacement of the object after 170 seconds.
4. **Interpret** the velocity–time graph to describe the motion of the object in words.
5. **Deduce** a potential identity of the object.
6. **Deduce** why it is unlikely to be a standard car.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

STEM activity: Tracking turtles

Background information

The motion of wildlife can be tracked by attaching satellite GPS tracking devices. This gives scientist information on the behaviour of animals and how this behaviour changes in response to environmental changes. Anthropogenic (human induced) climate change, oils spills, plastics in the ocean and even light pollution have affected turtle populations. By monitoring their movement, the turtles can be better protected, and the negative consequences of human activities can be mitigated.

Figure 17.37 A baby loggerhead sea turtle carries a tracking device on July 23, 2024. Due to climate change, the Mediterranean Sea is one of the seas that has warmed the most, and the presence of loggerhead turtles has increased in these waters.

GPS stand for global positioning system. The device emits a radio signal, this signal is received by an orbiting satellite which sends the signal back, similar to a reflection, the scientist has a receiver on his laptop or smartphone receives the signal. Remember radio waves area type of electromagnetic radiation that does not need a medium to travel through. Waves carry energy and can also carry information in a code made of frequency and wavelength modulations, similar to how morse code works with its dots and dashes. In this case the information is location of the transmitter. Knowledge of location and time between locations, the velocity of turtle can be calculated. However, when the turtle dive too deep is absorbed by the water not information is received by the scientist because the energy of radio waves is easily absorbed by water. Other limitations include individual animals need to be captured to attach the device making it a costly exercise and assumption are made on the information of the individual being indicative of a whole group of animals. Keep in mind also that the batteries of the device will eventually run out.

Analysing how waves and motion have changed society

To address waves and motion in context, this course requires you to create an argument to analyse how waves and motion have changed society. This STEM activity includes both motion (of the tracked wildlife) and waves (of the tracking technology) and could also be used in your argument and analysis.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400
521755134

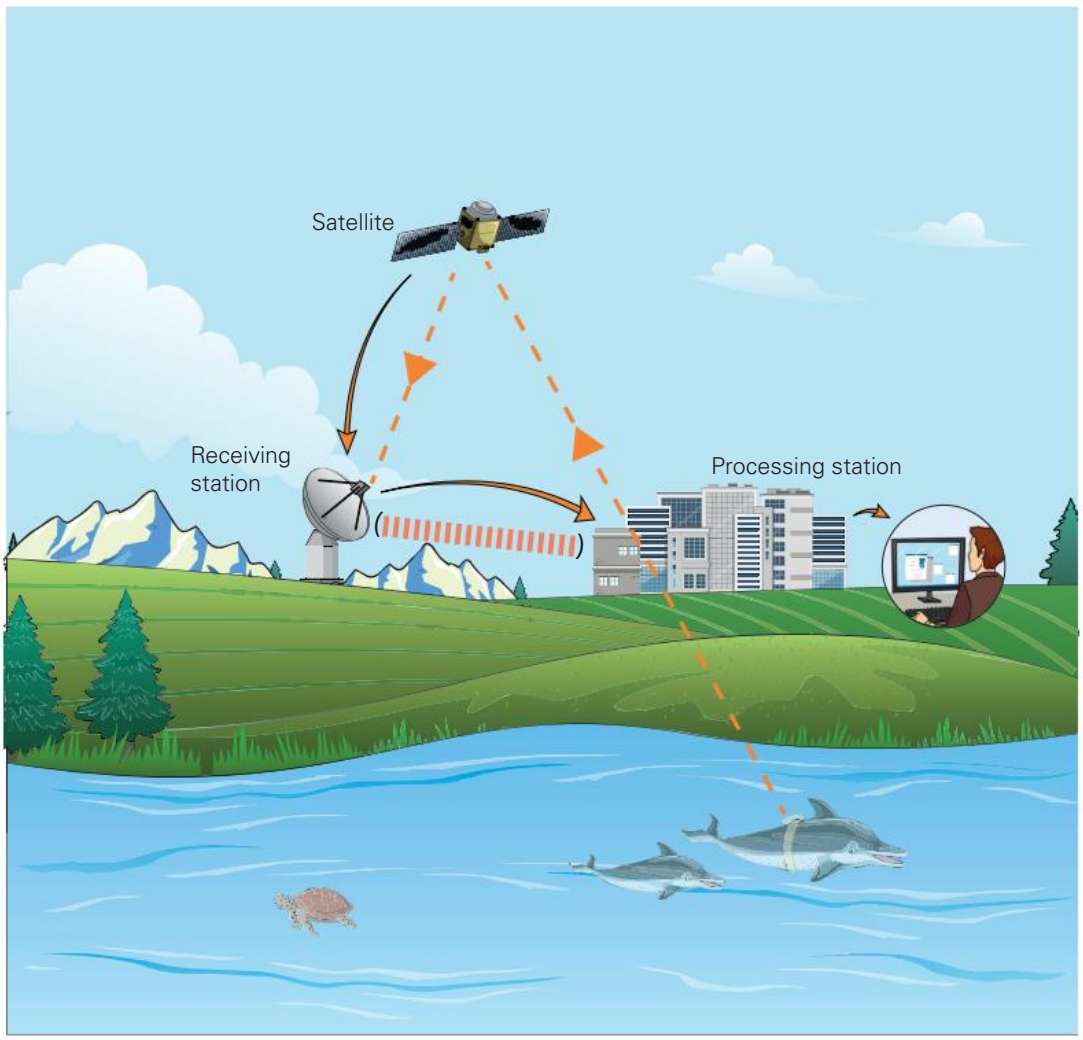


Figure 17.38 Radio waves send location information from the animal such as a dolphin or sea turtle to a receiving satellite, and then on to the scientist.

DESIGN BRIEF

Design a poster showing the benefits of tracking wildlife.

Activity instructions

In this activity, you will work in groups (three to four maximum). Your local elections are coming up and there is controversy on whether funding wildlife tracking should continue. Design a poster explaining the benefits of tracking wildlife. Ensure your poster includes:

- research on how the available technology works
- specific examples of how information provided by tracking systems has led to positive impact on maintain diversity and protecting ecosystems.

Suggested materials

- big pieces of paper
- markers
- access to the internet
- cardboard
- tape

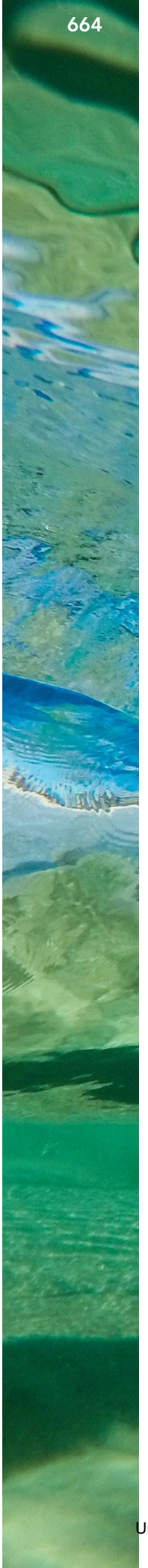
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

CHAPTER REVIEW TO FOLLOW

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

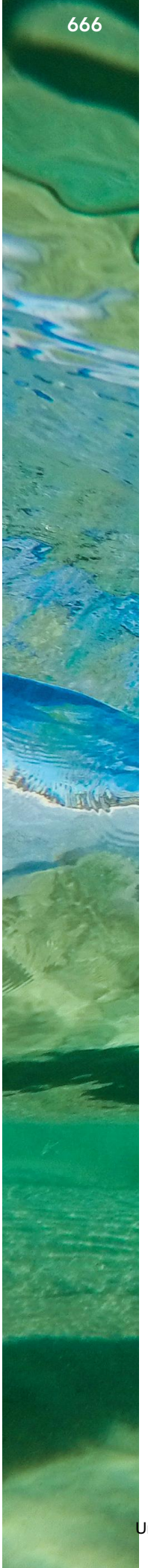


Focus area		Relevant chapters
Working scientifically	**Observing** • Select and use equipment correctly, including digital technologies, to make observations to increase the accuracy of measurements appropriate to the task • Make a series of observations with precision **Questioning and predicting** • Formulate questions or hypotheses that can be investigated scientifically • Predict outcomes based on observations and scientific knowledge **Planning investigations** • Describe the purpose of an investigation • Explain the use of variables and experimental controls in a valid scientific investigation • Assess the types of data that need to be collected in a range of investigation types • Select and explain investigation methods, including fieldwork and laboratory experimentation, to collect reliable data • Identify risks, consider ethical issues and select suitable materials and technologies for a range of investigations • Modify an investigation in response to new evidence **Conducting investigations** • Implement safe work practices and manage risks • Assemble, construct and manipulate identified equipment to perform the investigation • Follow the planned procedure and identify and respond to errors if they occur • Systematically and accurately collect and record data, information, evidence and findings • Extract information from a wide range of reliable secondary sources and acknowledge these sources using an accepted referencing style **Processing data and information** • Select and use a range of representations to organise data and information, including graphs, keys, models, diagrams, tables and spreadsheets • Select and extract information from texts, diagrams, flow charts, tables, databases, graphs and multimedia resources • Calculate a range of descriptive statistics using SI units • Identify data which supports or refutes questions, hypotheses and proposed solutions to problems • Describe specific ways to improve the quality of data collected in an investigation	**1 Working scientifically** Practicals throughout book cover these skills.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Focus area		Relevant chapters
	Analysing data and information • Describe patterns and trends, including inconsistencies in data and information • Describe relationships between variables • Assess the validity and reliability of first-hand data • Use graphed data from investigations to extrapolate or interpolate information to make predictions • Use knowledge of scientific concepts to draw conclusions that are consistent with evidence • Synthesise data and information to develop evidence-based arguments • Evaluate conclusions and evidence, including identifying sources of uncertainty and possible alternative explanations • Analyse the validity of information from secondary sources **Problem-solving** • Select suitable strategies and implement them to solve an identified problem • Develop evaluation criteria relevant to identified problems • Assess the solutions proposed based on the relevant evaluation criteria • Use cause-and-effect relationships and models to explain ideas and make predictions • Evaluate different approaches used to solve problems • Evaluate claims using scientific knowledge and findings from investigations **Communicating** • Present scientific arguments using evidence, correct scientific language and terminology, as appropriate to audience and purpose • Create written texts to communicate scientific investigations, explain scientific theories and principles, structure a scientific argument, and evaluate findings in light of scientific knowledge • Recognise that scientific texts develop arguments by encouraging the reader to adopt a specific perspective and positioning them to accept the authority of a text	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

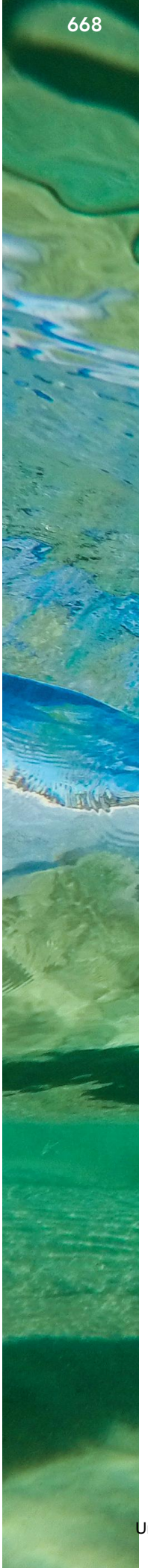


Focus area		Relevant chapters
Energy	**Law of conservation of energy** • Use the law of conservation of energy, and calculations, to explain that total energy is maintained in energy transfers and transformations in a closed system • Explain efficiency in relation to energy transfers • Explain how to improve energy efficiency in energy transfers and transformations **Sources of energy** • Identify different types of energy sources • Describe how electrical energy can be produced from different types of sources • Evaluate the advantages and disadvantages of using renewable and non-renewable sources of energy to generate electricity, including efficiency, economical and technological considerations **Global future energy needs** • Evaluate ways to optimise current energy use • Examine data to identify past trends in energy use, and predict possible future demands, at a state, national and global level • Explain reasons for the development of alternative sources of energy **Energy in context** Use data, evidence and research to evaluate the development of alternative energy sources to meet and reduce global energy demand	Chapter 2
	Electrical energy • Identify the elements of a complete circuit • Construct circuits and draw circuit diagrams that contain several components to show the flow of electricity through a complete circuit • Measure and compare voltage and current at different points in series and parallel circuits • Conduct an investigation to determine the relationship between voltage (V), current (I), and resistance (R), as described by Ohm's law ($V=IR$) • Conduct an investigation to compare the energy transformed over time in model circuits or appliances • Investigate the energy star ratings of a range of appliances and explain the criteria used to determine these ratings	Chapter 3

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Focus area		Relevant chapters
Disease	**Homeostasis** • Identify the importance of maintaining stable internal conditions in the body • Investigate examples of an organism's observable response to a stimuli • Identify the role of feedback loops in maintaining homeostasis • Compare and contrast the responses of the nervous and endocrine systems • Describe how the nervous and endocrine systems coordinate the body's response to stimuli	Chapter 4
	Infectious and non-infectious diseases • Distinguish between infectious and non-infectious diseases • Identify causes of non-infectious and infectious diseases • Compare the features and incidences of epidemics, endemics and pandemics • Investigate data relating to a common non-infectious disease affecting Australians today • Use modelling to investigate how infectious diseases can be spread • Identify how the body prevents the entry of pathogens and describe how it responds to pathogens that enter the body • Outline how a vaccination stimulates the body to produce antibodies to fight infection **Disease control and prevention** • Describe ways to reduce the incidence of non-infectious diseases • Assess ways to reduce the incidence and spread of infectious diseases • Investigate Aboriginal and/or Torres Strait Islander Peoples' use of plants to prevent or control disease • Analyse data about immunisation programs and the occurrence of infectious diseases to identify trends, patterns and relationships, and document conclusions in a written text **Disease in context** Investigate technological advances developed in Australia to address disease, disorders or physical trauma in the human body	Chapter 5

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

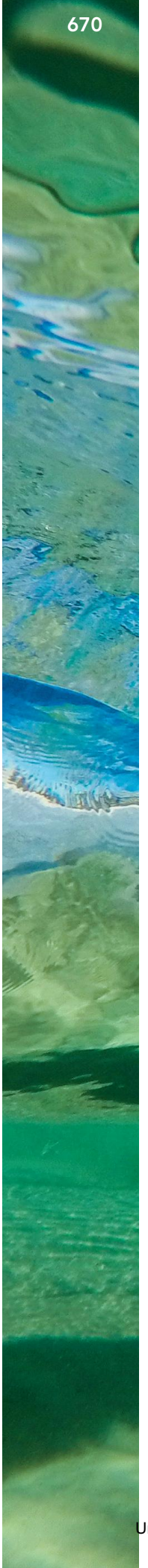


Focus area		Relevant chapters
Materials	**Resources** • Identify the finite nature of the minerals and resources extracted in Australia • Investigate the products produced from Australian minerals and resources • Explain how Aboriginal and Torres Strait Islander Peoples used minerals and resources for a wide range of purposes • Evaluate the environmental impact of extracting and using a named resource and document findings in a written scientific report	Chapter 6
	Bonding • Use valency to describe the number of electrons an atom needs to gain, lose or share to achieve a stable electron configuration • Explain noble gas configuration and identify that it occurs during chemical bonding • Describe types of chemical bonds, including ionic, covalent and metallic bonds • Use models to describe the formation of cations and anions • Recognise that some elements exist as diatomic molecules • Construct chemical formulas of some common ionic compounds and covalent molecules • Conduct an investigation to observe and compare the physical and chemical properties of ionic, covalent and metallic substances, and explain how these relate to their uses	Chapter 7
	Chemistry of organic compounds • Distinguish between organic and inorganic compounds • Describe how hydrocarbons can be separated from crude oil and identify the uses of these products • Use International Union of Pure and Applied Chemistry (IUPAC) nomenclature to name simple organic compounds • Identify and reproduce the structure of simple alkanes C1–C8 • Describe the differences between complete and incomplete combustion reactions of hydrocarbons, and use examples from everyday applications to compare the products of the chemical reaction and amount of energy released • Research the uses of hydrocarbon compounds and how this has changed over time **Polymers** • Identify the raw materials used to make polymers • Investigate and describe the properties of a range of polymers • Determine the quantity and types of polymers found in the environment by undertaking a physical survey of the local area	Chapter 8

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Focus area		Relevant chapters
	• Conduct an investigation to determine the biodegradability of different packaging materials • Investigate case studies to explain the effect of bioaccumulation of microplastics in the environment **Materials in context** • Assess the environmental impacts of materials that are used as alternatives to those derived from crude oil	
	Sustainability • Identify the principles and goals of sustainability • Apply scientific understanding to propose valid solutions to identified problems relating to sustainability **Alternative resource use and recycling** • Describe the causes of environmental pollution and discuss its implications • Research how Aboriginal and Torres Strait Islander Peoples have developed sustainable harvesting practices and Cultural protocols based on deep ecological understandings • Discuss alternatives to the current resource use, including how to reduce, reuse and recycle • Describe current processes for recycling materials • Investigate how scientists have developed innovative ways to recycle materials **Environmental sustainability in context** Discuss the link between human activity and one specific environmental pollution concern	Chapter 9
Environmental sustainability	**Climate science** • Distinguish between climate and weather • Investigate data to determine what trends are evident in the world's climate • Explain how the natural greenhouse effect influences global climate • Identify the advantages and limitations of methods used to reduce greenhouse gas emissions • Analyse data that shows the relationship between industrialisation and the rise in global temperatures **Impacts of present-day climate change** • Identify the characteristics of climate change • Investigate and report on the consequences of climate change	Chapter 10

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

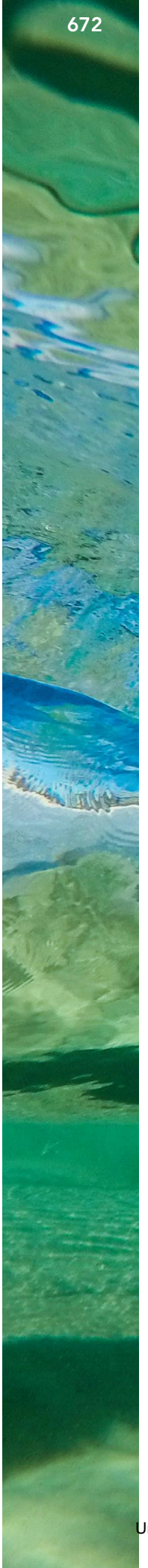


Focus area		Relevant chapters
	• Investigate the effects of climate change on the water cycle and ecosystems • Investigate how satellites collect global data, including data on ocean temperatures, sea levels, and forest and ice cover, and examine how this data is used to evaluate the impact of climate change	
Genetics and evolutionary change	**DNA structure and function** • Identify that all organisms have information coded in genetic material • Observe and model the arrangement of genetic information in an organism to define and compare the terms DNA, gene, chromosome and genome • Relate the structure of the DNA double helix to its functions • Discuss the nature of scientific discovery by comparing the contributions of scientists involved in the discovery of the double helix structure of DNA **Variation and inheritance** • Outline how genetic information is passed on to offspring by sexual and asexual reproduction • Identify that multiple genes and multiple environmental factors interact in the development of most traits • Explain how DNA mutation can result in genetic variation with beneficial, harmful or minimal effects on the functioning of an organism • Outline the connection between genotypes and phenotypes, using Mendelian inheritance for both plants and animals • Use pedigrees and Punnett squares to model monogenic gene-trait relationships and make predictions about patterns of inheritance **Genetic technologies** • Identify examples of current and emerging genetic technologies • Discuss applications of genetic technologies in conservation, agriculture, industry and medicine • Discuss the applications of genetic testing and its associated social, economic and ethical implications **Genetics and evolutionary change in context** Use an ethical framework to construct evidence-based written arguments about the implications of a genetic technology, including the ethical implications of the continued use of the immortal HeLa cell line	**Chapter 11**

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Focus area		Relevant chapters
Reactions	**The theory of evolution and evidence of natural selection** • Explain how the processes of natural selection and isolation can lead to changes within and between species • Investigate, using evidence, how the complexity and diversity of organisms have changed over geological timescales • Identify and discuss Aboriginal and/or Torres Strait Islander Peoples' artwork that indicate changes in plants and animals, including megafauna • Discuss how scientists developed and refined the theory of evolution, and explain why an understanding of the origins of species is important **Law of conservation of mass** • Explain the meaning of the law of conservation of mass • Conduct a practical investigation to demonstrate the law of conservation of mass in a chemical reaction • Investigate and explain how mass is conserved in closed systems **Chemical reactions** • Use IUPAC naming conventions to construct the chemical formula for common ionic and covalent compounds • Represent chemical reactions, by predicting products and writing word and balanced chemical equations with states, as they are encountered • Model simple chemical reactions to show that atoms are rearranged and mass is conserved during a reaction • Determine the features of reactions by conducting synthesis, decomposition, displacement and neutralisation reactions • Identify pH as the measure of acidity and compare the pH of a range of common substances to the pH of pure water • Use pH indicators or meters to measure the pH change of neutralisation reactions	Chapter 12
	Rate of chemical reactions • Investigate and explain how concentration, surface area, temperature and catalysts affect the rate of reactions • Conduct a practical investigation to test a measurable hypothesis, with a cause-and-effect relationship, that predicts changes to the rate of a chemical reaction, and graph data that communicates the investigation findings in a scientific report • Evaluate the societal benefits and considerations of using radioisotopes in medicine, industry and environmental monitoring	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

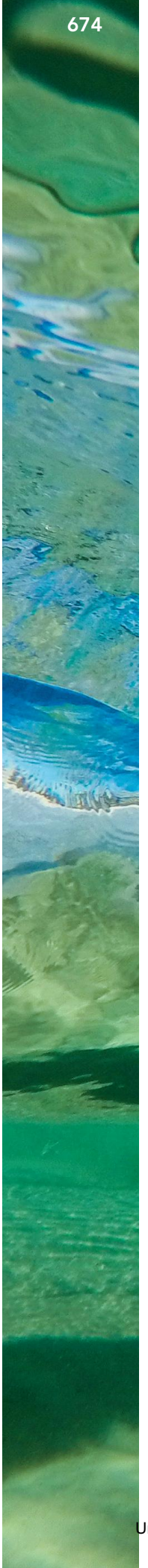


Focus area		Relevant chapters
	• Describe nuclear fission and nuclear fusion • Outline the impacts on the environment of nuclear reactions, including the raw materials used, the various stages of production and nuclear waste **Reactions in context** Investigate a chemical or nuclear reaction used in industry to produce an important product **Nuclear reactions** • Outline how the first elements were formed after the Big Bang • Describe the conditions that cause a nucleus to be unstable • Represent alpha and beta reactions as nuclear reactions • Identify that the half-life of a radioactive isotope is the time taken for half of the atoms in a sample to undergo radioactive decay	
Waves and motion	**Common properties of waves** • Demonstrate that a mechanical wave requires a medium to travel through, while an electromagnetic (EM) wave does not • Use the wave model to explain how energy is transferred without the net transfer of particles • Use models to compare and describe the features of transverse and longitudinal waves • Compare the different wave forms of the electromagnetic spectrum • Investigate the features of waves, including amplitude, frequency, speed and wavelength by exploring a range of wave types • Use the formula $\lambda = \frac{v}{t}$ to explain the relationship between a wave's frequency, speed and wavelength • Analyse data from secondary sources to compare the uses of different EM waves based on their properties **Sound waves** • Model the transfer of sound energy as compressions and rarefactions in waves • Investigate and describe how amplitude and frequency affect the pitch and volume of sound • Investigate the Doppler effect of waves • Describe how the ear responds to sound waves • Investigate and outline the impact of material selection on the transfer of sound energy in Aboriginal and/or Torres Strait Islander Peoples' traditional musical and communication instruments • Describe how sound waves are used in medical diagnosis	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Focus area		Relevant chapters
	Light waves • Describe how the eye responds to light • Investigate the properties of light, including absorption, reflection, refraction and scattering • Investigate applications of absorption, reflection and refraction in everyday life • Explain how the electromagnetic spectrum is used to learn about stars	
	Motion • Conduct an investigation to analyse the relationships between distance, time, speed, displacement and velocity • Investigate the motion of objects and represent them using motion diagrams • Conduct investigations to analyse the relationship between distance, time and speed, and draw and analyse a line graph of the results • Conduct an investigation to analyse the relationships between force, mass and acceleration • Investigate applications of Newton's laws of motion • Determine, using vector analysis, the net force on an object in one dimension • Use mathematical representations, including graphs and the algebraic formulas $F = ma$, $v_{av} = \frac{\Delta s}{\Delta t}$ and $a = \frac{\Delta v}{\Delta t}$, to quantitatively relate force, distance, time, speed, displacement, acceleration, velocity and mass	
	Waves and motion in context Structure an argument to analyse how waves and motion have changed society	
Data science 2	**Investigating questions and claims** • Discuss the features of investigable and non-investigable questions, including considerations of available resources • Investigate how scientific knowledge is verified and refined by scientists through hypothesis testing and peer review • Develop criteria and use them to evaluate whether online content is valid and reliable • Identify a claim that can be scientifically tested with an investigation, or series of investigations, to test the claim • Explain the evidence and reasoning used to support conclusions about claims, using data from investigations • Conduct a written scientific argument showing how a range of evidence supports a claim	**1 Working scientifically** Data questions at end of each chapter

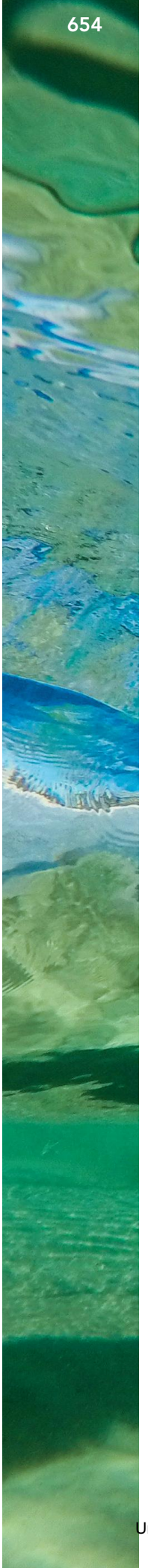
Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



Focus area		Relevant chapters
	Pseudoscience • Explain the distinction between science and pseudoscience using examples • Identify examples of pseudoscientific claims • Investigate incidences of pseudoscience in popular media • Investigate how data, or its analysis and interpretation, can be distorted to manipulate findings that support specific viewpoints • Determine if an assertion of a claim or theory is pseudoscientific **Large datasets and scientific argumentation** • Outline the features, collection, uses and applications of large datasets • Use available large datasets to develop and test a question • Conduct a descriptive analysis of a large dataset • Identify and outline the benefits of using descriptive statistical analysis techniques to assist in recognising or communicating patterns • Conduct a univariate analysis and a bivariate analysis using large datasets • Recognise the difference between causal and correlational relationships • Explore the role of large datasets and statistical analysis in validating scientific findings **Data science 2 in context** Use data to make evidence-based decisions about a familiar issue and assess the implications of these decisions	

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



Glossary

abiotic relating to the non-living things in an ecosystem

absolute dating determining the actual age of a material

absolute uncertainty the size of the range of values within which the actual 'true value' of a measurement probably lies

absorb to take up the energy of a wave (e.g. absorb light)

acceleration the rate of change in velocity of an object

accommodation automatic adjustments made by the eye when looking at objects at different distances

accuracy in experiments, how close a measurement is to the true value

acid a substance that, when dissolved in water, has a pH of less than 7

action potential the electrical impulse (message) that is transmitted along a neuron

activation energy the minimum energy required for a successful collision and therefore to start a reaction

adaptation a characteristic that contributes to an individual's ability to survive in its environment

adaptive immunity a specific immune response that develops over time, providing a stronger response upon re-exposure

agitating stirring or shaking a mixture

alcohol an organic compound with a hydroxyl functional group

alkali base that can dissolve in water

alkane simple organic compounds consisting of single bonded carbon chains single bonded to hydrogen atoms

alkene hydrocarbon containing at least one double bond

alkyne hydrocarbon containing at least one triple bond

allele different form of the same gene

allele frequency the relative proportion of a specific allele within a population

alpha particle a particle, identical to the nucleus of a helium atom, consisting of two protons and two neutrons

ammeter a device for measuring electric current

ampere the flow of 6.242×10^{18} electrons per second

amplitude the distance (height) of a wave crest or the depth of a wave trough from the centre line of the wave

analogous structures structures that have a similar function but evolved separately

aneuploidy the presence of an abnormal number of chromosomes in a cell

angle of incidence the angle between an incident light ray and the normal when the ray arrives at a surface

angle of reflection the angle between a reflected light ray and the normal, when the ray leaves a surface

anion a negatively charged ion formed from the gain of electrons

anthropogenic caused or influenced by people

antibiotic a substance that inhibits the growth of bacteria inside the body

antigen a substance that triggers an immune response in the body; can be foreign (non-self) or self-antigens.

antiseptic a substance that prevents the growth of disease-causing microorganisms

aqueous a physical state of matter that means dissolved in water

artificial selection intentional breeding of organisms with particular characteristics to produce offspring with more desirable traits at a particular gene locus

Atmosphere the mixture of gases above the surface of Earth

auditory nerve the nerve which connects the ear with the brain

autonomic nervous system the part of the peripheral nervous system involved in involuntary physiological processes such as heart rate and digestion

autosome any chromosome that is not a sex chromosome. in humans, these are chromosome pairs 1 to 22

B lymphocyte a type of white blood cell that produces antibodies to help identify and neutralise specific pathogens; also known as a B cell

bacteria (singular: bacterium) microscopic, unicellular organisms

base a substance that has a pH greater than 7 and that can react with an acid to form a salt and water

base triplet/codon a set of three nitrogenous bases that code for an amino acid

battery a portable source of power

beta particle a high energy electron (β^-) or positron (β^+) that is emitted from the nucleus of a radioactive element during beta decay of an unstable atom

binary fission the main asexual reproduction method in prokaryotes, where a cell divides into two identical cells.

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

bioaccumulation the gradual accumulation of substances, such as plastics of chemicals, in an organism

biodiversity the variety of life on earth, including the diversity of species, the genetic differences within a species, and the ecosystems where species are found

biogeography the study of the geographical distribution of plants and animals

Biosphere all the areas on Earth and in its atmosphere that contain life

biostratigraphy a branch of stratigraphy focused on dating rock layers using the fossils found in them

biota all the living organisms found within a particular region or ecosystem

biotic relating to the living things in an ecosystem

bivariate analysis investigating the relationship between two variables to determine how changes in one variable might affect the other.

blue shift a spectrum shifted towards shorter wavelengths

bottleneck effect the decrease in genetic diversity resulting from a rapid reduction in the size of a population, due to events such as natural disasters or human activities such as overhunting

budding an asexual reproduction process where a new organism develops from an outgrowth or bud on the parent.

calibration adjusting measuring equipment against a known standard value to ensure its accuracy cannot be inherited

carbon sink an area where carbon is stored (e.g. ocean, forests or fossil fuels)

carbon source a process or an area that releases carbon

carboxylic acid an organic compound with a carboxyl functional group

carrier an individual with a recessive allele for a disease but who does not have the disease due to being heterozygous

catalyst speeds up a chemical reaction by lowering the activation energy; does not get used up in the process

cation a positively charged ion formed from the loss of electrons

cell a single electrical energy source that produces a current

centromere a structure that holds two sister chromatids together

chromatin a mixture of dna and proteins that form chromosomes

chromosome a thread-like structure of tightly wound dna and proteins

chromosome mutation a mutation involving large segments of dna

climate the average or prevailing weather conditions of an area over long periods of time

climate change statistically significant change to a measurement of climate, such as mean global temperature, that has been sustained for an extended period, typically decades or longer

cochlea a spiral tube inside the inner ear that is the main organ of hearing

codominance both alleles are expressed equally in the phenotype

codon three nucleotides (base triplet) on mrna that code for an amino acid

collisions particles must collide for a chemical reaction to occur combustion the reaction of a fuel with oxygen, usually producing heat and light

complementary base pairing adenine only binds with thymine and cytosine only binds with guanine

compression the part of a longitudinal wave where the particles are close together

concave a mirror that is curved inwards, like a cave

concentrated solution a solution which contains a large amount of solute compared to solvent

concentration the amount of substance in a given volume

conductor (electricity) a material that allows electric current to flow easily

confounding variable an external factor that can unintentionally affect the outcome of an experiment, making it difficult to determine whether changes in the dependent variable are caused by the independent variable.

conservation of mass a law that states that matter can be neither created nor destroyed in chemical reactions

constant velocity when an object is travelling at the same speed and direction, and is not accelerating or decelerating

control centre often the brain or spinal cord, which receives signals from receptors and sends out signals to effectors to produce a response to a stimulus

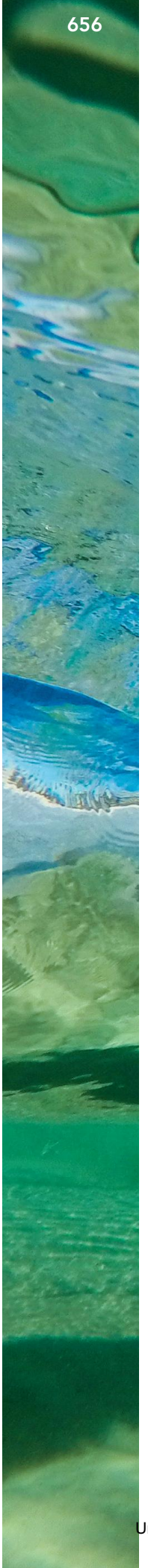
controlled variable a factor that remains constant throughout an experiment to ensure that any changes observed in the dependent variable are solely due to the manipulation of the independent variable.

convergent evolution the process by which unrelated species independently evolve similar traits due to similar environmental pressures

convex a mirror that bulges 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

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



coulomb unit of electric charge; the amount of charge transferred in 1 second with a current of 1 amp

covalent bond a strong bond, almost always between two non-metals which share electrons to form a molecule

crest the maximum displacement of a particle at the top of the wave

crossing over the exchange of genetic material between homologous chromosomes during meiosis, leading to genetic diversity in gamete

cycle one complete vibration or periodic movement of a particle through the crest and trough and back to its starting position; the length of a cycle is the wavelength

decomposition a reaction where a substance breaks down into two or more simpler substances

deletion where a nucleotide is deleted from the sequence

delocalised electrons freely moving electrons that are shared between more than two atoms in a substance

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

diatomic consisting of two atoms

dilute solution a solution which contains a small amount of solute compared to solvent

diploid (2*n*) a cell containing two sets of chromosomes

direct (evidence) evidence that supports an assertion without intervening inferences

direct transmission the immediate transfer of pathogens from an infected individual to a susceptible host through physical contact

disease is any condition that disrupts the normal functioning of the body

displacement how far you are from where you started and what direction you are from where you started

displacement reaction when a more reactive metal pushes out a less reactive metal from a compound

displacement the distance of a particle from its rest position on the centre line of the wave

dissociation the break up of ions that occurs when an ionic compound dissolves

distance total distance travelled; measured in metres

divergent evolution when closely related species evolve different traits, adapting to different environments or selection pressures from a common ancestral form

DNA hybridisation a technique that measures genetic similarity between two organisms

dna the molecular unit of heredity, containing the genetic information responsible for the development and function of an organism (deoxyribonucleic acid)

dominance a form of inheritance in which both alleles are partially expressed, producing a third intermediate phenotype

dominant a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

Doppler effect a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

ear canal a tube that connects the outer ear and the middle ear

eardrum a thin piece of membrane inside the ear that moves backwards and forwards very quickly (vibrates) when sound waves reach it

earthed having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

echolocation the location of objects using reflected sound (echo)

ecosystem diversity the variation in ecosystems in a given area

ecosystem the interrelationship between living and non- living components of a specific area

ectoparasite a parasite that lives on the surface of the host, feeding externally by consuming blood, skin or other bodily fluids

effector a muscle, a gland or an organ that carries out a response or action in response to a stimulus

efficiency a measure of the ability to produce useful energy

electrocution electric current passing through the body

electromagnetic radiation transfer of energy by electromagnetic waves

electromagnetic wave a wave made of oscillating electric and magnetic fields that can travel through matter or a vacuum

electrostatic force an attractive or repulsive force between particles caused by their electric charges

embryo the initial stage of early development in multicellular organisms

endangered a species that is in danger of becoming extinct

endemic a disease that is consistently present and regularly occurs within a specific geographic area or population

endemism a state of being confined to a small defined geographic location

endocrine system the system of glands that controls hormones in the body

endoparasite a parasite that lives inside the host's body and derives nutrients from the host's internal environment

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

enhanced greenhouse effect the intensifying of the natural greenhouse effect due to human activity

Environment Impact Statement <definition to come>

epidemic a sudden and widespread outbreak of a disease that exceeds the normal expected frequency within a specific area or population

eukaryote an organism made of cells that contain a nucleus and membrane-bound organelles

evolution change in the genetic composition of a population during successive generations, which may result in the development of new species

evolutionary tree a diagram used to represent evolutionary relationships between organisms

exothermic a reaction that releases heat

exploration looking for the location or extent of a resource

extinct a species that has no living members

extrapolation predicting values outside the range of known data points based on the existing trend

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

fermentation a chemical process by which energy is produced in the absence of oxygen

fertile able to reproduce

fertilisation the fusion of male and female gametes to form a zygote

force any interaction that, when unopposed, will change the motion of an object

fossil fuel a non-renewable energy source such as oil, coal or natural gas

fossil record the record of past life and evolution inferred from fossils

fossil the shape or impression of a bone, a shell or a once living organism that has been preserved for a very long period of time

fossilisation the process of forming a fossil

founder effect the decrease in genetic diversity that occurs when a population is descended from a small population that separated from a larger one

fovea a small part of the retina that contains the most light-sensitive cells

fractions groups of hydrocarbons with similar chain lengths

frequency the number of cycles per second

functional group a group of atoms responsible for the chemical properties of a group of compounds

fungus (plural: fungi) eukaryotic organisms which have a cell wall made of chitin and feed by secreting enzymes and then absorbing the digested nutrients.

gametes sex cells (sperm and ova) with half the usual number of chromosomes

gamma ray a high energy wave emitted from the nucleus of radioactive elements during radioactive decay

gamma ray high-energy ray with a very short wavelength produced when radioactive atoms decay

gene a length of chromosome made of dna, the basic unit of inheritance

gene flow the movement of genetic information from one population to another through migration

gene mutation a permanent alteration in the dna sequence that makes up a gene

gene therapy a process by which a copy of a functional gene is introduced into an organism

genetic diversity the number of different alleles of genes in a population

genetic drift the random change in allele frequencies in a population from generation to generation

genetic engineering deliberately modifying genetic material to manipulate the characteristics of an organism

genetic screening genetic tests carried out across the population to identify people at risk of genetic disorders

genetic variation the differences in DNA sequences between individuals within a population

genetically modified organism an organism that has had its genome altered using genetic engineering techniques

genetics the study of genes, genetic variation and heredity

genome the complete set of genetic material in an organism

genotype the combination of alleles an organism has for a particular gene

Geosphere includes Earth's magma, lava, rocks and minerals

geothermal energy thermal energy that originates from inside the earth

germline mutation a mutation of dna in gametes which can be inherited

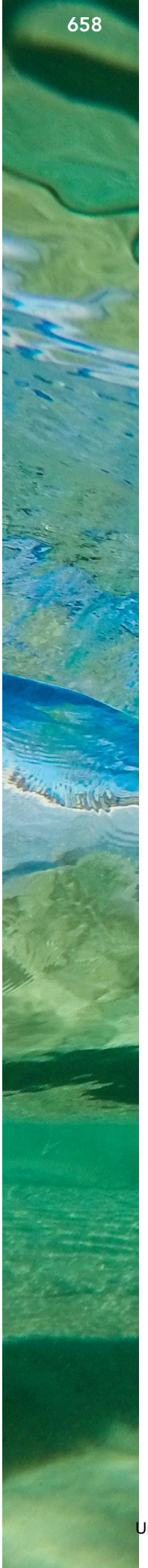
glacial period a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

global warming the long-term rise in the average temperature on Earth, primarily caused by the increase of greenhouse gases in the atmosphere

glucagon a hormone secreted by the pancreas that triggers the liver and muscle cells to convert glycogen into glucose, raising blood glucose levels

gonads the sexual organs: testes in males and ovaries in females

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



gradient the gradient of a graph is its slope calculated as the rise over the run

greenhouse effect the process by which gases in the lower atmosphere absorb and re-emit infrared radiation, trapping heat from the Sun

greenhouse gas a gas that contributes to the greenhouse effect

half-life the length of time needed for the radioactivity of a radioactive substance to be reduced by half

half-life the time taken for half of the nuclei in a radioactive sample to decay

haploid (n) a cell containing only one set of unpaired chromosomes

health is a state of complete physical and mental wellbeing

heredity the genetic passing on of traits from one generation to the next

hertz a unit for measuring the number of cycles that happen every second (frequency); abbreviation is Hz

heterozygous having two different alleles

homeostasis the process in which an organism maintains a stable internal environment despite changes in the external environment

homologous chromosomes a matching pair of chromosomes, with one having been inherited from each parent

homologous series a family of compounds with similar properties that share the same general formula

homologous structure a similar physical feature in organisms that have evolved from the same common ancestor

homozygous having two identical alleles at a particular gene locus

hormone a chemical messenger that is secreted by endocrine glands and circulated in the bloodstream to act on a target cell

hydrocarbon organic compound composed entirely of carbon and hydrogen atoms

hydroelectric power a renewable source of energy harnessing the gravitational potential energy of water to generate electrical energy

hydrogen bonds chemical bonds that hold the two dna strands together

hydrosphere all of the water found on Earth (e.g. lakes and rivers)

hypothesis an educated guess that can be tested through further experimentation

immune system the network of cells and tissues that enables the body to protect itself against disease

immunisation the overall process of triggering antibody production and providing future protection against a specific pathogen, often through vaccination with a weakened or dead version of the pathogen.

incident ray a ray of light arriving at a surface

independent variable the variable that is deliberately changed during an experiment

index fossil a fossil used as the basis for dating the strata it occupied

indirect (evidence) evidence that requires inferences to be made

indirect transmission when pathogens are spread to a susceptible host via contaminated objects, surfaces or airborne droplets

induced mutation a mutation produced by environmental factors

inertia a property of matter that keeps something in the same position or moving in the same direction unless acted upon by an external force

infectious disease caused by pathogens and can spread from person to person.

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

infrared radiation electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

innate immunity the body's immediate, non-specific defence mechanism against pathogens, involving physical barriers and immune cells that respond quickly to infections

inorganic compounds that generally do not contain carbon

insertion where one or more extra nucleotides are inserted into the dna

instantaneous speed the speed at any particular instant

insulator a material through which current cannot flow easily

insulin a hormone secreted by the pancreas that triggers cells to take up glucose from the bloodstream and store it as glycogen in the liver and muscle cells, lowering blood glucose levels

interglacial period a period in Earth's history when an increase in global temperatures is sustained for a long period of time

interneuron a nerve cell that transmits information within the brain and spinal cord (central nervous system)

interpolation the method of estimating unknown values within the range of known data points

inversion where two nucleotides reverse their order

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

ion a charged version of an atom, formed from the loss or gain of electrons

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

ionic bond a strong bond between an anion and a cation, formed via electron donation

ionising having enough energy to knock electrons off atoms, turning them into ions and changing their properties

ionising radiation higher frequency ultraviolet rays, X- and gamma rays which can turn atoms and molecules into ions; can potentially damage living cells

isotopes atoms of the same element with the same number of protons but a different number of neutrons

karyotype the chromosomes of an individual, often displayed according to size and gene band patterns

leachate <definition to come>

lens (eye) a small disc of transparent tissue behind the pupil that allows near and far objects to be focused on

load a device that transforms electrical energy to another form energy in a circuit

locus the location of a gene on a chromosome

longitudinal wave particles oscillate parallel to direction of energy transfer

mass number total number of protons and neutrons in the nucleus of an atom

mean the average value, found by adding all the numbers together and dividing by the count of numbers.

mechanical wave a disturbance in a medium that transfers energy through that medium

median the middle value in an ordered data set, or the average of the two middle values if the set has an even number of observations.

medium the matter through which a mechanical wave travels

megafauna large animals with a body mass of over 45 kilograms

meiosis the process by which the gonads make the haploid gametes

memory cell a type of white blood cell formed after exposure to a pathogen that retains a record of that pathogen, allowing for a faster and more effective immune response upon future infection.

microplastics extremely small pieces of plastic resulting from the breakdown of human and industrial waste

microwaves electromagnetic radiation used for cooking, communications and Wi-Fi; lies between radio waves and infrared radiation

mineral a solid element or compound with a well-defined chemical structure

mitosis the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

mode the most frequently occurring value in a data set.

monogenic a trait that is controlled by a single gene

monohybrid cross a type of genetic cross or breeding experiment that considers the inheritance of a single trait or characteristic, typically controlled by a

monomer a molecule that can be bonded to other identical molecules to repeat and form a polymer

monomer a single subunit that when joined together repeatedly makes a polymer

motor neuron a nerve cell that transmits messages from the central nervous system to effectors

multifactorial inheritance the key concept in genetics that traits develop in individuals by interactions between their genes, and environmental factors

mutagenic causing mutations in dna

mutation a change in the genetic code of a cell

natural selection a process in which organisms whose phenotype is best adapted to their environment are more likely to survive and reproduce

negative feedback a regulatory process that reduces changes in a system, bringing it back to its normal state when it deviates from its set point

negligible so small that it can safely be ignored without significantly altering results

nervous system the body system consisting of the brain, spinal cord and peripheral nerves and receptors that communicate messages quickly within the body

net force the sum of all the forces acting on an object

neuron a nerve cell

neurotransmitter the chemical messenger that is released from one neuron and travels across the synapse to bind to the next neuron

neutralisation reaction a reaction between an acid and a base, forming a solution that has a pH of 7

Newton's first law of motion an object will remain at rest or in constant motion in the same direction unless acted upon by an external unbalanced force

Newton's second law of motion describes the force (*F*) required to change an object's acceleration (*a*) for a particular mass (*m*)

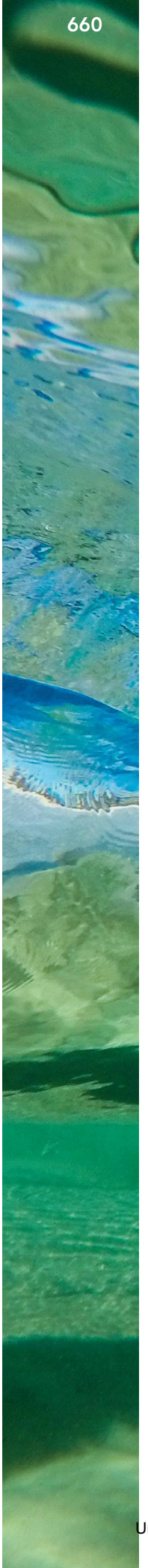
Newton's third law of motion for every action, there is an equal and opposite reaction

noble gas configuration an electron configuration where the outer shell is full, similar to the electron configurations of the noble gases

non-disjunction the failure of homologous chromosomes or sister chromatids to separate correctly in meiosis

non-homologous chromosomes chromosomes that do not belong to the same pair

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



non-infectious disease not caused by pathogens and cannot be transmitted between individuals.

non-renewable existing in limited quantities that cannot be replaced after they have all been used

non-specific immunity the branch of the immune system that provides immunity without recognizing specific pathogens. It includes the first and second lines of defence, such as physical barriers, inflammation and fever.

normal an imaginary line that is at right angles to a surface

nuclear fission a reaction where the nucleus splits into two or more smaller nuclei, releasing energy

nuclear fusion a nuclear reaction where the nuclei of two small atoms fuse to create an atom with a higher atomic mass, releasing a large amount of energy

nucleotide a monomer subunit of a nucleic acid, consisting of a phosphate group bound to a five-carbon sugar, which in turn is bound to a nitrogenous base

ohm the unit of resistance

Ohm's law the law that states there is a direct proportionality between the voltage applied across some conductors and the resultant electric current

opaque a substance that blocks the transmission of light completely

optic nerve the nerve that connects the eye with the brain

optical density an indicator of the refractive power of the substance, which is measured by comparing the amount incident light to the amount of transmitted light

organic class of compounds containing carbon covalently linked to other elements, usually also containing hydrogen

origin the point on a graph where the *x*-axis and *y*-axis intercept (0, 0)

oscillating moving back and forth with periodic motion somewhat like vibration

oscillation a type of motion back and forth about a central point, repeating regularly

osmoregulation the regulation of water levels in the blood/body

outlier anomalous data value that does not seem to fit the rest of the data

ova mature female reproductive cells (singular: **ovum**)

pandemic a global outbreak of a disease that affects a large number of people across multiple countries or continents

parallax error a measurement taken that is not the true value due to the position of the object along various lines of sight

parallel circuit a circuit in which several branched for current to flow where each component is connected to the battery

parent chain the longest continuous chain of carbon atoms in an organic molecule

pathogen an infectious agent that can cause disease

pathogen any agent that can cause disease, such as bacteria, viruses or fungi

pedigree a chart that shows relationships between family members and indicates which individuals have certain genetic traits

period time in seconds for one cycle

periodic motion a movement of a particle or object that returns to its starting position and repeats in the same time interval, like a swing; oscillation is an example

phagocytosis a cellular process where a white blood cell engulfs and ingests a cell or large particle to break it down using enzymes

phenotype the observable characteristics of an organism, resulting from both genotype and the environment

Phytomining <definition to come>

pitch how high or low a sound seems to our ears on a music scale

plagiarism the process or practice of using another person's idea or work and pretending that it is your own

point mutation a mutation in which a single nucleotide is changed

polymer a molecule made from many repeating subunits called monomers

polymer natural or synthetic substances composed of very large molecules made up of multiples of simpler molecules

polypeptide a chain of amino acids, forming part or the whole of a protein molecule

population (ecological) a group of a particular species living and interbreeding in the same geographical area

positive feedback a mechanism that maintains the direction of a stimulus and accelerates its effect

precipitate a solid formed in a solution

precision how closely repeated measures agree with each other

prediction a statement that describes what is expected to happen if the hypothesis is true

primary data data that researchers collect themselves for a specific purpose; obtained from observations, experiments, surveys or interviews

prokaryote a unicellular organism with no membrane-bound organelles

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

pseudoscience knowledge or claims that appear to be scientific but do not follow the rigorous methods of science, often based on beliefs or opinions rather than evidence, and which are not are not testable or reproducible

punnett square a specialised grid to show genetic crosses

qualitative a form of data that is a descriptive measurement

quantitative a form of data that is a numerical measurement

quark an elementary type of subatomic particle, fundamental component of matter

radio waves electromagnetic radiation that has the longest wavelength

radioactive decay when an unstable nucleus emits radiation and breaks down to form another element

radioisotope a radioactive isotope of a chemical element with an unstable nucleus that emits excess energy (radiation)

radioisotopes unstable isotopes that are likely to break down or decay into other elements to try to achieve a stable nucleus

random error error caused by limitations of the measurement device or the observer that does not follow a regular pattern

range the difference between the highest and lowest values in a data set.

rarefaction the part of a longitudinal wave where the particles are spread apart

reaction rate the quantity of reactant or product used up or made per unit time; how fast the reaction goes

reactivity series a list of metals ordered by their reactivity from highest to lowest

reading error a reading or measurement that is not the true value

receptor a specialised structure that allows the body to detect and respond to stimuli

recessive a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

recombination the rearrangement of genetic material, especially by crossing over

red shift a spectrum shifted towards longer wavelengths

reduction division cell division which results in a reduction of genetic material in the daughter cells

reflect to bounce back the energy of a wave (e.g. heat, light, sound) without absorbing it

reflected ray a ray of light that is reflected off a surface

reflex action a fast, involuntary motor action that protects the body from harm

refraction the bending of light as it passes from one medium to another

refractive index a measure of how much the speed of light changes as it passes from a vacuum into a particular substance

relative dating determining the order of past events without the specific age

relative uncertainty the ratio of the absolute uncertainty to the reported value, often expressed as a percentage

reliability how repeatable, replicable and reproducible the results are

renewable can be produced as quickly as it is used

repeatability how well the results match up when the same scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

replicability how well the results match up when a different scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

reproducibility how well the results match up when a different scientist repeats the experiment under different conditions to the original experiment, including different equipment and laboratory or field site

reproductive isolation when members of two related populations can no longer interbreed

resistance the degree to which a substance resists the flow of an electric current through it

response the reaction to a stimulus

retina an area of tissue at the back of the eye that contains cells that detect light and colour

salt a compound produced by the neutralisation of an acid by a base

sample size the number of test subjects that are tested or observed in an experiment

saturated an organic molecule that contains only single bonds between carbon atoms and is bonded to the maximum amount of hydrogen atoms

scalar a quantity that has magnitude only

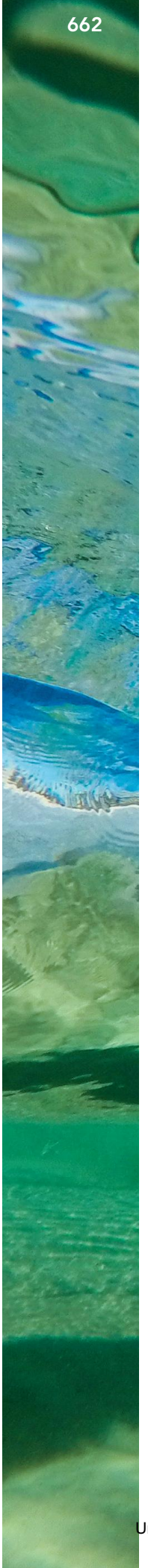
secondary data information that has already been collected and analysed by others that is used to support or inform new research.

seismic waves waves that travel through the Earth and over its surface which when large enough cause earthquakes

selection pressure a factor that affects the relative fitness or reproductive success of individuals within a population, leading to natural selection and potential changes in allele frequencies over time

selective advantage the characteristic of an organism that enables it to survive and reproduce better than other organisms in a population

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400



selective breeding another term for artificial selection

sensitivity the smallest change in a value that an instrument can detect or measure

sensory neuron a nerve cell that transmits messages from the sensory receptors to the central nervous system

septic the presence of harmful pathogens in living tissue

series circuit only one path for the current to flow

sex chromosomes chromosomes that determine the sex of an organism. in humans, these are chromosome pair 23

sexual reproduction form of reproduction that involves two parents and introduces variation to the offspring

SI units the standard international system of units used for measuring physical quantities, ensuring consistency and uniformity in scientific and technical communication globally

sign is an observable or measurable indicator of a disease single gene with two alleles

singularity a point at which infinitely dense matter occupies an infinitely small space

sister chromatids two copies of the same chromosome, connected at a centromere

somatic cells the body cells of an organism

somatic mutation a mutation that occurs in somatic (body) cells which

somatic nervous system the part of the peripheral nervous system involved with the voluntary control of body movements

SONAR a mode of navigation used by ships to located underwater objects using reflected sound

speciation the process by which populations evolve to become distinct species

species a group of organisms consisting of similar individuals who can interbreed with one another

species diversity the number and abundance of different species in a given area

specific immunity the branch of the immune system that targets each particular pathogen; the third line of defence

speed distance travelled per unit time, calculated by distance divided by time; this is the rate of change of distance with time

sphere one of Earth's major systems "atmosphere, hydrosphere, lithosphere or biosphere" that interact to support life and shape the planet.

spontaneous mutation a naturally occurring mutation

stable electron configuration an electron configuration where the outer shell of the atom is full

stem cell undifferentiated cells with the ability to develop into various specialised cell types

stimulus (plural: stimuli) a change in the environment that is detected by the human body

stratigraphy the branch of geology studying the rock layers

substitution where one nucleotide is swapped for another

surface area the area of the outer part or surface of an object

sustainable causing little or no damage to the environment and therefore able to continue for a long time

symptom is a subjective experience of a disease reported by the patient

synapse the junction between two neurons

synthesis a chemical process where two or more simple elements or compounds combine to form a more complex product

synthesise to make a chemical compound

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

T lymphocyte a type of white blood cell that helps regulate the immune response by directly attacking infected cells or coordinating the activity of other immune cells; also known as a T cell

tailings dam <definition to come>

target cell a cell affected by a specific hormone

telomeres structures made from dna and proteins that protect the ends of chromosomes

test cross a genetic cross between a homozygous recessive individual and an individual of unknown genotype showing the dominant trait to determine the unknown genotype

trace fossil a trace of an animal, such as footprint or imprint, that has become fossilised

transcription the first stage of protein synthesis in which the base sequence of dna is copied into mrna

transgenic organism an organism that possesses a foreign gene or segment of foreign dna in its genome because of human experimentation

translation the second stage of protein synthesis in which a sequence of mrna is translated into a sequence of amino acids

translucent allowing some light to pass through, but no clear image can be seen through them

transparent allowing light to pass through and a clear image can be seen through the substance

transverse wave a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

trisomy when an organism has a third copy of a chromosome

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400

trough the maximum displacement of a particle at the bottom of the wave

ultraviolet light radiation that lies between visible light and X-rays; is needed by our bodies to make vitamin D; short wavelength UV can cause sunburn and cancer

uncertainty the doubt that a measured value is the true value

univariate analysis examining the characteristics of a single variable to understand its distribution and key features

unsaturated a compound that contains at least one double or triple bond and does not therefore have the maximum amount of hydrogen bonds

useful energy energy that can be used for a specific purpose

vaccination the process of administering a vaccine to an individual to induce an immune response

vaccine a preparation made from a dead or weakened version of a pathogen, designed to stimulate immunity against that pathogen when administered through injection or ingestion.

vacuum a space totally devoid of matter

validating checking if something is accurate, correct or reliable

validity the extent to which an experiment is a fair test, with all relevant variables controlled, and appropriately addresses the research question, and accurately measures what it claims

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

variation the range of differences or diversity in traits, characteristics or genetic make-up among individuals

vector a quantity that has both magnitude and direction

vector transmission the transfer of pathogens from an infected host to a susceptible host through a living organism that carries the pathogen without causing the disease itself.

velocity displacement travelled per unit time, calculated by displacement divided by time; this is rate of change of displacement with time

viable able to survive

virus an extremely small, non-cellular pathogen that consists of genetic material encased in a protein coat and relies on invading living host cells to replicate

visible light the part of the electromagnetic spectrum that we can see

voltage a measurement of how much energy each charge carrier is given

voltmeter a device for measuring voltage (potential difference) between two points on an electric circuit

wave carrier of energy from one place to another without any matter accompanying it

wavelength the distance from one wave crest to the next

weather the atmospheric conditions (such as temperature, cloud, rain or wind) at a particular time over a particular area

X-rays short wavelength electromagnetic radiation that can pass through flesh to give images of bones; hazardous and can cause cancer

zero calibration error a measuring instrument giving a non-zero reading when the true value should be zero

zygote a fertilised egg produced by the fusion of male (sperm) and female (ovum) gametes

Uncorrected 4th sample pages • Cambridge University Press and Assessment © Dale, et al 2025 • 978-1-009-59637-4 • Ph 03 8671 1400