

oxford big ideas

australian curriculum

science 10

geoff quinton | sally cash | craig tilley | emma craven

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geoff quinton | sally cash |
craig tilley | emma craven |
greg laidler | eileen kennedy

series consultant: geoff quinton

first edition author team:

daniela nardelli, angela stubbs, lynda schulz,
kristen alford, francesca calati, craig cleeland,
karen drought, teresa eva, anita giddings, christina hart,
peter razos, david wilson, eric brons, gillian coyle,
rosemary koina, karen marangio, helen silvester

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Oxford University Press is a department of the University of Oxford. It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide. Oxford is a registeredtrademark of Oxford University Press in the UK and in certain other countries.

Published in Australia by

Oxford University Press
253 Normanby Road, South Melbourne, Victoria 3205, Australia
© Oxford University Press 2012

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First published 2012.
Reprinted 2012, 2013 (twice)

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National Library of Australia Cataloguing-in-Publication data

Title:	Oxford big ideas. Science 10 : Australian curriculum / Sally Cash ... [et al.]
Edition:	1st ed.
ISBN:	9780195573589 (pbk.)
ISBN:	9780195577099 (pbk. plus obook/assess)
ISBN:	9780195525281 (pbk. plus obook/assess/MULTI)
Notes:	Includes index.
Target Audience:	For secondary school age.
Subjects:	Science–Study and teaching (Secondary)–Australia.
Other Authors:	Geoff Quinton, Craig Tilley, Helen Silvester.

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Edited by Natalie Korszniak
Illustrations by Guy Holt Illustration and Design and Stuart Jackson-Carter www.the-art-agency.co.uk
Medical illustrations by Beth Croce, CMI
Typeset by Watershed Design, diacriTech, Chennai, India and Rose Keevins
Proofread by Sally Woollett
Indexed by Max McMaster, Master Indexing
Printed in China by Golden Cup Printing Co. Ltd

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What is... *Oxford Big Ideas Science?*

Oxford Big Ideas Science is an innovative suite of resources completely aligned to the Australian Curriculum. Based on a big ideas framework, the pedagogy enables students to develop deep, transferable understandings and skills.





Why big ideas?

Research shows that students achieve greater success when the information they learn is connected to key concepts. *The Australian Curriculum: Science* has identified nine **key science concepts** or **big ideas** that are developed through the curriculum content. It is expected that by the end of Year 10, all students will have an understanding of these big ideas. Each chapter in the *Oxford Big Ideas Science* student books—from Year 7 to Year 10—is engineered to build student understanding of these big ideas or key concepts.

What are the big ideas?

Biological sciences

- Diversity and evolution
- Interdependence
- Structure and function

Chemical sciences

- Properties and structure
- Interaction and change

Earth and space sciences

- Systems in space
- Dynamic Earth

Physical sciences

- Forces and motion
- Energy and its transformations

Oxford Big Ideas Science ...

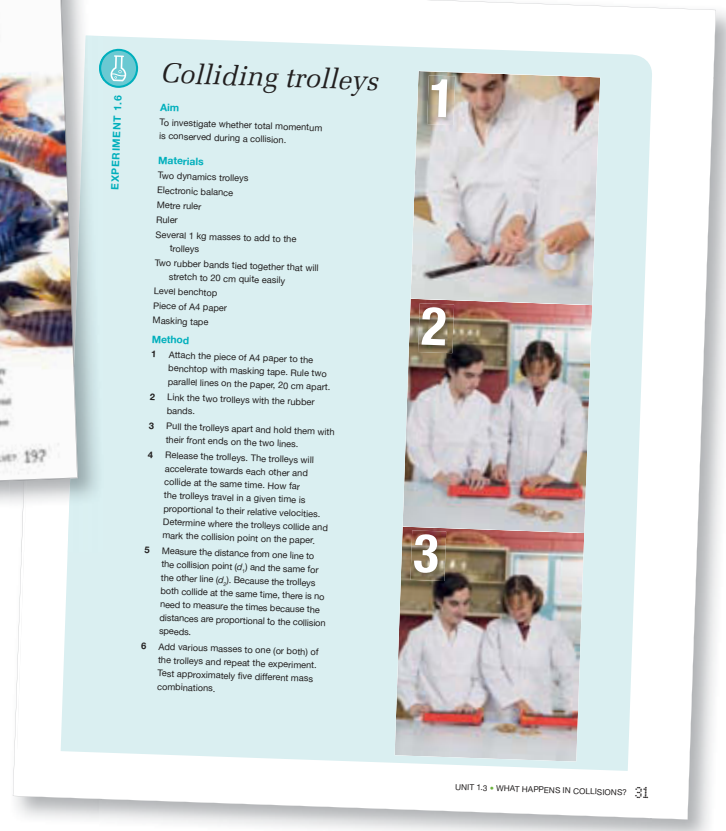
- organises learning around the nine **big ideas** of science and revisits these ideas with increasing complexity
- sorts content into meaningful inquiry-based big questions and establishes learning priorities
- focuses on developing scientific and inquiry skills
- takes a truly integrated approach to Science Understanding, Science Inquiry Skills and Science as a Human Endeavour
- includes a brand new Discovering Ideas inquiry task at the start of every unit
- uses the six **overarching ideas** from the *Australian Curriculum: Science* to connect content across the disciplines of science
- seamlessly covers the big ideas, overarching ideas, general capabilities, cross-curriculum priorities and three strands from the *Australian Curriculum: Science*
- engages students with topical stimulus material, stunning imagery and step-by-step instructional skills photography
- includes a workbook, **obook** and teacher kit to offer the complete teaching package at each year level
- offers innovative digital resources including a digital workbook and **obook**.



Spectacular and current photographs bring science to life.

ENGAGING LEARNING

Each student book chapter is designed to visually and creatively engage students with beautiful artwork, photographs, case studies, source material and in-depth coverage of the topic being studied.



Chapter openers introduce the key inquiry questions of the chapter and are designed to spark interest, elicit prior knowledge and unravel current misconceptions.





Discovering Ideas tasks allow students to discover science themselves, before they have all the answers.

INQUIRY-BASED LEARNING

The Australian Curriculum: Science presents an opportunity to re-imagine the science classroom by integrating supported inquiry, collaborative inquiry and full student-directed inquiry. Experience first-hand an inquiry-based approach to science education.

DEEP LEARNING

Content is designed for depth of learning. Concepts are revisited with increasing levels of complexity so that students gain a rich understanding of key concepts.



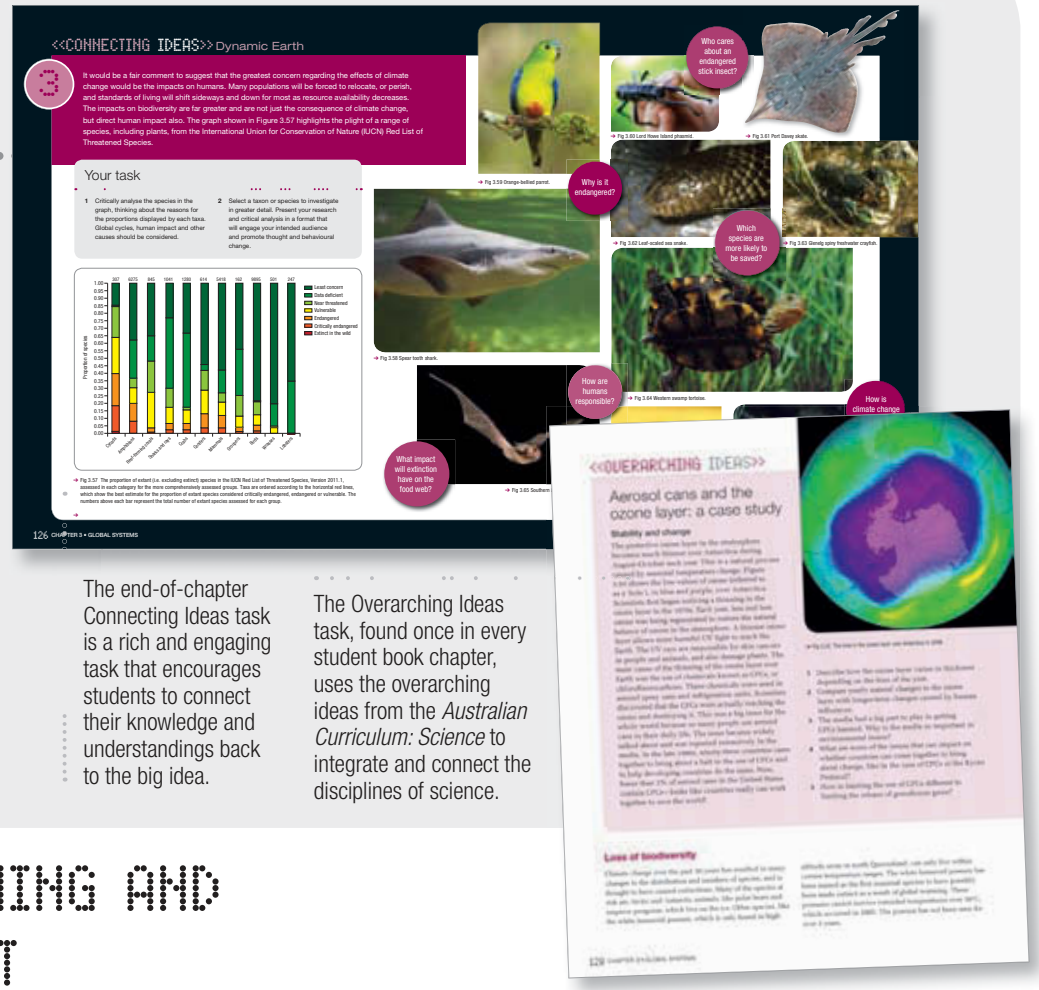


Big Ideas activity blocks at the end of each section use Bloom's Taxonomy and other strategies to cater for a multiplicity of learning styles.

Science as a Human Endeavour is integrated meaningfully throughout the chapters, providing depth and relevance.

CONNECTED LEARNING

Oxford Big Ideas Science takes a truly integrated approach to Science Understanding, Science Inquiry Skills and Science as a Human Endeavour. The student book series uses the six overarching ideas from the *Australian Curriculum: Science* to connect content across the disciplines of science and seamlessly covers the big ideas, general capabilities, cross-curriculum priorities and three strands from the *Australian Curriculum: Science*.



The end-of-chapter Connecting Ideas task is a rich and engaging task that encourages students to connect their knowledge and understandings back to the big idea.

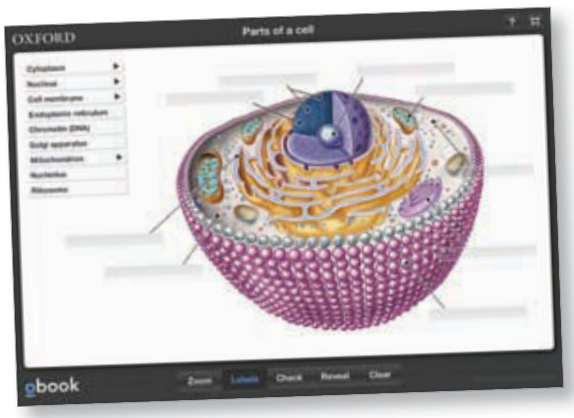
The Overarching Ideas task, found once in every student book chapter, uses the overarching ideas from the *Australian Curriculum: Science* to integrate and connect the disciplines of science.

INTEGRATED TEACHING AND LEARNING SUPPORT

obook

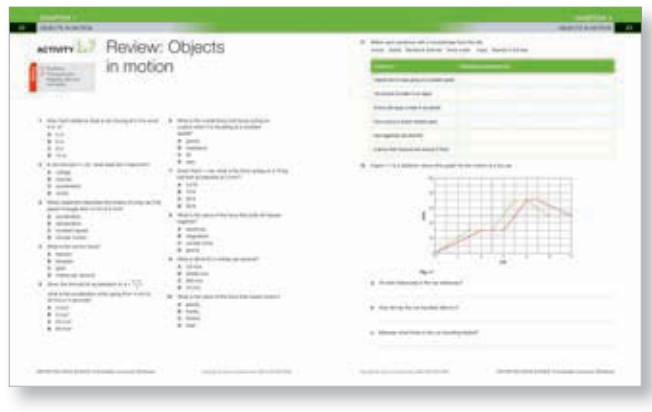
Oxford's next generation ebook—the **obook**—offers online and offline access to core student content.

The **obook** provides the complete student textbook in an easy-to-read format for any device or screen size, with multimedia links, interactive learning objects, a note-taking study tool and dynamic question blocks. Oxford's obook is compatible with laptops, iPads, tablets and IWBs. *Oxford Big Ideas Science* **obooks** include access to the *Virtual Laboratory*—the online video portal. Speak to your Oxford representative about networking options.



Workbook

Oxford Big Ideas Science is supported by a workbook at each of years 7–10. The workbooks provide extra practice of key skills and encourage an inquiry-based approach to learning—perfect for in-class or homework. An innovative digital workbook is also available.



Teacher kit

Each teacher kit includes all pages from the student book scaffolded with teaching strategies, lesson planning tips, assessment advice and suggested answers—everything you need to integrate Oxford resources into your teaching.

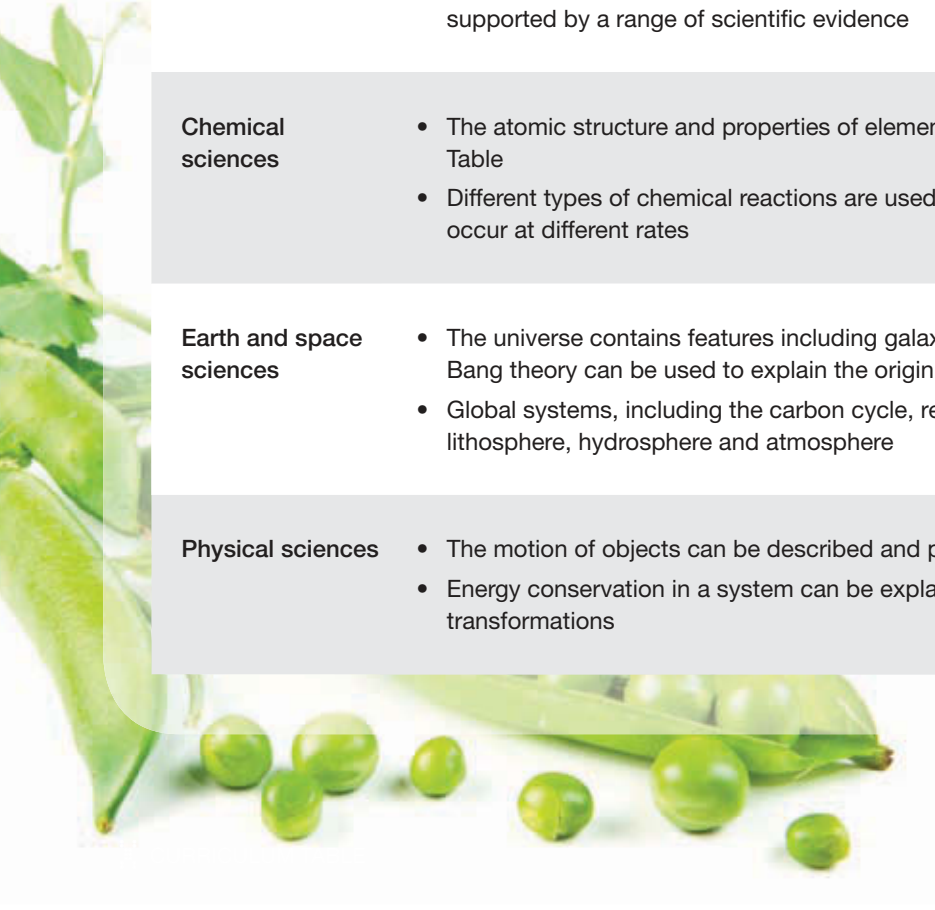
What is...

The Australian Curriculum: Science?



Science understanding (Year 10)

Sub-strand	Content descriptor	Chapter
Biological sciences	• The transmission of heritable characteristics from one generation to the next involves DNA and genes	4
	• The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence	5
Chemical sciences	• The atomic structure and properties of elements are used to organise them in the Periodic Table	6
	• Different types of chemical reactions are used to produce a range of products and can occur at different rates	7
Earth and space sciences	• The universe contains features including galaxies, stars and solar systems and the Big Bang theory can be used to explain the origin of the universe	2
	• Global systems, including the carbon cycle, rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere	3
Physical sciences	• The motion of objects can be described and predicted using the laws of physics	1
	• Energy conservation in a system can be explained by describing energy transfers and transformations	



Science as a human endeavour (Years 9–10)

Sub-strand	Content descriptor	Chapters
Nature and development of science	• Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community	1, 2, 3, 4, 5 & 6
	• Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries	1, 2, 4, 6 & 7
Use and influence of science	• People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions	2 & 3
	• Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities	1, 2, 3, 4 & 7
	• The values and needs of contemporary society can influence the focus of scientific research	1, 2, 3, 4 & 7

Science inquiry skills (Years 9–10)

Sub-strand	Content descriptor	Chapters
Questioning and predicting	• Formulate questions or hypotheses that can be investigated scientifically	ALL
Planning and conducting	• Plan, select and use appropriate investigation methods, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods	ALL
	• Select and use appropriate equipment, including digital technologies, to systematically and accurately collect and record data	
Processing and analysing data and information	• Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies	ALL
	• Use knowledge of scientific concepts to draw conclusions that are consistent with evidence	
Evaluating	• Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data	ALL
	• Critically analyse the validity of information in secondary sources and evaluate the approaches used to solve problems	
Communicating	• Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations	ALL

Key concepts

Big idea	Key concept	Chapter
Diversity and evolution	A diverse range of living things have evolved on Earth	4, 5
Interdependence	Living things are interdependent and interact with each other and their environment	N/A
Structure and function	The form and features of living things are related to the functions that their body systems perform	N/A
Interaction and change	Substances change and new substances are produced by rearranging atoms through atomic interactions and energy transfer	7
Properties and structure	The chemical and physical properties of substances are determined by their structure	6
Systems in space	Earth is part of a solar system that is part of a larger universe	2
Dynamic Earth	Earth is subject to change within and on its surface over a range of timescales as a result of natural processes and human use of resources	3
Forces and motion	A range of forces affect the behaviour of objects	1
Energy and its transformations	Energy can be transferred and transformed from one form to another	N/A



Overarching ideas

Patterns, order and organisation	Chapters 4, 5 & 6
Form and function	Chapters 4, 5, 6 & 7
Stability and change	Chapters 1, 3 & 7
Scale and measurement	Chapters 1 & 2
Matter and energy	Chapters 1, 3, 6 & 7
Systems	Chapters 2 & 3

General capabilities and cross-curriculum priorities

Literacy	ALL
Numeracy	ALL
ICT	ALL
Critical and creative thinking	ALL
Ethical behaviour	Chapters 3, 4, 5, 6 & 7
Personal and social competence	Chapters 1, 4 & 5
Intercultural understanding	Chapters 2 & 4
Sustainability	Chapters 3, 6 & 7
Aboriginal and Torres Strait Islander histories and cultures	ALL
Asia and Australia's engagement with Asia	Chapter 3

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1 Objects in motion



→ Fig 1.1 A free-fall ride like this can be great fun!

1.1 What are the characteristics of movement?

High-speed movement can be exciting. The rides at theme parks are exhilarating because they all involve some form of movement, such as circular movement, vertical movement or twisting, turning or bumping. Movement, and the effect it has on our bodies, gives some of us a natural adrenaline rush and others an upset stomach! Understanding the movement we experience and the characteristics of movement is a fascinating part of science. Sports scientists, for example, work with athletes to better understand how the athletes' bodies move in order to improve their technique. Through the study of science and sport, researchers have developed a greater understanding of human movement.

1 What is your understanding of the term 'speed'?
2 What type of ride do you enjoy at theme parks?
3 How does your body respond to this type of movement?
4 How do you feel before, during and after the ride?

1.2 How do force and mass affect movement?

Formula One cars are extremely powerful vehicles and it takes great skill on the part of the driver to keep the car under control at high speeds, when braking and in cornering situations. In fact, the g-forces on the driver can be as high as 5*g*, which puts a lot of stress and strain on the driver's body. (Note: 1*g* is equivalent to the force of gravity that we feel every day, so 5*g* is five times the force of gravity.) Aircraft pilots can 'blackout' if they pull too many *g*s in high-speed turns.

When a Formula One car accelerates off the start line, the driver is 'pushed' back into the seat. When braking before entering a corner, the driver is 'pushed' forward against the seatbelt. When turning corners, the driver is 'pushed' to the side. The drivers of Formula One cars have to be exceptionally fit to withstand these forces.

1 Are the drivers really 'pushed' around by a force in the examples given above?
2 Why would pilots blackout if they pulled too many *g*s?
3 Formula One cars also experience 'down force'. Why is this important in a race?
4 What features do Formula One cars have, apart from a powerful engine, to enable them to reach extremely high speeds?
5 What do a Formula One car driver and an aircraft pilot have in common during their high-speed motion?

Movement, in all its different forms, is essential to our lives. You might remember feeling bored when you were sick and stuck in bed all day, or frustrated when you were stranded without a lift home. Many sports involve movement of a ball and all involve movement of the human body. We are all familiar with movement in various forms, yet how much do we know about it and how it relates to force, mass and energy? And how good are we at measuring it? In this chapter we will start to unravel how force, mass and movement are linked together within the big idea of energy.



→ Fig 1.2 Air force pilots must withstand significant *g*-forces on their bodies.



→ Fig 1.3 Scientists conduct controlled crash tests on all makes and models of vehicles to give them a safety rating.

1.3 What happens in collisions?

When a driver loses control of their car, the result can be disastrous. Modern vehicle design has come a long way with improvements, inventions and new technologies to make cars safer and easier to control—for example, cars are now fitted with features such as an anti-lock braking system (ABS), electronic brake distribution (EBD), electronic stability control (ESC) and up to eleven airbags. Despite these safety measures, collisions still occur. We have all heard the expression 'speed kills' but, in a collision, it's not how fast you are going that is the important thing, but how fast you stop! Sudden stops can do catastrophic things to the human body. It is the cushioning effect of a car's airbag, similar to the big soft crash bags you land on after doing a high jump or pole vault, that minimise the effects of a collision. Collisions involve the scientific principles of momentum, work and energy. These concepts will be explored later in this chapter.

1 Why is how fast you stop more important than how fast you are going? Can you think of an example?
2 Give an example of something that stops rapidly.
3 Give an example of something that stops gradually.
4 What are the consequences of stopping rapidly compared with stopping gradually? In a group of three, find a safe way to model this concept.

1.1

What are the characteristics of movement?



How did you get to school today? How would you describe the movement of the car, bus, train, bike or your own feet that takes you to and from school each day? Several specific scientific terms and mathematical formulas can be used to describe moving objects and very precise measuring equipment is used to measure the motion of objects. It is important to understand these terms, because movement is an everyday event for all of us.



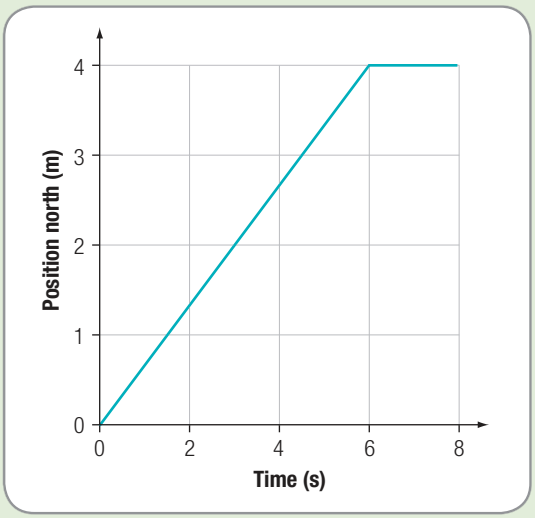
DISCOVERING IDEAS

Graphing motion

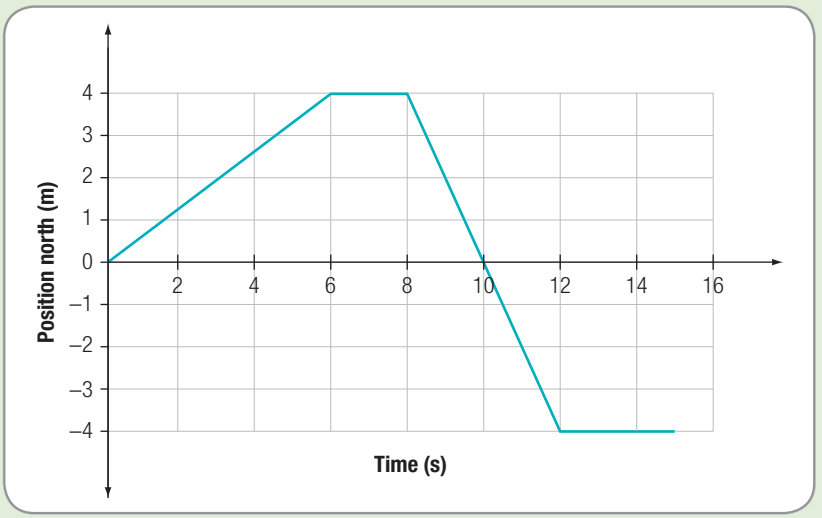
Examine the graphs below with two other members of your class and brainstorm answers to the questions that follow.

- Describe, in words, the motion of object A.
- Object A covers a distance of 4 metres. How do you know this?
- The final displacement of object A is 4 metres north. How do you know this?
- Between 6 and 8 seconds, object A was stationary. How do you know this?

- Describe, in words, the motion of object B.
- Object B covers a distance of 12 metres. How do you know this?
- The final displacement of object B is 4 metres south. How do you know this?



→ Fig 1.4 A position–time graph for object A.



→ Fig 1.5 A position–time graph for object B. The negative *y*-axis represents positions south of the starting point.

Distance and displacement

During a normal day you may cover a considerable distance—on the way to school, on the way home, around school from classroom to classroom—and, if you play sport, the distance you cover can really add up. However, at the end of the day you will most likely end up in exactly the same place as where you started the day: bed! So, you could say that you haven't really gone anywhere at all. We can describe an end result like this as having zero displacement, despite the huge distance you may have covered in one day. These two terms—*distance* and *displacement*—are the first of several concepts we will look at for describing motion.

Distance is how far an object travels over a certain period of time. **Displacement** describes the *change in position* of an object *and its direction* over a certain period of time. Displacement only compares the end position with the starting position, not all the in-between movements. If an object ends up back where it started, its displacement is always zero. If an object travels hundreds of kilometres in a given period of time but ends up 1 metre north of its starting point, its displacement for that period of time is 1 metre north. For both distance and displacement, the symbol we use is *d* and the standard unit (or SI unit) is the metre (m).

Remember: 1000 metres (m) = 1 kilometre (km).

Distance is known as a scalar quantity because it only has size (or **magnitude**) and no direction. Displacement is known as a **vector** quantity because it has size and direction. The direction part can be a compass direction (north, south, east, west) or a bearing, or it may be as simple as left, right, up, down, forward or backwards. Table 1.1 lists some examples of distance and displacement measurements.

→ Table 1.1 Distance and displacement measurements

Distance	Displacement
42 m	12 m left
12 cm	44 cm forward
1.9 km	5.6 km north



Position–time graphs

Have you ever seen a movie or read a book where a cryptic code is used to find the buried treasure or precious artefact? These codes often contain instructions like 'walk 15 paces south and then 20 paces west', which could lead to a very different outcome depending on how big, or small, your steps are!

PRACTIVITY 1.1

Bringing graphs to life!

Working in pairs, act out the position–time graphs from the Discovering Ideas activity.

What you need: a clear space (maybe outside), tape measure, stopwatch, masking tape, marker pen

1. Lay out a 4-metre piece of masking tape on the floor and mark it at intervals of 1 metre.
2. Rehearse the motion shown in Figure 1.4 by discussing it with your partners and even doing a walk-through rehearsal.
3. Start the stopwatch and try to match your motion to the graph. The person timing you will give you feedback on how you went.
4. Swap roles and repeat the activity until everyone in your group has had a turn.
5. Try it again with Figure 1.5, but this time you will need another piece of masking tape on the floor going 4 metres in the opposite direction.



- How did your group perform in this task?
- What difficulties did you have in demonstrating the motion?
- Draw your own position–time graph and try to act out the motion. How did you go this time?

In the real world, many professionals find it necessary to describe motion accurately, but using words to do this can be very time consuming and is often inaccurate (just like in the movies). It is often more convenient, and accurate, to display the motion of an object on a graph.

'Motion graphs' are a model or visual representation of a movement and can take many forms. The simplest is a position–time graph (also called a displacement–time graph). A position–time graph is a picture of the motion of an object. The 'picture' is a line to show the object's position (or displacement) at a given time from its starting point. Position–time graphs are really only useful when the motion is linear—that is, in the same line, such as north–south or east–west or up–down. Time is always on the *x*-axis and position is always on the *y*-axis. Always remember to mark the units (e.g. seconds, metres) on the graph. The graphs you examined with your partners in the Discovering Ideas activity were position–time graphs.

ZOOMING IN

Hawk-Eye

The tennis and cricket matches we see on television use a computerised system, called Hawk-Eye, to track the ball's path. In tennis, it is part of the adjudication (judging) system. In cricket, it is used to predict the ball's path, mainly for leg before wicket decisions, where the ball's path is extended past the batsman's legs to see whether it would have hit the stumps. Both systems are based on using visual images and timing information from at least four high-speed cameras located around the tennis court or cricket ground.

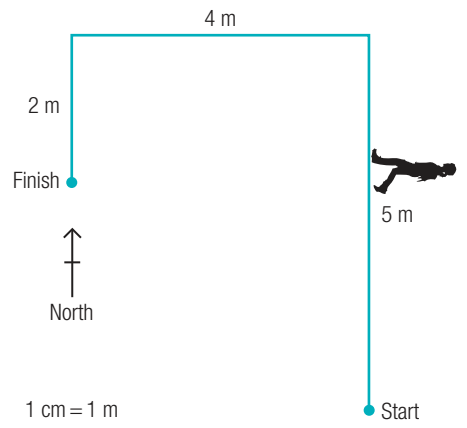
Distance and displacement diagrams

The distance an object travels can also be represented by diagrams. Distance and displacement diagrams (as opposed to graphs) are most useful when the movement changes from linear to two dimensions. We can use arrows to show the directions and a scale to show the distances. North commonly points towards the top of the page. For example, Figure 1.6 shows a diagram of a person walking 5 metres north, then 4 metres west and then 2 metres south. This gives a total distance covered of 11 metres. However, this is not their displacement. Their displacement only compares where they finish to where they started. Look carefully at Figure 1.7 to see how to work out the displacement. You will see why learning Pythagoras' theorem, trigonometry and bearings in mathematics can help us in science!

$$5 + 4 + 2 = 11$$

TIP The displacement is the final position compared with the starting position. Some of the mathematical tools we can use to calculate this include Pythagoras' theorem and trigonometry.

➔ Fig 1.6 The total distance covered is 11 metres.



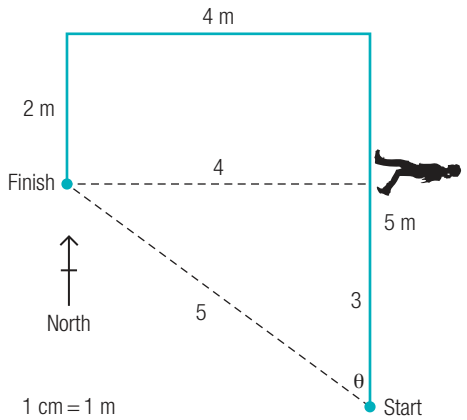
1 Calculate the distance between the start and finish points using Pythagoras' theorem.

If x = displacement:

$$x^2 = 3^2 + 4^2$$

Therefore, $x = 5$ m (the triangle is a 3–4–5 triad).

➔ Fig 1.7 A person walks a total of 11 metres. What is their displacement?



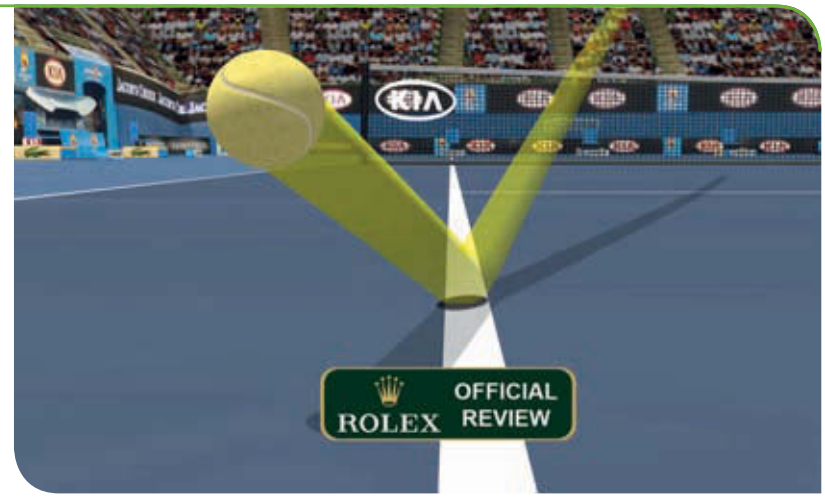
2 Work out the angle between the start and finish points using trigonometry.

$$\tan \theta = \frac{4}{3}$$

$$\theta = \tan^{-1}\left(\frac{4}{3}\right) = 53°$$

Therefore, the displacement is 5 m north 53° west, or 5 m on a bearing of 307°.

Rapid processing of the video feeds allows the generation of a three-dimensional visual image on the television screen of the path of the ball. Using the laws of physics, the future path of the ball can be predicted. This is just one example of how physics impacts on our everyday lives. Most of the time we can see an object's position but, in the tennis example above, the movement may be too quick for our eye to give us an accurate answer. In cricket, the ball is blocked by the batsman's pads and the umpires need to use their judgment to estimate the ball's path and its position relative to the stumps.



→ Fig 1.8 In this image, Hawk-Eye shows where the tennis ball has hit the court.

What do you know about distance and displacement?

1 Describe a motion that has zero displacement.

2 What is the difference between *displacement* and *distance*?

3 An object moves 14 metres north and then 14 metres south. What distance has it covered? What is its displacement?

4 What is the difference between a *vector* and a *scalar* quantity?

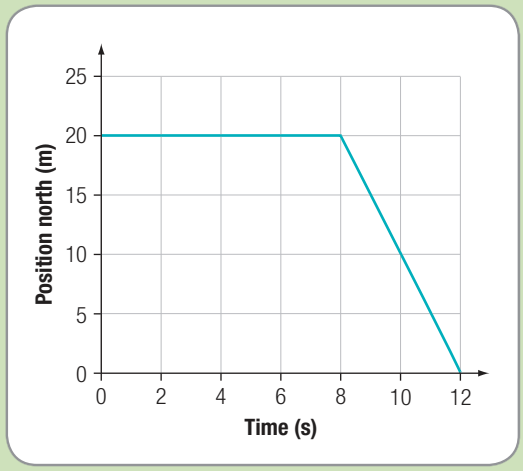
5 On the school oval, a person runs 50 metres north, then 20 metres south and then 30 metres west. What is the total distance covered? What is the person's displacement?

6 A car starts from rest (stationary) and moves north at a constant rate for 400 metres, then stops for 10 seconds before moving north another 150 metres. Draw this movement as a position–time graph.

7 Describe the motion shown in Figure 1.9.

8 What is the distance covered in Figure 1.9?

9 What is the displacement shown in Figure 1.9?



→ Fig 1.9



Speed and velocity

Speed is a measure of how fast a car or a person or any moving object is travelling. It is measured in SI units of metres per second (m/s or ms^{-1}), although kilometres per hour (km/h or kmh^{-1}) is often used instead, especially for cars and planes.

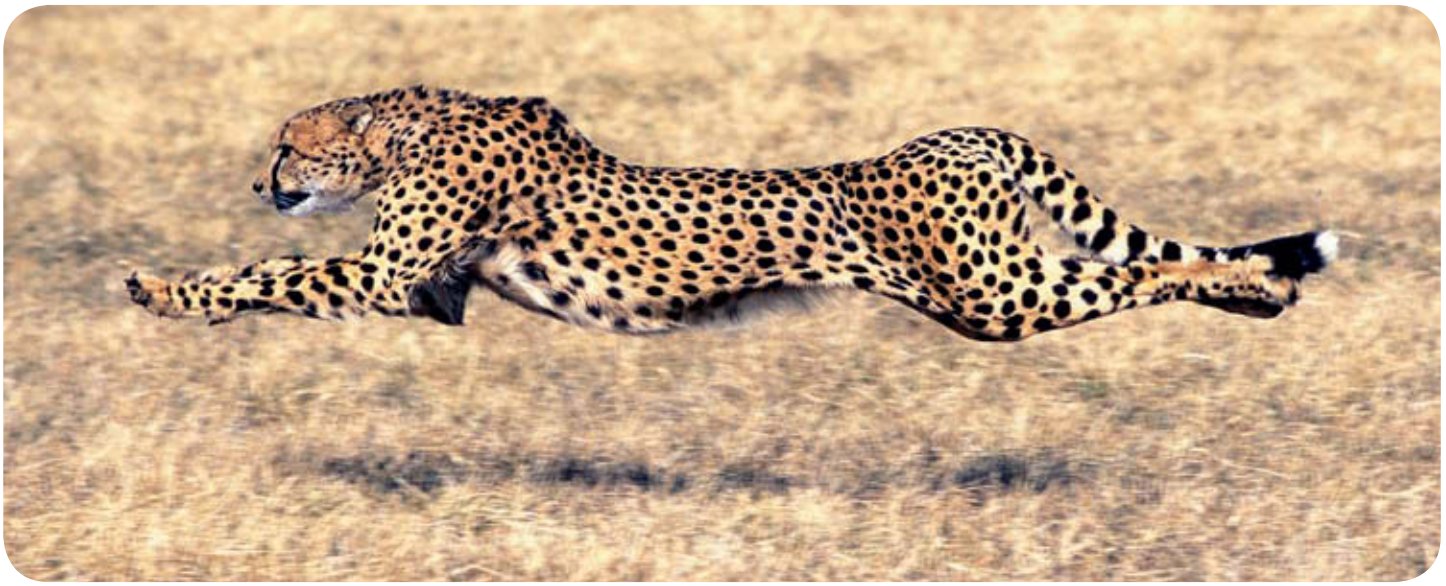
Speed is defined as the distance travelled per unit of time. Hence, a speed of 5 m/s means the object travels 5 metres in every second of its motion. Speed is a scalar quantity because it only has size and no direction.

Average speed

Often it is more convenient to work out (or calculate) an object's average speed. The symbol for average speed is s_{av}. To calculate average speed, divide the total distance travelled by the total time taken. The units for speed depend on the units of distance and time.

The formula for calculating the average speed is given in the box below. This rule, or formula, can also be expressed in a triangle. The triangle is a good memory tool to help you work out three formulas from the one diagram.

Average speed can also be determined by the gradient (or slope) of a position–time graph. In maths, you have probably already learned that the gradient is calculated using 'rise over run'. Take another look at Figure 1.4. The speed of the object between 0 and 6 seconds is calculated as: 4 ÷ 6 = 0.67 m/s. This is because the rise is 4 and the run is 6, giving a gradient of 0.67.



→ Fig 1.10 The cheetah is the fastest land animal. It can travel at speeds up to 112 km/h.

AVERAGE SPEED

$$\text{Average speed} = \frac{\text{distance}}{\text{time}}$$

The average speed triangle is used to work out the formula for average speed. Cover the quantity you want to calculate with your finger and the other two quantities will form the formula.

This gives:

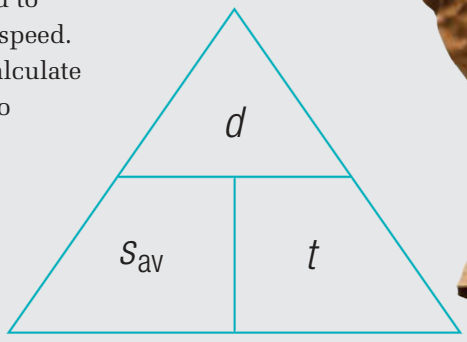
$$s_{av} = \frac{d}{t}$$

but also

$$d = s_{av} \times t$$

and

$$t = \frac{d}{s_{av}}$$



→ Fig 1.11 The average speed triangle.



PRACTIVITY 1.2

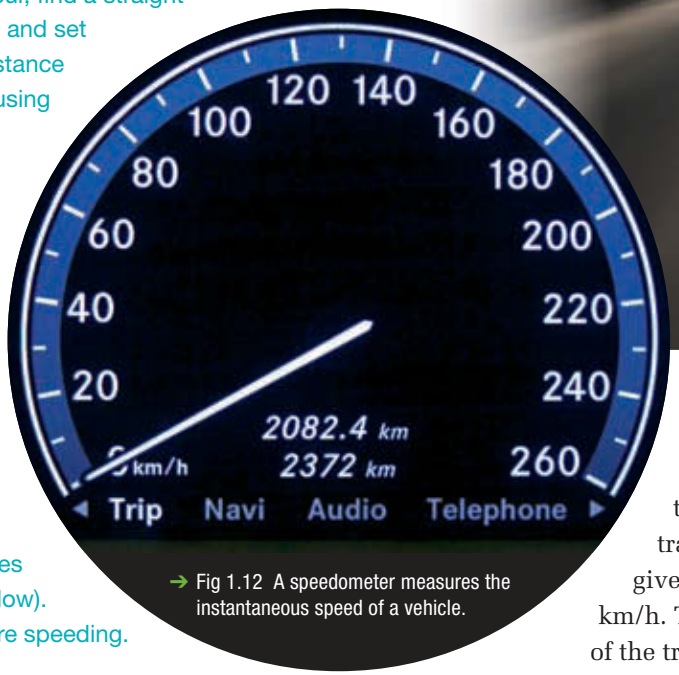
Speed trap

What you need: stopwatches, trundle wheel

It is important that you do not distract drivers in any way during this activity because this could have serious consequences. Always remain on the footpath at a safe distance from the road.

1. Working in a group of three or four, find a straight stretch of road near your school and set up a 'speed trap'. Measure a distance along the side of the road and, using a stopwatch, time the motion of vehicles over that distance.
2. You will need one person to stand at the start of the distance and wave to the others as each car passes them to indicate to the people in your group to start their stopwatches.
3. From your times and distance, work out the average speed of the vehicles in metres per second and then in kilometres per hour (see Numeracy Lab below). Decide if any of the vehicles were speeding.

- What percentage of vehicles tested were speeding?
- How accurate do you think your answers are? Give your reasoning.
- How could you improve this activity to make your answers more reliable?



→ Fig 1.12 A speedometer measures the instantaneous speed of a vehicle.

Instantaneous speed

Over the course of a bus or car trip, the speed at which you are travelling changes. The speedometer gives the instantaneous speed in km/h. This is the speed at each moment of the trip.

A ticker timer is commonly used to measure the speed of objects in the science laboratory. In Experiment 1.1 you will learn how these devices work. A motion sensor is also used to measure speed, in addition to position, displacement and acceleration. If your school has these devices, you should become familiar with how to use them.

NUMERACY LAB

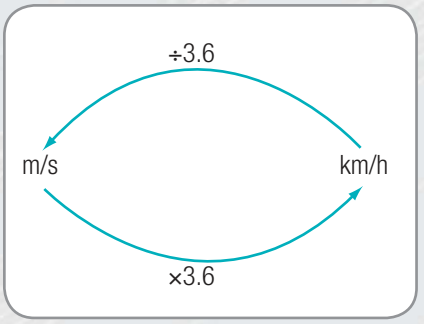
Unit conversion

The basic unit of speed is metres per second. However, the unit of kilometres per hour is also commonly used and most vehicle speedometers use this unit.

To convert from:

- m/s to km/h, *multiply* by 3.6
- km/h to m/s, *divide* by 3.6.

The 3.6 arises because there are 60 seconds in a minute and 60 minutes in an hour, giving 60 × 60 = 3600 seconds in an hour; in addition, there are 1000 metres in a kilometre, so 3600 ÷ 1000 = 3.6.



→ Fig 1.13 To convert from one unit to the other, follow the arrows.

EXPERIMENT 1.1

The ticker timer

Aim

To learn how a ticker timer operates and to use it to produce a speed–time graph.

Materials

Ticker timer
Power supply
Two electrical wires
Ticker tape
Ruler
Scissors
Graph paper
Glue
Carbon circles

Method

1 Connect the ticker timer to the AC terminals of the power supply using the two electrical wires.

2 Thread a 30-cm length of ticker tape through the slots in the ticker timer. Turn on the power and pull the tape through the timer. Examine the tape to see if the dots are clear.

3 If the dots are too faint, adjust the equipment by increasing the voltage of the power supply. A new carbon disc may be required if this doesn't solve the problem. It can also help to loosen or tighten the screw holding the 'arm' of the ticker timer.

4 Repeat with a 1-metre length of ticker tape. As you pull the ticker tape through, adjust your pulling speed so that there is a very slow section, a medium section and a very fast section, in any order.

Results

1 Start your analysis by finding the first clear dot. Number this dot '0'. Count along another five dots and rule a line right through the middle of the fifth dot. This gives a five 'gap' section of tape. The gap between successive dots is 0.02 seconds, so five gaps equals 5 × 0.02 or 0.1 seconds.

2 Divide the rest of your tape into five-gap sections by ruling lines through the middle of every fifth dot.

3 Number the sections of your tape and cut along the lines.

4 Glue each section of tape onto your graph paper, side by side, to form a column graph.

5 Add axes to your graph (speed on the *y*-axis and time on the *x*-axis) and work out a scale for each axis (see the hint below).

Discussion

1 Why does the length of each tape column indicate the speed?

2 How could you work out the average speed of each section? (*Hint*: Average speed = distance ÷ time.)

3 Why is it only the 'average' speed?

4 Design another experiment you could do using a ticker timer. Ask your teacher for permission to carry out your experiment.



→ Fig 1.14



→ Fig 1.15

EXPERIMENT 1.2

Using a motion sensor

Aim

To become familiar with the operation of a motion sensor and to use it to produce motion graphs.

Materials

Motion sensor

Dynamics trolley

Laptop computer

Method

1. Connect the laptop to the motion sensor and open the appropriate software on the laptop.
2. Position the motion sensor several metres in front of the dynamics trolley and push the trolley towards the sensor. (The trolley may need a cardboard reflector attached to the front of it to reflect the signal from the motion sensor back to the sensor.)

Results

Analyse the data on the laptop to produce a position–time graph (and speed–time graph and even an acceleration–time graph if possible).

Discussion

1. Can you work out what each graph is showing you?
2. How well did the graphs represent the actual motion of the trolley that you witnessed?
3. Design another experiment you could do using the motion sensor.
4. Evaluate this experiment compared with Experiment 1.1 in which you used the ticker timer. Which measuring instrument did you prefer and why?



Velocity

Pilots and sailors need to know both the speed of the wind and its direction. **Velocity** is speed in a particular direction and is therefore a vector quantity (a measurement of both size and direction). It has the same unit as speed (m/s). The average velocity of an object is calculated in a similar way to average speed, but displacement is used instead of distance (see Figure 1.16).

The direction of the average velocity is the same direction as the displacement. Like speed, average velocity can be determined from the gradient of a position–time graph, but the nature of the gradient indicates the direction. Look again at Figure 1.5. From 0 to 6 seconds, the average velocity is:

$$4 \div 6 = 0.67 \text{ m/s north}$$

The direction is north because the gradient is positive and positive is north on the graph.

From 8 to 10 seconds, the average velocity is:

$$4 \div 2 = 2 \text{ m/s south}$$

The direction is south because the gradient is negative and negative is south on the graph.

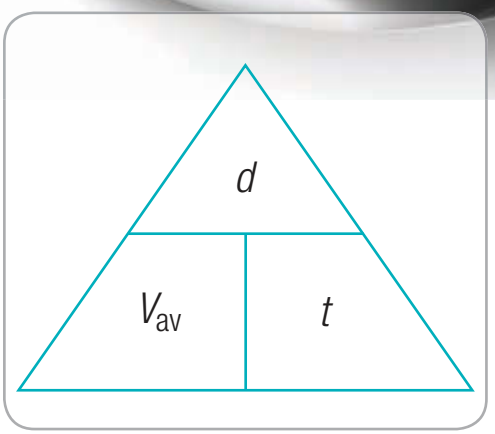
Look again at Figures 1.6 and 1.7. In these figures, the distance is 11 metres and the displacement is 5 metres in a direction of north 53° west. If the motion occurred over 11 seconds, the average speed would be:

$$s_{av} = 11 \div 11 = 1 \text{ m/s}$$

but the average velocity would be:

$$v_{av} = 5 \div 11 = 0.45 \text{ m/s}$$

in the same direction as the displacement: N 53° W or on a bearing of 307°.



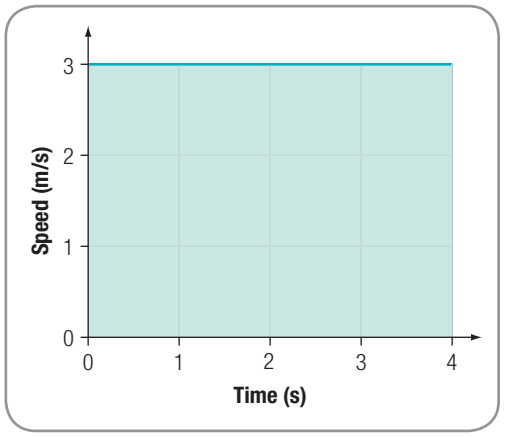
→ Fig 1.16 The average velocity triangle.

Graphing speed

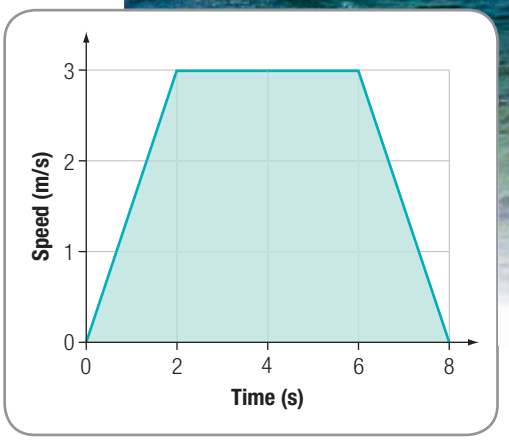
It is useful to represent an object's speed graphically. This is called a speed–time graph, as shown in Figures 1.17 and 1.18. In these graphs, speed is plotted on the *y*-axis and time on the *x*-axis.

Figure 1.17 shows an object with constant speed of 3 m/s for 4 seconds. The object would cover a distance of 12 metres in this time, which is calculated from the area under the graph (actually the area between the graph line and the *x*-axis) up to 4 seconds (i.e. 4 × 3 = 12).

Figure 1.18 shows an object with changing speed. The object increases speed from 0 to 3 m/s in 2 seconds, maintains this speed for another 4 seconds, then slows down in the final 2 seconds before coming to a rest (stopping). The distance formula cannot be used to calculate the distance covered because the speed of the object changed. The total distance is calculated from the area under the graph. The area can be broken up into two triangles and a rectangle, giving 3 + 12 + 3 = 18 metres, or it can be treated as a trapezium: ½ (8 + 4) × 3 = 18 metres.



→ Fig 1.17 A speed–time graph showing constant speed.



→ Fig 1.18 A speed–time graph showing changing speed.



→ Fig 1.19 The wind's speed and direction affect the speed of a yacht.

What do you know about speed and velocity?

1. Is 4 m/s a speed or a velocity? Explain your answer.
2. Use the average velocity triangle to write three different formulas.
3. What does the gradient of a position–time graph indicate?
4. What does the area under a speed–time graph indicate?
5. What other units do you know that are used to measure speed?
6. Convert 80 km/h to metres per second.
7. An object travels 40 km in 5 hours. What is its average speed?
8. Could the object in question 7 have had an instantaneous speed greater than the average speed? Explain your answer.

Acceleration

Pressing the accelerator pedal in a car makes the car move forward and increase in speed. This is the same as saying the car accelerates. Acceleration is the rate of change of speed. The term 'rate' in this case refers to time, so acceleration is the change of speed over time (see Figure 1.21).

Just as the accelerator pedal causes a car to speed up, the brake pedal causes a car to slow down. We call this **deceleration** (or negative acceleration).

Acceleration is measured in units of metres per second per second (m/s/s) or metres per second squared (m/s^2 or ms^{-2}) because speed is usually in metres per second and time is usually in seconds. However, other units are possible depending on the units of speed and time.

To understand acceleration we will only consider objects travelling in one direction in a straight line and under constant acceleration. Consider a falling object, such as a rock, as shown in Figure 1.20.

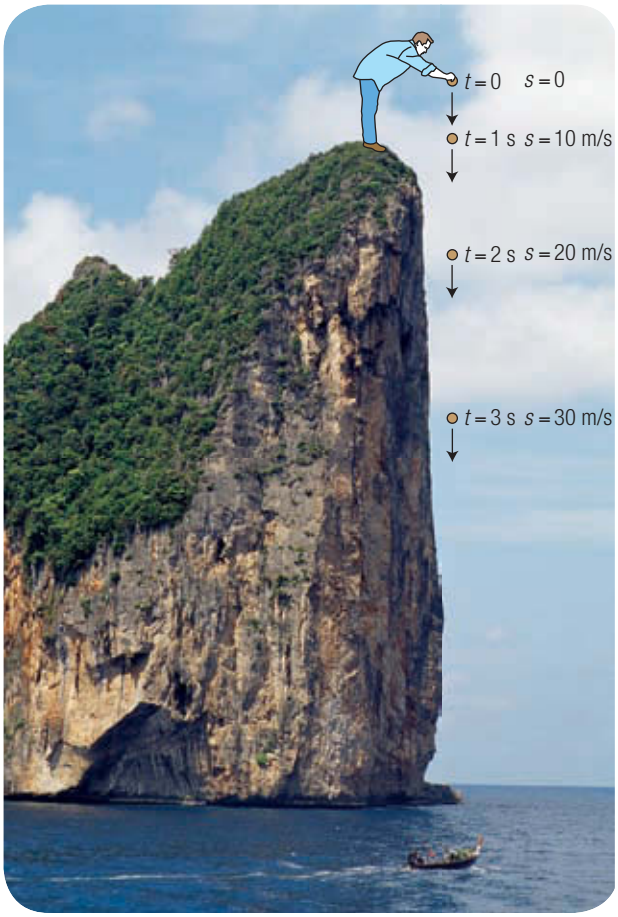
When held out to one side and dropped vertically (not thrown), the rock starts at rest and increases in speed as it falls. If it were dropped from high enough, the rock may accelerate to quite a high speed.

After 1 second, it should reach a speed of almost 10 m/s due to gravity (actually, it is 9.8 m/s, which is very close to 10). We say it has accelerated at a rate of 10 metres per second in 1 second or at 10 metres per second per second (written as 10 m/s/s or 10 m/s^2 or 10 ms^{-2}).

After another second at the same rate, the rock would reach a speed of almost 20 m/s.

After 3 seconds, it would reach a speed of almost 30 m/s. Of course, this analysis ignores the effects of air resistance, which would prevent the rock from reaching a speed of 30 m/s after 3 seconds.

→ Fig 1.20 Each second, the speed of the falling rock increases by almost 10 m/s, ignoring air resistance. This means the acceleration is 10 m/s^2.



The acceleration value of 10 m/s^2 is called **acceleration due to gravity** and is given the special symbol of '*g*'. You may recall earlier in the chapter the term '*g*-force' was used. People's movement follows the pattern of the rock when they go skydiving. They speed up as they fall until they open their parachute and slow down to land.

ACCELERATION

$$\text{Acceleration} = \frac{\text{change in speed}}{\text{change in time}}$$

$$= \frac{\text{final speed} - \text{initial speed}}{\text{time taken}}$$

$$a = \frac{\Delta s}{\Delta t}$$

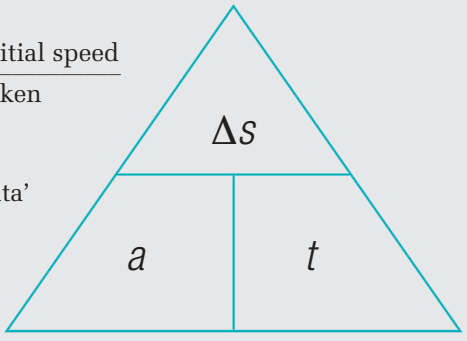
where Δ is the Greek letter 'delta' and means 'change in'.

This can also be written as:

$$\text{Acceleration } (a) = \frac{v - u}{t}$$

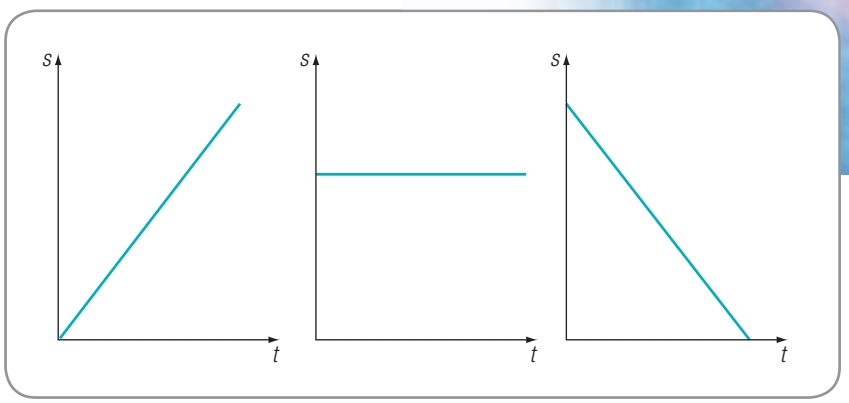
where v is the final speed and u is the initial, or starting, speed.

→ Fig 1.21 The acceleration triangle.

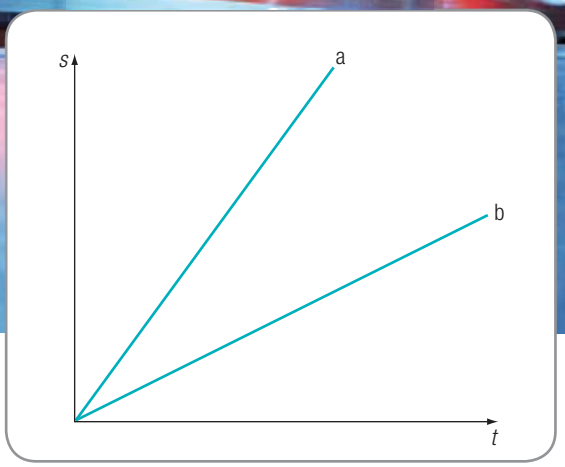




So, how can we calculate acceleration from a speed–time graph? Acceleration is indicated by the gradient of a speed–time graph. The size of the gradient indicates the size of the acceleration. This is shown in Figures 1.22 and 1.23.



→ Fig 1.22 Speed–time graphs showing (a) constant positive acceleration (i.e. speeding up), (b) zero acceleration (i.e. constant speed) and (c) negative acceleration (i.e. slowing down or decelerating).



→ Fig 1.23 Speed–time graphs showing (a) a steep gradient, indicating high acceleration, and (b) a gentle gradient, indicating lower acceleration.

PRACTIVITY 1.3

Measuring acceleration by timing or using a motion sensor

What you need: ball, stopwatch, tape measure, motion sensor

In this simple activity you will determine acceleration due to gravity by simply dropping a ball and measuring the time it takes to fall through a certain distance. For more accuracy, or as a comparison, a motion sensor connected to a computer could be used to measure the acceleration directly. The ball will be released from a measured height h metres above the ground and it will take a time t seconds to reach the ground.

⚠ Never drop objects from high places without looking below to make sure the area is clear. Never drop objects off buildings or bridges.



1 Use the results to determine the acceleration due to gravity in units of m/s^2. The formula that describes this situation is:

$$h = \tfrac{1}{2} \times a \times t^2$$

2 Rearrange the formula to make a the subject and substitute your values for h and t. The resulting value for a is the acceleration due to gravity (although it usually has the symbol g), which should be 9.8 m/s^2 near the Earth's surface, although we often round it off to 10 m/s^2 for calculations.

- How close to 9.8 m/s^2 were your results?
- Can you account for any differences?

Challenge: You may like to make several different measurements and plot them as an h–t^2 graph on your calculator. If you do a regression fit to the data, the gradient is h/t^2, which is $\frac{1}{2}g$. Double the gradient to get an average value for g.



EXPERIMENT 1.3

Linking time and distance

Aim

To investigate the mathematical link between time and distance and hence calculate a person's reaction time.

Materials

Metre ruler

Method

1. One member of the group holds the metre ruler vertically from the top while another student stands ready to catch it between their thumb and first finger.
2. When the ruler is dropped, the position of the catcher's fingers shows how far the ruler fell. For example, if the fingers were originally opposite the 50 cm mark when the ruler was dropped and the fingers catch the ruler at the 90 cm mark, the ruler fell 90 – 50 = 40 cm or 0.40 m.
3. Convert the distance each time into metres and record it in a table for each member of the group.
4. The time is then calculated from the formula $d = \frac{1}{2}gt^2$ as $t = \sqrt{(2d/g)}$, where $g = 9.8$ m/s^2 (or 10) and d is the distance dropped (in metres).



→ Fig 1.24



Extension

1. Repeat the experiment with people of different ages and report back with the results.

Results

1. Include your results in an appropriately formatted table.
2. Use a computer or graphics calculator to plot the reaction times as a histogram.

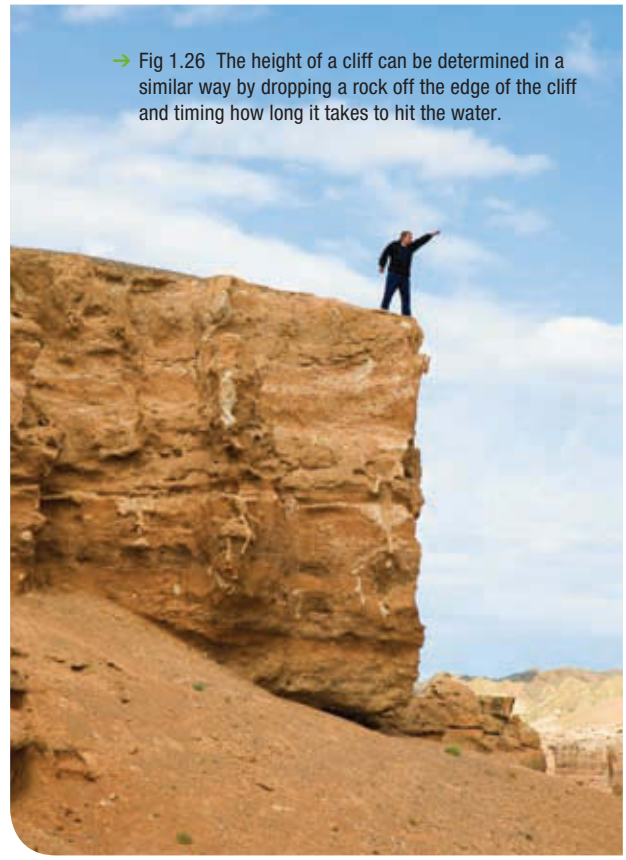
Discussion

1. Critically analyse and comment on the results.
2. Reaction time is an important skill in learning to drive, but it is only one factor that determines the quality of a driver.
   - **a** Why is reaction time important when driving a car?
   - **b** What other factors can affect the driver?





➔ Fig 1.25 Timing how long an object takes to fall also provides a practical way to measure distance. If you drop a rock into a well and measure the time required for it to reach the bottom, the depth of the well can be calculated from the formula $d = \frac{1}{2}gt^2$.



➔ Fig 1.26 The height of a cliff can be determined in a similar way by dropping a rock off the edge of the cliff and timing how long it takes to hit the water.

PRACTIVITY 1.4

Make an accelerometer

What you need: small glass jar and lid, paperclip, short length of cotton, sticky tape

1. Tie one end of the cotton to the paperclip.
2. Stick the other end of the cotton to the underside of the lid so the paperclip hangs vertically inside the jar without touching the bottom.
3. Fill the jar with water and screw the lid on.
4. Test your accelerometer by pushing it slowly along a table, then speed it up, go at constant speed and finally slow it down.
5. Take your accelerometer with you in the car, bus or train and observe the position of the cotton and paperclip when the vehicle is:
   - accelerating
   - decelerating
   - travelling at constant speed in a straight line
   - travelling at constant speed around a corner.

- What position does the cotton and paperclip have for each of the above types of motion?
- How can you tell if the vehicle is undergoing a small or a large acceleration?
- How do our own bodies tell us we are accelerating, decelerating or travelling around a corner?



➔ Fig 1.27 Any mass on a string can be an accelerometer, even a stationary hanging mass on a string used to find which way is vertical. This device is known as a 'plumb bob' and is used sometimes in the building industry, although a spirit level is more convenient.



→ Fig 1.28

DESIGN YOUR OWN ...

Balloon car race

Challenge

To build a balloon-powered model car and race it against other student cars. Any small model car can be used or you could build one from Lego or other materials. The model car needs to have freely spinning wheels and an aerodynamic design to travel far and fast. Real drag racing cars are very powerful and sleek in design.

Questioning and predicting

Work out how you will attach the balloon to your car so that it can be easily inflated each time.

Planning and conducting

Race your car along a model drag strip at school and against cars made by other students.

Processing, analysing and evaluating

How did your car perform? What improvements could you make to your car to increase its performance? You could even use a motion detector to analyse the motion of your car. How fast did your car go?

Communicating

Present your investigation in a formal practical report.

What do you know about acceleration?

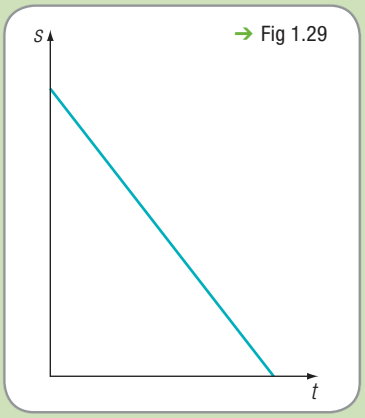
1 Use the acceleration triangle to write three different formulas.

2 What is meant by the term 'deceleration'?

3 What is the acceleration of an object if its velocity is constant?

4 Describe the motion of an object with the speed–time graph shown in Figure 1.29.

→ Fig 1.29



5 An object starts from rest and accelerates at a rate of 4 m/s^2. State its speed after each second for 5 seconds.

6 What do accelerating and decelerating objects have in common?

7 How can you, as a passenger in a moving car, detect whether the car is accelerating or decelerating without looking out of a window or at the speedometer?

1.1

What are the characteristics of movement?



Remember and understand

1 Match each word with its meaning:

a	vector	speed of an object at a moment in time
b	average velocity	measures how an object's speed changes
c	average speed	slope of a graph
d	acceleration	graph where speed is plotted against time
e	distance	quantity that has magnitude and direction
f	instantaneous speed	calculated by dividing distance by time
g	gradient	measures how far an object has travelled
h	speed–time graph	calculated by dividing displacement by time

2 What happens to an object's speed if it travels with zero acceleration?

3 What happens to an object's speed if it travels with constant acceleration?

4 What happens to an object's speed if it travels with constant deceleration?

Apply

5 A car is driven along a straight road. Starting from rest it takes 10 seconds of steady acceleration for the car to reach a speed of 20 m/s. The car then cruises for 60 seconds at 20 m/s, before slowing down to a halt over a period of 30 seconds.
- **a** What is the maximum speed of the car in km/h?
- **b** Plot a speed–time graph for the car using SI units.
- **c** Use the graph to calculate the distance moved in metres and then in kilometres.

Analyse and evaluate

6 On a wet Monday morning, a school bus that has to travel 24 km leaves its starting place at 7.35 a.m. and only manages an average speed of 36 km/h on its trip to school. There is a clear section on the highway when the bus actually has a speed of 74 km/h. The bus then does various runs during the day and arrives back at the school in time to depart at 3.45 p.m. It arrived back exactly at its starting place at 4.25 p.m.
- **a** What is the displacement of the bus between 7.35 a.m. and 4.25 p.m.?
- **b** At what time will the bus arrive at school?
- **c** What is the average speed of the bus?
- **d** The bus's average speed on the way to school is 36 km/h, but on one stretch the bus moves at 74 km/h. Use this data to explain the difference between 'average speed' and 'instantaneous speed'.

7 A section of a position–time graph has a gradient of +7 and another section has a gradient of –4. If the units on the graph are metres and seconds, and positive means south, what do these numbers mean about the motion being studied?

Critical and creative thinking

8 Some objects or devices require high accelerations that are many times greater than 9.8 m/s^2, the acceleration due to gravity. Think of an object or device in this category. Does it have an engine or some other propulsion mechanism? What fuel does it use? How does this enable it to achieve such a high acceleration?

CONNECTING IDEAS Forces and motion

9 Motion is the result of forces acting in different directions. Describe the forces you believe to be acting when an object is stationary, moving, accelerating and changing direction. Which forces are always acting?

How do force and mass affect movement?

1.2



Sometimes high-speed movement, such as cruising in an aeroplane, is barely noticeable. You may not even feel that you are moving until you look out of the aeroplane's window and see the gradual movement of the land far below you. How can you be going so fast and hardly notice it? A force is a push or a pull acting upon an object as a result of its interaction with another object. Force has the symbol *F* and is measured in newtons (N). In relation to motion, a force is something that can change an object's motion. A force is not necessarily needed to keep an object moving, but most objects slow down because of the force of friction.



<<DISCOVERING IDEAS>>

Finding out about inertia

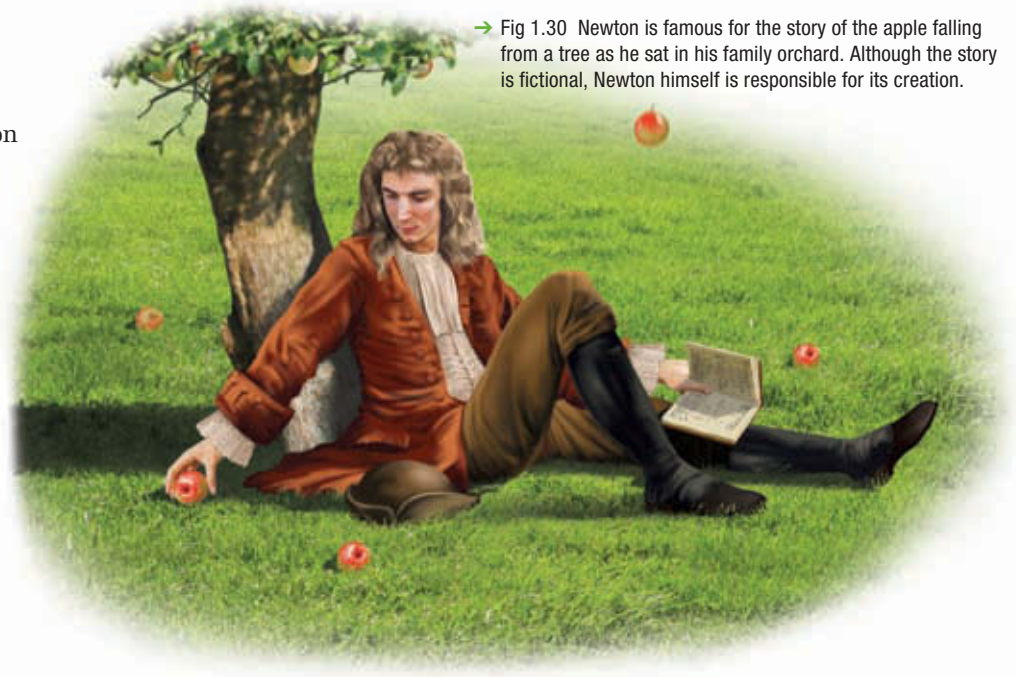
Place a small object, such as a coin or a pen, on top of a sheet of A4 paper on the lab bench. Now pull the paper slowly with the object on top. What happens? Try now pulling the paper really fast from under the object.

What happens? Discuss your findings in a group and see whether you can justify what happened in each case. You will soon find out how this activity demonstrates Newton's first law.



Newton's first law

The famous English scientist Isaac Newton (1642–1727) formulated three laws of motion. Newton was a professor of mathematics and physics and wrote what is possibly the greatest scientific publication of all time, the *Principia*. In his book Newton outlined his laws of motion and his law of universal gravitation. Newton's formulation of his second law of motion and his law of universal gravitation led to nearly all the important advances in physics in the areas of magnetic, electrical and atomic forces for the next 200 years.



→ Fig 1.30 Newton is famous for the story of the apple falling from a tree as he sat in his family orchard. Although the story is fictional, Newton himself is responsible for its creation.



→ Fig 1.31 Zero net force.

The law of inertia

Newton's first law, also known as the law of inertia, has two applications. First, look around you and find something that is stationary … maybe even yourself! Why is the object stationary? It has the force of gravity (its weight force) acting on it to pull it down. But why doesn't it move? This is because there is another force, equal in magnitude (strength) to the weight force but acting in the opposite direction, pushing up on the object from the surface. Because these two forces are equal in magnitude and opposite in direction, and because they both act on the same object, we say that the object has zero **net force** (or zero resultant force) acting on it. The two forces are balanced.

Newton's first law states, 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force'.

How does Newton's first law apply if the object is already moving?

Think of any motion you have experienced today, maybe in the car or on the bus, train or tram, or even on your bike. In constant motion we sometimes hardly notice we are moving, but stop or start suddenly or turn a sharp corner and your body may move unexpectedly. That's **inertia**. Inertia keeps stationary objects stationary too. Its effect is to keep an object in the motion it was in. The larger the mass of the object, the more inertia it has. Think now of the Discovering Ideas activity. In terms of inertia, why did the object stay in place on the bench when the paper was rapidly pulled out from under it?

→ Fig 1.32 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.



EXPERIMENT 1.4

Resultant forces

Aim

To investigate the addition of vectors using three spring balances.

Materials

Three spring balances (0–10 or 0–20 N are best)
Two rubber bands
Graph paper
Masking tape

Method

1. Test to see that each spring balance reads zero with no force exerted on its hook. (This is known as checking the 'calibration'.) If not, adjust it so it does.
2. Tape a piece of graph paper to the bench and draw a large dot in the centre of the paper.
3. Tie one rubber band to the centre of the other to create three 'loops' with a knot in the centre.
4. Hook each spring balance onto the loops and position the knot directly above the dot on the graph paper.
5. Pull on the spring balances in different directions so that the knot stays directly over the dot.
6. Record the force reading on each spring balance and draw the direction of the force onto the graph paper. This can be done by drawing a line directly below the rubber bands.
7. Repeat the experiment twice more using different sized forces and different directions.

Results

Drawing a force diagram

Remove the graph paper and create a force diagram by choosing an appropriate scale (usually 1 cm = 1 N) and drawing the three forces acting from the dot in the correct directions. The forces are drawn as lines with arrowheads. The direction of the arrowhead shows the direction of the force. The length of each line should show the size of each force.

Drawing a vector diagram

To convert the force diagram into a vector diagram, leave one of the force arrows in position where it is, then 'slide' the other two force arrows so that all three join head to tail with each other. When all three forces are added, determine the net force by drawing a line from the start to the end and head-to-head and tail-to-tail. This shows the result of the three individual vectors, which should be very small or even non-existent if you did the experiment correctly.

Discussion

Write several statements analysing your results.

If you are a passenger in a car and *not* wearing a seatbelt and the car comes to a very sudden stop, your body will continue moving forward because inertia keeps it in the same motion it was in (moving forward). The same thing happens on a bike and may cause you to continue your motion over the handlebars. The same thing also happens in a bus, train or tram, especially if you are standing up and not holding onto something. It is also this effect that causes us to feel lighter or heavier in an elevator or on a roller coaster.



→ Fig 1.33 Seatbelts are an inertia device. They are often called 'inertia reel seatbelts'. The aim of a car seatbelt is to transfer the force on the car to the passenger wearing the seatbelt so that the person moves with the car. You start moving when the car starts moving and, when wearing your seatbelt, you stop moving when the car stops moving.

PRACTIVITY 1.5

How do you like your eggs?

Eggs are great for demonstrating inertia.

What you need: two eggs in their shells—one fresh and one hard-boiled, but no indication of which is which!

1 Spin both a hard-boiled egg and a fresh egg on a flat surface.

2 Stop the eggs gently with one finger placed momentarily on top of the spinning egg, then release the egg by lifting your finger off it. Does it stay stopped or keep spinning?

- How does the egg's motion after you release your finger help you to predict whether the egg is hard boiled or fresh? Open the shells (over a rubbish bin or sink) to see if you are correct.
- Think about the inside of the egg and the motion of the shell and the egg itself while they are spinning. Think also of Newton's first law. Describe what you did in terms of inertia.

What do you know about Newton's first law?

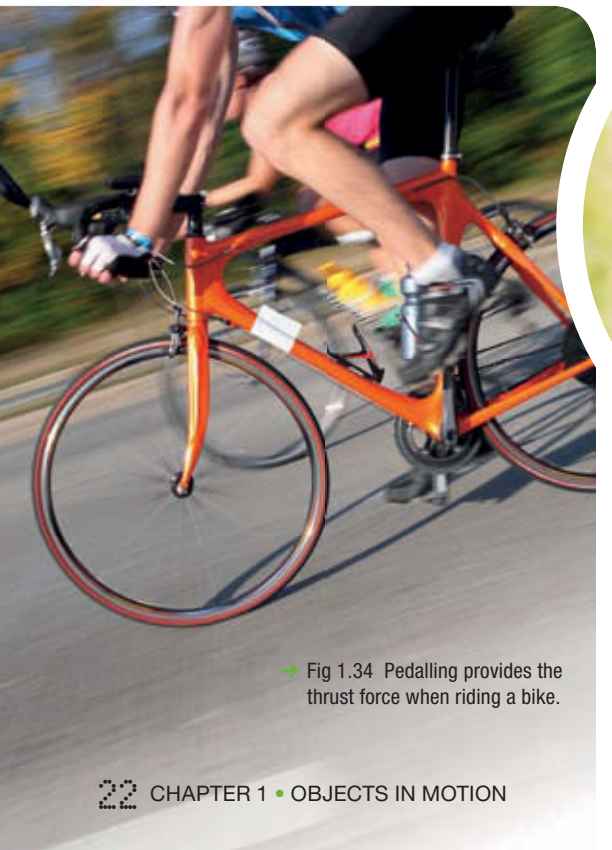
1 What is meant by the term 'net force'?
2 What happens to a stationary object with zero net force acting on it?
3 What happens to a moving object with zero net force acting on it?
4 What is inertia?
5 Give an example of how inertia affects your motion inside a car, bus, tram or train.
6 Why do people lurch backwards in a tram when it starts moving suddenly?

Newton's second law

Newton's first law deals with the consequences of zero net force, but what if an object *does* have a net force acting on it? How will its motion change? The answer is that the object will change its speed, direction or both. A moving object will speed up (accelerate) if a net force acts on it in the same direction as it is moving. In the case of riding a bike, the bike will speed up if you pedal harder to increase the driving force (known as thrust).

When the net force acts in the opposite direction, the moving object will slow down (decelerate) and eventually stop. A moving bike will slow down when you squeeze the brake lever.

Acceleration depends on the net force, but does mass have a role too? Would it be easier to push and accelerate a small car or a truck? Of course it would be easier to push and accelerate a small car because it has a lower mass than the truck. Heavier objects are harder to accelerate with the same force. Hence, acceleration increases if the net force increases and if the mass decreases (see Figure 1.37 for a triangle linking net force, mass and acceleration).



→ Fig 1.34 Pedalling provides the thrust force when riding a bike.



→ Fig 1.35 Braking provides a drag force.

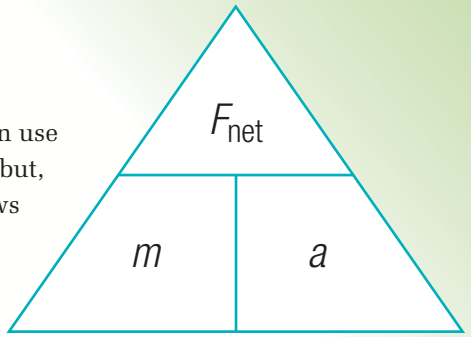
Newton's second law states, 'The acceleration of an object is directly related to the magnitude and direction of the force acting on the object, and inversely related to the mass of the object: $F = ma$'.



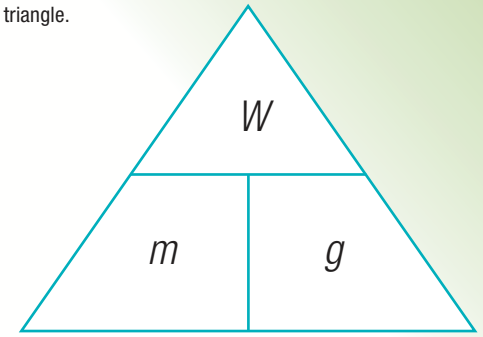
→ Fig 1.36 Cars can accelerate faster than trucks due mainly to their smaller mass.

Mass versus weight

Newton's second law also connects an object's mass to its weight. We often use the term 'weight' to indicate how much mass something has in kilograms but, strictly speaking, in Physics *weight is a force not a mass*. Figure 1.38 shows how weight and mass are linked with the acceleration due to gravity, *g*. Weight is the force of gravity acting on an object. Every object on or above the Earth has weight. The only time objects don't have weight is when there is no gravity, like in deep space, but all objects always have mass.



→ Fig 1.37 The net force triangle.



→ Fig 1.38 The weight triangle.

Often all the individual forces acting on an object need to be taken into account to work out the net force. In Experiment 1.4 you learnt how to draw a **vector diagram** to add forces together.

Consider the cyclist and bike shown in Figure 1.39. In this case, the weight force of 900 N is balanced (or cancelled out) by the 900 N upward force of the road on the cyclist and bike. The forward-acting thrust force is 400 N and the total drag force from air resistance and friction is 300 N backwards. As a result, the net force is 100 N forward. This would produce acceleration.

The mass of the cyclist and bike can be determined using the weight triangle:

$$m = W \div g$$
$$m = 900 \div 10$$
$$m = 90 \text{ kg}$$

and the acceleration can be worked out using the net force triangle:

$$a = F_{net} \div m$$
$$a = 100 \div 90$$
$$a = 1.11 \text{ m/s}^2 \text{ forward}$$

If the thrust was reduced to 300 N, there would be zero net force and therefore zero acceleration and the cyclist would continue at constant velocity. If the cyclist stopped pedalling, the thrust force would become zero and the net force would be 300 N backwards, causing the cyclist to decelerate and eventually stop. Can you work out what this deceleration value would be?


→ Fig 1.39 Various forces act on a cyclist.

NET FORCE

Net force = mass × acceleration

$$F_{net} = m \times a$$

When the mass is in kilograms (kg) and the acceleration is in metres per second squared (m/s^2), the net force will be in newtons (N). Acceleration and net force are both vectors and always act in the same direction.

WEIGHT

Weight = mass × acceleration due to gravity

$$W = m \times g$$

where $g = 9.8$ m/s^2 at sea level on the Earth's surface (10 m/s^2 can be used to simplify calculations).

EXPERIMENT 1.5

Accelerating masses

Aim

To determine the relationship between mass and acceleration.

Materials

Dynamics trolley

String

Mass hanger and brass 50 g masses

Several 1 kg masses

Desk-mountable pulley wheel with clamp

Electronic balance

Motion sensor or stopwatch

Tape measure or ticker timer

Power supply

Ticker tape

Method

1. Clamp the pulley wheel to the edge of the desk. Try to arrange the largest height above the floor as possible.
2. Attach one end of the string to the dynamics trolley and the other end to the mass hanger, carrying a total of approximately 200 g of mass.
3. Hang the masses over the pulley so they can pull the trolley along as they fall to the floor.
4. Record the motion of the trolley as the masses fall using either a motion sensor, timing with a stopwatch or recording the motion on ticker tape.
5. Successively add 1 kg masses to the trolley and repeat your measurements several times.

Results

1. Determine the acceleration of the trolley for your method.
2. If you used a motion sensor, use software (see Experiment 1.2) to determine the acceleration directly or from the gradient of a velocity–time graph.
3. If you used a stopwatch, calculate the acceleration as (2 × the distance travelled ÷ time squared).
4. If you used a ticker timer, use the 'every fifth dot method' as per Experiment 1.1 to divide the tape into sections. Determine the speed of each section by dividing the distance covered by 0.1. Plot a speed–time graph and determine the acceleration from the gradient of the graph.
5. Plot a graph of acceleration versus total mass. This should give a truncated, or inverse, graph.
6. Plot a second graph of acceleration versus the inverse of mass. This should give a straight-line graph.

Discussion

Analyse and evaluate your results.

Conclusion

What is the relationship (or formula) between mass and acceleration?







What do you know about Newton's second law?

1. What is meant by the term 'weight force'?
2. What happens to a moving object if it is acted on by a net force in the same direction as its motion?
3. What happens to a moving object if it is acted on by a net force in the opposite direction to its motion?
4. How does the acceleration of a bus full of passengers compare with an empty bus for the same net force?
5. Why does a bike slow down on a level road when the rider stops pedalling?
6. A net force causes a mass of 10 kg to accelerate at 2 m/s^2. What is the magnitude of the net force?

ZOOMING IN

Albert Einstein's theory of motion

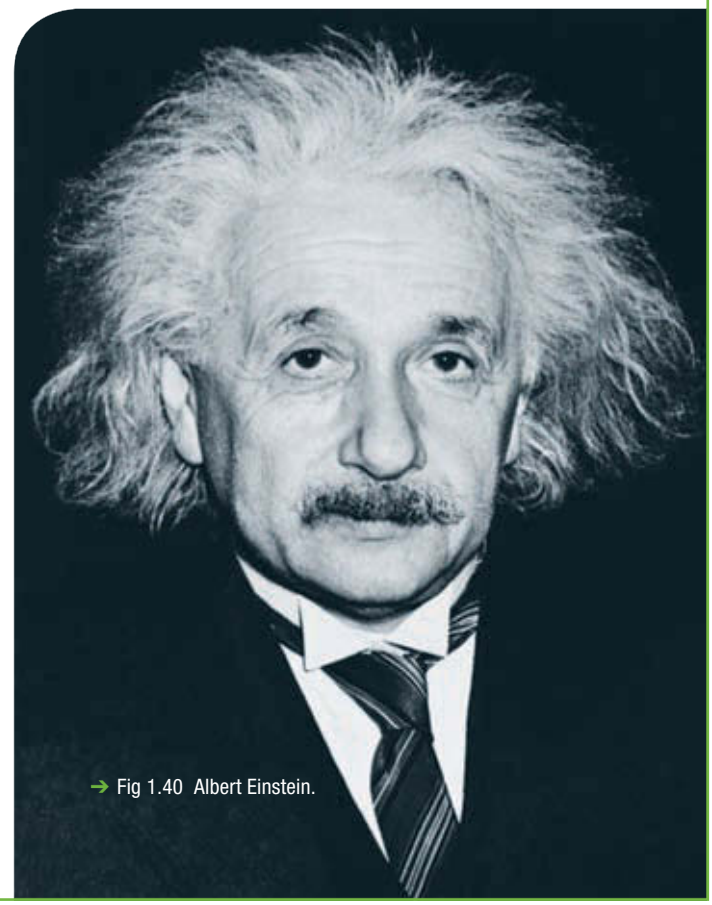
Albert Einstein (1879–1955), another great scientist, was born 152 years after the death of Isaac Newton. Einstein proposed a different theory of motion to Newton known as the general theory of relativity. Einstein won a Nobel Prize for this theory in 1922. His theory has been modified these days, but describes the relative rather than absolute nature of motion and mass and the interdependence of matter, time and space (some of the big ideas of science!). It proposes that the properties of space–time are modified by the presence of a body with mass.

In his lifetime, Einstein made major contributions to a wide range of physics concepts. He is best known for his suggestions about the curvature of the Universe; that there are four dimensions, with time being the fourth dimension; that energy and mass are equivalent via his famous formula $E = mc^2$; and that the speed of light (c) is always constant relative to any object in a state of motion. In 1999, *Time* magazine named Einstein as the 'person of the century'.

The important thing to note about Einstein is that his research built on what Isaac Newton had established over two centuries earlier. Many other modern scientists have built on both Newton's and Einstein's theories.

Knowledge round robin

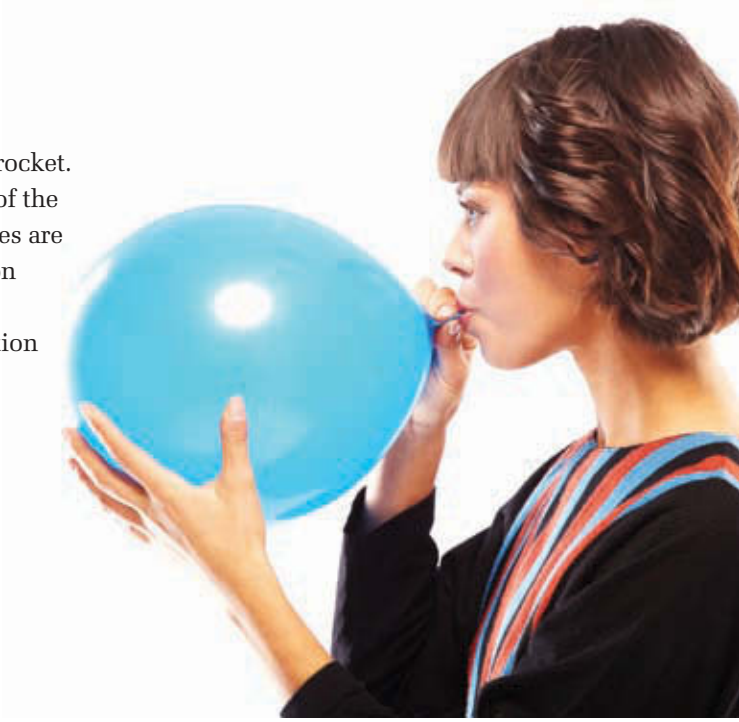
1. Working in a small group, brainstorm science concepts that you know of that have changed over the years. You may consider the development of models of the atom, or ideas about light or cells, or our knowledge of human anatomy or any other topic. After an amount of time (decided by your teacher), pass your list on to the next group. Add to the list you receive, but do not repeat any ideas that have already been included. Keep passing the list on to the next group after the time limit, but stop when your original list is returned to your group.
2. Again working in a small group, brainstorm what may happen if you could travel close to or faster than the speed of light. Follow the same procedure as above. Stop when your original list is returned to your group.



→ Fig 1.40 Albert Einstein.

Newton's third law

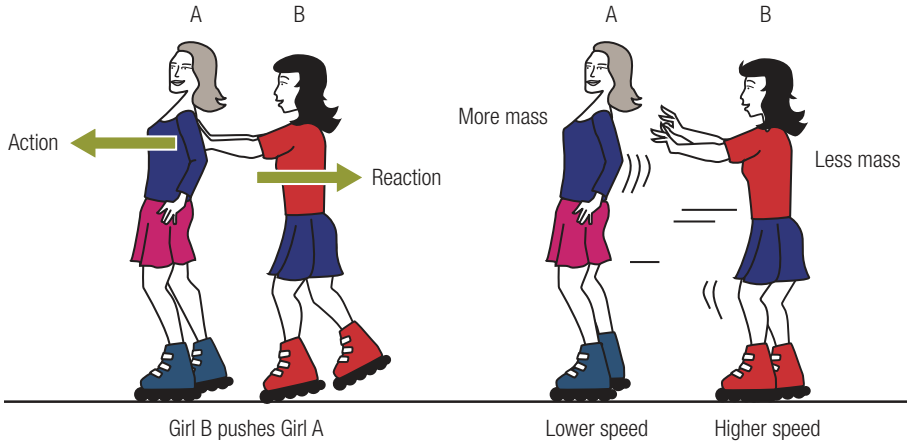
If you blow up a balloon and let it go, it flies around the room like a crazy rocket. Why does it do this? The answer is that as the air is forced backwards out of the opening, the balloon is propelled forward by another force. These two forces are equal in magnitude and opposite in direction. They form an action–reaction pair and obey Newton's third law. The action force in this example is the rubber of the balloon contracting and pushing the air backwards. The reaction force is the force of the air rushing out, pushing forward on the balloon.



> *Newton's third law* states, 'For every action force, there is an equal and opposite reaction force'.

The motion of a girl on roller blades pushing off from another girl (see Figure 1.41) works in a similar manner. What happens if the two girls have different masses? Newton's second law tells us that smaller masses have higher accelerations for the same force. So, a lighter person will have a higher acceleration and will reach a higher speed while the force is acting.

→ Fig 1.41 Different masses have different accelerations and reach different speeds even though the forces shown by the arrows are equal in size.



You may think that if the two forces in the action–reaction pair are always equal and opposite they must cancel each other out and that no net force exists, and hence no motion is possible. But the forces *cannot* cancel. It is important to remember that the two action–reaction forces act on *different* objects. Only forces acting on the *same object* can cancel or balance.

Rockets, missiles and jet engines work on the action–reaction principle. So does the firing of bullets and shells from rifles and guns. The reaction force in this instance is known as recoil.

PRACTIVITY 1.6

Bombing run

What you need: empty rubbish bin, tennis ball

1 In a clear space, set up an empty rubbish bin.

2 Hold a tennis ball or other object in your hand with your arm outstretched to the side. As you walk or run past the bin, try to release your 'bomb' so that it lands in the bin.

- Do you score a 'hit' every time?
- Which of Newton's laws do you have to take into account?

What do you know about Newton's third law?

1 A person pushes forward on an object with a force of 30 N. What reaction force acts on the person?

2 A boy of weight 500 N sits on a chair. What reaction force acts on the boy?

3 In space, an astronaut pushes on another astronaut with a force of 80 N. What is the reaction force in this case? Why might the second astronaut have a higher acceleration than the first astronaut?

4 Identify the action–reaction pair when a sprinter uses a set of starting blocks for the start of a sprint race.

5 Identify the action–reaction pair when a softball player hits a home run.

1.2

How do force and mass affect movement?



Remember and understand

1 Match each word with its meaning:

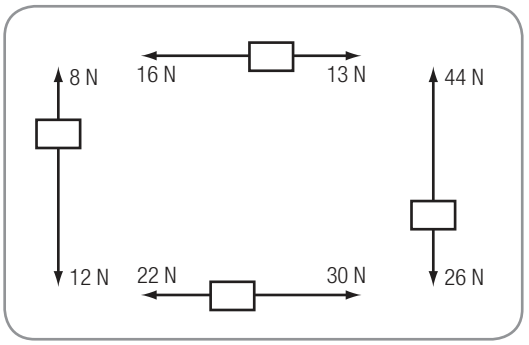
a	mass	when the net force on an object is not equal to zero
b	thrust	the force applied by an object to move it
c	net force	amount of matter in an object
d	balanced	force on an object forces due to gravity
e	unbalanced forces	overall effect when all forces are combined together
f	weight	causes an object to remain in its state of motion
g	inertia	when two forces are equal in magnitude and opposite in direction

2 Which of the following are true and which are false? For the false statements, rewrite them to make them true.

- **a** A force will only change an object's speed.
- **b** A force is always needed to keep an object in motion.
- **c** The quantity of weight is measured in kilograms.
- **d** A force has magnitude and direction, making it a vector.
- **e** Acceleration increases if the net force increases and the mass is kept constant.
- **f** A stationary object can have several forces acting on it.
- **g** Mass is a measure of how much space an object occupies.

Apply

3 For each of the diagrams in Figure 1.42, calculate the magnitude and direction of the net force acting on the object. (Use left, right, up, down.)



➔ Fig 1.42

Analyse and evaluate

4 Renee catches a softball.

- **a** What is the action force?
- **b** What does the action force do?
- **c** What is the reaction force?
- **d** What does the reaction force do?

5 What mass object would accelerate at 3.5 m/s^2 under the influence of a net force of 70 N?

6 Calculate the acceleration of a 500 g object under the influence of a net force of 500 N.

Critical and creative thinking

7 Design a poster on motion that explains each of Newton's three laws. Give a detailed example that illustrates each law and is not already mentioned in the text.

CONNECTING IDEAS Forces and motion

8 Extend your ideas about Newton's laws, weight and motion to freely falling objects. Explain why falling objects eventually reach a constant velocity. Find out the term used to describe this velocity. Explain why all objects fall at the same rate in a vacuum.

1.3

What happens in collisions?



Modern cars are fitted with many safety devices, but arguably the most important are the airbags that deploy in the case of a crash. But what triggers the airbags? Sensors inside the car act like mini accelerometers and when they detect rapid deceleration, the airbag system is operated. These innovations are the result of the scientific understanding of movement and, more importantly, collisions. All collisions involve force, mass and momentum and these quantities link together to provide the laws of motion as we know them.

DISCOVERING IDEAS

Balls in motion

Throw a tennis ball vertically into the air and catch it again. The motion of the ball seems pretty straight forward, but this simple activity shows all the elements of motion.

Working in pairs, repeat the activity again and again and then observe it as your partner does it. Together, think about and discuss the motion quantities, such as distance, displacement, speed, velocity, acceleration, mass, weight, action force, reaction force, Newton's laws—all the big ideas—and explain which part of the motion of the ball demonstrates each of these.

Record your observations in a table and discuss with the class.





Momentum

All moving objects possess something called **momentum**. Momentum is not a form of energy, although the faster an object travels, the more momentum it has. A cricket ball is harder to stop than a tennis ball travelling at the same speed. This is because the cricket ball has more mass than the tennis ball. So, objects with more mass have more momentum. The formula for calculating momentum is illustrated in Figure 1.43.

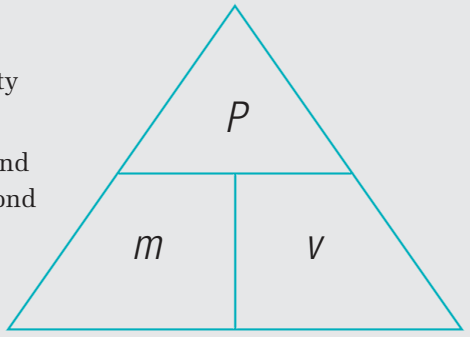


MOMENTUM

Momentum = mass × velocity

$$p = m \times v$$

If mass is in kilograms (kg) and velocity is in metres per second (m/s), then the units for momentum are kilogram metres per second (kg·m/s).



→ Fig 1.43 The momentum triangle.

LAW OF CONSERVATION OF MOMENTUM

Initial total momentum = final total momentum

$$p_{initial} = p_{final}$$

Law of conservation of momentum: 'For an isolated system, the total momentum does not change during a collision'.



→ Fig 1.44 Newton's cradle clearly demonstrates how momentum can be passed from one object to another.

In a collision, momentum is passed from one object to another but the total momentum of the system is conserved, or remains constant. This is known as the **law of conservation of momentum** and is similar to the law of conservation of energy.

The isolated system referred to in the law of conservation of momentum is the set of objects that interact in the collision. In the case of a car crash, this would be the two cars and their occupants. Because velocity is a vector, momentum is also a vector quantity. We can indicate opposite directions in a collision as positive and negative. The 'initial' momentum is before the collision and the 'final' momentum is after the collision (see the example in Figure 1.46).

To stop a moving object, a force is used to reduce its momentum. A car crash often involves a large force over a short time and the large force can be very destructive to the cars and their occupants. Using brakes to slow to a stop involves a smaller force over a longer stopping time, but often in a car crash that longer stopping time isn't available … and the cars come together.



→ Fig 1.45

The average force involved in a collision equals the change in momentum divided by the duration time. The quantity change in momentum (Δp) is also known as **impulse** and has the symbol I and the unit kg·m/s or newton second (Ns). See Figure 1.47 for the impulse triangle.



EXAMPLE

Figure 1.46 represents a relatively safe head-on collision between two dodgem cars at Luna Park.

If we take movement to the right as positive, the initial momentum of the green car is given by:

$$p = m \times u$$
$$= 701 \times 0.8$$
$$= 561 \text{ kg·m/s}$$

The initial momentum of the blue car is given by:

$$p = m \times u$$
$$= 660 \times 0.7$$
$$= 462 \text{ kg·m/s}$$

Therefore, the total initial momentum of both cars is 561 – 462 = 99 kg·m/s to the right.

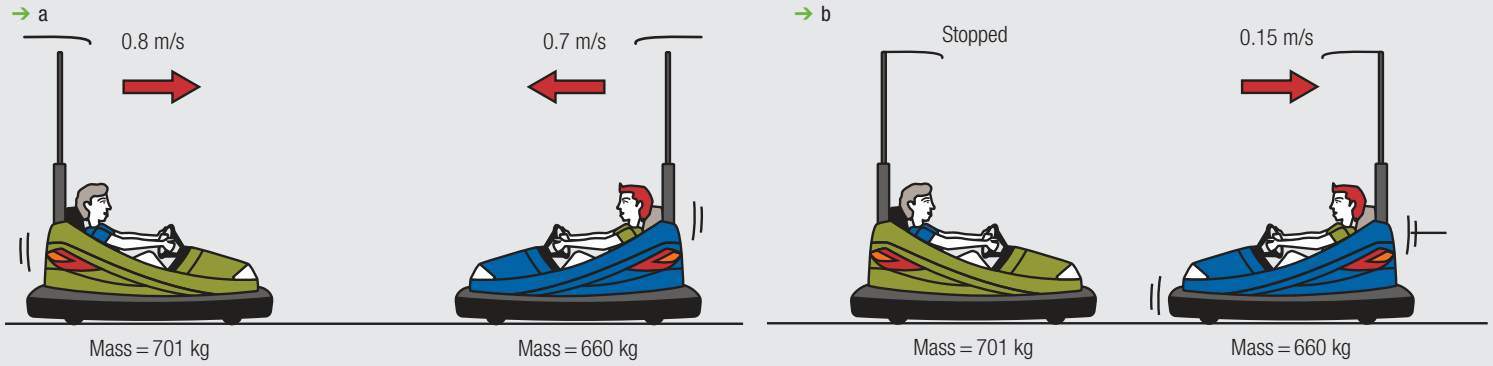
The final momentum of the blue car is given by:

$$p = m \times v$$
$$= 660 \times 0.15$$
$$= 99 \text{ kg·m/s to the right}$$

The final momentum of the green car is zero because it stops. Therefore, the total final momentum is 99 kg·m/s to the right.

This shows that there is no change in the total momentum for the isolated system of the two dodgem cars and their drivers during the collision.

→ Fig 1.46 (a) Before the collision. (b) After the collision.

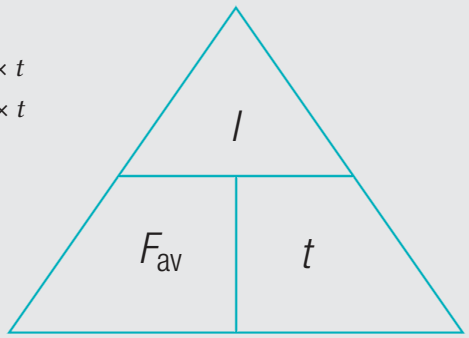




IMPULSE

Average force = change in momentum ÷ time

$$F_{\text{average}} = \frac{\Delta p}{t}$$
$$\Delta p = F_{\text{av}} \times t$$
$$I = F_{\text{av}} \times t$$



→ Fig 1.47 The impulse triangle.

EXPERIMENT 1.6

Colliding trolleys

Aim

To investigate whether total momentum is conserved during a collision.

Materials

Two dynamics trolleys

Electronic balance

Metre ruler

Ruler

Several 1 kg masses to add to the trolleys

Two rubber bands tied together that will stretch to 20 cm quite easily

Level benchtop

Piece of A4 paper

Masking tape

Method

1. Attach the piece of A4 paper to the benchtop with masking tape. Rule two parallel lines on the paper, 20 cm apart.
2. Link the two trolleys with the rubber bands.
3. Pull the trolleys apart and hold them with their front ends on the two lines.
4. Release the trolleys. The trolleys will accelerate towards each other and collide at the same time. How far the trolleys travel in a given time is proportional to their relative velocities. Determine where the trolleys collide and mark the collision point on the paper.
5. Measure the distance from one line to the collision point (d_1) and the same for the other line (d_2). Because the trolleys both collide at the same time, there is no need to measure the times because the distances are proportional to the collision speeds.
6. Add various masses to one (or both) of the trolleys and repeat the experiment. Test approximately five different mass combinations.







Results

Record the following result headings in a spreadsheet or table.

- m_1 = mass of trolley 1 plus any 1 kg masses added (total in kg)
- d_1 (in m)
- $m_1 \times d_1$
- m_2 = mass of trolley 2 plus any 1 kg masses added (total in kg)
- d_2 (in m)
- $m_2 \times d_2$
- $(m_1 \times d_1) - (m_2 \times d_2)$

The final column gives a measure of the total momentum of the two trolleys just prior to the collision. The minus sign is used because the two trolleys are travelling in opposite directions and therefore one momentum is negative.

Discussion

1. When the trolleys are released, do they travel towards each other for the same period of time? Explain.
2. Is the magnitude of the force acting on each trolley the same? Explain.
3. If both trolleys come to a stop after the collision, what was the final total momentum of the 'system'? Explain.
4. According to the last column of results, what was the initial total momentum of the 'system'?

Conclusion

What did this experiment demonstrate about the total momentum before and after a collision?

EXPERIMENT 1.7

Crash testing

Aim

To investigate the effectiveness of crumple zones during collisions.

Materials

Dynamics trolley

Plasticine

Talcum powder

Solid vertical surface, such as a wall

Additional materials for making a crumple zone (e.g. paper, masking tape, foam)

Method

1. Build a plasticine person to act as 'Buster', the crash test dummy.
2. Lightly coat the deck of the dynamics trolley with talcum powder so that Buster won't stick. Sit Buster in the middle of the trolley.
3. Push the trolley and crash it into a solid surface. Observe the effect of the collision on Buster for several different collisions: low speed, medium speed and high speed. Find the lowest speed collision that would cause damage to Buster if he were a real person. Repeat this collision to try to gain consistency of impact speed.
4. Build a 'crumple zone' at the front of the trolley. Ideally, it should absorb the energy of the collision and not be too springy. Repeat the test collision with the crumple zone in place. Improve the crumple zone, if necessary, to increase Buster's chances of survival.

Results

1. Record the observations of the lowest speed collision that caused damage to Buster.
2. Record the observations of the same collision with the crumple zone in place.

Discussion

Scientifically account for the differences between the two collisions. Relate the findings to real-life collisions.

Conclusion

How effective are crumple zones during collisions?

What do you know about momentum?

1 What are the units of momentum?

2 Give the three formulas obtained using the momentum triangle.

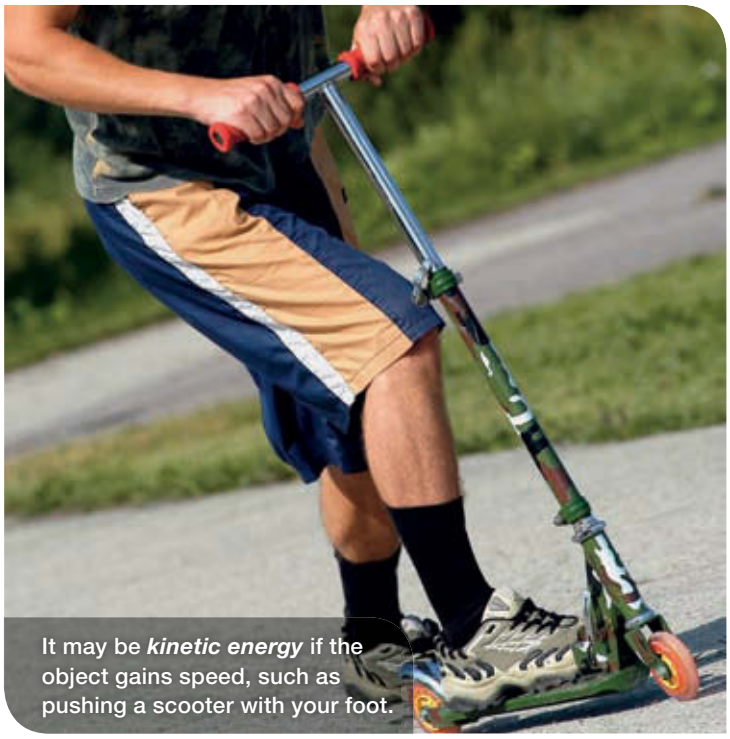
3 Is it harder to stop a cricket ball or a tennis ball travelling at the same velocity? Why?

4 Is it harder to stop a fast-moving tennis ball or a slow-moving tennis ball? Why?

5 What is the law of conservation of momentum?

6 What is another name for change in momentum?

→ Fig 1.48



It may be ***kinetic energy*** if the object gains speed, such as pushing a scooter with your foot.

→ Fig 1.49



It may be ***elastic potential energy*** if the object is squashed or stretched, such as stretching the rubber band of a sling shot.

Work

In a car crash, the crumple zones of a car are designed to absorb energy by crumpling. In scientific terms we say that *work* is done. **Work** happens whenever things are moved or rearranged by a force. The larger the force acting, the greater the work done. The longer the distance over which the force acts, the greater the work done. Hence, the amount of work done depends on the size of the force and the distance (see Figure 1.51).

Work and energy are scalar quantities, so no direction is needed. If you apply a force to an object and it doesn't move, no work is done.

When a force is applied to an object and it moves, the object will gain energy. This energy can be in different forms— see Figs 1.48–50.

→ Fig 1.50



It may be ***gravitational potential energy*** if the object is lifted, such as lifting books onto a shelf.

WORK

Work = force applied × distance moved

$W = F \times d$

If the force is measured in newtons (N) and the distance is measured in metres (m), the work done will be in units called joules (J). Joules are the units of energy, and work is a form of energy.

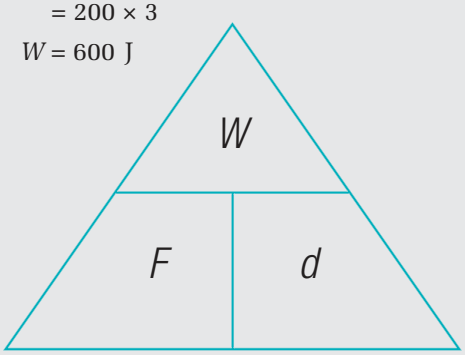
EXAMPLE

A heavy object takes a force of 200 Newtons to move it 3 metres. How much work is done?

$W = F \times d$

$= 200 \times 3$

$W = 600$ J



→ Fig 1.51 The work triangle.

What do you know about work?

1. When is scientific 'work' done?
2. Give three formulas from the work triangle.
3. How much work is done if a force of 200 N moves an object 6 m?
4. How much work is done if a force of 400 N is applied to a heavy object and it doesn't move?
5. What do the crumple zones at the front and rear of modern cars do?

Energy

Kinetic energy

Motion is needed for cars to crash. The energy of motion is called **kinetic energy** (KE). The larger the mass of an object, the greater its kinetic energy. In addition, the faster an object is travelling, the greater is its kinetic energy. Actually, kinetic energy depends on the speed of the object, squared.

Kinetic energy = ½ × mass × speed squared

$KE = \frac{1}{2} \times m \times v^2$

with mass in kilograms (kg), speed in metres per second (m/s) and KE in joules (J).

When a car driver presses on the brake pedal, all the kinetic energy of the car is dissipated (or released) by the brakes as heat. In a car crash, the kinetic energy is dissipated much quicker, mainly as work as the car crumples and deforms.

Gravitational potential energy

If we lift an object to a height, it gains **gravitational potential energy** (GPE). The larger the mass and the height, the more gravitational potential energy the object gains.

Gravitational potential energy = mass × gravity × height

$GPE = m \times g \times h$

with mass in kilograms (kg), height in metres (m) and GPE in joules (J). Gravity has its normal value of 9.8 or 10 m/s².

Elastic potential energy

Bouncing a ball is a collision—with the ground. It involves gravitational potential energy, kinetic energy and **elastic potential energy** (EPE), plus usually a small amount of each of sound and heat energy. As the ball hits the ground, it compresses and stores elastic energy. This energy returns when the ball expands again and is propelled upwards into the air. A 'flat' ball cannot return this energy, so it doesn't bounce.

Elastic potential energy = ½ × spring constant × extension/compression squared

$$EPE = \frac{1}{2} \times k \times x^2$$

where k is the spring constant, a measure of how 'stiff' the object is measured in units of newtons per metre (N/m), x is the extension/compression, measured in metres (m), and EPE is measured in joules (J).



NUMERACY LAB

How speed affects kinetic energy

Example

A car of mass 1400 kg is travelling at 40 km/h. What is its kinetic energy?

1 Convert the speed to m/s.
Speed = 40 ÷ 3.6
= 11.1 m/s

2 KE = ½ × m × v^2
= ½ × 1400 × 11.12
KE = 86 247 J or 86 kJ (1000 J = 1 kilojoule or kJ)

Your turn

Make the same car travel twice as fast, at 80 km/h. What is its kinetic energy now?

Answer

KE = 344 988 J or 345 kJ. The car now has *four* times as much kinetic energy.

Law of conservation of energy

Whenever energy is converted from one form into other forms, the total energy of the system is always constant because extra energy cannot be created, nor can energy be destroyed. This is called the **law of conservation of energy**.

If you lift an object of mass 0.1 kg through a distance of 1 metre, you give it close to 1 joule of GPE. When you drop the object and it falls the 1 metre, its GPE is converted into KE and it speeds up. After falling 1 metre, it has lost the 1 joule of GPE it had and gained 1 joule of KE. The total amount of energy is constant. In reality, there may be a slight amount of heat energy produced as the object falls due to air resistance. This 'loss' of energy is not really a loss, just a transfer of energy to a non-usable form. The usable energy is the kinetic energy. If 1 J of GPE was transformed into 0.9 J of KE and 0.1 J of heat, then the system would be said to be 90% efficient.

Energy efficiency = amount of usable final energy ÷ amount of initial energy × 100

In this example:

Energy efficiency = 0.9 ÷ 1 × 100 = 90%

The law of conservation of energy still applies because the 1 J of initial GPE = 0.9 J of KE + 0.1 J of heat energy.

ZOOMING IN

Crumple zones and airbags

An airbag is like an automatic cushion that undergoes rapid inflation and deflation during a high-speed car crash. It is designed to complement other restraining systems in a car (e.g. seatbelts) and not replace them.

The front and rear crumple zones of a modern car are designed to crumple evenly during a car crash to absorb the energy of a collision. A common misunderstanding about crumple zones is that they allow a car's bodywork to crush the passengers. This is incorrect; instead, the crumple zones absorb the energy of a collision by deforming the bodywork, keeping the passenger cell intact and undamaged.

Both airbags and crumple zones are standard equipment on modern cars. Both work on the principle of cushioning.





PRACTIVITY 1.7

One newton and one joule

What you need: object with mass as close as possible to 100 g

(An object with a mass of 100 g has a mass of 0.1 kg; this means it will weigh $0.1 \times 9.8 = 0.98$ N, or very close to 1 N.)

1 Hold the object in your hand. This is equivalent to 1 N of force.

- Is 1 N a very large force?

2 Now lift the object through a distance of 1 metre at a steady rate. You have just given the object gravitational potential energy.

$GPE = m \times g \times h = 0.1 \times 9.8 \times 1$

$= 0.98$ J (or very close to 1J)

- Is 1 J a lot of energy?

Our food gives us energy too. This is usually measured in units of kilojoules (kJ), where 1000 J = 1 kJ.

Conservation in action

Analysis of a simple pendulum follows a similar pattern to dropping a mass.

What you need: simple pendulum made from a mass on the end of a length of string, retort stand

1 Hang a simple pendulum from a retort stand.

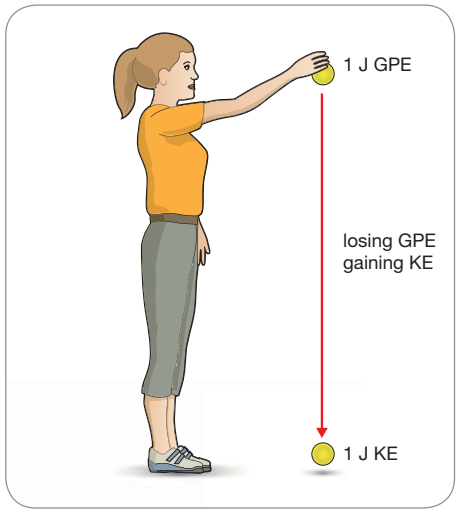
2 Lift up the mass and release it. As it swings, its GPE is converted into KE and back into GPE then back into KE etc, the process continues until the pendulum finally comes to rest.

3 Measure how much GPE the pendulum mass had at the start before it was released by measuring its mass and starting height above the bench and using the GPE formula.

4 Allow the pendulum to complete 10 full swings (the release point is swing 0) and stop it at the end of its 10th swing.

5 Remeasure the finishing height and determine how much energy was 'lost' to air friction each swing (divide by 10 swings).

6 Work out the energy efficiency of the pendulum. Lay out your calculations clearly and accurately.







→ Fig 1.52 This conversion is shown as 100% efficient and isn't possible in reality.

What do you know about energy?

1 How is the kinetic energy of an object affected if its mass decreases and the other variables remain constant?

2 How is the gravitational potential energy of an object affected if its height increases and the other variables remain constant?

3 How is the elastic potential energy of an object affected if its stiffness increases and the other variables remain constant?

4 Explain the law of conservation of energy using an example of your own with an estimate of the amount of joules of energy at the start and the finish.

5 The following statements are incorrect. Rewrite them to make them correct.

a The energy efficiency of all systems is always 100%.

b The law of conservation of energy doesn't always apply.

1.3

What happens in collisions?



Remember and understand

1 Copy and complete:

a The _____ an object travels, the more momentum it has.

b The _____ acting on two objects for the duration of a collision are always _____.

c Work happens whenever things are moved or rearranged by a _____.

d Work and energy are _____ quantities, so no _____ is needed.

e The energy of motion is called _____ energy.

f If we lift an object to a height, it gains _____ _____ energy.

2 Complete the following table.

Quantity	Symbol	Unit	Unit symbol	Formula
	p			
Impulse			Ns	
				$W = F \times d$
	KE			
Gravitational potential energy				
	EPE			

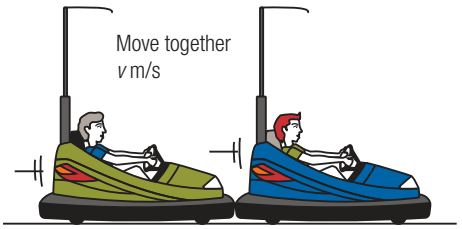
Apply

3 Show, using the formula for kinetic energy, that if the speed is doubled the energy of a car crash would be four times as high.

Analyse and evaluate

4 A car without crumple zones is involved in a car crash. What do you think happens if there are no crumple zones to crumple and absorb the energy of the collision?

5 Figure 1.53 shows a rear-end car crash. Before the collision, the green car had a velocity of 2.2 m/s and a mass of 140 kg. The blue car had a velocity of 1.7 m/s and a mass of 160 kg.



Combined mass = 300 kg

→ Fig 1.53

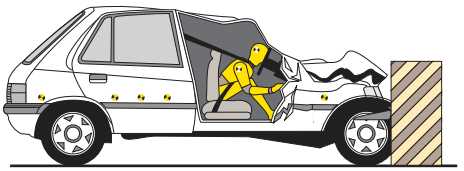
a Calculate the momentum of each of the two dodgem cars before the collision.

b Calculate the total momentum of the two dodgem cars before the collision.

c Calculate the velocity of the two dodgem cars after the collision.

Critical and creative thinking

6 Identify the safety features of the car shown in Figure 1.54. Which safety features are missing?



→ Fig 1.54

CONNECTING IDEAS Forces and motion

7 The kinetic energy formula demonstrates that speed contributes to the seriousness of a car crash in a major way. Extend your ideas about collisions to include other factors that contribute to car crashes. Produce a fact sheet for learner drivers to inform them of your findings.

Research

Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

Car safety features

Modern cars may be equipped with electronic stability control (ESC), anti-lock braking systems (ABS), electronic brake distribution (EBD), an RVC tachometer, traction control systems (TCS) and Park assist. Find out about each of these and other car safety features under development. How do they contribute to the safety of passengers?

g-forces

Aircraft pilots flying military jets and those in the Red Bull Air Race commonly experience *g*-forces. A ride at Luna Park is called '*g*-force'. When do pilots experience *g*-forces? What is the human tolerance of *g*-forces and what effect do they have on the body? What other examples are there of theme park rides or situations where people experience *g*-forces?

Movement of aircraft

Aircraft are the second fastest mode of transport, after rockets. Find out about the different types of aircraft and how they move. Explain the interactions between lift, weight, thrust and drag in aircraft movement. What speeds can aircraft attain?

Drag forces

The modern design of vehicles involves the study of drag forces and how to reduce them. This involves knowledge of streamlining and aerodynamics. What are these areas of science and how are new designs tested?

Reflect

Me

1 How is the information you have learned in this chapter relevant to your life?
2 What is the most interesting thing you learned about movement?
3 Did you take movement for granted before you read this chapter? Do you still?

My world

4 How has increased scientific knowledge and understanding of movement improved the world?
5 What skills or knowledge can you take from your study of movement and apply to another school subject or another part of your world?

My future

6 Has studying movement made you interested in studying VCE Physics?
7 What careers might you pursue if you are interested in force, mass and movement?

Review

Key words

acceleration
acceleration due to gravity (*g*)
deceleration
displacement
elastic potential energy (EPE)
gravitational potential energy (GPE)
impulse
inertia
kinetic energy (KE)
law of conservation of energy
law of conservation of momentum
momentum
net force
scalar
speed
ticker timer
vector
vector diagram
velocity
weight
work

Building an energy converter: the come-back can

Challenge

To build a can that, when rolled across the floor, comes to a stop and then rolls back to where it started, illustrating the law of conservation of energy.



Materials

Cylindrical can or tin with removable lid (like a small Pringles tin)
Rubber band
Mass to be attached to the centre of the rubber band
Method of attaching the rubber band to the ends of the tin



Questioning and predicting

Open the can and work out a method of securing the rubber band between the ends of the can and how to attach your mass to the rubber band so it causes the rubber band to wind up when the can is rolled across the floor.

Planning and conducting

Write out your method in steps, then follow these steps to see if your method works.

Processing, analysing and evaluating

Consider the results of your experiment.

If necessary, modify your method and try it again.

This demonstration should illustrate the conversion of kinetic energy to elastic potential energy and back. The potential energy is stored internally in the twisted rubber band.

Communicating

Write a formal report of this activity, including as many of the motion concepts we have covered in this chapter as possible, such as speed, acceleration, deceleration, Newton's laws, momentum and energy conservation.



2 The Universe: past, present, future …



→ Fig 2.1 To ancient people, the night sky must have made them wonder about what they were seeing.

2.1 How did we find out about the Universe?

Humans have always been fascinated by the night sky. In many ancient civilisations, structures and monuments were built to study and record the movements in the Universe. The Great Pyramid at Giza in Egypt and the Mayan El Caracol at Chichén Itzá, in Mexico, were both built using astronomical alignment and orientation. It is believed that El Caracol was designed to observe the irregular movements of Venus. It is the oldest standing observatory in the Americas. Our understanding of the Universe has developed greatly but scientists know that the more they understand about the Universe, the more there is to know.

1 Why do you think humans have always been fascinated by the night sky?

2 What sorts of information did ancient civilisations obtain from studying the night sky?

3 What astronomical events would the people of ancient times have had difficulty explaining?

Where do we come from? Are we alone in the Universe? Do black holes actually exist? Will the Universe last forever? Your science class could probably fill the whiteboard with questions about the Universe. Scientists don't know all the answers. We are constantly discovering new planets and other objects in the Universe and new information about our closest planets. It's a big Universe and it's constantly changing. Only recently, new ideas about planet size resulted in much-loved Pluto being reclassified as a dwarf planet. Understanding our Universe better may provide clues as to the future of our own planet and, ultimately, us.



→ Fig 2.2 The Southern Cross in the night sky.

2.2 What is happening in the Universe?

The night sky, in all its glory, is truly an awe-inspiring spectacle. However, out of the countless billions of stars in the known Universe, only several thousand are visible from the Southern Hemisphere on any one night. The stars we can see are either close to the Earth, very bright or actually galaxies rather than individual stars. Apart from the Sun, our closest star, visible in the night sky with the naked eye, is Alpha Centauri, one of the Pointers. Its distance from Earth is 4.4 light years. This means the light it emits takes 4.4 years to reach us on Earth. By looking at the light from Alpha Centauri, we are seeing how it appeared 4.4 years ago, so we are actually looking back in time.

1 Have you heard of the Pointers? Do you know what they point to in our night sky?
2 How far back in time do we see when we look at Beta Centauri? What about when we look at the Large Magellanic Cloud?
3 Are all the stars in the night sky the same? What differences can you see?

2.3 How is the Universe changing?

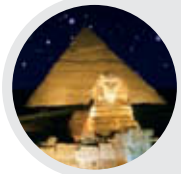
In the movie *Deep Impact*, a comet is heading towards a collision with the Earth. This is known as an extinction level event (or ELE), and the movie focuses on its effects on the Earth and humans' attempts to avoid disaster. Such a significant collision is a real but very unlikely possibility for the Earth. Astronauts face other dangers when travelling in space. Astronauts working on the International Space Station are exposed to low-intensity radiation for long periods of time. In the future, astronauts travelling on missions to other planets will need strong radiation shielding to withstand high-intensity radiation exposure for long periods. This is one of the most challenging problems to solve for long-distance space travel.

1 What other difficulties will interplanetary space missions face?
2 Would you like to travel in space one day? Explain.
3 How could a collision between the Earth and an asteroid or comet lead to mass extinction?



→ Fig 2.3 Astronauts need strong radiation shielding to protect them from high-intensity radiation.

2.1 How did we find out about the Universe?



Many different cultures and religions on Earth have their own creation stories that explain how the Universe came into existence. Science has its own stories too. The study of cosmology attempts to explain how the Universe began. Modern scientific views of cosmology began with Edwin Hubble's discovery in the 1920s that the Universe is expanding like a balloon. The Hubble Space Telescope is named after Edwin Hubble.

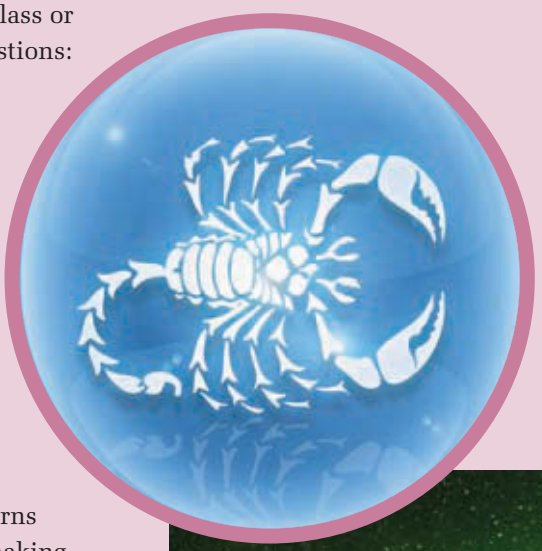
DISCOVERING IDEAS

Astrology

Discuss the topic of Astrology as a class or in small groups. Consider these questions:

1. What is astrology?
2. What is astronomy?
3. How does *astrology* differ from *astronomy*?
4. How are the zodiac signs linked to astronomy?
5. Is astrology a science or a pseudo-science? Why?

In the past, astrology and astronomy were indistinguishable. People observed the paths and patterns of celestial bodies with the aim of making clear parallels to human affairs, personality and other earthly matters. Detailed observations made by early astrologists paved the way for the emergence of astronomy as a scientific discipline.



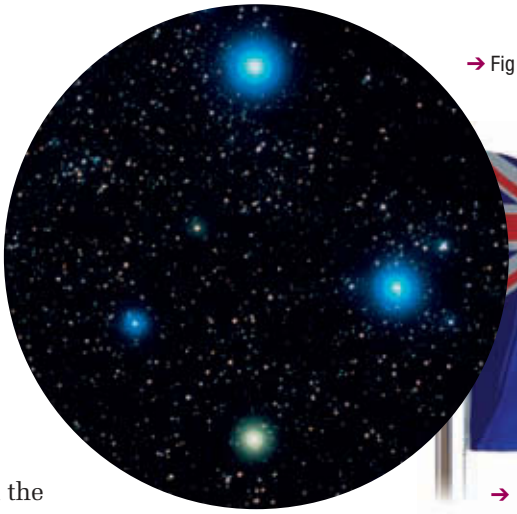
To distinguish between ideas that are considered facts and those that are opinions or beliefs, we need to find evidence. So how did the ideas of astronomy become distinct from those of astrology? Research the topic of astrology in your group. Try to understand the ideas behind astrology and how you can distinguish it from astronomy.

Present your research as a PowerPoint presentation, animation or any other visual media.



The age of discovery

When the Ancient Greeks looked at the stars in the sky, they saw them in groups that made up images. The Ancient Greeks depicted these images as ancient gods, heroes, animals or even everyday items, mostly from Ancient Greek mythology. These groups of stars form what we call **constellations**. Some of the constellations are easy to recognise and you may already know them. One of the easiest constellations to find at night in the Southern Hemisphere is the Southern Cross, or Crux. The Southern Cross is so famous and significant to Australians that it appears on the Australian flag.



→ Fig 2.4 The constellation 'Crux'.



→ Fig 2.5 The Australian flag.

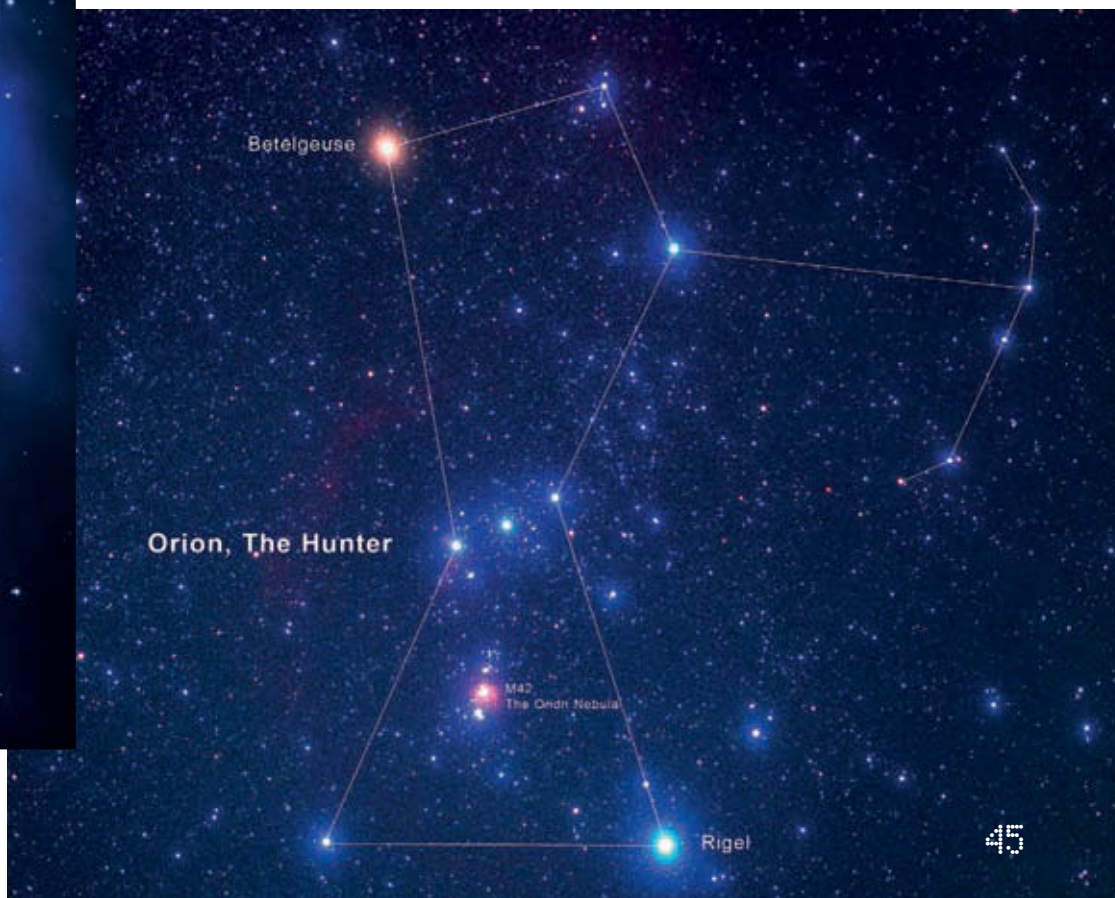
Two stars, Alpha and Beta Centauri, are known as the Pointers to the Southern Cross, pointing or lining up in the direction of the Southern Cross. Alpha Centauri is only 4.4 light years away from Earth. Beta Centauri is much further away, at 525 light years. When the sky is dark, well away from city lights, you might be able to see the Coalsack, which is a dark nebula just under the Southern Cross on the side nearest to the Pointers.

Another well-known constellation is Orion the hunter (Figure 2.6). Part of this constellation is also sometimes called the 'Saucepan'. Three stars close together in a row form the base of the saucepan and Orion's scabbard forms the handle. For Orion the hunter, the three stars in a line form Orion's belt. The Orion constellation also contains the well-known stars Rigel and Betelgeuse. Rigel is the brightest star in Orion and has a bluish white appearance, which indicates that it is very hot. Betelgeuse is a cooler star and appears reddish orange in colour. It is one of the largest red supergiant stars and, if placed in our solar system in the position of the Sun, it would reach out past Mercury, Venus, Earth and Mars! There are many other interpretations of Orion in other cultures. See what you can find out about this amazing group of stars.



→ Fig 2.6 Orion the hunter.

→ Fig 2.7 The 'Saucepan' is part of the constellation Orion the hunter.



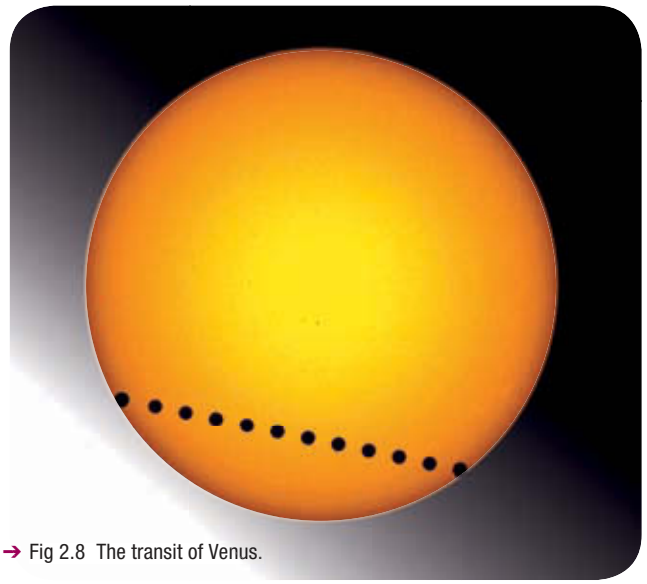
The brightest star in the night sky is Sirius, which is found just to the east of Orion. With the naked eye Sirius appears to be only one star, but it is actually two stars. Sirius is also known as the Dog Star because it is the prominent star in the constellation Canis Major, which means 'big dog'. Another interesting constellation is Virgo, which is the second largest constellation. The largest constellation is Hydra.

When you have looked at the night sky, have you noticed how stars appear to move across the sky? Until the 16th century, people thought that the Earth was the centre of the Universe and all the stars and planets rotated around the Earth. Each night the stars and constellations appear to move across the sky as the Earth spins around on its axis. The constellations also appear to move across the sky with the seasons. As the Earth orbits around the Sun over a year, we view the night sky from different perspectives, so the position of the constellations appears to change. Ancient civilisations used these changing positions of the stars and constellations to determine the seasons.

Transit of Venus

When Captain Cook discovered Australia, he was actually on a different mission altogether. It was predicted that on 3 June 1769 the planet Venus would cross in front of the Sun, a phenomenon known as the transit of Venus. This event happens in pairs, approximately 8 years apart, only every 120 years.

Astronomers at the time believed that to observe this event from different places on the Earth would enable them to calculate the size of the solar system, which was unknown at the time. Captain Cook, who was a very capable astronomer as well as an explorer, was chosen to lead an expedition to Tahiti, while other British contingents went to other places around the world, such as Norway and Hudson Bay in Canada. Unfortunately, the timing of the transit from all points of observation was not precise enough to calculate the size of the solar system. It was not until the 19th century, when astronomers used photography to record the next pair of transits, that this was determined. As the story goes, after Captain Cook had recorded his observations in Tahiti, he opened an envelope that contained secret orders for the next stage of his voyage. These orders told him to 'search between Tahiti and New Zealand for a continent'. We all know the outcome of his search … he found Australia!



→ Fig 2.8 The transit of Venus.

PRACTIVITY 2.1

Moving stars

What you need: star chart (optional), paper, pencil

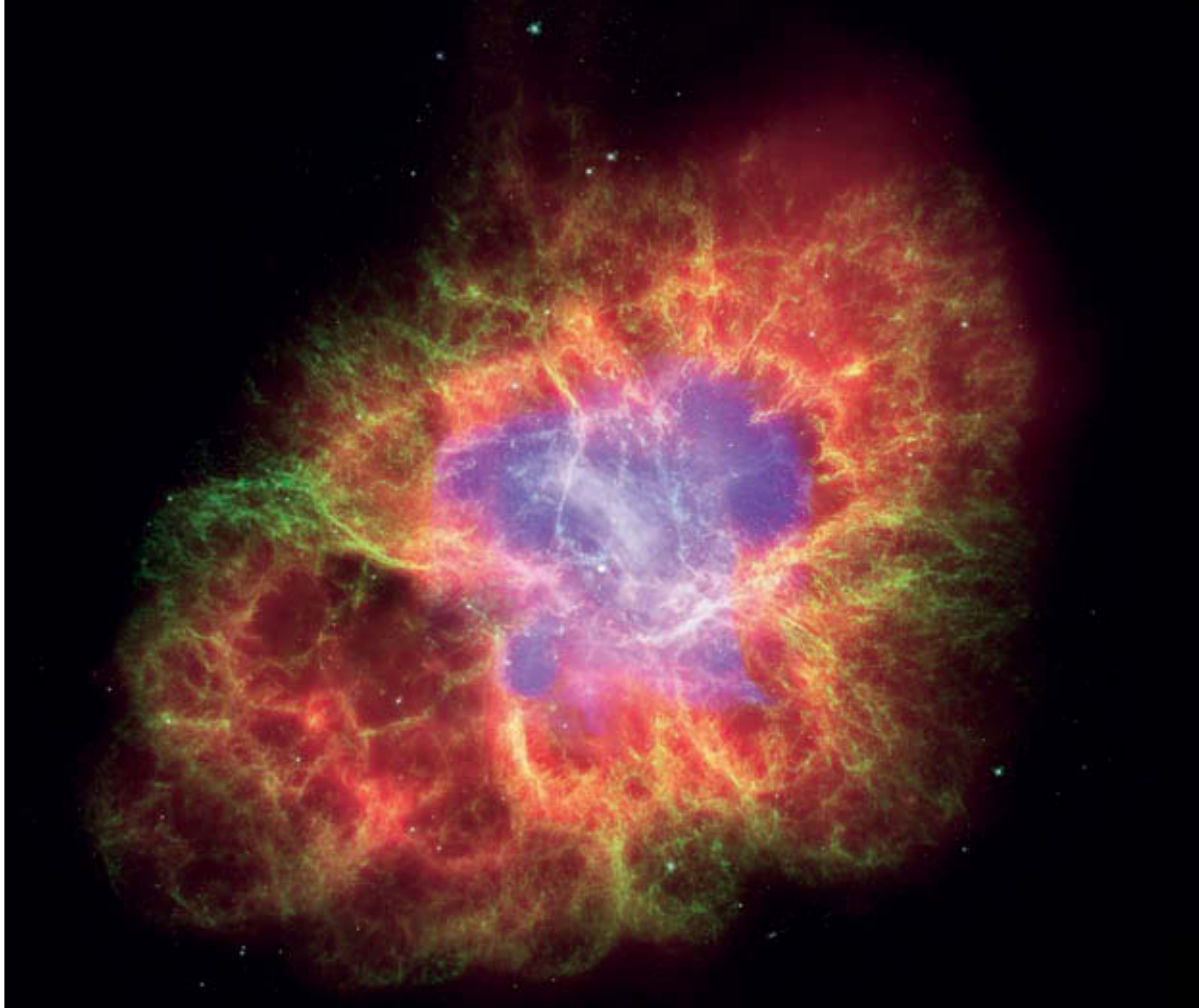
1. Observe the night sky on a clear night and locate the Southern Cross, Orion or any other constellation that can be easily identified.
2. Make a sketch of the orientation of the stars in your chosen constellation and note the time (e.g. 8.00 p.m.).
3. Go outside again after 1 and 2 hours and, standing in the same place, observe and plot the star positions as accurately as possible.
4. If possible, repeat your observations at the same time every 2 weeks for a month or two.

- During one night, how do the stars move across the night sky?
- Are the stars really moving?
- Over the course of a month or two, how do the stars move?
- What accounts for this motion, because your observations should have been taken at the same time each night?

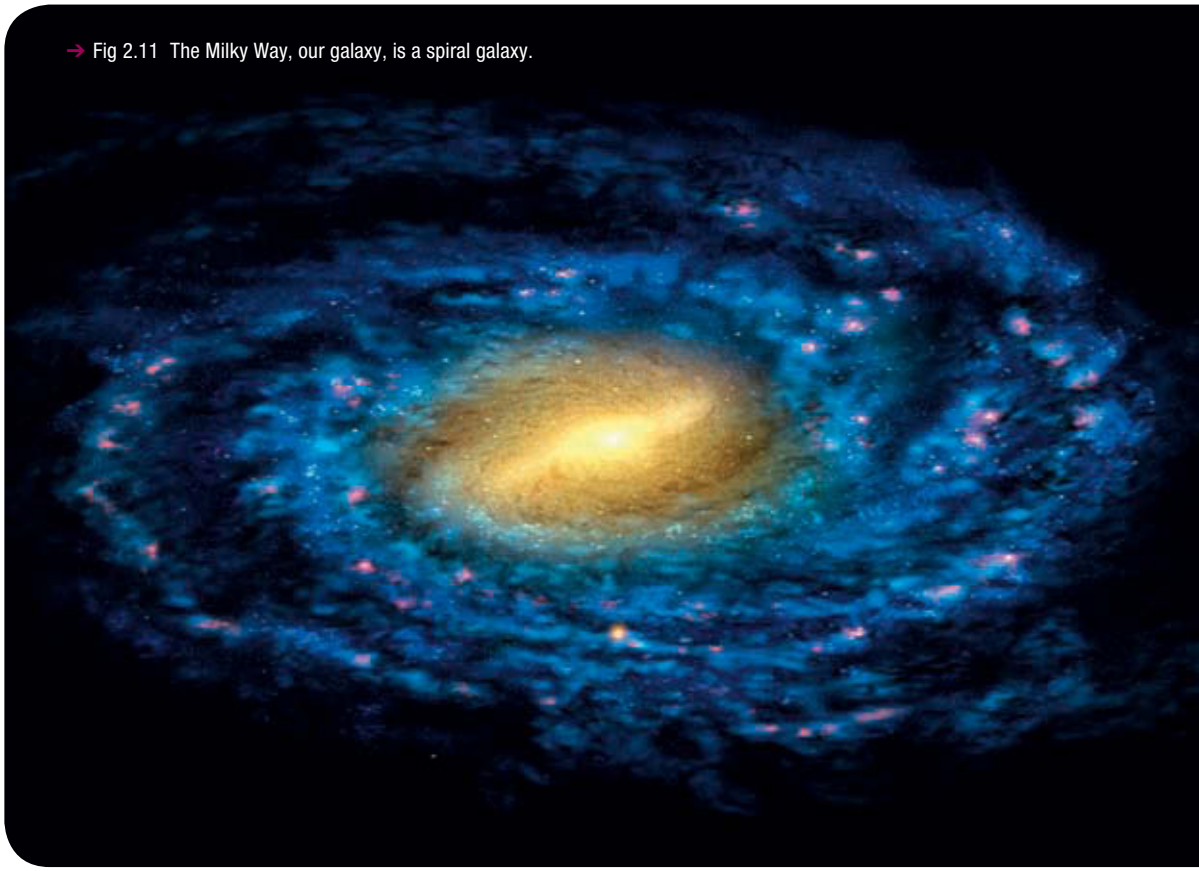


Galaxies

When you've looked at the night sky you may have noticed a whitish hazy band across the sky. This is the Milky Way, which is the galaxy we live in. The stars we see in the night sky are all part of our galaxy, the Milky Way. **Galaxies** are huge collections of stars held together by their own gravity. But galaxies were a mystery to astronomers because they appear as 'fuzzy objects' and were called **nebulae** (meaning clouds) until William and Caroline Herschel discovered that many of these 'clouds' were actually made up of billions of stars. Other nebulae had no stars and so they are still called nebulae, clouds of gas and dust that form brilliant patterns in the sky.



→ Fig 2.10 The Crab nebula is believed to be the remnants of a supernova.



→ Fig 2.11 The Milky Way, our galaxy, is a spiral galaxy.

→ Fig 2.9 Captain Cook was a very capable astronomer.



SKILLS LAB

Using a star chart

Planispheres or star charts are very useful maps for locating various stars in the night sky. A sky chart can be easily downloaded each month from www.skymaps.com. A sky chart and calendar are given on page 1, whereas page 2 has various notes and explanations about the objects you can see.

Download a copy of this month's sky chart. (Make sure you click on the Southern Hemisphere option.)

Read the instructions on how to use the sky chart, which are printed around the outside of the circular chart, along with other useful information about the chart.

Find the south celestial pole (SCP), which is marked a few centimetres above South on the chart. This is just a place in the sky; there is no star nearby. Over the course of a night, the stars appear to rotate about this point. Interestingly, in the Northern Hemisphere, the North Star is located at the north celestial pole (NCP) and so it is used in navigation to find north.

Look at the bottom right-hand corner of the chart, which gives a key to the symbols on the chart. The star magnitudes give the brightness of the stars as viewed from Earth.

1 Can you see that Sirius is the brightest star in the sky?

2 Which star is the second brightest?

3 Which is brighter, Alpha or Beta Centauri?

4 Use your star chart to observe the night sky. How many stars and constellations can you identify? Report back to your class.

What do you know about the age of discovery?

1 What is the difference between a galaxy and a constellation?

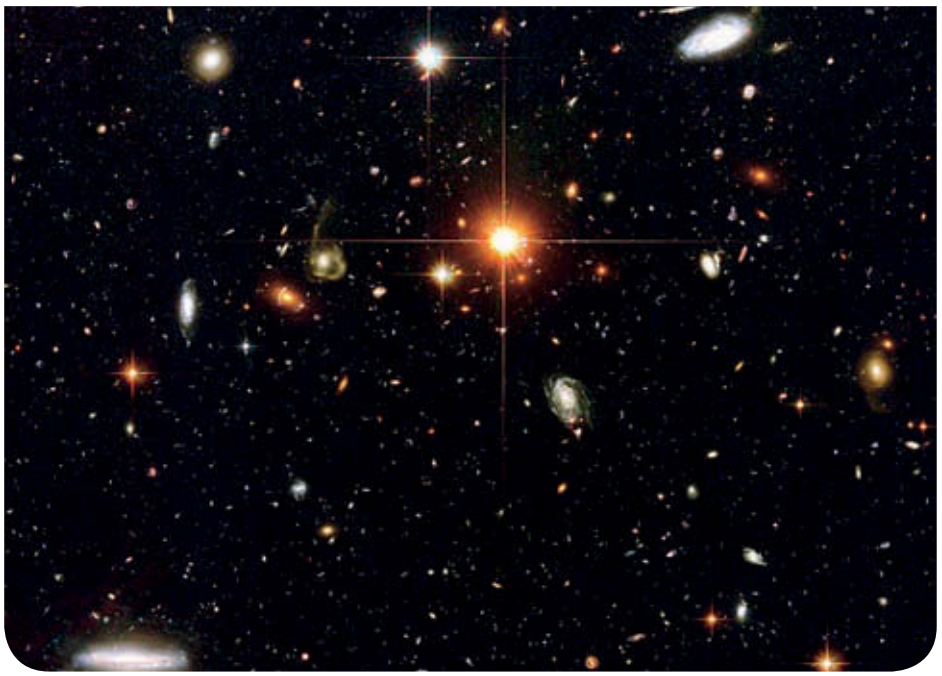
2 Why was Captain Cook chosen to observe the transit of Venus?

3 What is the Coalsack?

4 Is Orion a galaxy or a constellation? What features help you to find Orion in the night sky?

5 What is our galaxy? What does it look like in the night sky?

6 Why can't we see individual stars at night from other galaxies?



→ Fig 2.12 Far off galaxies, as seen by the Hubble Space Telescope.

Big Bang theory

How the Universe began has been much debated and studied. In ancient civilisations, people believed that the Earth was at the centre of the Universe. Astronomers today believe that there is no centre to the Universe and that the Universe is bigger than we have been able to see even with our most powerful telescopes.

Scientific theories of the origins and evolution of the Universe first appeared in the early 20th century. These were based on ideas that celestial bodies obey identical physical laws to those that apply on Earth. The concept of celestial mechanics was developed on the basis of Newton's laws of motion. Einstein's 1915 theory of relativity led to the development of the field of physical cosmology—the study of the origins and evolution of the Universe.

The concept of the Big Bang was originally proposed in the 1920s, although it wasn't called this then. In 1929, the US astronomer Edwin Hubble discovered that the spectra of light from galaxies inferred that they

were moving away from the Earth. Hubble also found one of the most significant results in the history of the origin of the Universe: that the further away galaxies were from the Earth, the faster they were moving. The speeds were enormous. In fact, it is not the galaxies themselves that are moving away; rather, space is expanding and taking the galaxies with it.

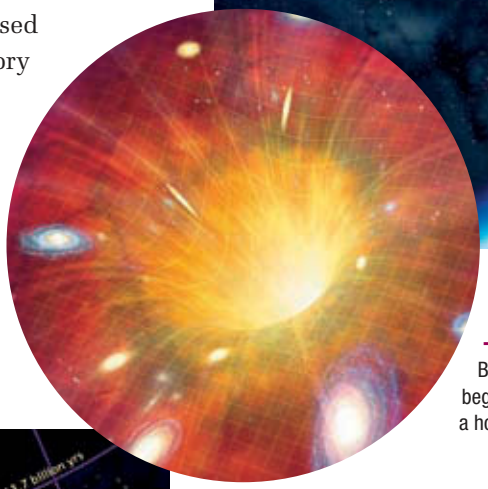
But what is the Universe expanding into? Based on Hubble's observations that the galaxies are racing away from each other, the obvious conclusion is that if you run things in reverse, everything must have come from the same spot, as if the Universe was born from some sort of explosion. This idea led to the development of the **Big Bang**.

Other astronomers had other theories. In 1948, Fred Hoyle, a UK astronomer, proposed the **Steady State theory** as the theory of the origin of the Universe. In the Steady State theory, Hoyle proposed that the Universe has always existed and always will—that the Universe has no beginning and no end. He also proposed that matter is constantly being created in the Universe at an enormous rate and that this is causing the Universe to expand.

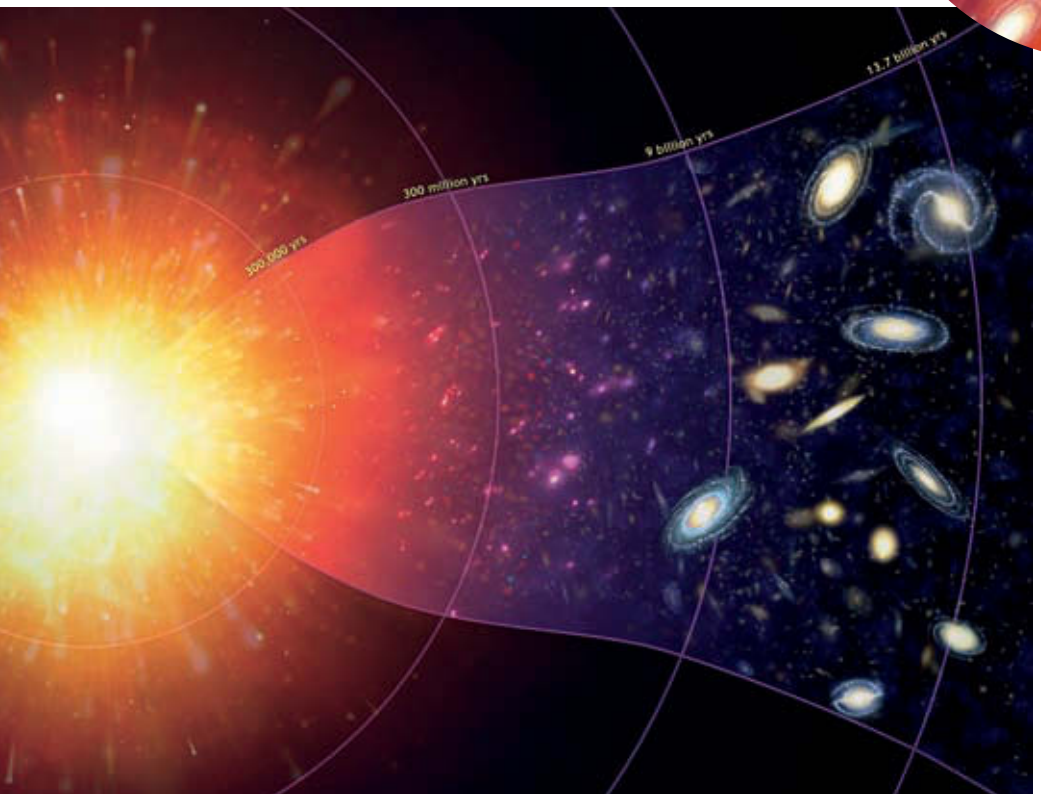
The Steady State and Big Bang theories seemed to be on opposite sides. The 'Big Bang' is a term used in cosmology to describe how the Universe began from a hot, dense state at some point in time in the past and how it has continued to expand and will continue to do so into the future. Because there is no evidence of the initial state of the Universe that caused the Big Bang, the theory relates more to the expansion and evolution of the Universe since that point in time, rather than the 'Big Bang' itself.



→ Fig 2.13 Edwin Hubble made his observations from the Hooker Telescope—an older, less powerful telescope than the Hubble Telescope shown, which was named in his honour.



→ Fig 2.14 According to the Big Bang theory, the Universe began from a rapid expansion from a hot, dense state.



→ Fig 2.15 The evolution of the Universe, according to the Big Bang Theory.

Evidence for the Big Bang theory

The concept of the Big Bang relied on the idea of the existence of some sort of radiation—the fading heat from the formation of the Universe at the time of a huge event. In 1965, two US scientists, Arno Penzias and Robert Wilson, found that evidence.

While testing a new, sensitive radiotelescope antenna, Penzias and Wilson found a strong background noise that was interfering with transmission. They weren't trying to find it, they just happened to notice it. This background noise was found to be a form of electromagnetic radiation known as cosmic microwave background (CMB) radiation.

Modern measurements and calculations place the Big Bang as happening approximately 14 billion years ago, with the CMB radiation emitted approximately 400 000 years later.

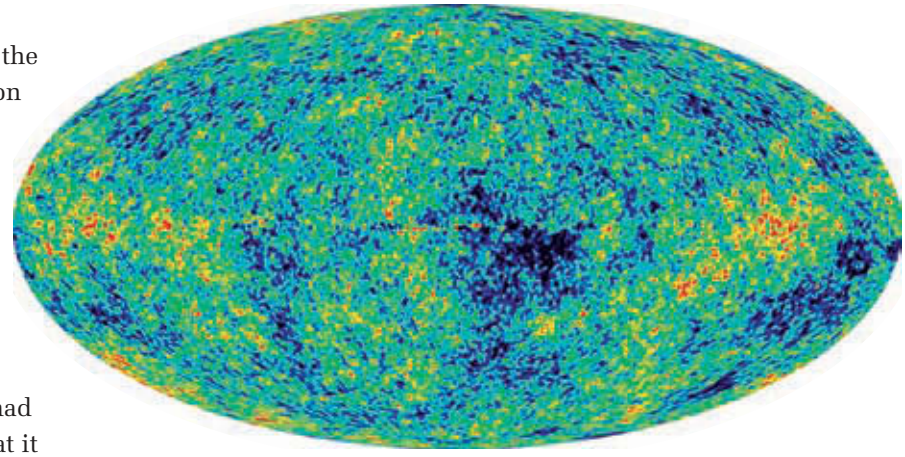
The existence of CMB radiation was one of the greatest discoveries of all time, so important that Penzias and Wilson were awarded a Nobel prize for their discovery.

Although the existence of CMB radiation provided evidence for the Big Bang theory, it had a problem: measurements on Earth showed that it was too smooth. The overall property of the Universe is 'lumpiness'. Much of the visible material in the Universe is found in stars, which, in turn, are grouped into galaxies. The Universe is not even. Similarly, there should be slight variations in the temperature of the CMB radiation. In 1992, the Cosmic Background Explorer (COBE) satellite detected these ripples in temperature fluctuations.

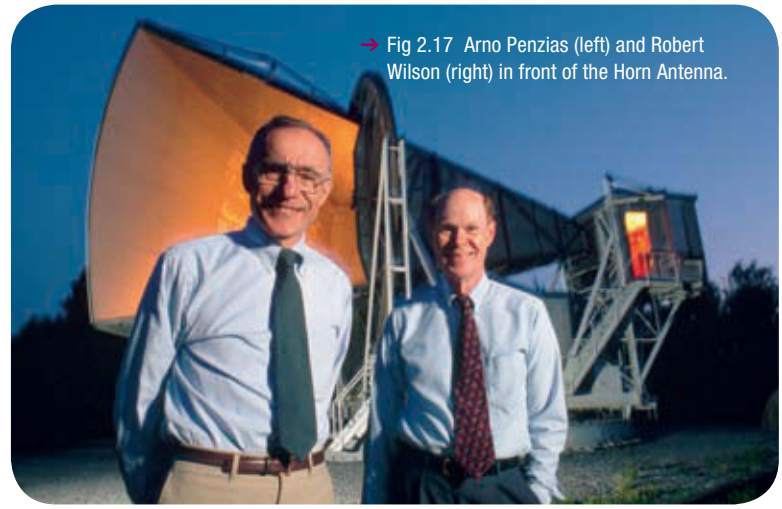
In an endeavour to understand more about our Universe, the Planck satellite was launched in 2009. This satellite was designed to examine the CMB radiation in even greater detail to give us a more accurate idea of the origins and evolution of the Universe.

NASA hopes to build a Big Bang Observer system at some time in the future to detect gravitational waves. It is thought that the information obtained from gravitational waves will also contribute to this theory.

Hopefully, these missions will help explain which version of the scientific creation story best fits the data collected.



→ Fig 2.16 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky.



→ Fig 2.17 Arno Penzias (left) and Robert Wilson (right) in front of the Horn Antenna.



→ Fig 2.18 The Planck satellite was designed to examine cosmic microwave background radiation. The information it provides will give us a better idea of the origins of the Universe.

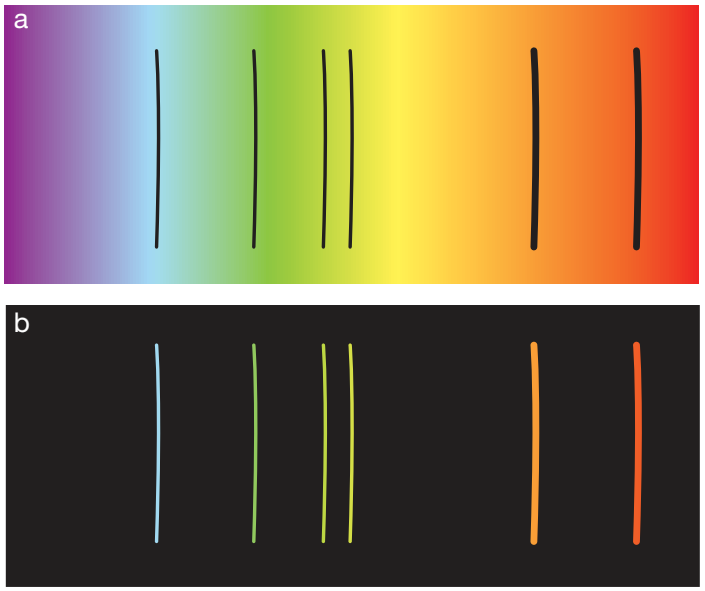
What do you know about the Big Bang theory?

1. Write a description of the Big Bang theory in your own words.
2. A theory is never final. Evidence is always needed to reinforce a theory. How do you think evidence obtained from the Planck satellite will help support the Big Bang theory?
3. What is CMB radiation? Why is its existence important?
4. CMB radiation has been called 'ancient whispers'. Why is this name appropriate?

Measuring the movement of galaxies

In the 1920s, using the most powerful telescope in the world at the time, Edwin Hubble examined the spectra of light emitted by the galaxies.

Each element emits its own unique **emission spectrum**. Stars give out light and, if that light passes through a gas on its way to Earth, the gas absorbs the same wavelengths of light as it emits when heated. The result is an **absorption spectrum**. An absorption spectrum is made up of a continuous spectrum with lines missing.



→ Fig 2.19 Dark lines in the absorption spectrum of any element (a) match exactly the bright lines in its emission spectrum, as shown for helium (b).

Compare the emission spectrum and the absorption spectrum of helium in Figure 2.19. You will notice that the absorption spectrum contains lines in exactly the same positions as in the emission spectrum.

Just like an emission spectrum, absorption spectra can be used to identify the elements present in stars. Absorption spectra can also reveal another important aspect of a distant star—its velocity—which is what Hubble discovered.

The same thing can be observed on Earth with sound, instead of light. When a racing car races past you, the pitch of its sound appears to change. This can be modelled by making a 'yeee … owww' sound with your voice. The 'yeee' is the high pitch from the car's engine as it approaches you: its sound waves are being bunched up as the car speeds in your direction and the resultant shortening of the wavelength increases the pitch, or frequency, of the sound. As the racing car passes you, the pitch you hear drops—that's the 'owww' part. The car is now speeding away from you and sending the sound waves back to you, lengthening their wavelength and dropping the pitch. The faster the car goes, the more pronounced the effect. This is known as

EXPERIMENT 2.1

Investigating emission spectra

Aim

To investigate the light emitted by various elements using spectroscopy.

Materials

Spectroscope

Discharge tubes for different elements—hydrogen, helium and neon

Power supply for discharge tubes

Method

1 Connect the equipment and darken the room.

2 Aim the spectroscope at the discharge tube and observe the emission spectrum.

3 Repeat for each tube.

Results

Record the position and colour of the emission lines for each element. Present the results in a table.

Discussion

1 Each element has a distinct emission spectrum. How is this used to identify the elements present in the Universe?

2 If the light from a distant nebula had lines missing from its spectrum, what would that mean?

Conclusion

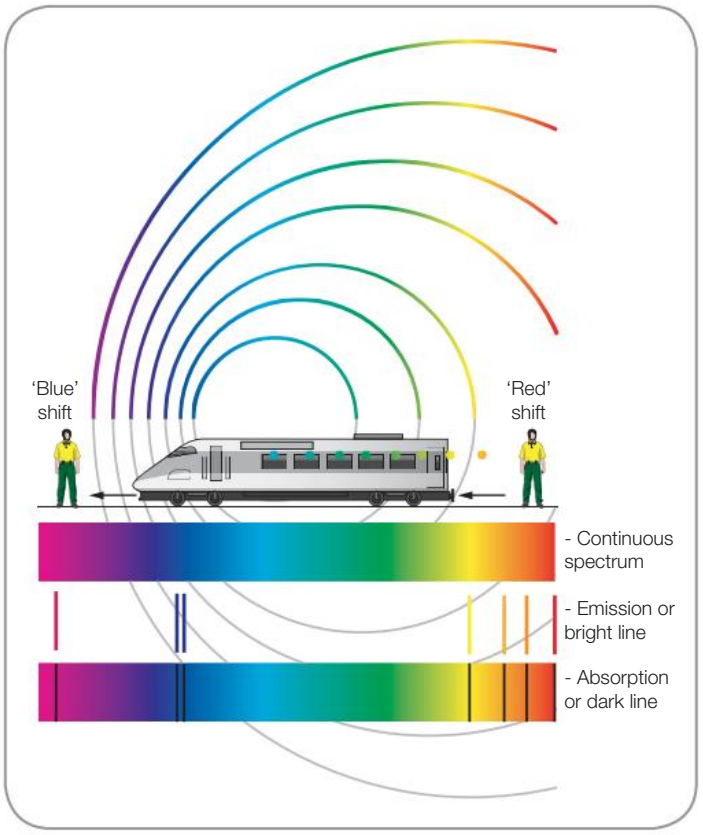
Respond to the aim.



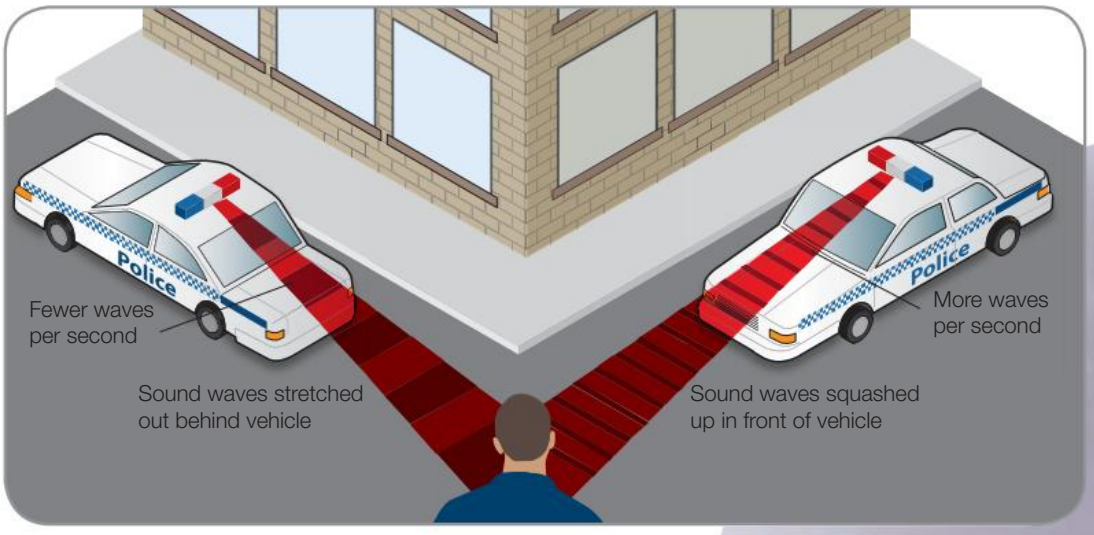
the Doppler effect, named after its discoverer, Christian Doppler. It happens with ambulance and police car sirens, trains, any fast, noisy object and, of course, also with light.

When Hubble looked at the absorption spectra of distant galaxies, he saw that the lines were shifted in the red direction of the spectrum. Red light has a lower frequency; blue light, at the other end of the visible spectrum, has a higher frequency. A shift in the red direction, which is known as a red shift, indicates that the galaxy is moving away from Earth at a velocity that is proportional to the amount that the spectrum has shifted towards the red end. The greater the shift, the greater the velocity of the galaxy. A shift in the blue direction, a blue shift, indicates that the star is moving towards Earth at a velocity proportional to the amount of shift in the blue direction.

Edwin Hubble's big discovery was that the more distant galaxies tended to have more red-shifted spectra and, hence, were travelling faster away from Earth. This discovery became known as Hubble's Law and provides compelling evidence, along with the existence of the CMB radiation, for the Big Bang theory. Hubble also determined an age of the Universe based on his observations. Originally calculated at approximately 1.8 billion years, astrophysicists now estimate that the Universe is 13.7 billion years old.



➔ Fig 2.21 'Red shift' and 'blue shift'.



➔ Fig 2.20 The Doppler effect.

PRACTIVITY 2.2

Exploring the Doppler effect

What you need: source of sound that can be spun on a rope (known as a Doppler apparatus)

1 Switch on the sound source and spin it around, making sure no one is in its path.

2 Listen carefully to the pitch of the sound.
- What happens to the pitch of the sound as the Doppler apparatus spins around?
- When is the pitch higher? When is it lower?
- Relate this demonstration to the red shift and blue shift that are seen with starlight.

What do you know about measuring the movement of galaxies?

1 How would you know you were looking at an absorption spectrum?

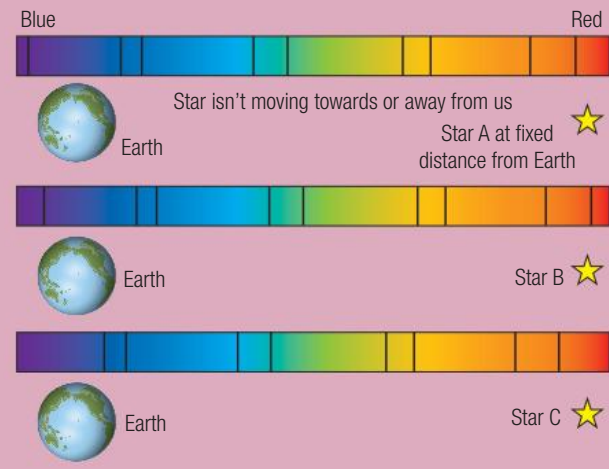
2 How are the emission and absorption spectra for helium similar?

3 How does red-shifted light show that a galaxy is moving away from us?

4 Figure 2.22 shows the spectra observed from three stars. Star A is at a fixed distance from Earth, whereas stars B and C are moving.

   a What produces the dark lines on each spectrum?

   b Which star—B or C—is moving towards the Earth? Explain your answer.



→ Fig 2.22

ZOOMING IN

It's all relative

Einstein made one of the greatest discoveries of the 20th century when he proposed his two theories of relativity in the early 1900s. These theories relate to the relative nature of motion and mass—that is, how they depend on each other and how matter, time and space interrelate.

In his *special* theory of relativity (1905), Einstein postulated (suggested) that:

- the speed of light is always the same, regardless of how fast an observer is travelling
- the laws of physics are the same in all non-accelerating (inertial) frames of reference (just about everywhere).

From these two statements, our understanding of the nature of the Universe was changed. Einstein showed that distance and time are different for a stationary observer and for one who is moving at near the speed of light. When an object is moving near the speed of light and is viewed by a stationary observer, the observer will see the length of the object as less than it really is (length contraction) and time will pass more quickly for the stationary observer (time dilation). Fig 2.23.

In his *general* theory of relativity (1915), Einstein changed our ideas of gravity as a pulling force. Instead, he suggested that objects with mass change, or warp, the fabric of space. His idea predicted the possibility of black holes, which warp the space around them so much that not even light can escape.



Example 1:
Travel through space (X) = 0%
Spacetime always = 100%
Therefore, time travels at 100% the 'normal' rate
(Our only experience on Earth)



Example 2:
Travel through space (X) = 50%
Spacetime always = 100%
Therefore, time travels at ~80% the 'normal' rate
(TIME SLOWS DOWN!)



Example 3:
Travel through space (X) = 99%
Spacetime always = 100%
Therefore, time travels at ~2% the 'normal' rate
(TIME NEARLY STOPS!)

→ Fig 2.23 Einstein's special theory of relativity postulates that time is different for an observer who is moving at near the speed of light.

LITERACY LAB

The big bangs … before the Big Bang

Written by Carmelo Amalfi
Wednesday, 9 February 2011



→ Fig 2.24

COSMOLOGISTS say they have found evidence the universe has existed forever. Dr Roger Penrose shares his theory on time before the Big Bang to West Australians.

Oxford University researcher and frequent visiting academic to WA Roger Penrose says evidence of 'events' that occurred before the Big Bang can be observed in the background microwave radiation left in the wake of 'creation' about 14 billion years ago.

Sir Roger says analysis of this cosmic microwave background revealed echoes or imprints of previous Big Bang-like events.

First detected in 1964, the cosmic microwave background radiation consists of the remnants of the extremely hot radiation from the bang, which have now cooled to near absolute zero after nearly 14 billion years of expansion.

Professor Penrose, knighted in 1994 for his services to science, says he was never a fan of the widely popular 'inflationary theory' in which the universe was shaped by the fast expansion of space from a single point.

'In the scheme I'm proposing, you have an exponential expansion but it's not in our aeon—I use the term to describe [the period] from our Big Bang until the remote future,' Professor Penrose says.

'I claim that this aeon is one of a succession of such things, where the remote future of the previous aeons somehow becomes the Big Bang of our aeon.'

He says his 'conformal cyclic cosmology' allows the laws of nature to evolve with time without having to include a theoretical beginning to the universe.

Professor Penrose and his colleague Vahe Gurzadyan, of Yerevan State University, studied data from vast surveys of the cosmic microwave background by the WMAP satellite, which is now in a graveyard orbit around the sun after having scanned the entire sky for the past nine years.

They surveyed nearly 11 000 locations.

Penrose and Gurzadyan argue the same objects may have undergone the same processes more than once in history, each sending a shockwave of energy rippling into space.

Their search produced twelve candidates with concentric circles, each circle representing massive events having originated from the same object through the course of history.

The circles, he suggests, were generated by collisions between supermassive black holes that occurred during this earlier aeon.

These colliding black holes would have created spherical and uniformly distributed gravitational waves Albert Einstein predicted rippled out from catastrophic events.

Penrose says the waves are converted into a pulse of energy carried from the previous aeon into the current aeon.

The rings represent pre-Big Bang events taking place toward the end of the last aeon.

1 What does the CMB radiation consist of?

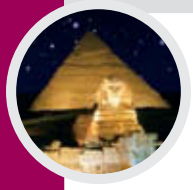
2 According to Professor Penrose, what is an 'aeon'?

3 What did Professor Penrose and his colleague find during their search of the data from WMAP?

4 Do you think Professor Penrose's 'conformal cyclic cosmology' is a feasible theory or too far fetched to be believable?

2.1

How did we find out about the Universe?





Remember and understand

1 Match each word below with its correct meaning.

Sun	study of the origins and evolution of the Universe
galaxy	theory of the creation of the universe in a huge explosion-like event
star chart	theory that claims that the universe had always existed and always will
constellation	huge collection of stars held together by gravity
Universe	used to locate and identify objects in the night sky
Big Bang	our closest star
cosmology	groups of stars that are close together in the sky
Steady State theory	everything that exists in space

2 What is the main difference between *astronomy* and *astrology*?

3 What is the transit of Venus?

4 What are Penzias and Wilson famous for discovering?

5 Rewrite the following paragraph by selecting the correct word(s) from the options given.

Most galaxies are moving towards/away from the Earth. The further away the galaxies are, the faster/slower they are moving. This is known as Doppler's/Hubble's Law.

Apply

6 Briefly describe the Doppler effect.

7 What was the link between Hubble's observations and the Doppler effect?

Analyse and evaluate

8 Why did the Big Bang theory replace the Steady State theory of the Universe?

9 Many ancient cultures had legends about the origin of constellations. Investigate either Koori, Polynesian or Ancient Greek legends on constellations. Do these legends still influence how we view and understand the constellations today?

10 **a** How does the pitch of an ambulance siren change as it races past you while you watch from the footpath?

b Why does this change occur?

c Would the driver of the ambulance hear this change?

Critical and creative thinking

11 View a space movie. What is its plot? Create a poster showing what things in the movie are scientifically correct and what things are not.

12 Create a table that compares and contrasts the Steady State and Big Bang theories.

13 Invent a new kind of space exploration tool with a name that ends with '-scope'. Write a short instruction manual for your new tool. Make sure you include a diagram.

CONNECTING IDEAS Systems in space

14 A system is made of inputs and outputs that all impact one another. How does this relate to what you have just learned about the Universe? Why might an understanding of systems on Earth be beneficial to those investigating areas beyond our planet?

2.2 What is happening in the Universe?



The Universe is an amazing place. When you look up at the sky at night and observe the stars and the various patterns they make, imagine what it was like in ancient times when humans had a very limited understanding of what they were seeing. They thought the stars formed pictures in the sky. When we look at stars, we are looking at the light they give off. Many of the stars are so far away from the Earth that their light takes thousands or millions of years to reach us. This means that we are actually looking back in time, because the light from a star tells us how that star looked thousands or millions of years ago and not how it looks today. If a star is 3000 light years away, it takes 3000 years for the light to reach us and, when we look at it, we are seeing it as it appeared 3000 years ago!

DISCOVERING IDEAS

Classifying galaxies

Galaxies are classified according to their shapes. The formation of galaxies can be studied using images from the Hubble Space Telescope archive—but there is so much out there that everyone's assistance is required. In addition, like all good scientific investigations, repetition is the key to reducing errors.

Visit the galaxyzoo website and find out what this project is. Read 'the story so far' and 'how to take part' and then get classifying. Summarise what you learn from this activity.

→ Fig 2.25 An elliptical galaxy.



→ Fig 2.26 A red spiral galaxy.



→ Fig 2.27 A blue spiral galaxy.



Stars

We are surrounded by stars. At night our sky is lit up by the stars, but in the daytime their glow is overpowered by the brightness of our Sun.

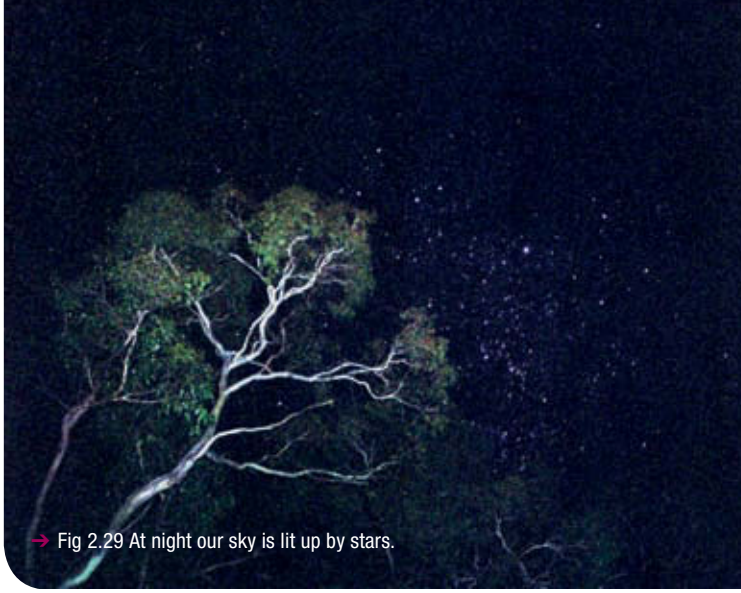
A star is a giant ball of hot glowing gases. Most stars are made almost entirely of hydrogen and helium. These gases are constantly reacting at the core (centre) of the star and provide energy to the star through nuclear fusion (when atomic nuclei join). This energy is emitted as light (and other forms of electromagnetic radiation) and is what we see when we look at the stars at night.

Stars vary in their size, mass, temperature and brightness. The colour of a star is determined by its temperature. For example, the coolest stars are red and the hottest stars are blue. The temperature of our Sun is 5500°C, so it appears yellow.

Some stars appear bright in the sky, whereas others appear dim. The brightness of the stars depends on how far away they are from us: a star that looks bright in the sky might be a dim star that is very close. The magnitude of a star is a measure of its brightness. Bright stars have a low magnitude and dim stars have a high magnitude. Sirius is the brightest star in the sky.

Galaxies are groups of stars and the space between the stars is filled with clouds of dusty gas. These dust and gas clouds are called nebulae (singular 'nebula'). It is thought that stars are 'born' in gas nebulae. When a star dies, its explosion is called a supernova.

Light travels very fast—at 300 000 km/s, in fact. The distance that light travels in 1 year is called a **light year**. Light years are used to measure the distance of stars from Earth. The nearest star to Earth is our Sun, which is only 500 light *seconds* from Earth. The next closest star to Earth is Proxima Centauri, which is 4.2 light years away.



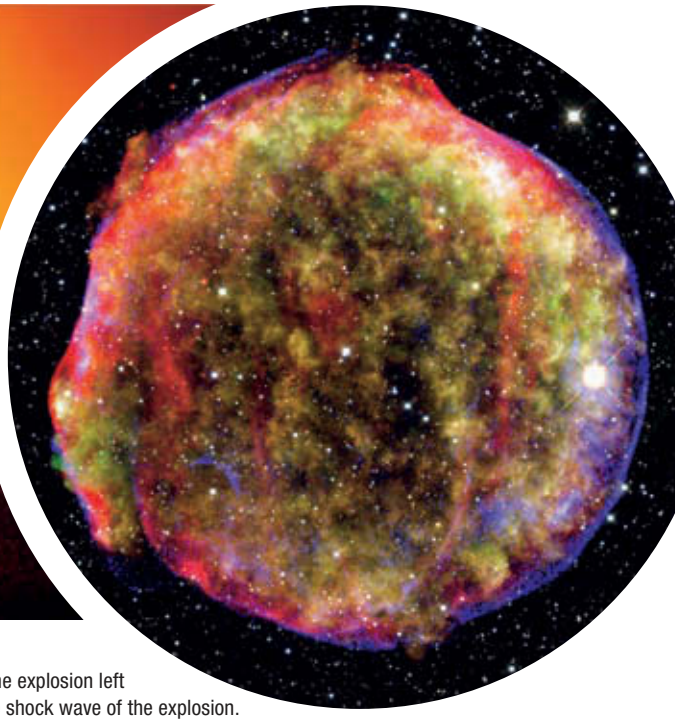
→ Fig 2.29 At night our sky is lit up by stars.



→ Fig 2.30 Don't be mistaken—Venus appears bright, but is really just reflecting the light of the Sun.



→ Fig 2.28 The Sun is Earth's closest star.



→ Fig 2.31 The Tycho supernova. This star explosion was seen by Tycho Brahe in 1572. The explosion left behind a hot cloud of expanding debris (green and yellow). The outer blue ring shows the shock wave of the explosion.

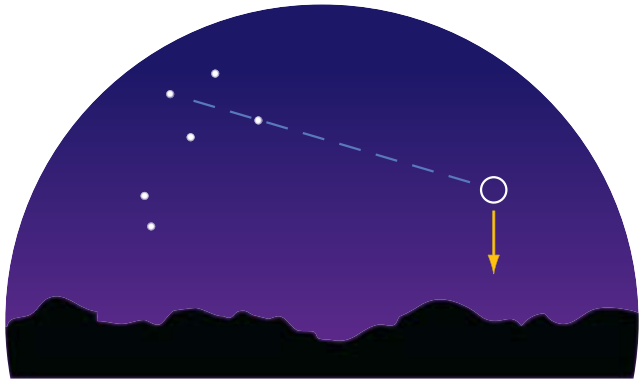
Finding south and north with the stars

The stars and the Sun can be used to find your way if you are lost.

Finding south

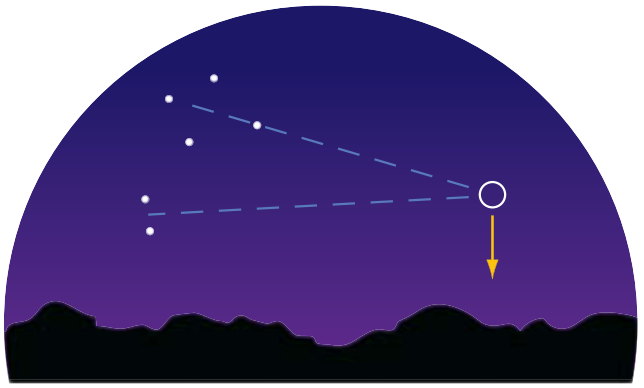
There are two methods of finding south using the stars. The stars actually help you find the south celestial pole; south lies on the horizon directly below this point.

1 Locate the Southern Cross in the night sky. Extend the long arm of the cross by four times its length (Figure 2.32). This gives the approximate position of the south celestial pole.



→ Fig 2.32 Finding south using the stars—method 1.

2 Locate the Southern Cross and the Pointers in the night sky. Extend the long arm of the cross. Find the midpoint between the two Pointer stars and draw a line from this at right angles to the midpoint (Figure 2.33). This line is known as the 'perpendicular bisector'. The intersection of this line and the extension of the long arm of the Cross is the approximate position of the south celestial pole.

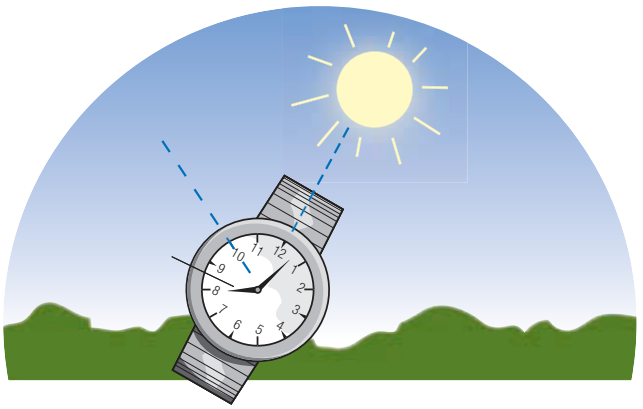


→ Fig 2.33 Finding south using the stars—method 2.

Finding north

North can be found using the Sun. You will need a watch with a dial.

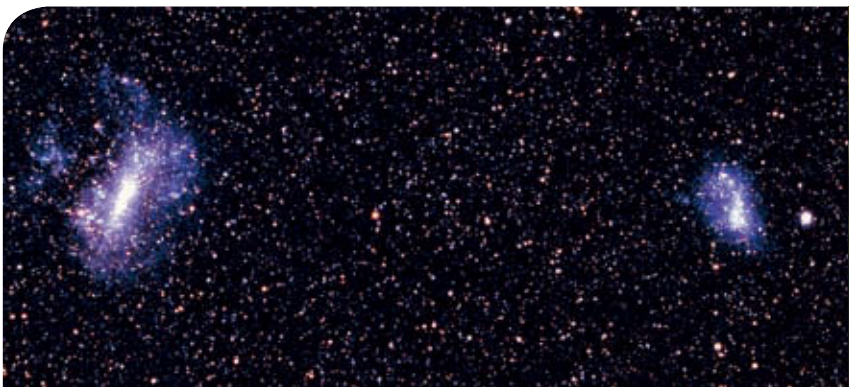
1 Point your watch so that the '12' is pointing in the direction of the Sun. North is found halfway between the '12' and where the hour hand is (Figure 2.34).



→ Fig 2.34 Finding north using the Sun.

What do you know about stars?

1 What is a star?
2 If a star that was 20 light years away exploded right now, when would we see it exploding?
3 What does it mean if a star is a bluish white colour?
4 What is a galaxy?
5 Which galaxy do you live in?
6 What shapes can galaxies have?
7 Why does the Milky Way galaxy appear so large in the night sky compared with other galaxies?
8 Name two galaxies that are visible from Earth with the naked eye.

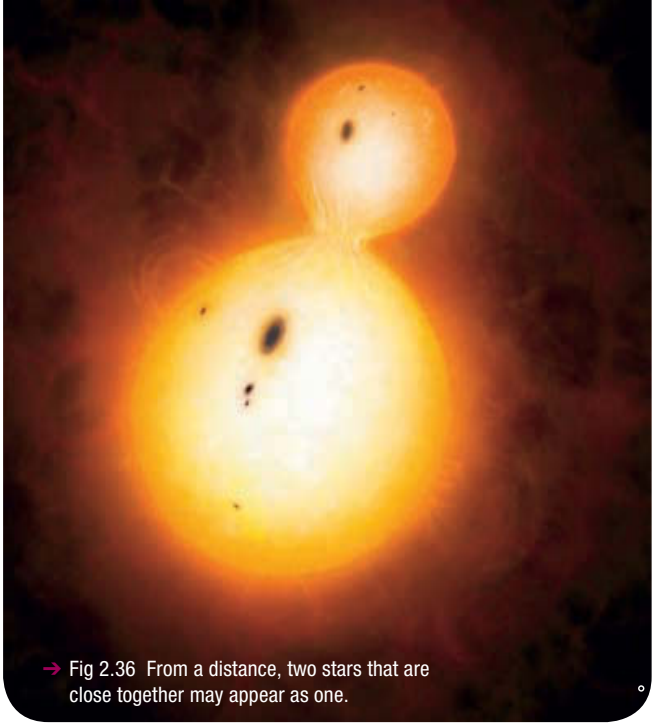


→ Fig 2.35 There are two galaxies that are visible from Earth with the naked eye or with binoculars in a very dark sky: the Small Magellanic Cloud (SMC) and the Large Magellanic Cloud (LMC). Most galaxies are too faint to be seen with the naked eye and a telescope is needed to reveal the most amazing images. The Milky Way galaxy is a spiral galaxy containing at least 200 billion stars. It is 100 000 light years across and 1000 light years thick. Our Sun is just one of the stars in this galaxy and is located in one of the spiral arms.

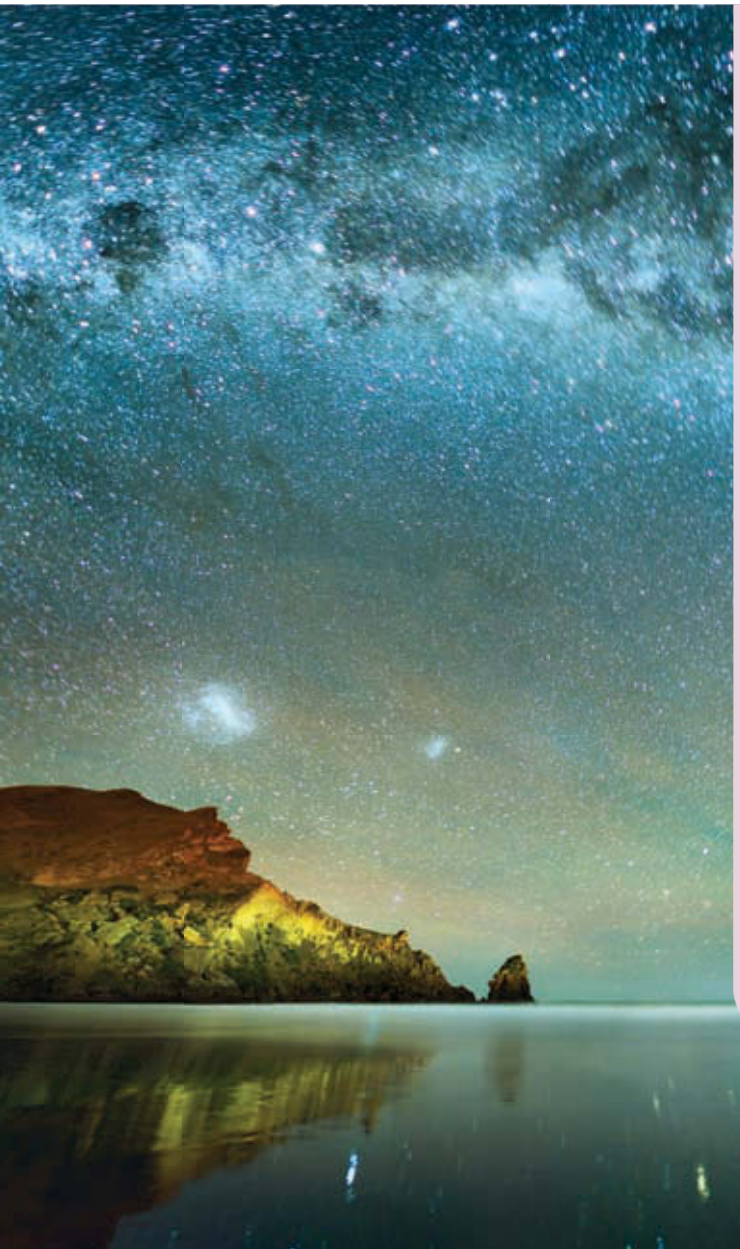
How big is our Universe?

The Universe that we can observe consists of all the stars, galaxies and other objects that we can see from Earth—it's enormous. We can only see these objects because light, or other types of signals, from these objects has had time to reach the Earth and we are able to detect the signal. The time it takes for this light or signal to reach Earth depends on how close the object is to the Earth, as well as how old it is in the history of the Universe. The older an object is, the more time its light or signals have had to reach the Earth.

The discovery of the telescope in the 16th century allowed many objects in the night sky to become visible. These included unique double stars, called binary stars, huge groups of stars called galaxies, clusters of galaxies and clouds of gas and dust called nebulae. Alpha Centauri, one of the Pointers to the Southern Cross, is actually a binary star: it consists of two stars that rotate around each other.



→ Fig 2.36 From a distance, two stars that are close together may appear as one.



How far away are the stars?

The closest star to the Earth, apart from the Sun, is Proxima Centauri, which is 4.2 light years away. But how far away is this? It's a bit confusing because a 'light year' is not a measure of time. It is the distance light travels in 1 year, travelling at the speed of light. Because light travels very, very fast (at 300 000 km/s), 1 light year is an enormous distance!

Example

In 1 light year, light travels at:

300 000 km × 365 days × 24 hours × 60 minutes × 60 seconds

This means that light travels 9 460 800 000 000 km in 1 year. In science, we write this number as 9.46×10^{12} km. So, the distance of Proxima Centauri from Earth is:

$$4.2 \times 9.46 \times 10^{12} = 3.97 \times 10^{13} \text{ km}$$

And this is our closest star!

Our Sun is approximately 8 light minutes away from Earth. This means its light takes 8 minutes to reach us travelling at the speed of light.

1 Why are the units 'light years' used to measure distances between stars?

2 Compare the distances between stars with the distances between planets in our own solar system.

3 You may have seen road signs such as 'coffee 3 minutes ahead'. Is this a measure of time or distance? Discuss your answer with others.

Calculating the distance to the Sun

EXPERIMENT 2.2

Aim

To determine a value for the distance from the Earth to the Sun using a pinhole screen and compare this with the known value.

Materials

Metre ruler
Retort stand (about 76 cm in height)
Clamp
Coat hanger
Sticky tape
Needle or pin
Two sheets A4 paper
Calculator
Sun visible in the sky

Theory

This experiment uses ratios to determine the distance from the Earth to the Sun. If we know the distance from the pinhole to the image of the Sun, the diameter of the Sun's image and the diameter of the Sun, we can calculate the unknown—the distance to the Sun.

We will use the following symbols:

- length from pinhole to Sun's image, L_i
- distance to the Sun, L_S
- diameter of Sun's image, d_i
- diameter of the Sun, d_S

→ Fig 2.37



You can write an equation using these four quantities. Try writing this equation or ask your teacher for help. It can be written in either fraction or ratio form.

Method

1. Wrap the A4 paper around the coat hanger and tape securely into place.
2. On one screen, draw two lines approximately 7 mm apart and measure the distance as accurately as possible. It doesn't matter if they are not 7 mm apart, but measure them as carefully as possible and record this value.
3. Make a tiny pinhole in the centre of the other screen.
4. Tape the A4 paper with the two lines to the top of the base of the retort stand, making sure that the two lines are centred on the base horizontally.
5. Clamp the coat hanger with the pinhole to the clamp horizontally so both screens are facing each other, about 40 cm away from the base.
6. Go outside and point the screen with the pinhole at the Sun. Adjust the position of the pinhole screen along the rod so that the circle of light from the Sun through the pinhole falls exactly between the two lines you drew on the base of the retort stand. The circle of light has to also fill the two lines by just touching both lines.

Results

1. Measure and record the distance between the two lines on the screen. This is d_i in the equation.
2. Measure and record the distance between the two screens in millimetres. This is L_i in the equation.
3. The accepted value of the diameter of the Sun, d_S, is 1 392 000 km.
4. Use the equation to perform a calculation based on the measurements to determine a value for L_S.

Discussion

1. The correct value for the distance to the Sun is approximately 149 600 000 km. Work out the difference between L_S and this value. Call this value the difference.
2. Divide the difference by the correct value and multiply by 100. This converts it to a percentage and is called the percentage error. Round it off to the nearest whole number.
3. What factors contributed to this error? (Hint: Which measurements were not exact?)

Conclusion

Write a conclusion for this experiment that relates the findings to the aim. Mention the size of the percentage error and comment about how the experiment could have been modified to reduce the errors.

Stellar parallax

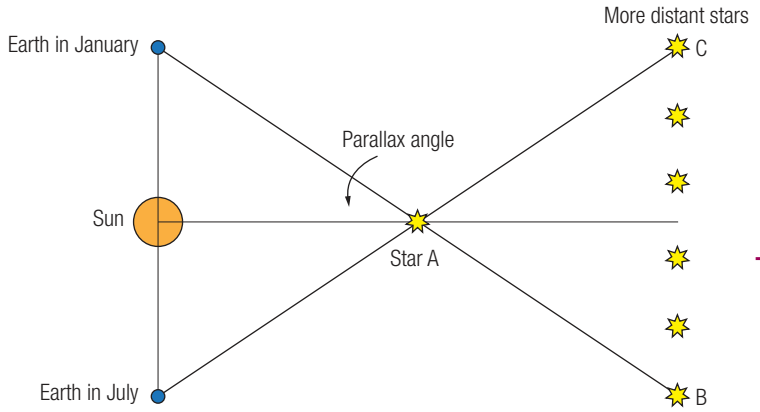
Every night, the stars and planets appear to move across the night sky. During the day we can observe the 'movement' of our Sun through the sky as it rises and, much later, as it sets. All stars 'move' in the sky, although, because they are so far away, their movement is much less noticeable. People in ancient civilisations were fascinated by the movement of the stars across the night sky and used it to predict planting and harvesting times, as well as to navigate across the oceans.

The first person to measure the distance to a star was Friedrich Bessel, a German astronomer, in 1837. He used the concept of stellar parallax. When a star is observed from two different positions (e.g. in January and then 6 months later in July), its position relative to other stars may appear to be different (Figure 2.39).

This effect, known as **stellar parallax**, is used by astronomers to calculate the distance to nearby stars (i.e. those stars closer than 100 light years). Beyond this distance, spacecraft are needed to calculate the distance accurately.

➔ Fig 2.38 Navigating using the stars.





➔ Fig 2.39 Measuring the distance to stars using stellar parallax. In January, star A, a close star, is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth's orbit, the distance to star A can be calculated.

ZOOMING IN

The Hipparcos satellite

The Hipparcos satellite, which was dedicated to measuring the distance to stars, has measured the stellar parallax of stars 100–500 light years away, giving us a more accurate distance for these stars. Launched in 1989, the Hipparcos satellite helped establish the distances of stars that possess planets, identified stars that will pass close to the Sun and identified a group of stars that invaded our galaxy when it was young. During its mission, it was discovered that the Milky Way is changing in shape. Also discovered was a different distance scale for space, which made the Universe bigger and younger.

➔ Fig 2.40 The Hipparcos satellite.



PRACTIVITY 2.4

Understanding parallax

What you need: whiteboard, whiteboard marker

1 Position a student in front of the class and approximately 2–4 metres in front of the whiteboard (if possible).
2 Write a series of numbers across the whiteboard at the same height as the student.
3 Ask each member of the class to decide which number is in line with the student.

- Why do most members of the class see a different alignment of the student and the numbers on the whiteboard?
- Relate this activity to the night sky. What do the numbers represent? What does the student represent? What do the members of the class represent?
- How would the results of this demonstration be different if the student stood only approximately 30 cm in front of the whiteboard?

What do you know about the size of our Universe?

1 How many kilometres away from Earth are the following celestial objects?
   a the Large Magellanic Cloud at 180 000 light years
   b Beta Centauri at 525 light years
   c the Andromeda galaxy at 2.5 million light years
2 What is meant by the term 'parallax'?
3 Why do you think the distance to stars beyond 100 light years can only be measured using spacecraft?

Classifying stars

Looking at the night sky, it becomes apparent that not all stars are the same. Some are brighter than others and some appear yellow, whereas others are reddish, bluish or white. These differences are due to the fact that stars vary in size, mass, chemical composition, colour, temperature, speed and distance from the Earth.

What does a star's brightness mean?

The brightness of a star viewed from Earth is measured on a scale called the **apparent magnitude scale**—a measure of how bright it 'appears' to be. The Sun is the brightest object in the sky and has an apparent magnitude of –27. In comparison, a full Moon has an apparent magnitude of –13. It may seem strange to give bright objects negative numbers. This scale dates back to ancient times when there were six classes of stars: class 1 was the brightest star and class 6 was the dimmest star. So, the more positive (and the less negative) the number, the dimmer the star.

A star that appears to be quite bright may appear that way because it is close to the Earth; it may not actually be very bright. The Sun, for example, is not a very bright star compared with other stars, but it is the closest star to the Earth.

The **absolute magnitude scale** measures a star's brightness as if all stars are the same distance from the Earth—its actual brightness.

→ Table 2.1 The apparent and absolute magnitudes of stars

Star	Apparent magnitude	Absolute magnitude
Alpha Centauri	–0.33	+4.7
Beta Centauri	+0.6	–5.0



→ Fig 2.41 The star Antares is a red supergiant.

What does a star's colour mean?

Another way of comparing stars is to analyse their colour (see Table 2.2). The colour of a star depends on its surface temperature. Blue stars are the hottest and red stars are the coolest. There are seven main groups of stars based on their colour,

LITERACY LAB

Australian astronomers

Two prominent, currently practising astronomers in Australia are Penny Sackett and Brian Schmidt. Below is a list of facts about these two scientists, but the facts are jumbled.

Your task

Match the facts below to the correct person based on your own research. Answer any questions below and add any other interesting or up-to-date facts about each person. Find some images to go with your information.

- Conducted major research into extrasolar planets. (What are these?)
- Headed the SkyMapper project. (What is this?)
- Was a member of the High-Z SN search team. (What did this team do?)
- Served on the Board of Directors of the Giant Magellan project. (What is this?)
- Born in 1967 in the USA.

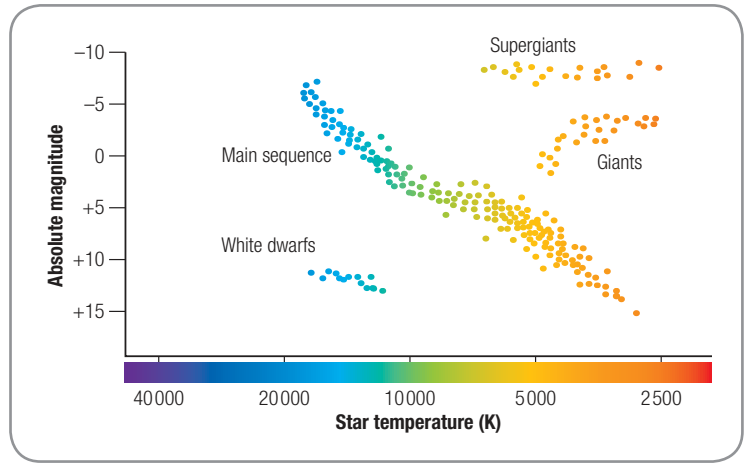


→ Fig 2.42 Brian Schmidt and Penny Sackett.

- Has worked as a Science reporter for *Science News*.
- Born in 1956 in the USA.
- Made a major scientific breakthrough in 1998. (What was it?)
- Worked as Director of the ANU Research School of Astronomy and Astrophysics. (When?)
- Worked mainly with exploding stars called supernovae.
- Appointed as the Chief Scientist of Australia. (When?)
- Been jointly awarded the US$1 million Shaw prize for astronomy. (When and why?)

→ Table 2.2 The spectral class of stars

Spectral class	Colour	Surface temperature (Kelvin)	Example
O	Blue	>30 000	Zeta Puppis
B	Blue-white	11 000–30 000	Rigel
A	White	8000–11 000	Sirius
F	Yellow-white	6000–8000	Canopus
G	Yellow	4800–6000	Sun
K	Orange	3500–4800	Aldebaran
M	Red	<3500	Betelgeuse/Antares



→ Fig 2.43 A Hertzsprung–Russell diagram.

or spectral, type. They are each given a letter representing their **spectral class**. Each spectral class is further broken up into ten subgroups, from 0 to 9. The Sun, for example, is a G2 star.

The sequence of letters representing the spectral classes can be remembered by the mnemonic 'Oh, Be A Fine Guy/Girl, Kiss Me'!An interesting method of displaying star data is on a graph called a Hertzsprung–Russell diagram (Figure 2.43). This shows a plot of the star temperature or spectral class on the *x*-axis and the absolute magnitude on the *y*-axis. When plotted this way, most stars, including our Sun, fall into a narrow diagonal band called the main sequence. Bigger stars are hotter and brighter and appear above the main sequence. Smaller stars are cooler and fainter and appear below the main sequence.

A star usually remains on the main sequence in a steady state for approximately 90% of its lifetime. For the other 10% of the time, the star changes into different forms, such as a red giant or supergiant, until it finally becomes a white dwarf.

What do you know about classifying stars?

1 Use Table 2.3 to answer the following questions.
   - **a** List the three stars in order of brightest to dimmest when viewed from the Earth.
   - **b** List the three stars in order of actual brightness from brightest to dimmest.

2 The size of a star determines which three features of the star?

3 Which is hotter, a red star or a blue star?

4 Later in its life our Sun will become a red giant and then a white dwarf. What colour changes will it undergo? What do these colour changes indicate about its temperature?

→ Table 2.3

Star	Apparent magnitude	Absolute magnitude
Sirius	−1.5	+8.7
Rigel	+0.11	−7.5
Betelgeuse	+0.8	−5.0



→ Fig 2.44 An image of Kn 61, a newly confirmed planetary nebula, taken by Professor Travis Rector, University of Alaska, Anchorage, using the 8.1-m Gemini Telescope. The nebula appears as a blue bubble, and a bright star and spiral galaxy can also be seen.

PRACTIVITY 2.5

Star profiles

There are many different types of stars, some of which we've already heard about in the previous section. Working in a small group, find an image of each of the following stars, print each one out on a full page in colour and paste them onto a large sheet of butcher's paper with their name. After studying this section you will be able to link them up in a particular order.

- red giant
- white dwarf
- protostar
- gas nebula
- black hole
- neutron star (pulsar)
- main sequence star
- supergiant
- variable star
- supernova

Life cycle of stars

In the constellation of Orion lies a group of stars known as the 'Saucepan'. A misty patch, just visible to the naked eye, is the M42, or Great Orion Nebula. This region of gas and dust also has new stars just as they begin to emit light. It is a stellar nursery, with stars being born all the time. Our own Sun would have been born in a similar region. Throughout the Universe, the stars are at various stages of their lives. Young, medium, old and dying stars can be found, as well as exploded stars.

Birth of a star

When stars are born, their fuel—hydrogen—is changed into helium through nuclear fusion in the core. A star like the Sun may do this in a relatively stable way for 10 billion years, existing as a main sequence star on a Hertzsprung–Russell diagram.

Star adolescence

Over the life of a star, the hydrogen runs out and the fusion reaction occurs in a shell around the core. Helium produced through nuclear fusion at the core eventually fuses into heavier carbon. The core contracts and the shell cools and expands, forming a **red giant** star. Our Sun will do this in about 5 billion years from now. Because of its size, it will swallow up the inner planets of the solar system—Mercury, Venus, Mars and Earth.

Adult stars

As the outer regions of the red giant fade away, the shell is called a **planetary nebula**, although it has nothing to do with planets. William Herschel thought the rounded shape of the fading red giants made them look like a planet. Only the core remains at the centre. Further nuclear reactions occur, increasing the rate of energy production and therefore

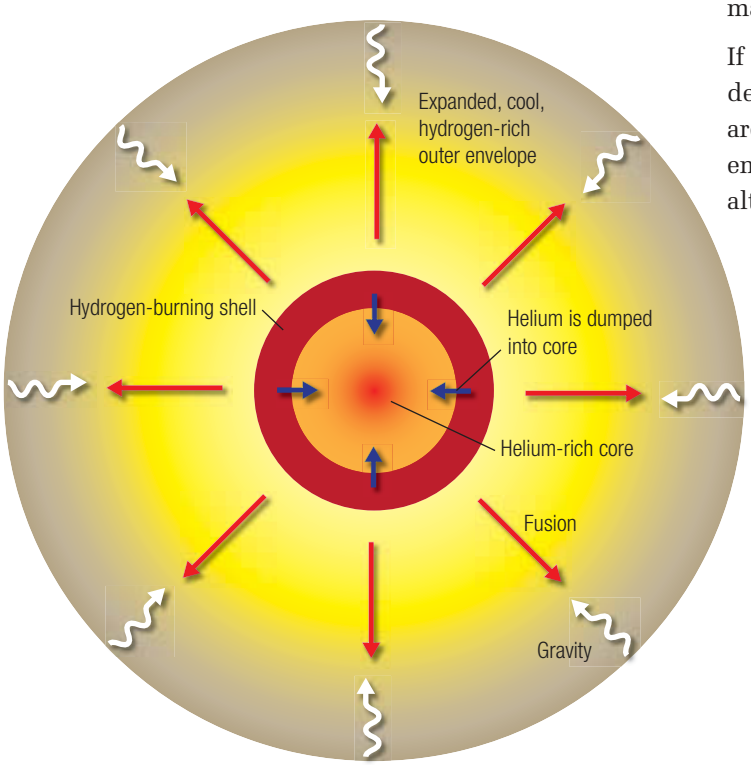
the temperature. The core becomes white hot and the star is called a **white dwarf**. As this mass cools, the star gradually fades away to become a **black dwarf**.

Heavier stars seem to have a different fate. The nuclear fusion process continues through various elements until iron is formed. The star then collapses and the resulting explosion is the largest explosion in the Universe—a **supernova**.

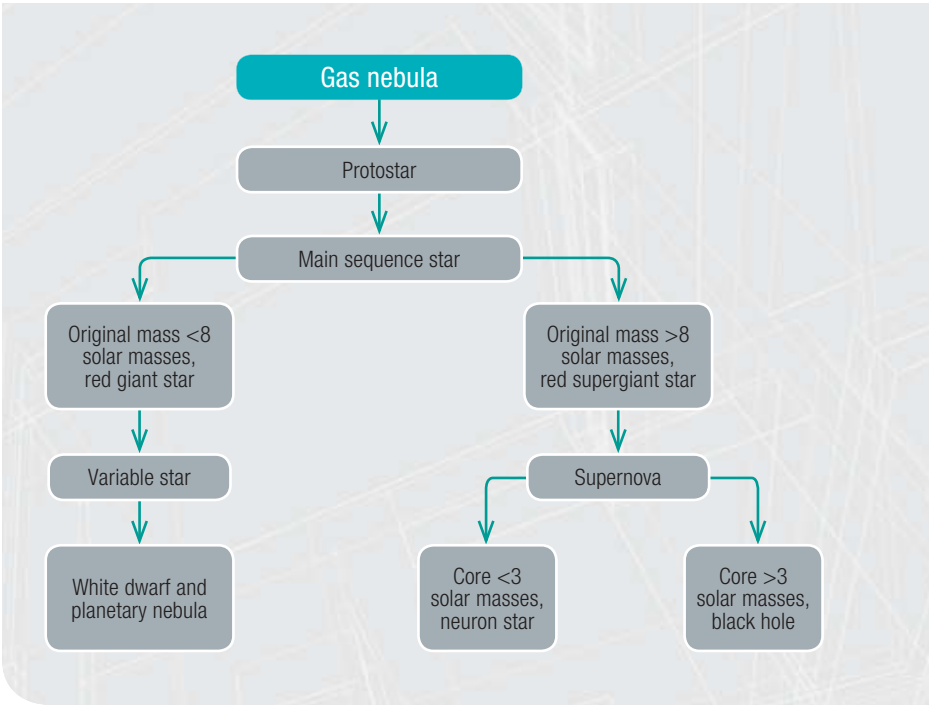
In July 2011, researchers at Macquarie University, NSW, confirmed the discovery of a new planetary nebula. Dimitri Douchin, a PhD student at Macquarie University, and his supervisor Orsola De Marco, had a pivotal role in the latest discovery. Using the telescope at the Kitt Peak National Observatory, near Tucson, Arizona, Douchin and De Marco confirmed that the object known as Kn 61 was a planetary nebula. Kn 61 will be monitored by NASA's planet-hunting telescope Kepler over the next 12 months.

Currently, there are approximately 3000 planetary nebulae known in the Milky Way galaxy and more are being found all the time.

It is hoped that the information provided by the Kepler Telescope will enable scientists to answer questions such as how planetary nebulae produce their fantastic shapes and even determine the origin of these nebulae.



→ Fig 2.45 How a red giant star forms.



→ Fig 2.46 The life cycle of stars.

Death of a star

The remaining core is amazingly dense and collisions of electrons and protons form neutrons, creating a **neutron star**. Neutron stars are only tens of kilometres in diameter and amazingly dense. Imagine a teaspoonful of neutron star material having the same mass as 100 000 cars!

If a neutron star collapses further, its gravitational pull and its density become so huge that not even light can escape. These are **black holes**. As matter falls towards a black hole, X-rays are emitted and this is how possible black holes are detected in space, although their existence is still to be proven absolutely.

What do you know about the life cycle of stars?

1. What event marks the birth of a star?
2. Why are the majority of stars main sequence stars?
3. Draw a flow chart to show the life cycle of a star the size of our Sun.
4. What is left after a supernova?
5. Blue stars are much larger than the Sun. Draw a flow chart to show the life cycle of a blue star.

LITERACY LAB

A star is torn

http://sydney.edu.au/news/84.html?newscategoryid=2&newsstoryid=7468

8 August 2011

A University of Sydney researcher was part of an international team of astronomers that has observed an incredibly rare event that occurs once every 10,000 years per galaxy.

The astronomers saw a star that had strayed too close to a super massive black hole being literally torn apart. The Australian, Dr Sean Farrell, an ARC post-doctoral fellow in the School of Physics, said the observation was first made in 2006 through the European Space Agency's X-ray Telescope, XMM-Newton.

The astronomers were researching archival data when they noticed the bright flare, which they realised was the signature of a star being ripped apart in a galaxy 500 million light years away.

The star, initially detected in 2006 by Dr Dacheng Lin, who led the study, was observed again in 2007, by which time it had increased in brightness. Dr Lin researched data from 1992, which showed there was no trace on any X-ray source dating back to that time.

In February 2011, using NASA's SWIFT X-ray Telescope, Lin observed the area again and found the flare had dimmed significantly. It was then that the international collaborators knew they had witnessed something truly astonishing.

'Dr Lin's research raised the possibility that we had indeed stumbled onto a very rare extreme event,' says Dr Farrell. 'We were very lucky that the telescope happened to have this event in its field of view.

'Of course when we realised that the star had been obliterated because it had gone too close to a super massive black hole we knew what we had observed was something even more extraordinary.'

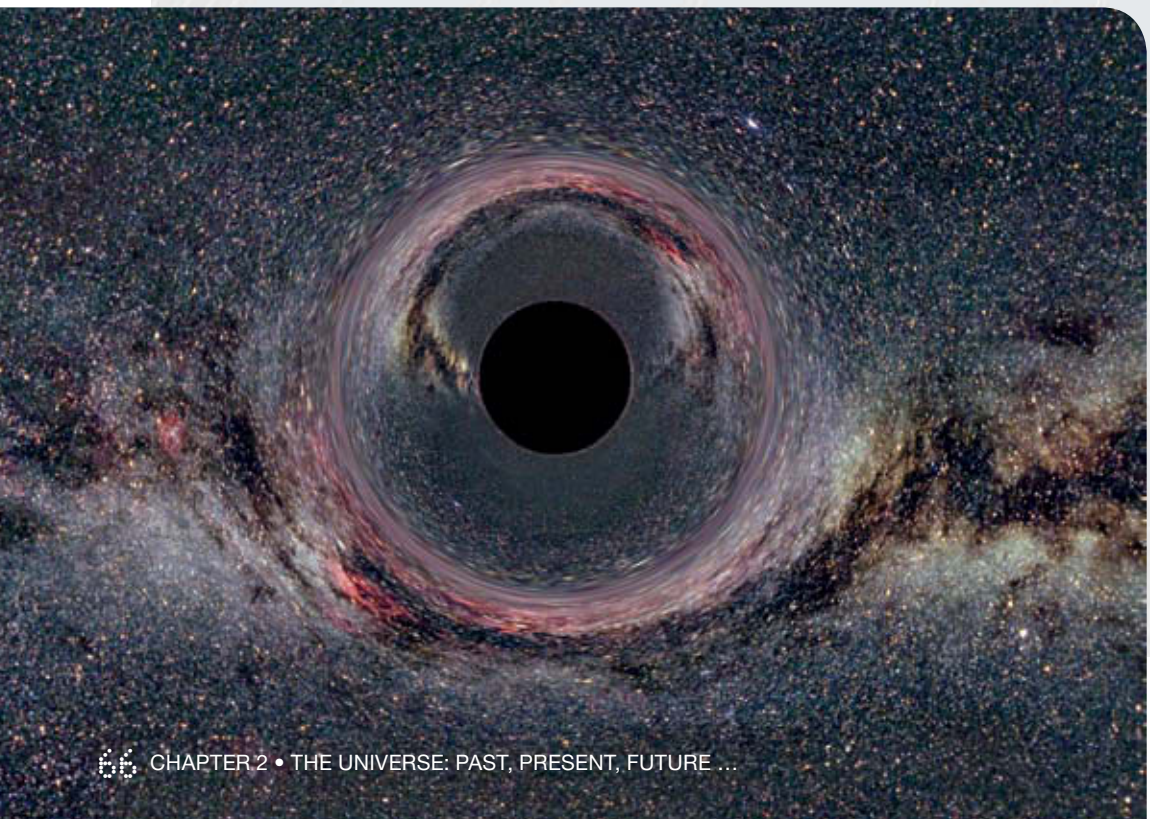
Super massive black holes (SMBH) have been theoretically predicted by theories Einstein wrote in 1915, but little is known about them. 'We know that they exist in the middle of galaxies and have three known traits: mass, spin and charge.

'The first two of these can be measured but the third cannot. We do know if something goes into a SMBH it will never be seen again,' says Dr Farrell. 'So to have witnessed such a rare event provides us with an incredible opportunity to study what happens to stars when they get too close to the edge of a SMBH.'

Dr Farrell says that these observations will be important for testing theories on gravity as well as helping us understand how SMBH grow or 'feed'. 'Black holes are crucial in how galaxies form and evolve. This is very important as their influence on galaxies has an enormous effect on gas, stars, planets, and, of course, life itself,' Dr Farrell explains.

'By studying the boundaries of black holes we can gain crucial knowledge about these extreme objects and their impact in the universe.'

The team's paper, titled 'Discovery of an ultrasoft X-ray transient source in the 2XMM catalog: a tidal disruption event candidate', will be published in the *Astrophysical Journal*.



1 What was the rare event observed by the international team of astronomers?

2 How often is 'rare' in this situation?

3 When did the astronomers actually see this event?

4 How much of a role did luck play in this observation?

5 Why is it so incredible that Einstein actually predicted the existence of super massive black holes?

→ Fig 2.47 An artist's impression of a super massive black hole.

2.2

What is happening in the Universe?



Remember and understand

1 Decide whether the following statements are true or false. Rewrite the false statements to make them true.
   - **a** All stars are yellow and very hot.
   - **b** All stars are the same shape and size.
   - **c** The brightness of a star when viewed from Earth is its absolute magnitude.
   - **d** Bigger stars are usually hotter, brighter and burn for longer than smaller stars.
   - **e** The colour of a star is determined by its surface temperature.

2 What is meant by a light year? Is it a time, a distance or a speed?

3 Write the sequence of star spectral class letters in order from O to M.

4 What colour are type O stars?

5 Why are light years used instead of kilometres as a measure of distance?

6 Explain why it is difficult to judge the distance of a star by measuring only its brightness.

7 How does the night sky enable us to look back in time?

8 What information do we get from the colour of a star?

9 In your own words, explain why the International Space Station is an important tool for astronomers.

Apply

10 Why can't you see the stars (apart from the Sun) during the day?

11 Draw a diagram to show why different stars are visible from different places on the Earth's surface.

12 The *Mariner* and other space probes launched towards Mercury and Venus carried large solar panels to supply energy. The *Voyager*, *Pioneer* and *Galileo* space probes did not have solar panels or use solar energy. Explain why.

13 Draw a diagram that shows how astrophysicists use the method of stellar parallax to determine the distance to a nearby star.

Analyse and evaluate

14 If the Sun is 149 600 000 km from Earth and light travels at 300 000 km/s, calculate how long it takes for light to reach us from the Sun. Express your answer to this question in minutes.

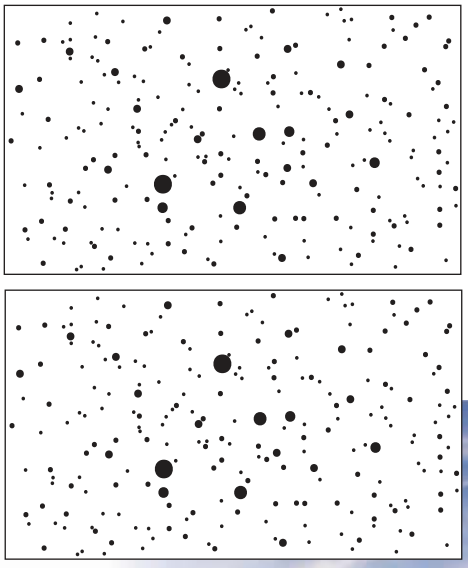
15 Why are so many class O and B stars seen in the night sky when most stars are actually class G, K and M?

16 The Sun is a G2 star of absolute magnitude +4.8. Explain what the G2 and +4.8 signify about the Sun.

17 How many kilometres from Earth are each of these celestial objects?
   - **a** the star Altair at 16.7 light years
   - **b** the Coalsack nebula at 600 light years
   - **c** the Jewelbox star cluster at 7600 light years

18 If the speed of light is 300 000 km/s, what distance does light travel in:
   - **a** 1 second?
   - **b** 1 minute?
   - **c** 1 hour?
   - **d** 1 day?

19 Why don't we use light years for measuring distances within our solar system?



→ Fig 2.48

20 Look at Figure 2.48 and identify the star that has 'moved'. Account for the 'movement' of the star.

Critical and creative thinking

21 Investigate some other telescopes that view the Universe from above Earth's atmosphere.

22 What are some other space probes that have explored other parts of our solar system? Use the Internet to find out more information.



CONNECTING IDEAS Systems in space



23 On 27 September 2007 the space probe *Dawn* was launched from Cape Canaveral at a cost of US$357 million, excluding the cost of the rocket. *Dawn*'s 4.8 billion kilometre journey includes exploration of the asteroid Vesta in 2011 and the dwarf planet Ceres, between Mars and Jupiter, in 2015. Humans hunger for knowledge. But does this knowledge enhance our civilisation? And is space exploration vital to our survival?

→ Fig 2.49 The *Dawn* space probe is on an 8-year interplanetary cruise.

How is the Universe changing?

2.3

The Universe has evolved over approximately 14 billion years, but what exists now is not stable. The Universe is constantly in a state of flux—expanding and taking everything with it—with the stars converting mass into energy at a phenomenal rate. Recent observations indicate that even the rate of expansion is increasing and that most of the matter and energy in the Universe is basically different from that observed on Earth—the supposed dark matter. However, observations are unable to predict the ultimate fate of the Universe. What doesn't seem to change in the Universe are the physical laws and constants that govern its existence—well, as far as we know …



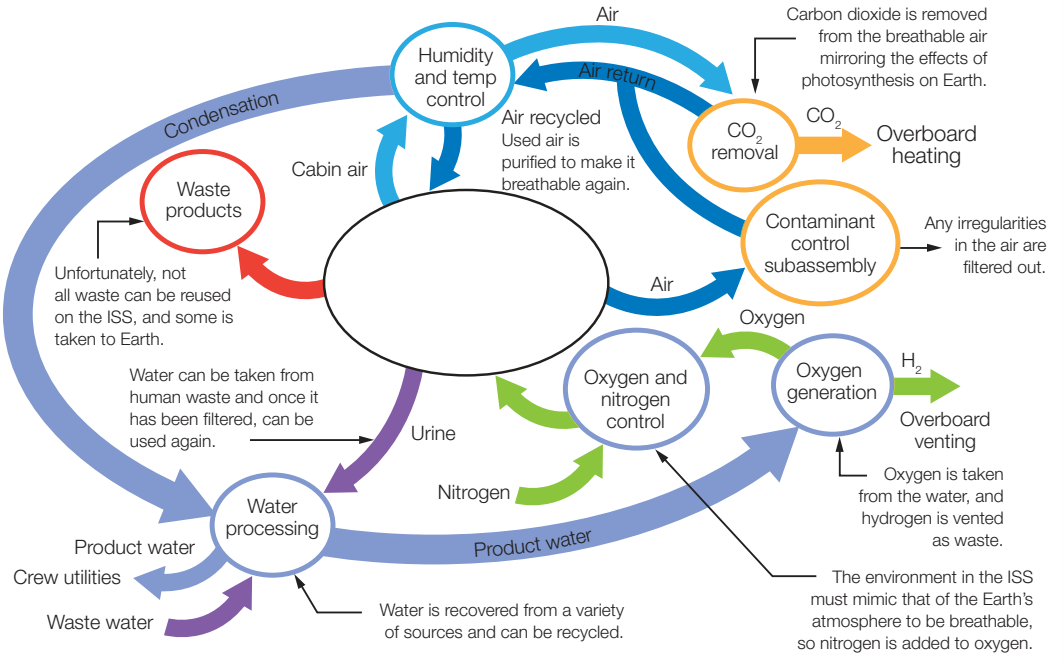
DISCOVERING IDEAS

Living in space

Investigating the universe involves a range of methods. Many observations are made from Earth, but these are limited owing to their distance from the objects they are observing. Some observations are made from unmanned space craft, such as probes that are designed to either land on planets or collect information as they travel. The most significant observation platform so far is the International Space Station (ISS). The ISS is home to a team of carefully selected and trained experts who process, analyse and evaluate the data collected by the instruments on board as it is collected. But living in space comes with its own issues. Consider the diagram shown:

1 Convert the information in the diagram into a table that identifies the requirements of the ISS crew and how these needs are met.

2 Evaluate the efficiency and amount of waste produced, and comment on the self-sustaining nature of the ISS.



→ Fig 2.50 How air and water are recycled on the International Space Station.

Future space travel

It is no secret that Earth will one day be inhospitable to human existence. Many factors, both long and short term, act to ensure Earth's bleak future. Short-term concerns range from human activity, with impacts on the global climate, to depletion of our resources and our ability to sustain the growing human population. Long-term factors include the ever-present risk of an asteroid impact on our planet. Earth is no stranger to collisions with extraterrestrial objects and such impacts have wreaked global havoc and caused mass extinctions throughout Earth's history. But the death of our Sun spells the death of our planet no matter what we do. The human race faces many obstacles and, if we are going to overcome them, we must explore our Universe for solutions.



→ Fig 2.51 The Earth's atmosphere provides protection, but makes space travel difficult.

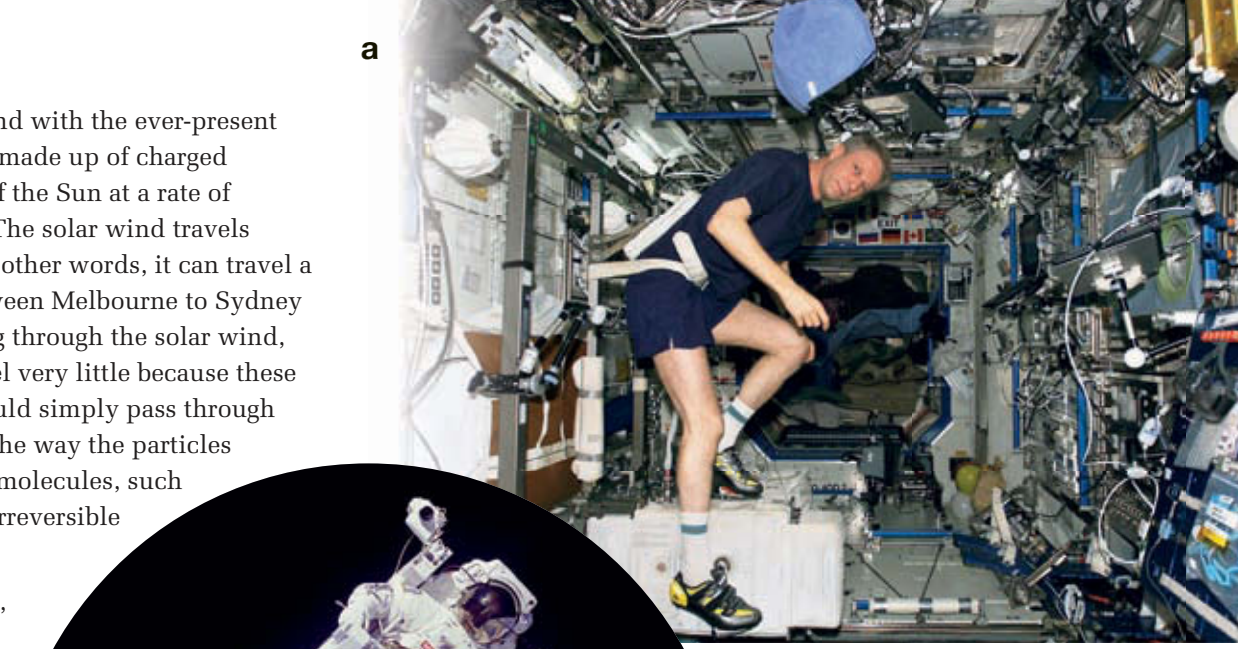
The dangers of space travel

We may take the Earth's atmosphere for granted, but it offers protection from radiation, moderates the temperature, provides breathable oxygen, allows water to boil at 100°C and even protects us from small meteors. Humans travelling into space face a number of challenges as they leave the safety of the Earth's atmosphere.

The Van Allen radiation belts are a sea of energetic charged particles that are held in place around the Earth by its magnetic field. Highly energised radioactive particles that can penetrate 1 mm of lead exist between the belts. However, the danger of exposing astronauts to unacceptable doses of radiation is minimised by planning the spacecraft's route so that astronauts spend minimal time in the Van Allen radiation belts.



→ Fig 2.52 Solar winds are responsible for brilliant light displays when the charged particles strike Earth's upper atmosphere.



→ Fig 2.53 (a) Astronauts exercise during space missions to reduce bone loss and muscle wastage. (b) Rocket packs help astronauts move around in space.

Astronauts also have to contend with the ever-present solar wind. The solar wind is made up of charged particles that constantly fly off the Sun at a rate of 1 million tonnes per second. The solar wind travels through space at 400 km/s. In other words, it can travel a distance the same as that between Melbourne to Sydney in just over 2 seconds! Passing through the solar wind, astronauts would probably feel very little because these highly energised particles would simply pass through their bodies. However, along the way the particles would be smashing into vital molecules, such as DNA inside cells, causing irreversible damage.

In the weightlessness of space, when all seems calm and peaceful, something sinister is taking place inside an astronaut's body. With every day that passes in the weightlessness of space, an astronaut's bones are depleted of calcium and the muscles weaken so much that they are unable to support an astronaut on return to Earth. Special exercise machines have significantly reduced the muscle wastage and bone loss suffered by astronauts in weightless environments.

Space has no temperature of which to speak. There is nothing in space that can heat up, no molecules or particles. Our atmosphere is full of molecules and particles that absorb heat and give air a temperature. However, objects that are left in direct sunlight in space can heat up to 121°C. When in the shade, an object's temperature can drop to –129°C. There is no atmosphere to moderate the temperature, so astronauts rely on the careful design of their space suit.

The lack of atmosphere has other problems too. Besides the lack of oxygen, the absence of air creates a situation in which liquids can boil at body temperature. In other words, in space, the body temperature would be enough to cause the water in the blood to boil. Space suits protect against astronauts being boiled too!

The effect of air pressure on us is significant, but we do not notice it. For example, 300 kg of air is present in an average-sized classroom, so this must have some impact on our surroundings. Living in a vacuum, with no air pressure, is harder than you think. Consider how you get about here on Earth. You push off the ground to propel yourself forward. When swimming, you push water back to move forward. Birds push air down in order to keep themselves flying through the air. In space, astronauts need to have a rocket pack to help them move about in their own spacecraft.

Why colonise the Moon?

Demand for Earth's resources to sustain human progress is quickly placing a crippling burden on the planet. Many people believe it makes sense to use the many resources on our nearest neighbours, namely the Moon and Mars.

The Moon is an ideal place to set up a permanent base. We can mine its many minerals and use it as a research and training ground for launching missions to Mars, perfecting the many techniques for living on other planets on our closest neighbour before we venture any further.

With no atmosphere, the surface of the Moon is exposed to a vacuum. In direct sunlight, temperatures climb to 120°C, whereas in the shade they remain below –173°C. Any gas that may have existed is now long gone because the Moon's gravity, being one-sixth that of the Earth's, is not strong enough to trap it.

Not only does the Moon have places of perpetual darkness, but its south pole is also a place of almost endless daylight. This makes the acquisition of electricity from solar energy a viable alternative.

Before we can colonise the Moon we need precious water. The cost of transporting water to the Moon is prohibitive, at between US$2000 and US$20 000 per litre. NASA has conducted missions to investigate the presence of water on or near the surface of the Moon. Although the tests conducted are not conclusive, initial data indicate that ice may be present in permanently dark craters at the poles of the Moon. Scientists suspect that water may have been brought onto the Moon by meteorites, which have relentlessly bombarded the surface of the Moon over the past 3–4 billion years.



→ Fig 2.54 An astronaut's footprint on the Moon is similar to one that would be made in mud on Earth—does this mean there is water on the Moon?



→ Fig 2.55 The Moon has a mineral-rich surface and its southern pole has almost continuous daylight.

DESIGN YOUR OWN …

Moon base

Challenge

A renewed interest in the Moon has been sparked by a recent announcement by the US President to send people to Mars and to establish an extended presence on the Moon. Your challenge is to create a Moon base with an Earth-like environment.

Questioning and predicting

Because the Moon has no atmosphere, you will need to create a sealed and pressurised living environment with the right mixture of gases. The living and working chambers will not be buildings like on Earth, but pressure chambers. The loads on the walls of such structures will be immense because the internal pressure will be applying a stress on the external walls. The leakage of essential gas will be an ever-present problem.

You must also offer the inhabitants protection against the dangers of ultraviolet radiation and the constant threat of meteorite impact. Creating a shield for the Moon base will add weight to the supporting structures and offset the benefit of a low gravitational field. It is estimated that rock of 2 metres in depth will offer enough protection from radiation.

A self-sufficient Moon colony is essential for further space exploration. According to investigations of lunar samples, the Moon contains deposits of the elements iron (Fe), manganese (Mn), magnesium (Mg) and titanium (Ti) in the form of ilmenite ($FeTiO_3$). Ilmenite could be used as the source of life-sustaining oxygen.

Obtaining energy for the self-sufficient base should not be a problem because there is an area at the pole that is almost permanently bathed in sunshine. Solar energy could be captured by carefully placing solar panels at the pole.

Oxygen and water are necessary to sustain a closed ecological life-support system. Oxygen can be obtained by the chemical processes involved in purifying metals from the lunar soil.

Each person will need a daily amount of 0.6 kg of food, 0.85 kg of oxygen and 29 litres of water. Assuming that we can find water on the Moon, we then require approximately 20 square metres of cultivated land for each person in order to produce the required daily amount of food.

What do you know about the future of space travel?

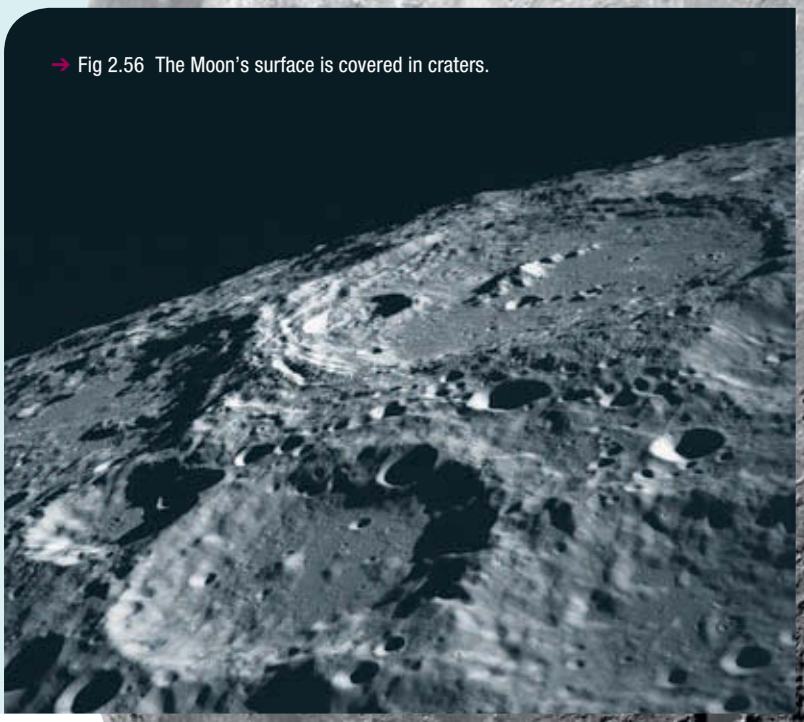
1 Describe the Van Allen radiation belts.
2 What happens to an astronaut's bones in the weightlessness of space?
3 What happens to the boiling point of water as you go above sea level?
4 Why can't astronauts move around without a rocket pack in space?
5 Why does the Moon not have an atmosphere like we have on Earth?
6 Why is the Moon covered in craters?
7 What is thought to exist in the dark craters on the Moon?
8 What is the potential benefit of the south pole of the Moon?

Planning and conducting

Design a Moon base, either on paper or by creating a model. In your design, show how you have accounted for:

- transportation, purification and storage of air, water, wastes, supplies and energy
- food production
- water synthesis
- power generation
- water and air purification
- pressurised atmosphere
- radiation and meteorite protection
- water and sewage recycling
- food production
- recreation
- recycling of waste.





→ Fig 2.56 The Moon's surface is covered in craters.

Processing, analysing and evaluating

1 What do you think is the main difference between building a structure on Earth and building it on the Moon?
2 Engineers believe that any long-term habitat on the Moon will need to be buried by piling a blanket of rock on top of the structures or in mineshafts. Why is this necessary?
3 Every science fiction story has Moon bases essentially on the surface formed from glass domes. Why is such a structure so impractical?

Communicating

Present your Moon base plan and/or model to the class.

Earth's bleak fate

Asteroids are large rocky objects that are smaller than planets but greater than 10 km in diameter. Meteors are also rocky objects, but are less than 10 km in diameter. Asteroids can reach sizes of up to tens of kilometres across. Most asteroids are found within the asteroid belt, which is located between the orbits of Mars and Jupiter. This belt contains 750 000 asteroids that are larger than 1 km across, and millions of smaller ones. **Comets** are distinguished from asteroids by their visual appearance: they have a fuzzy atmosphere and asteroids don't.



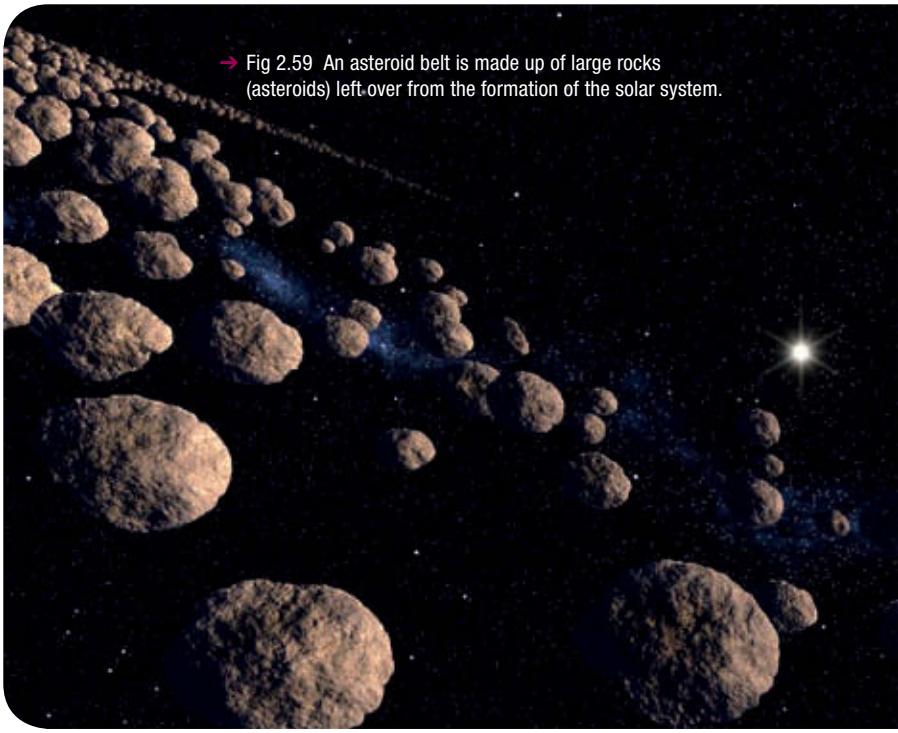
→ Fig 2.58 The asteroid Gaspra, as viewed from the spacecraft *Galileo* while on its way to Jupiter. Gaspra is approximately 19 km in diameter.

Asteroid impacts

An impact from an asteroid with the Earth is always on the cards. Asteroids have hit the Earth in the past but, unlike on the Moon, evidence of such impacts has been weathered away. NASA scientists have predicted that a 10-km sized rock strikes the Earth every 100 million years.

Earth is no stranger to catastrophic collisions with astronomical objects. Approximately 65 million years ago an asteroid, 300 km wide, crashed through our atmosphere and slammed into what is now the Gulf of Mexico. The impact would have been so violent that it would have liquefied rock and sent earthquakes reverberating around the planet. Giant tsunamis would have travelled at great speeds across the oceans, and huge clouds of dust and rock would have been blasted high into the atmosphere, blocking out sunlight. Photosynthesis would have ceased in the months of darkness that would have followed. Mass extinctions are believed to have followed, such as the extinction of the dinosaurs.

Asteroids are called meteorites when they successfully pass through Earth's atmosphere and impact Earth's surface.



→ Fig 2.59 An asteroid belt is made up of large rocks (asteroids) left over from the formation of the solar system.

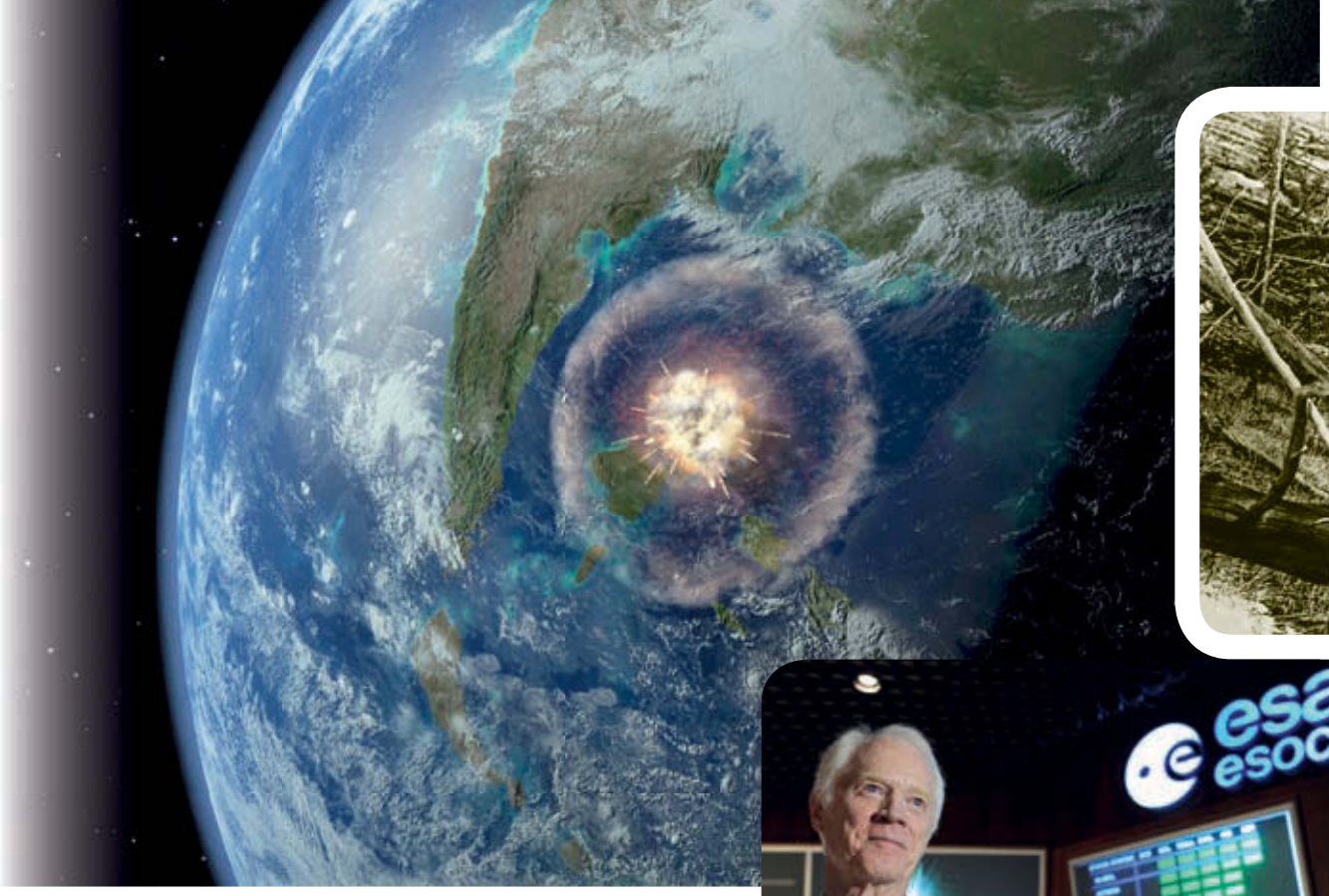
→ Fig 2.57 Halley's Comet is the only comet that is visible to the naked eye from Earth on a semi-regular basis. It is visible every 75–76 years and was last seen in 1986. Will you see it in your lifetime?



Recent impacts

Similar events have also occurred during more modern times with devastating effects. In 1908, an asteroid exploded over Tunguska in Siberia. Even though this asteroid did not hit the ground, the explosion flattened over 2200 square kilometres of Siberian forest. If the asteroid had hit the ground, its devastation would have rivalled that of a large nuclear bomb.

NASA has set up the Near Earth Object Program to monitor objects near Earth that are large enough to cause catastrophic damage if they were to collide with the Earth. With the development of technology, such as powerful rockets and nuclear devices, we may be able to deflect an approaching asteroid.



→ Fig 2.60 A large asteroid hit Earth 65 million years ago. The impact formed the Chicxulub crater on Mexico's Yucatan Peninsula, which is approximately 200 km wide. The catastrophic impact may have been a factor in the extinction of the dinosaurs at the end of the Cretaceous period.



→ Fig 2.61 The Tunguska event was a powerful explosion, believed to have been caused by a large meteoroid or comet, in Siberia on 30 June 1908. Although the meteoroid or comet exploded in the air, rather than colliding with the Earth, it still caused considerable damage.



→ Fig 2.62 Rusty Schweickart is a former NASA astronaut who cofounded the B612 Foundation, a group that aims to protect Earth from asteroid impacts.

ZOOMING IN



Comet Shoemaker-Levy 9 collides with Jupiter

In July 1994, Comet Shoemaker-Levy 9 collided with Jupiter. This was the first time that astronomers were able to observe two objects in the solar system colliding and not involving Earth. Comet Shoemaker-Levy 9 was first observed by telescope in 1993 orbiting the planet Jupiter. This was the first comet astronomers had observed orbiting a planet rather than the Sun. The comet collided with Jupiter at a speed of 60 km/s, leaving prominent scars on Jupiter's surface that were easily visible for months after the impact.

The observations of the impact of Comet Shoemaker-Levy 9 on Jupiter have led to Jupiter being described as a 'cosmic vacuum cleaner' of the solar system. The planet's strong gravitational field causes many small comets and asteroids to collide with it. In fact, the rate of comet collisions with Jupiter has been estimated at between 2000 and 8000 times more than with Earth. Without Jupiter, the number of asteroid and comet collisions with planets in the inner part of the solar system, such as Earth, would probably be greater.

→ Fig 2.63 In July 1994, Comet Shoemaker-Levy 9 collided with Jupiter. This photo was taken from the spacecraft *Galileo*.

Death by supernova

A supernova is a massive explosion that results from the death of a star many times bigger than our own Sun. The supernova that created the Crab nebula was observed by Chinese astronomers in the 11th century. The most recent supernova in our galaxy, the Milky Way, was discovered recently by NASA's Chandra X-ray telescope and is believed to have happened approximately 140 years ago.

When huge stars run out of fuel, they collapse under the influence of immense gravitational forces. This dramatic collapse takes less than a second and causes the release of an enormous amount of radiation energy, equivalent to the energy produced by 100 of our Suns during their lifetime of approximately 10 billion years.

Some 440 million years ago a mass extinction occurred, which is known as the Ordovician extinction. Some scientists believe that this was caused by a supernova approximately 10 000 light years away. They believe that the immense outburst of radiation from a supernova may have reached Earth, plunging it into an ice age and resulting in the Ordovician mass extinction.

Birth by supernova

Although the dramatic and sudden release of radiation from a supernova is highly destructive, it can also give birth to other stars and solar systems, as well as the elements present on Earth that help create life as we know it.

During a supernova, enough energy is generated to produce nuclear fusion reactions. These reactions fuse smaller atoms, such as iron and silicon, to form heavier elements, such as copper and lead. In fact, all elements with atomic masses heavier than iron were created during a supernova. What remains after a supernova is a rapidly expanding cloud of gas, which is called a nebula, and sometimes a black hole.



→ Fig 2.64 This supernova is thought to have happened approximately 140 years ago.



→ Fig 2.65 The Ordovician extinction is thought to have been caused by a supernova.

We can sometimes see a supernova in the night sky. Such events glow bright for many days, months or even years. Many supernovae are discovered every year, but supernovae that can be viewed without a telescope are rare.

Studying the light that comes from bright supernovae can help us work out the speed at which the Universe is expanding. From this information we can determine how much matter there is in the Universe and therefore determine its ultimate fate. The more matter that is present, the more likely it is that the Universe will stop expanding and collapse back on itself. Perpetual (ongoing) expansion will only occur if there is not enough matter in the Universe.

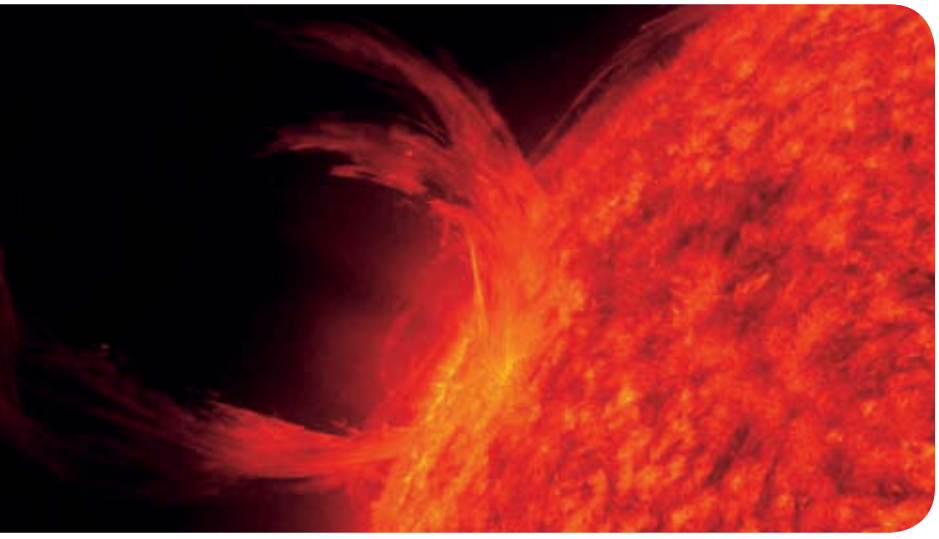
Annihilation by the Sun

Another hazard for our planet is our very own Sun. Our Sun contains an extraordinary amount of mass, which creates gravitational forces large enough to keep it from expanding violently due to the heat. In fact, 98% of the total mass of our solar system is in our Sun.

The Sun's outer layer has a temperature of 6000°C. Deep in the core of the Sun, solar energy is created at temperatures of 15 000 000°C. At such high temperatures, violent nuclear reactions take place and four hydrogen atoms fuse to form one helium atom. Every second, 700 million tonnes of hydrogen are converted into helium. As the Sun ages, it gets lighter because more mass is converted into energy and radiated out into space.

The Sun is 4.6 billion years old and contains enough hydrogen to go on for another 5 billion years. As the Sun gets older and runs out of hydrogen, the helium will start to fuse together to form heavier elements. During this phase the Sun will start to swell into a red giant star and engulf Mercury, Venus and maybe Earth. Venus and Mercury will most certainly be vaporised, and the Earth will become a lifeless landscape devoid of water and atmosphere. After a billion years the Sun will end its life as a red giant and suddenly collapse into a white dwarf star, taking a trillion years to cool.

But how can we predict with any certainty the fate of our Sun? The answer is found in astronomy. A group of stars in our galaxy, the Milky Way, have captured the interest of astronomers for more than 400 years. This group of stars, known as Mira stars, are red giants; they represent older versions of Sun-like stars. By observing them we can glimpse the fate of our Sun in approximately 5 billion years. Mira stars eject large amounts of gas and dust into space and have a shell composed of vapour that, if in the same location as our own Sun, would reach beyond Mars.



→ Fig 2.66 A close-up of the Sun's surface showing the jets of super-heated gas constantly bursting from the Sun's surface.



→ Fig 2.67 Mira A, on the left, is a highly evolved red giant star. Mira B, on the right, is a white dwarf star. Mira A is losing gas rapidly from its upper atmosphere, whereas Mira B exerts a gravitational force that sucks the gases into it.

What do you know about Earth's bleak fate?

1. What is the Near Earth Object Program? Why did NASA initiate this program?
2. What is happening to the mass of the Sun as it gets older? Explain why.
3. Why will the Sun grow into a red giant as it runs out of fuel (hydrogen)?
4. Where does the energy given off by the Sun come from?
5. Why will Earth lose its atmosphere and water as the Sun expands into a red giant?
6. How do astronomers predict, with accuracy, the future of our Sun?

LITERACY LAB

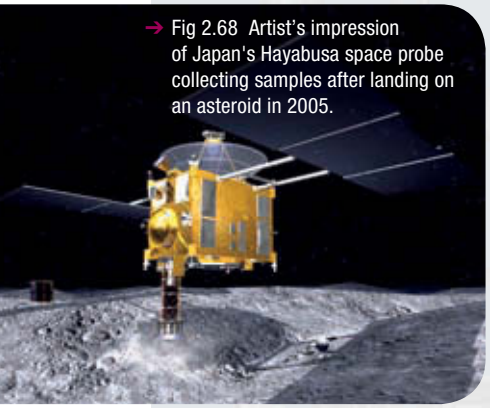
NASA Plans 2025 Manned Mission to Asteroid

25 March 2011 • by Lee Speigel

It's a little soon for astronauts to suit up, but NASA is planning to send a manned mission to an asteroid in 2025.

In keeping with President Barack Obama's 2010 vision, the space agency has shifted its sights from returning to the moon and, instead, is aiming for a smaller—and possibly more dangerous—rock in space, Space.com reports.

'By 2025, we expect a new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the moon into deep space,' Obama said last year at the Kennedy Space Center in Florida.



→ Fig 2.68 Artist's impression of Japan's Hayabusa space probe collecting samples after landing on an asteroid in 2005.

In this artist's rendering, Japan's Hayabusa space probe collects surface samples after landing on an asteroid in 2005. NASA is now planning to send a manned mission to an asteroid in 2025.

'So we'll start by sending astronauts to an asteroid for the first time in history. By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth, and a landing on Mars will follow.'

At least the first asteroid-bound trip won't follow the script of the 1998 sci-fi adventure *Armageddon*. In that scenario, a deep core drilling team, led by Bruce Willis, is sent to a huge asteroid on a collision course with Earth. Their mission: to nuke it before it arrives and causes chaos to our home planet.

While scientists consider ways to avoid a possible future asteroid-Earth collision, they're also figuring out which of the 7000 known rocky asteroids between Mars and Jupiter might make a suitable landing spot for astronauts.

'Long outbound and inbound trip times are going to be very challenging,' said Andy Thomas, a veteran space shuttle astronaut who works for the exploration branch of the Astronaut Office.

'These missions are going to be very, very risky,' he added. 'They are going to be as much risk as the Apollo missions were. To try and sell it to the public purely on the basis of the scientific return … would probably not work.'

A round-trip journey to an asteroid in a cramped spacecraft would take about 6 months. Part of the risk of sending humans to one of these giant space rocks involves the weak gravitational field of many asteroids. It would be very difficult to actually land on one. The option would be to travel side-by-side with the asteroid as astronauts go back and forth collecting samples and doing science experiments.

Are the scientific results worth the effort? Is it better to send people instead of robots? And is there an available budget for this endeavour?

All good questions.

First, asteroid materials can provide scientists with clues about how the solar system was created and, in turn, help us learn how life started on Earth.

Asteroids may also become valuable sources of metals, minerals, gases and even water that can be used as future resources.

Sending robots vs. humans to an asteroid would certainly be less risky and expensive, but experts need to address the question of whether robots can perform all of the intricate tasks that astronauts would be better trained for.

And, of course, as with any scientific and enormous technological endeavour, there's the cost factor.

'Despite national advisory council recommendations, congressional mandates and the newly recognised needs for both exploration and planetary defence, there is no new funding and, thus, no administrator who wants to get stuck with the bill,' said Richard Binzel, a planetary science professor at the Massachusetts Institute of Technology.

'The issue is sorely in need of an adult sense of responsibility.'

1 Why do you think it will take until about 2025 to be ready for manned missions beyond the Moon?

2 Andy Thomas is mentioned in this article. Compile a brief life story about this man.

3 Are the astronauts likely to actually land on the asteroid?

4 Why is the study of asteroids useful?



→ Fig 2.69 Australian Andy Thomas, a veteran space shuttle astronaut who works for the exploration branch of the Astronaut Office.

LITERACY LAB

Key decisions made on giant telescope

4 April 2011 • by Myles Gough

SYDNEY: Key decisions around the Square Kilometre Array (SKA), a next-generation telescope expected to revolutionise radio astronomy, were announced on Saturday.

The international SKA project office (SPO)—the institution responsible for designing the specifications and costing the project—would be housed at Jodrell Bank Observatory in Manchester, it was revealed on the weekend.

At the same time key signatories to the project including Australia, China, France, Germany, Italy, the Netherlands, New Zealand, South Africa and the UK signed a 'Letter of Intent' in Rome, agreeing to work together to secure funding for the project.



→ Fig 2.70 Artist's impression of dishes that will make up the SKA radiotelescope. Credit: Swinburne Astronomy Productions/SKA Program Development Office.

Hundred of antennas

A decision on where the telescope will be built—either in Australia and New Zealand or South Africa—will be made in early 2012.

The proposed radiotelescope will consist of some 3000 dishes spread over a wide area, and promises to be 10 000 times faster than current technology, but carries a hefty price tag at around A$2 billion.

'Given the current economic environment, it is reassuring that so many partners have recognised the importance of supporting the SKA,' said John Womersley, from the UK's Science and Technology Facilities Council and chair of the Founding Board that announced the decision.

Inspirational megascience project

'Our partners have taken this step not only because of the inspirational nature of the discoveries that the SKA will make, but also because of the economic benefits that international megascience projects can bring to participating countries.'

Brian Boyle, SKA director at Australia's national science organisation CSIRO told *Cosmos* he is 'quietly confident' with the amount of support expressed by integral funding partners.

'We're moving with a significant degree of momentum around establishing a robust governing structure and shoring up potential investors,' said Boyle. 'Over the past few months I've been very encouraged by the statements of support from key countries.'

Hurdles expected

It's an optimistic outlook from a man who is well versed on the inner-workings of the complex decision-making processes propelling the SKA forward.

'This is arguably one of the biggest scientific infrastructure projects of this century given the number of nations collaborating,' said Boyle.

'It's a global project with huge benefits, so it's expected that there will be significant hurdles to overcome in order to reach agreements and move forward.'

Choosing a home

A final decision on the site of the SKA will be made by a Site Selection Group, based on criteria such as the site's radio frequency interference levels, atmospheric conditions, physical geography and climate, and the ability of each site to preserve radio-quietness over the coming decades.

'Selection of the host site for the SKA is a tremendously important decision and is one that will be made with the utmost care to ensure the best possible operating environment for the telescope,' said Richard Schilizzi, head of the SKA project development office at the UK's University of Manchester.

The new body at Jodrell Bank Observatory will supersede the SPO with the move planned for 1 January 2012.

1 What are the perceived benefits the SKA will provide?
2 What factors will determine the ultimate site of the SKA?
3 Where would a likely site for the SKA be if it comes to Australia?
4 What benefits are there in having so many countries involved with the SKA?

2.3

How is the Universe changing?



Remember and understand

1 List the following in order of size from largest to smallest: neutron star, our Sun, white dwarf, red giant.

2 Give one difference between a black hole and a pulsar.

3 Give two differences between a white dwarf and a red giant.

Apply

4 With current rockets it is unlikely that humans will become space travellers. Suggest a reason why humans cannot leave the vicinity of Earth.

5 Astronomers believe that the Earth has been peppered with asteroids in the past, yet the Earth does not have a cratered landscape like the Moon. Explain why.



Analyse and evaluate

6 If our Sun is 4.6 billion years old, about how far is it through its life?

7 Do you think we will be able to discover extraterrestrial life in space? Would this life be similar to humans? What sort of conditions would this life need to be maintained?

8 Comet Tempel-Tuttle passed the Earth in 1900, 1933, 1966 and 1998. The Earth passes through the dust trail left by this comet on about 18 November each year. The dust strikes the atmosphere at 72 km/s. Thousands of pieces of dust strike the Earth every hour during the 10 hours it takes for Earth to pass through the dust trail.

- **a** Suggest how this comet got its name.
- **b** What is the time period between visits of this comet? Calculate it to the nearest year.
- **c** List the next 3 years that this comet will pass the Earth.

Critical and creative thinking

9 Create a poster showing the fate of the Sun as it expands from its current size into a red giant and then as it contracts into a white dwarf. Label each stage and find photos from the Internet to illustrate the process.

10 Return to your butcher's paper poster of the different types of stars (Practivity 2.5) and link up the different stars in order according to the flowchart in Fig. 2.46, on page 65. Alternatively you may like to re-do your poster of pictures so that it looks like the flowchart, with each image in the correct place. Link up the pictures with the same arrows as in the flowchart.

CONNECTING IDEAS Systems in space

11 If you could travel anywhere in the Universe, where would you like to go to and why? How long would it take? What would you do when you got there? How would you find your way back to Earth? Would you even return to Earth?

Research

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

Dark matter

Scientists believe that there is extra matter in the Universe that is invisible. This is called *dark matter*. What is the difference between ordinary matter and dark matter? What evidence do scientists have for the existence of dark matter? What is the composition of dark matter? Scientists believe that the Universe started from the Big Bang and that it will expand before gravitational forces pull it back in to start the entire process all over again. What effect does dark matter have on the future of our Universe?

Ion propulsion

On 27 September 2007 the space probe *Dawn* was launched from Cape Canaveral. *Dawn*'s 4.8 billion kilometre journey includes exploration of the asteroid Vesta in 2011 and the dwarf planet Ceres in 2015. The spacecraft's engines use a unique, hyper-efficient system called ion propulsion. What is an ion? Can such an engine lift a spaceship from the Earth's surface? Why? What is the fuel used? How does this fuel produce thrust? Why are such large solar collectors necessary? What is the thrust produced by the engines?

Australian observatories

The Parkes Radio Telescope is a well-known Australian telescope. Find out a brief history of this telescope and what it is used for. The movie *The Dish* might be helpful in your research.

Reflect

Me

1 What was the most surprising thing you found out about the Universe?
2 What were the most difficult aspects of this topic?
3 How has your understanding of the Universe changed?
4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know about the origins and evolution of the Universe?
6 How has a quest to understand the Universe helped us develop new technologies that are useful on Earth?

My future

7 Why is it important to understand what might happen in the future with the Universe?
8 What sort of careers might a study of the Universe lead to?

Review

Key words

absolute magnitude scale
absorption spectrum
apparent magnitude scale
asteroid
Big Bang theory
black dwarf
black hole
blue shift
comet
constellation
cosmic microwave background (CMB) radiation
Doppler effect
emission spectrum
galaxy
Hertzsprung—Russell diagram
light year
main sequence nebula
neutron star
planetary nebula
red giant
red shift
spectral class
Steady State theory
stellar parallax
supernova
white dwarf

2 The Time and Space of Uncle Albert



'… It's my job to look after you and see that everything runs smoothly. All you have to do is … well … just enjoy it. Right. Are you ready?'

Gedanken looked happier and nodded.

'OK. Strap yourself in.'

She fastened her seat belt.

'Now, all you have to worry about is that red button in front of you. When you want to start up the motor, you just press the button. Keep your finger on it for as long as you want the rocket to fire. All right?'

'Yes,' she nodded, getting more and more excited.

'OK, when you're ready, you can blast off.'

Gedanken took a deep breath, reached out and pressed the button. Immediately, from the rear of the spacecraft, there came a throaty roar of engine noise. She felt herself flattened against the back of the seat.

'How thrilling!' she thought.

After a while the computer called out, 'You can let go of the button when you like.'

She did so, and the engine noise died away. No longer was she pressed against her seat. She had a floating sensation and felt she would go drifting off if the seat belt hadn't continued to hold her in position. It was very pleasant once one got used to it.

'That's our speed, is it?' asked Gedanken, pointing to a digital read-out just above the button in front of her. It said SPEED RELATIVE TO EARTH and was reading '0.500 times the speed of light'.

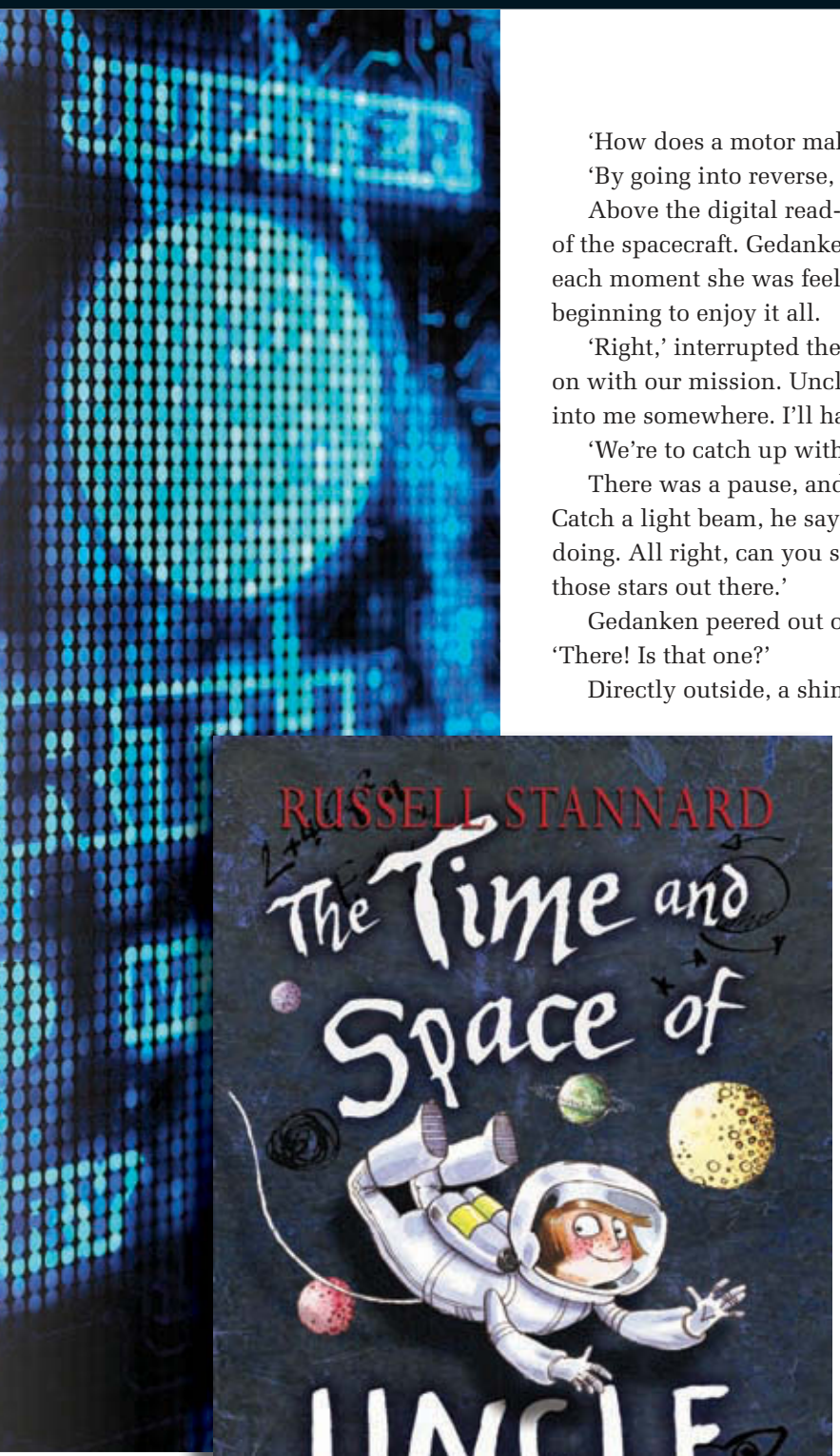
'That's right,' said the computer. 'We're now travelling at half the speed of light.'

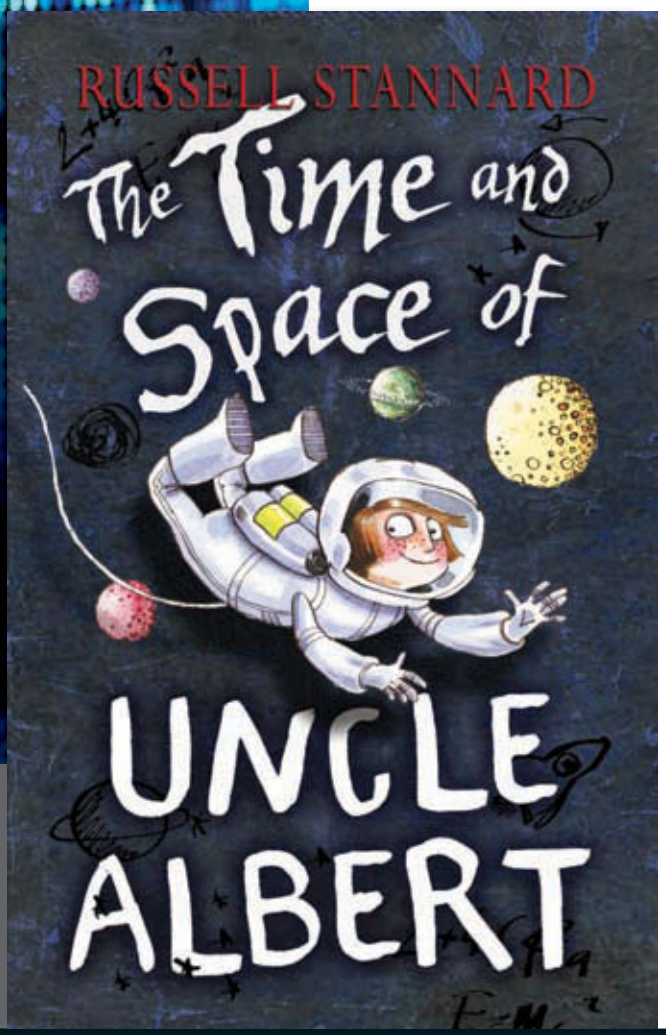
'Then why aren't we slowing down?'

'Why should we?'

'Because the engine's off. We ought to be slowing down.'

'This is not a bicycle,' the computer said in a superior tone of voice. 'This is a spacecraft. Once a spacecraft is up to speed it doesn't need pushing any more. Out here, there is no air or anything to slow us down. So, we just keep cruising along. We only need to rocket motor when we want to *change* speed—when we want to go faster or slower.'





'How does a motor make you go slower?'

'By going into reverse, of course.'

Above the digital read-out was a large window facing out of the front of the spacecraft. Gedanken looked at the stars laid out before her. With each moment she was feeling more relaxed and at home. She was really beginning to enjoy it all.

'Right,' interrupted the computer, 'if you're ready, we had better get on with our mission. Uncle Albert has programmed some instructions into me somewhere. I'll have a look in my memory bank.'

'We're to catch up with a light beam,' Gedanken volunteered eagerly.

There was a pause, and the computer resumed, 'Ah, yes. Quite right. Catch a light beam, he says. How peculiar. Suppose he knows what he's doing. All right, can you see one? There ought to be plenty about with all those stars out there.'

Gedanken peered out of the window. Suddenly she pointed excitedly. 'There! Is that one?'

Directly outside, a shimmering glow sped by. It seemed to Gedanken to have a face—an impish face … and … yes, it was giggling! She definitely heard a faint high-pitched giggle, like an over-excited schoolgirl, and a teasing voice that called: 'Go on, catch me if you can.' As it got further away the fuzzy light patch got smaller and fainter.

'Yes,' cried the computer, 'that's one. After it before it gets away!'

'Easy,' shouted Gedanken. 'We're already doing half its speed.' And with that she pressed the button, the engines roared into life once more, and they were giving chase.

After a few minutes the computer called out, 'OK. That should do it. We ought to have caught up with it by now.'

Gedanken released the button and looked for the light button. Her face fell.

'Oh. It's further away than ever,' she said.

'What? Further away … That's impossible.'

'But it is.'

'Can't be. What speed are we doing?' asked the computer.

'Er … 0.900. Nine-tenths the speed of



light—I think.'

'Is that all?'

'Yes,' she confirmed.

'How odd. According to my calculations we ought easily to be doing the speed of light.'

Gedanken heard a far-off voice giggling and laughing: 'You'll have to do better than that.'

'Give it another go,' said the computer. 'I'll put you on full power this time.'

Gedanken pressed the button again. The engine noise was deafening—far louder than before. The spacecraft shuddered and shook in a most alarming manner. It was as though it were about to shatter into tiny pieces.

After what seemed an age, the computer instructed her to let go the button, and she thankfully did so. She peered out of the window. At first she could see nothing. Then she spotted the light beam.

'Oh no. It's miles away now—and it's still going away from us.'

'Impossible. What's our speed now?'

'0.999 times the speed of light.'

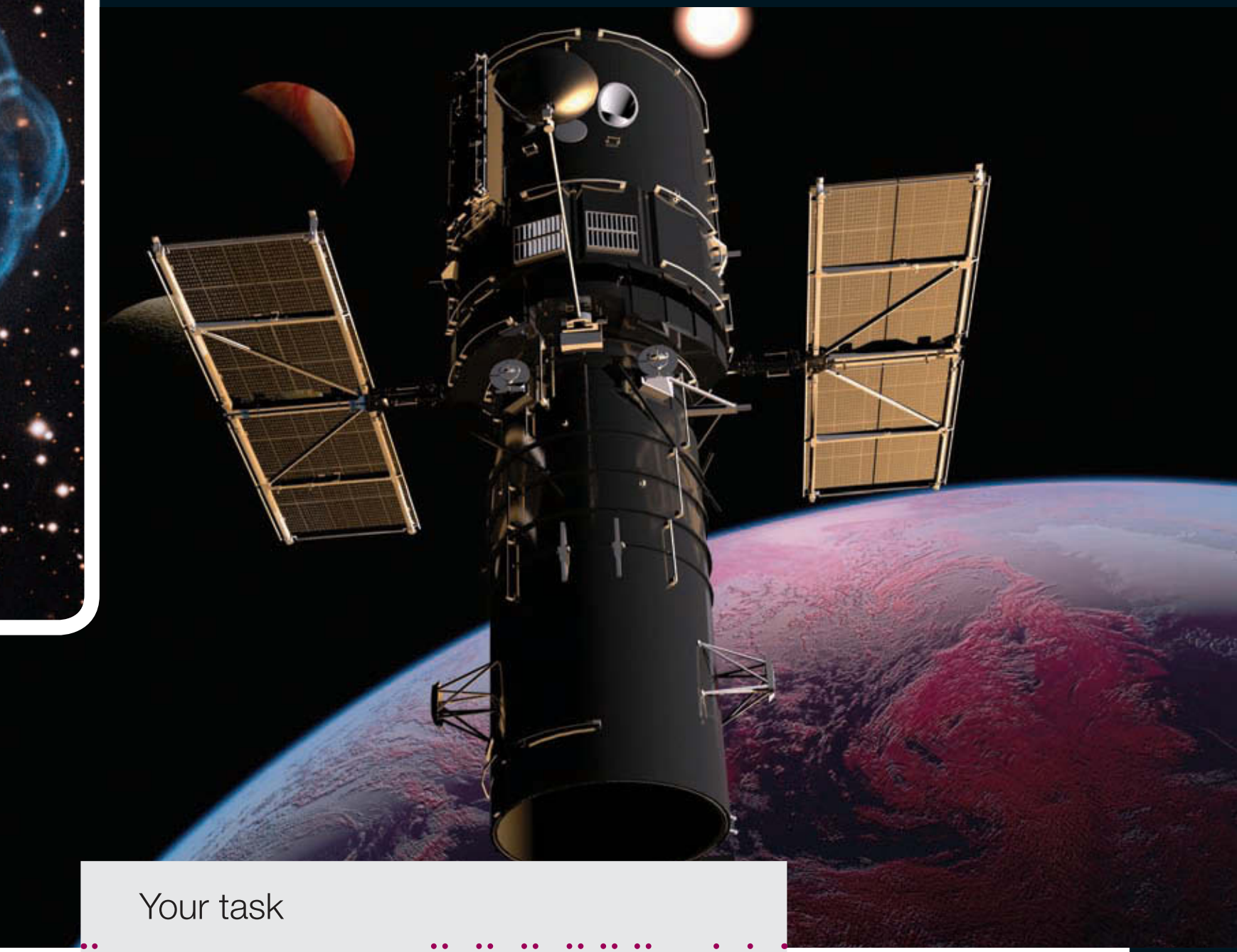
'Most irregular. The answer I've got is quite different.' Then, with a note of disgust in its voice, it added, 'I must have been misprogrammed. I've heard of this sort of thing. Never thought it would happen to me, though. How embarrassing. I'll have to do a check on myself.'

'… can't wait … can't wait … must be on my way …'

Gedanken heard the light beam's voice dying away in the distance. The fuzzy patch of light faded—and finally disappeared.



Astronomy, cosmology, astrophysics, quantum mechanics—these are all science disciplines that are seen by many as 'another language'. In the story of Uncle Albert and his niece Gedanken, one aspect of space travel has been translated into descriptions and language that even a primary school student could understand.



Your task

Select a concept from this chapter and transform it into a children's story, complete with illustrations. Consider the systems involved in your concept—what are the objects involved? How do these objects interact? What results from the interaction of these parts? How have we come to understand the various elements of this concept?

In your thinking, you may be required to refer back to big ideas studied throughout your secondary schooling in science. For example, your understanding of the big ideas of motion, forces and energy will be vital.

3 Global systems

3.1 What are Earth's major interactions?

Everything on Earth can be considered to be within four spheres: the lithosphere (land), atmosphere (air), biosphere (living things) and hydrosphere (water). When disaster struck in Haiti on 12 January 2010, it was the lithosphere that shook with a category 7 earthquake, resulting in the deaths of approximately 230 000 people, 300 000 injured and one million rendered homeless. One man, Evans Monsignac, survived 27 days in the rubble and is thought to be the longest ever earthquake survivor. Evans was trapped between concrete slabs; he sipped sewage run off to survive and tried to lie perfectly still so as not to unsettle the rubble and be crushed. Finally, after 27 days, he was rescued and taken to a hospital in the United States. His amazing story has baffled doctors and he himself can't believe he is alive.



Fig 3.1 On 12 January 2010, Haiti experienced a catastrophic earthquake that destroyed many buildings, killed many people and left many more homeless.

1. How do you think the earthquake in Haiti would have affected the other spheres (air, living things and water)?
2. What do you already know about earthquakes? Brainstorm on your own and then pair up with a friend to share information and ideas.
3. Aside from earthquakes, can you think of other types of natural disasters?
4. Drawing on past knowledge and experiences, write a definition of a natural disaster. In your definition, use an example of a human-made disaster to highlight the differences between the two.
5. Using your understanding of the human body, suggest how it was possible for Evans to survive on a diet of sewage for nearly 1 month.



Fig 3.2 Acid rain can have a devastating effect on plants and aquatic animals.

Throughout human history, one thing has held the interest and curiosity of the human race like no other: our home, planet Earth. At one time we thought the Earth was flat, for thousands of years it went unmapped and unexplored and, recently, we have started to see that the actions of the human race can seriously harm it. It is the only planet we know of that can support life, and that's no simple job. There has to be an exact mix of very specific parts and ingredients to support life, just like a living organism. The Earth has similar systems in place; in fact, some people choose to think of the Earth as a living being itself. The Ancient Greeks called this idea *Gaia*, or Mother Nature.



3.2 How does matter cycle on Earth?

One of the most well known natural cycles is the water cycle. But what happens when something unnatural starts to affect a natural process like the water cycle? How does a change in one cycle affect other systems and cycles? One example of this is acid rain. Acid rain is the result of water in the atmosphere being polluted by emissions of sulfur dioxide and nitrogen oxides and becoming acidic. This acidic rain can affect animals, plants and even buildings. Acid rain can also affect countries that are not even releasing harmful acids into the atmosphere! For example, pollution from England is blown by winds into Scandinavian countries, which then have to suffer the effects of acid rain. It doesn't seem fair, does it?

1 Acid rain is an example of a problem affecting the water cycle. What other cycles or natural systems are you aware of?
2 Can you think of ways that acid rain may also affect the lithosphere (land), hydrosphere (water), biosphere (living things) and atmosphere (air)?
3 Explain how pollution in one country can cause acid rain in another country. Reflect on this and suggest how countries may react to the presence of acid rain that they have not caused.



→ Fig 3.3 The vast and rapid increase in the world's population has impacted how we use the world's natural resources.

3.3 How do humans impact the environment?

Let's get into a time machine and go back over 2000 years—welcome to the year 1 CE. Here we find the population of the Earth at approximately 200 million people. A thousand years later, the world's population had increased by 110 million people. Back then, it took a thousand years for the population to grow by 110 million people. Now it takes just over 1 year to grow the same amount. The vast increase in population has changed the way we use natural resources, like timber, water and even animals for food. Around the world, approximately fifty football fields of forests are cut down every hour, leading to loss of biodiversity and also increased carbon levels in the atmosphere.

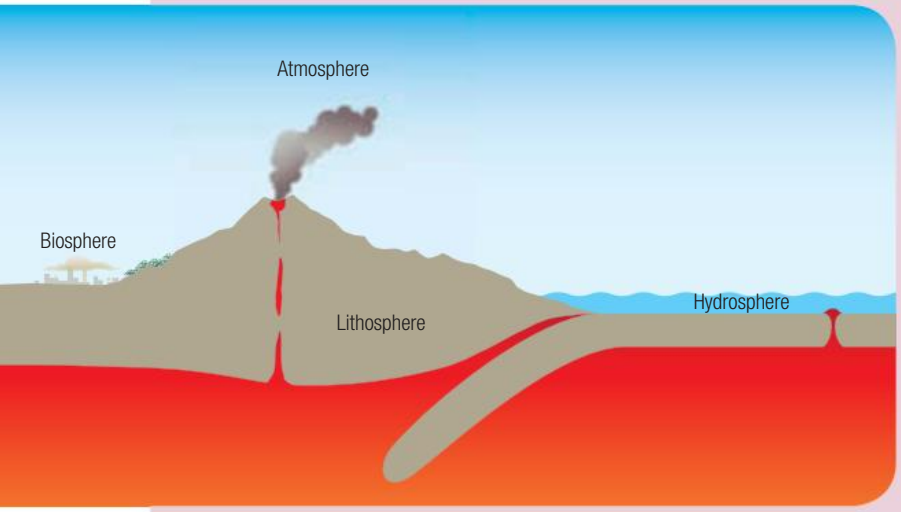
1 What problems do you think we will encounter should the Earth's population keep increasing at the rate it is?
2 What other impacts have humans had on the natural environment? Which do you think are the most significant?
3 How do you think technology has changed the way we harvest natural resources, such as wood from forests and fish from the sea?

3.1 What are Earth's major interactions?



Everything on Earth can be considered within four spheres, the lithosphere (land), atmosphere (air), biosphere (living things) and hydrosphere (water). Earth Systems Science is the study of the interactions between these four spheres. Each sphere maintains a balance and can interact with other spheres. Humans, like all organisms, impact on the Earth's systems. The ability of humans to actively manipulate their environment sometimes stretches these spheres to their limits—and occasionally beyond. How can we tell when this is occurring? What does it mean for life on Earth?

<DISCOVERING IDEAS>



Remembering spheres

1 On an A3 sheet of plain paper, create a large Venn diagram showing the four spheres of lithosphere (land), atmosphere (air), biosphere (living things) and hydrosphere (water) interconnecting. Consider exactly how each would overlap.

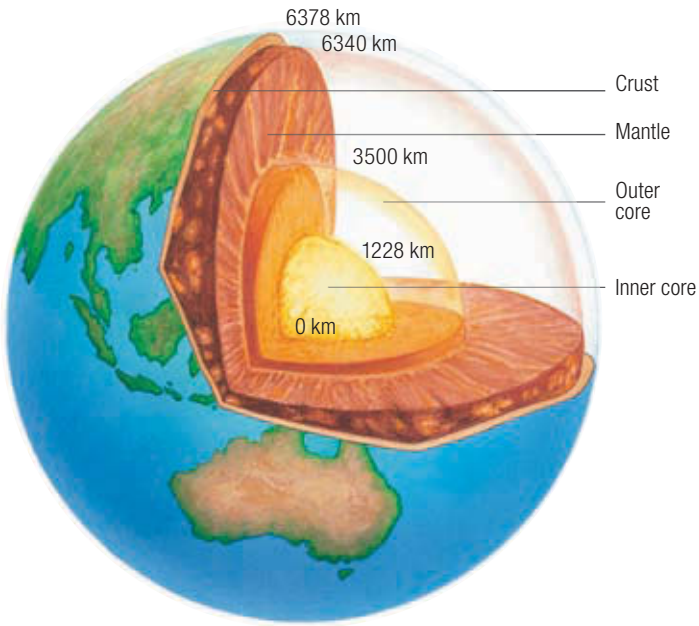
2 Label each sphere and fill the circles with illustrations to help you remember what each sphere contains.

→ Fig 3.4 The four spheres – lithosphere, biosphere, hydrosphere and atmosphere.



The lithosphere

If you cut the Earth in half, it is clear to see that inside it is made up of multiple layers. The outermost rocky layer of the Earth is the **lithosphere** and is made up of the upper **mantle** and the **crust**. To travel down through the crust and upper mantle we are only talking about going down approximately 80 km. Does that sound like a lot? Although few of us would be happy going 80 km underground, if you think of it in terms of the scale of the size of the Earth, it is actually a very thin layer.



→ Fig 3.5 The layers of the Earth.

As far as Earth's systems go, the lithosphere changes on a very long time-scale: changes are extremely slow and can take thousands, even millions, of years.

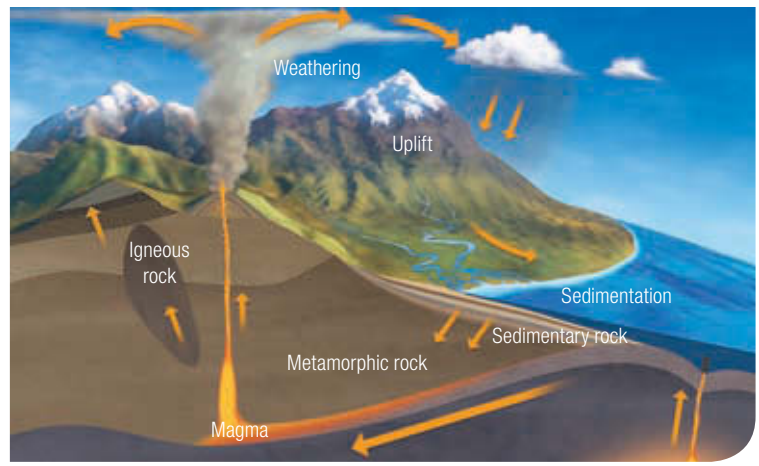
Heading towards the middle of the Earth, it gets hotter and, due to the heat, more molten (melted) and liquid. However, the **inner core** does not melt or boil because the weight of the rest of the Earth is pushing down on it. Next time you are complaining about a summer day getting close to 40°C, remember the inner core is almost 10 000°C!

The rocky crust of the Earth is made from **magma** (molten rock)—which cools very slowly and at different times all over the surface of the Earth. The crust settles as uneven giant plates of rock that are mismatched and butt up against their neighbours, covering the entire Earth. The giant pieces are called **tectonic plates**. These plates float on the semi-liquid magma at the top of the mantle. The heat in the mantle creates currents that slowly stir through the molten rock, moving the tectonic plates as well. The speed of movement (around 2–10 cm per year) is similar to the growth of your fingernails. These extremely slow-going processes are what shape the Earth as we know it—an uneven surface riddled with deep underwater trenches, enormous mountain ranges, canyons and picturesque lakes.

The rock cycle

Magma, called **lava** when above ground, cools and solidifies to form **igneous rocks**. Other rocks are brought to the Earth's surface through the uplifting of land when tectonic plates collide.

Sediments are deposited in layers and, over time, they cement together under pressure to form **sedimentary rocks**. When rocks are under extreme heat or pressure, they change into very hard **metamorphic rocks**. If too much heat or pressure is applied to rocks, they melt and form magma and the whole cycle begins again. Someone who studies rocks (as well as the other solid and liquid matter that the Earth is made up of) is called a **geologist**. Geologists can work in a range of industries, including mining, natural disaster preparation (for volcanoes and earthquakes) and often work outside and in very remote areas.



→ Fig 3.6 Rocks change as they move through the rock cycle.

Earthquakes

Earthquakes occur when rocks on the sliding plates become jammed. The pressure between the plates builds up until the rocks break and the plates jolt free. The jolt causes vibrations on Earth we know as an **earthquake**. Most damage caused by earthquakes occurs near the epicentre, which is the point on the surface of the Earth directly above where the earthquake occurred.



➔ Fig 3.7 On 22 February 2011, a magnitude 6.3 earthquake rocked the city of Christchurch in New Zealand.



➔ Fig 3.8 An undersea earthquake off the coast of Japan in March 2011 triggered massive tsunami waves that engulfed many coastal communities.

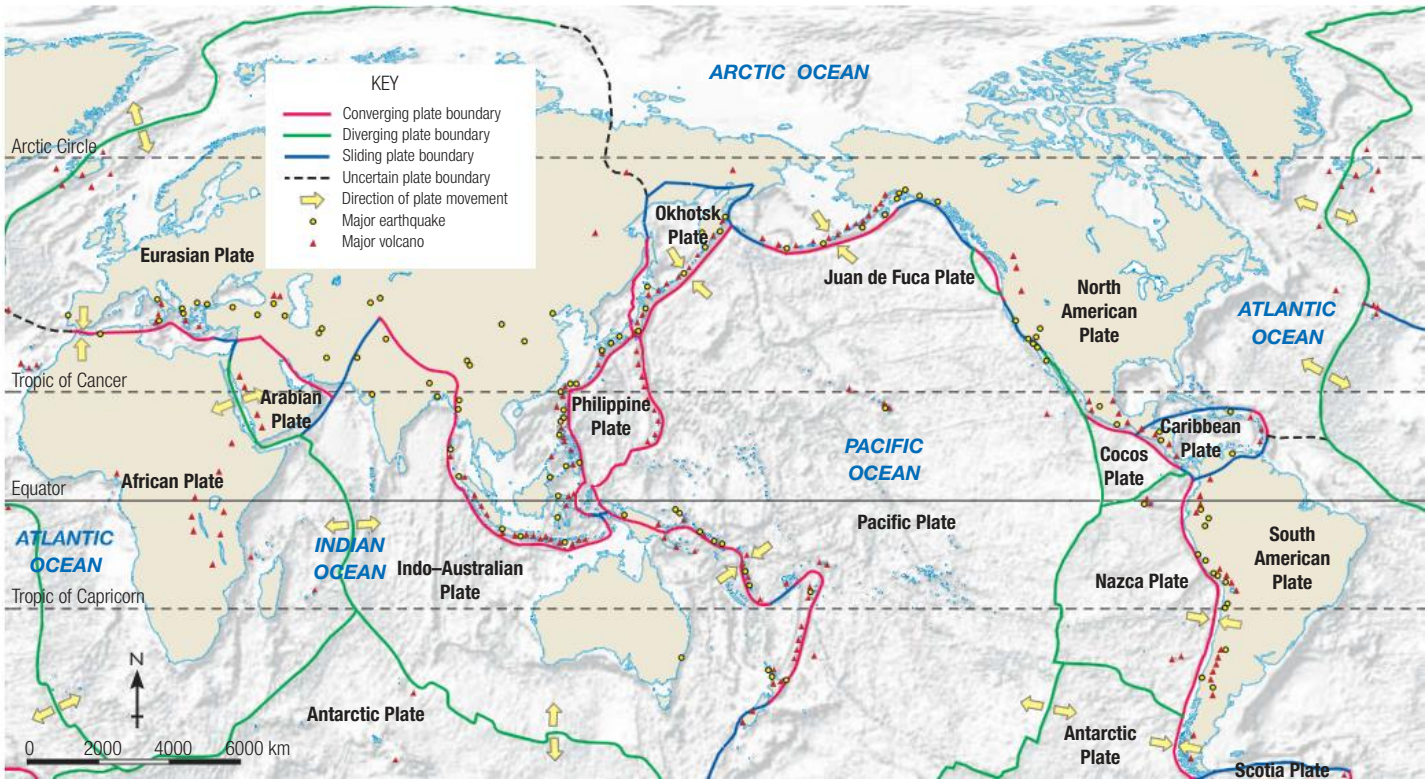
You may not realise just how common earthquakes really are; we only hear about a few major ones every year or so. In fact, every year the Earth experiences more than a million earthquakes! It's just that most of these are so small that people don't know they are going on. Scientists are able to study plate tectonics and carefully monitor movements to give people warning of impending earthquakes.

Undersea earthquakes can push up the water to form deadly waves known as tsunamis, like the one that devastated the north east–coast of Japan in 2011.

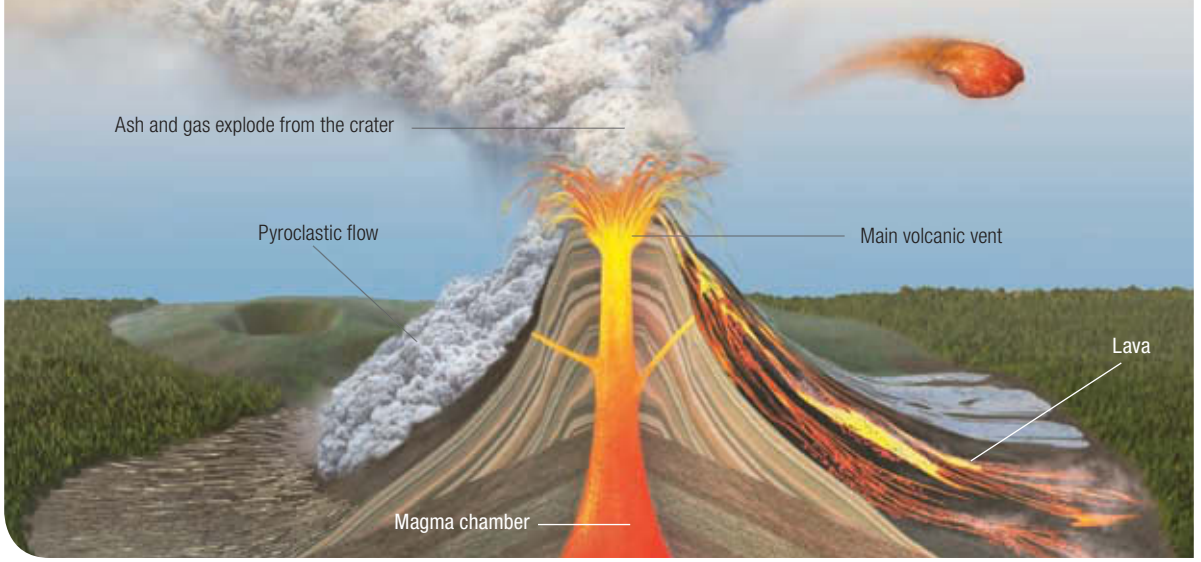
Volcanoes

A **volcano** is a vent or hole in the Earth where molten rock, ash and other materials escape onto the surface. Volcanic eruptions can be triggered by the movement of tectonic plates, similar to earthquakes, or they can be the result of a build–up of pressure below a thin section of plate. Volcanoes have different shapes, depending on the forces acting on and around them.

The **magma chamber** under a volcano is the source of molten rock for the volcano. Magma is under great pressure because it is squashed by the surrounding rocks. As the magma rises towards the surface of the Earth, there is less



➔ Fig 3.9 Volcanoes and earthquakes are located along the edge of the Earth's tectonic plates.



➔ Fig 3.10 A cross-section through an active volcano.



➔ Fig 3.11 Volcanoes are surrounded by rich, fertile soil.

pressure on it. Decreased pressure allows the gases in the magma begin to form bubbles and may be enough to cause the volcano to erupt.

In an explosive eruption, the red-hot magma rushes out through the **vent**. Larger pieces of rock are shot into the air as volcanic bombs, as well as dust, ash and steam, are thrown high into the air. Volcanic eruptions also ooze lava and ash onto the surrounding land. The cooler temperatures on the Earth's surface help the lava quickly become solid igneous rock. When igneous rock is broken down by the action of wind and water, and mixed with organic material from plants and animals, it forms some of the richest soil in the world.

When Mount Pinatubo in the Philippines erupted in 1991, ash fell up to 3500 km away and 4% of the Earth's sunlight was blocked for an entire year. Other volcanic eruptions are much quieter because molten rock oozes slowly from the vent.

There are approximately 1300 active volcanoes on the land, as well as numerous undersea volcanoes. Only twenty or so of these are currently erupting. Those volcanoes that are not erupting but may erupt in the future are called dormant (sleeping) volcanoes. Volcanoes that were once active but are never likely to erupt again are referred to as extinct volcanoes. There are active volcanoes in New Zealand and Papua New Guinea. All the volcanoes on the Australian continent are extinct, but the volcanic landforms formed in the past remain.



➔ Fig 3.12 Mount Pinatubo is an active volcano in the Philippines that last erupted in June 1991.



➔ Fig 3.13 Blue Lake at Mount Gambier in South Australia is a lake within the crater of an extinct volcano.

Like earthquakes, volcanoes pose great danger to those who live near them. The volcanic eruption of Krakatoa in 1883 caused a tsunami that raced across the ocean and crashed onto nearby islands, killing 36 000 people. The blast was heard 5000 km away and ash rose 80 km into the atmosphere. Despite the dangers, people continue to live near volcanoes due to the fertile soil they provide.

What do you know about the lithosphere?

1. What is the lithosphere made up of?
2. What is the rock cycle?
3. How do earthquakes occur?
4. What is the difference between a dormant and extinct volcano?
5. Why do you think scientists can't predict earthquakes ahead of time?

The atmosphere

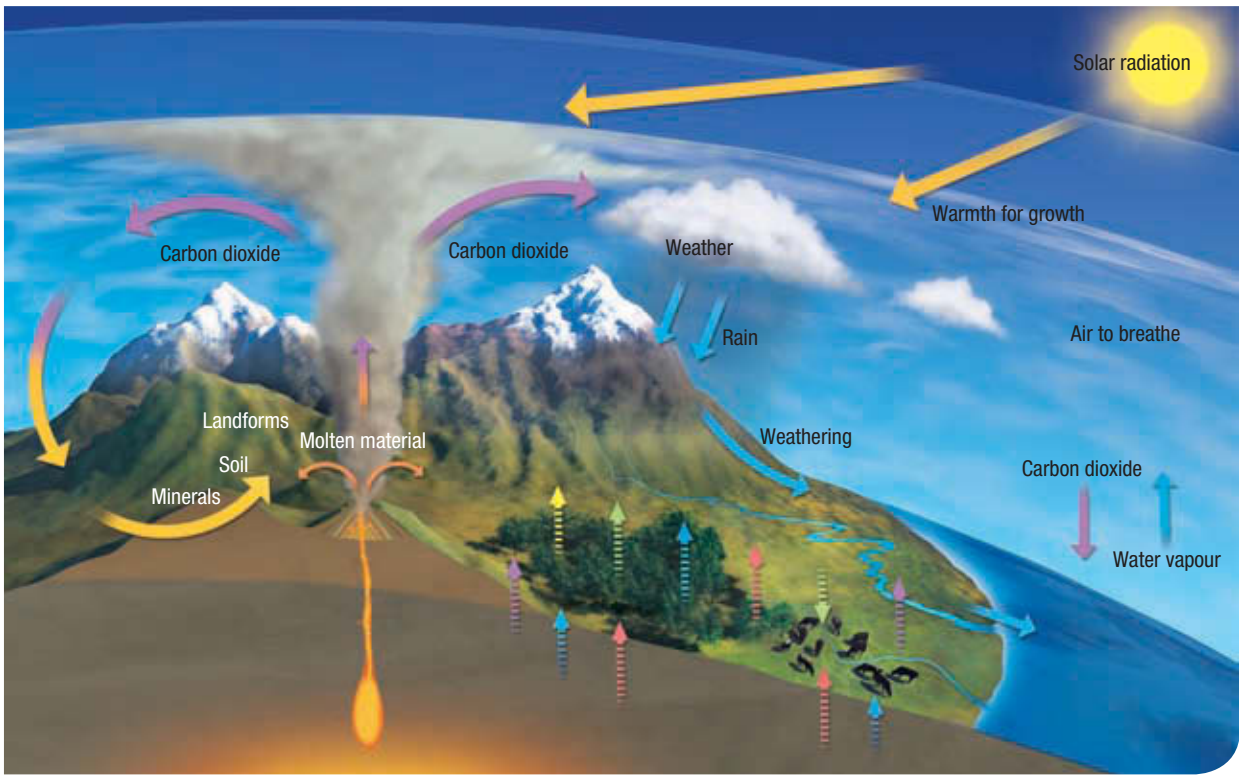
The **atmosphere** is a layer of gases that we commonly call *air*. The atmosphere is relatively thin compared with the size of the Earth: if the Earth were the size of a party balloon, the atmosphere would only be as thick as the rubber skin of the balloon.

The Earth is the only planet in our solar system that has an atmosphere that sustains life. It helps keep us warm, controls our weather, protects us from the dangers from space and carries sounds. The Moon has no atmosphere, so there is no wind, no noise, no life and no protection from meteorites, which crash into the Moon's surface.

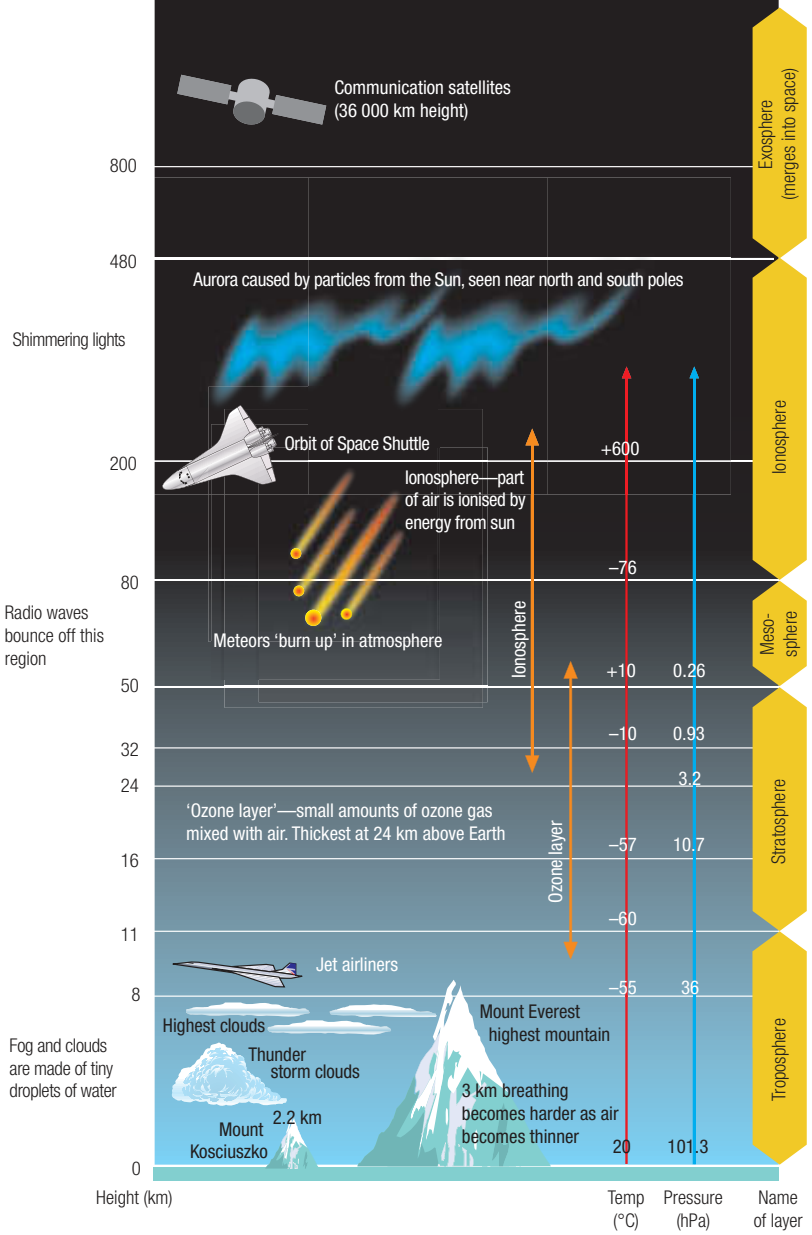
The most important gas for humans and other animals is oxygen, which makes up 21% of the atmosphere. Oxygen in the Earth's atmosphere allows organisms to respire (O_2); ozone (O_3) offers protection from the Sun's UV radiation; and carbon dioxide (CO_2) and other greenhouse gases trap heat to keep us warm. Nitrogen (N_2) makes up 78% of the atmosphere. Nitrogen dilutes the oxygen gas to levels that our lungs can handle.

Layers in the atmosphere

The atmosphere is more dense at ground level and thins out as you go higher above the Earth's surface: 99% of all the air in the atmosphere is found within 80 km of the Earth's surface. There is not really a top to the atmosphere—the air just thins out, with decreasing pressure, until you reach the emptiness of space. These changing conditions are identified as several atmospheric layers.



→ Fig 3.14 The inputs and outputs of the Earth's living and non-living systems.



→ Fig 3.15 Each layer of the Earth's atmosphere has different characteristics.



→ Fig 3.16 Aurora australis, also known as the Southern Lights, is seen here over icebergs in Antarctica. Aurora occur in the ionosphere and are caused by UV radiation and X-rays from the Sun.

THE TROPOSPHERE

The *troposphere* is the bottom layer of the atmosphere, where we live. In this layer:

- all our weather occurs
- due to gravity, 75% of all the atmosphere's air is found
- air temperatures drop rapidly as you climb higher, being approximately –60°C at the top of the troposphere
- due to the Earth spinning, the troposphere is thicker at the equator (18 km) and thinner at the poles (8 km)
- most aircraft fly.

THE STRATOSPHERE

The *stratosphere* extends from the troposphere up to 50 km above the ground. In this layer:

- the temperature changes only slightly with increasing altitude—from –52°C at its lowest level to –30°C at the top
- a layer of ozone gas occurs, which blocks most of the harmful UV radiation that comes from the Sun
- the atmospheric conditions are very stable and there is little or no air turbulence
- there are almost no clouds or other forms of weather
- passenger jets sometimes fly to take advantage of the fast jet stream winds.

THE MESOSPHERE

The *mesosphere* sits above the stratosphere and the temperature here again gets colder. In this layer:

- temperatures can fall to –93°C
- millions of meteors burn up daily as a result of the heat caused by collisions with the gas particles that are contained here.

THE IONOSPHERE

The *ionosphere* (or thermosphere) is the thickest of the atmospheric layers. In this layer:

- just 1% of air particles occur
- temperatures are very high because of radiation from the Sun
- meteors begin to burn up
- some space shuttles and some satellites orbit
- aurora (a glow in the sky caused by UV radiation and X-rays from the Sun) happen.

THE EXOSPHERE

The *exosphere* is the top of the atmosphere. In this layer:

- the atmosphere merges with space
- communication satellites are found that receive messages from the other side of the Earth.

EXPERIMENT 3.1

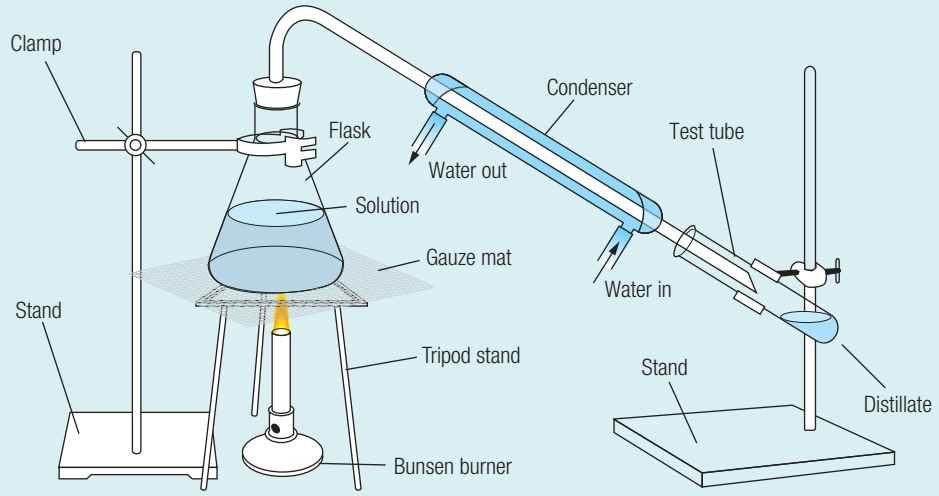
Make your own clouds

Aim

To simulate the process of condensation.

Materials

Ice cubes
Bench mat
Water
Tripod
250mL beaker
Gauze mat
Evaporating dish
Matches
Bunsen burner
Safety glasses



→ Fig 3.17 Experiment set-up.

Method

1 Set up the apparatus as shown in Figure 3.17.
2 Heat the water in the beaker until it boils.
3 Turn the gas off and place an ice-filled evaporating dish on top of the beaker.
4 Carefully observe what happens.

Results

Include your observations in an appropriate format here.

Discussion

1 What action produced water vapour?
2 What happened to the water vapour?

Conclusion

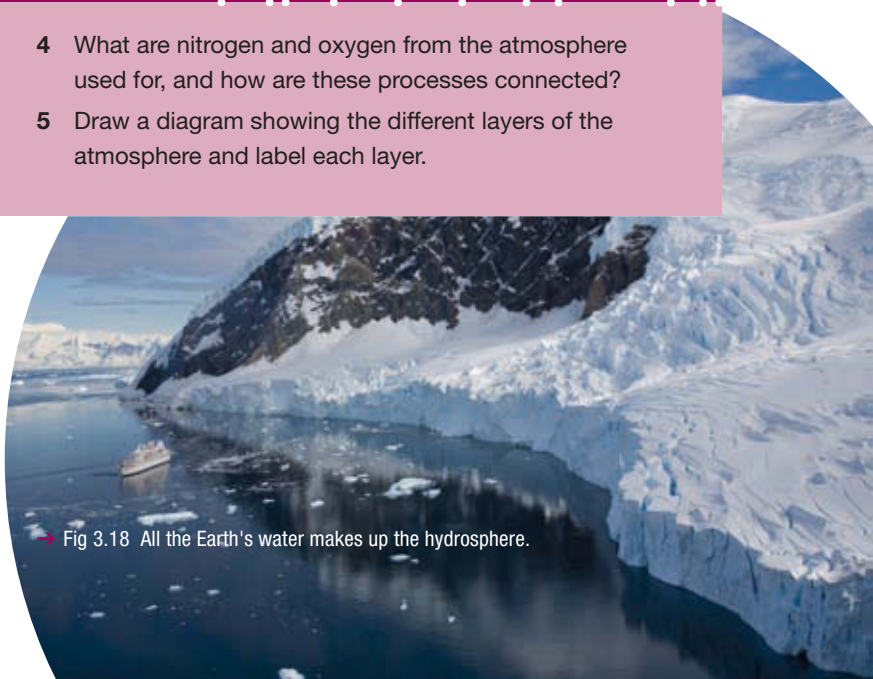
Write a brief statement linking this experiment to the process of condensation.

What do you know about the atmosphere?

1 In which layer of the atmosphere do we live?
2 What happens to the amount of air as you go higher into the atmosphere?
3 What gases make up the atmosphere?
4 What are nitrogen and oxygen from the atmosphere used for, and how are these processes connected?
5 Draw a diagram showing the different layers of the atmosphere and label each layer.

The hydrosphere

The **hydrosphere** is made up of all the Earth's water. Not just the obvious—oceans and lakes—but also glaciers, the soil and even in the air. The hydrosphere covers approximately 70% of the Earth's surface, making Earth the 'blue planet' when viewed from space. The huge amount



→ Fig 3.18 All the Earth's water makes up the hydrosphere.



→ Fig 3.19 Colours reflect heat better than dark colours. This applies to cars and even the Earth. The Earth's ability to reflect heat is called its albedo.

of water, in all its various forms, is also home to many types of plants and animals. The hydrosphere interacts with and is influenced by each of the other spheres. For example, in the atmosphere you can find water in three different states: liquid, vapour and solid (glaciers and ice).

The cryosphere

The part of the hydrosphere that is made up of frozen water is called the **cryosphere**. The cryosphere is really important in regulating the climate on Earth, and it does this in a number of ways: it influences atmospheric and ocean circulation and currents, as well as the amount of moisture in the atmosphere, and reflects rays from the Sun. As far as measuring climate change goes, scientists carefully monitor what is going on in the cryosphere. This has been seen in more recent times with the breaking of huge ice shelves and melting sea ice in the Arctic. We will look at this further in the final unit of study, which considers human impacts and climate change.

PRACTIVITY 3.1

How do we use water?

What you need: two packets of stick-on notes per group, some pens

1. Divide the class into groups of four or five. Each person has a small pile of stick-on notes and a pen.
2. In 2 minutes, write down every use of water you can think of. (Hint: Don't just think of water that humans use, think about animals, the environment, business, farms etc.) Write each use on a separate stick-on note. Spread out the notes on the table in front of you.
3. When the time is up, arrange the notes into common topics.

- Display your group's uses of water on a wall (temporarily).
- Check the displays created by other groups. Make a note of any uses your group did not think of.
- Count up the number of different uses of water that the whole class has described.

What do you know about the hydrosphere?

1. What is the hydrosphere made up of?
2. What is the difference between the hydrosphere and the cryosphere?
3. Why do you think conserving water is important?

The biosphere

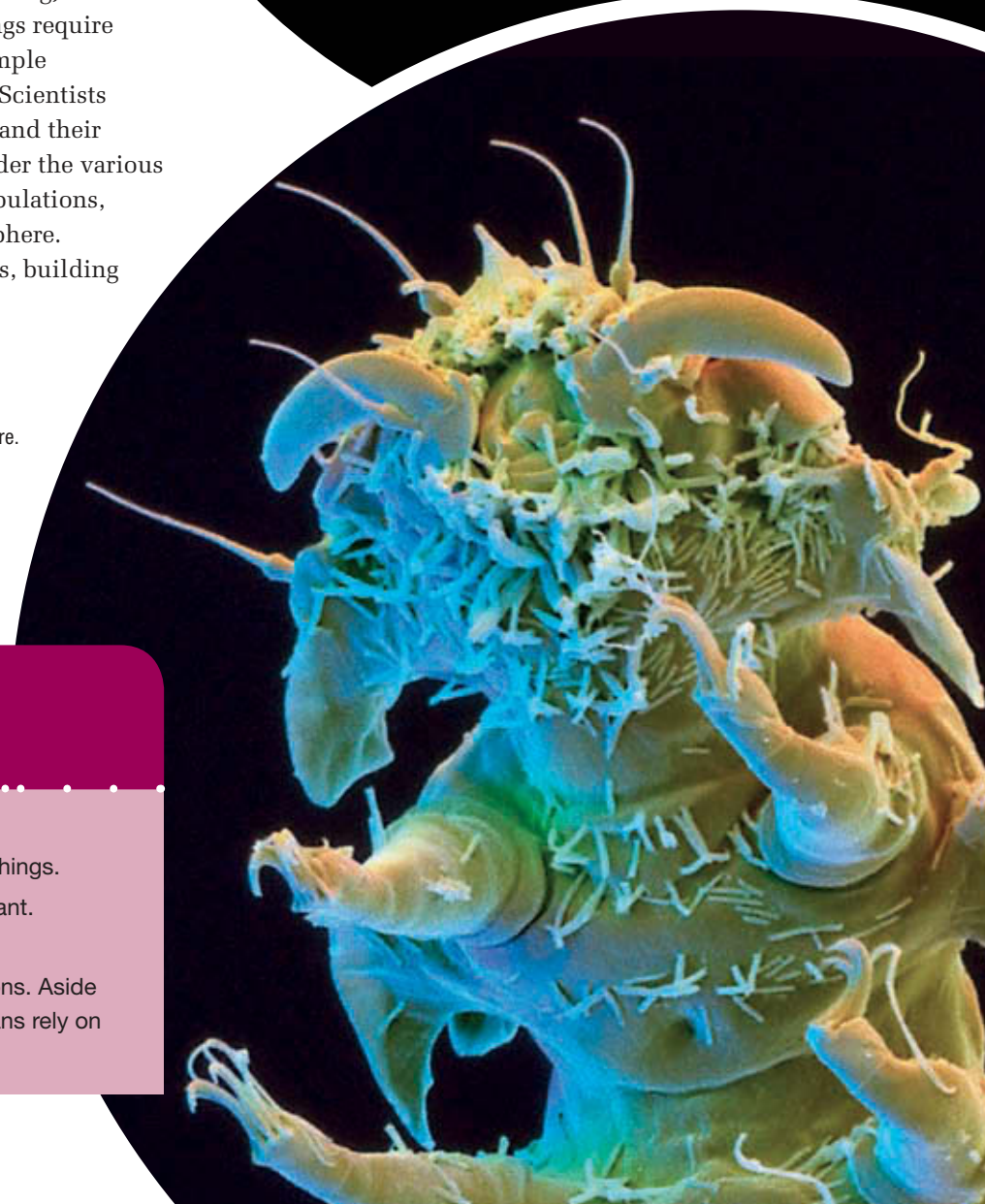
The **biosphere** is made up of all the living things on Earth, including plants, animals and bacteria. Within this sphere there is an enormous degree of organisation and amazing biodiversity. There is also great interdependence between different parts of the living world. From eating relationships to more obscure dependencies, there is a fine balance between organisms that must be maintained.

Earth is the only planet in our solar system that is able to support a biosphere. Although life is able to exist in all spheres on Earth, most living things can only survive in a fairly narrow range—from deep under the ocean to high mountains. The wide range of conditions that exist in all these habitats is accommodated by a wide range of different organisms—*biodiversity* (*bio* = life; *diversity* = variety).

Like the interactions and interconnections between Earth's spheres, interactions also occur between **biotic** (living) and **abiotic** (non-living) parts of the Earth. Living things require a number of non-living things to survive, for example water and gases like oxygen and carbon dioxide. Scientists who study this interaction between living things and their environment are called **ecologists** and they consider the various levels of **ecology**, including single organisms, populations, communities, ecosystems or even the entire biosphere. Humans rely on the biosphere for food, medicines, building materials and fuel.



→ Fig 3.20 The Pompeii worm is able to withstand temperatures of up to 80°C. It is considered a 'thermophile' because it thrives in hot conditions.



→ Fig 3.21 Tardigrades are tiny invertebrates found almost everywhere. They have been known to survive without water for over 100 years and can live at temperatures ranging from as low as –272.8°C to as high as 151°C, under massive amounts of pressure, in vacuums and even at radiation doses that would kill all other known life forms!

What do you know about the biosphere?

1. What makes up the biosphere?
2. List some abiotic (not living) and biotic (living) things.
3. Define *biodiversity* and explain why it is important.
4. What is *ecology*? Why is it important?
5. Humans rely on the biosphere for a lot of reasons. Aside from those aspects listed above, how do humans rely on the biosphere?

3.1 What are Earth's major interactions?



Remember and understand

1 From what does our ozone layer protect us?
2 Name the three different layers of the Earth.
3 In which layer of the Earth are the tectonic plates found?
4 What does an ecologist study?
5 Which part of the atmosphere protects us from meteors?
6 What gases are found in our atmosphere and why are they important to life on Earth?
7 What is a drought and which sphere does it relate to?
8 Even though the Earth's inner core is hotter than its molten outer core, it is thought to be solid. How can this be the case?

Apply

9 The hydrosphere can have a huge effect on the other spheres. Consider a drought. Australia is prone to devastating droughts when there is not enough water available for the needs of Australians.
   a How could drought affect the biosphere?
   b How would this affect the atmosphere?

Analyse and evaluate

10 As you now know, the biosphere includes parts of the lithosphere, the troposphere (the lowest part of the atmosphere) and the hydrosphere. Create a list of the parts of the biosphere you may find in each of these three spheres.

Critical and creative thinking

11 Draw a mind map showing the potential connections and dependencies between the four spheres of the Earth and their components. Challenge yourself to find as many links as possible.



CONNECTING IDEAS Dynamic Earth

12 List the key terms covered in this unit. Represent these terms and their meanings and connections with the concept of 'dynamic Earth' in a visual format. This could be anything from a model or diagram to an animation of some type. Present your work to the class for constructive feedback.

3.2 How does matter cycle on Earth?



Earth Systems Science is the study of the Earth's four spheres—the lithosphere, atmosphere, hydrosphere and biosphere. To appreciate the importance of these spheres, it is necessary to consider how they interact and are dependent on each other. Naturally occurring systems and cycles are responsible for connecting the spheres. These cycles include the water cycle; the carbon cycle; the phosphorus, oxygen and nitrogen cycles, deep ocean currents; and some smaller cycles that occur daily, including the weather.

DISCOVERING IDEAS

Using computer simulations

Scientists can't always find answers to big questions by doing experiments. Often the risks are too great or the experimental method is outside the limits of current technology. Answers to problems like this can sometimes be found using computer simulations.

A computer simulation takes an established pattern and extends it to make a prediction about further events. A simulation is a type of model and, just like other models, it isn't always accurate, but it is the best possible inference or answer to a big question that cannot be tested in any other way. Computer simulations can also be used for experiments that require a lot of repetition that would take a scientist a long time to complete manually, or to infer data about places we can't go to, like other planets or below the crust of our own planet.

Scientists know that the Earth's mantle is 2800 km thick and that the temperature near the point where the crust and mantle meet is approximately 500°C. Your job is to find out the temperature of the mantle at its deepest point: 2800 km below the Earth's surface.

1 Enter the information from Table 3.1 into a spreadsheet program, like Microsoft Excel or similar.

2 Create a scatter graph of this information using the graphing function of the computer program. Make sure that temperature is on the *y*-axis and depth is on the *x*-axis.

3 Extend the data in the table until you reach a 'Depth under mantle' of 2800 km. Do this by using the 'fill handle' tool (select the cells in the Excel worksheet and click and drag the small square that appears in the lower right corner of the selection).

4 Update your graph to represent this new data.

- Does the temperature at a depth of 2800 km match the information you have read on this page? Explain why there is a variance.
- The process you have just followed only works for 'linear' data, which is data that increases or decreases at a constant level. Suggest another experiment you have conducted this year that you could have completed using this process.
- Similar modelling is conducted using data about weather and climate. What predictions would scientists want to make with regard to weather and climate? Why would these predictions be useful?

More complex computer simulations are also available to process much more complicated, or non-linear, data.

→ Table 3.1

Depth under mantle (km)	Temperature (°C)
100	500
200	598
300	696
400	794
500	892
600	990

Natural cycles

The cycling of all nutrients through Earth's spheres is essential to sustaining life. If every time we exhaled carbon dioxide it was lost to the atmosphere for good, plants would die out, animals would starve and the biosphere would collapse. We know this is not the case—plants are able to absorb carbon dioxide from the atmosphere. Similar interactions between the various spheres enable a flow of matter and energy.

Cycling water

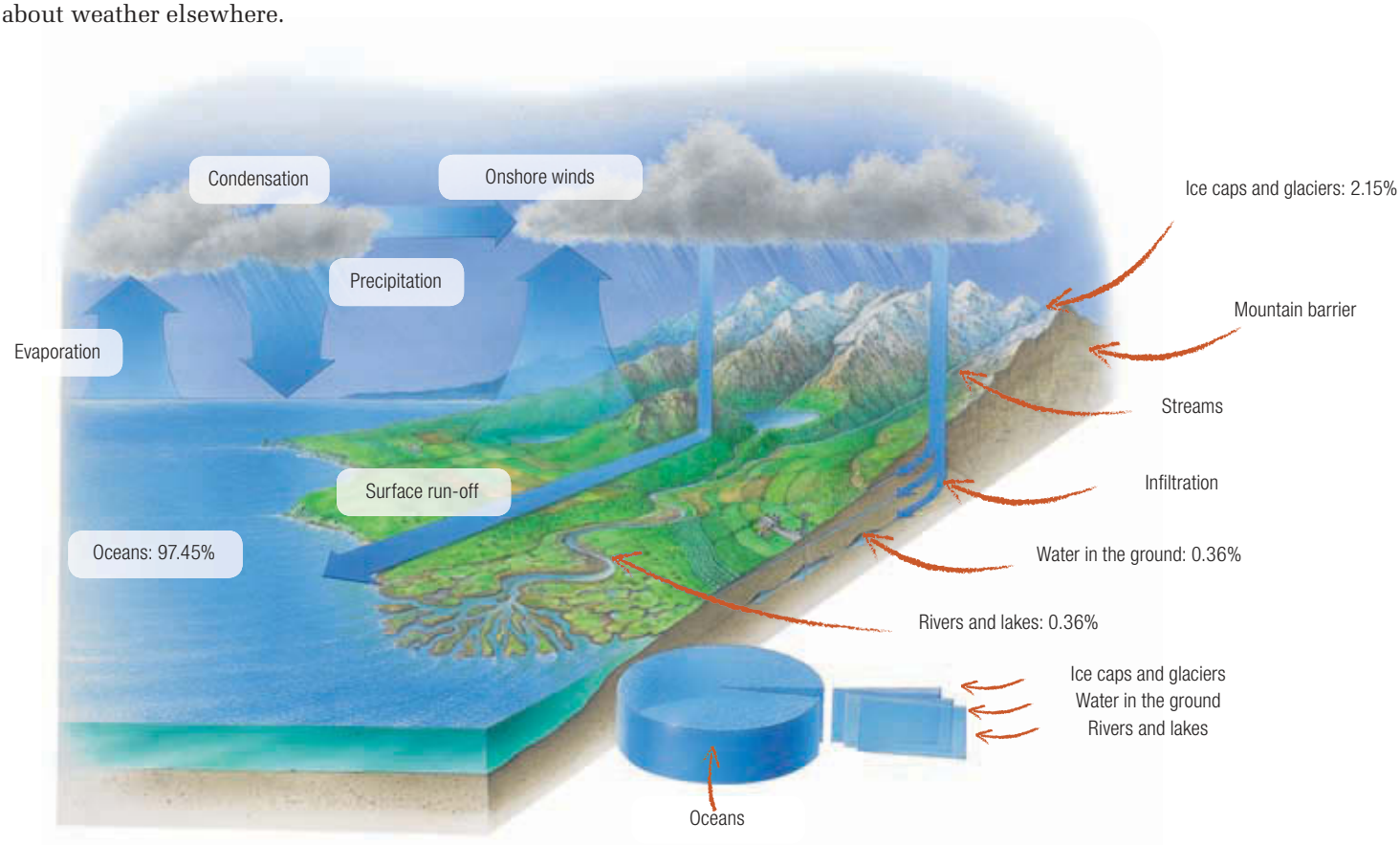
Water is an essential part of life and is important for many metabolic processes in your body. It is continuously cycled between the biosphere, hydrosphere and atmosphere. However, this does not mean that there is a never-ending supply of water. This is because the water cycle (see Figure 3.22) is a *global* cycle. This means that water is not equally available in all ecosystems. For example, water that is evaporated from the desert may later fall as rain on a forest thousands of kilometres away. For this reason, an ecosystem may have too little water (drought) or too much water (floods) for the organisms within it to continue to survive. This is why it is important to monitor and analyse the patterns of rainfall across the globe to make predictions about weather elsewhere.

The four major features of the water cycle are:

1. evaporation (and transpiration from plants)
2. condensation
3. precipitation (rain, hail or snow)
4. collection (run–off on land).

CLOUDS AND RAIN

Water vapour is the source of all clouds and precipitation and is therefore the most important gas in the atmosphere when it comes to understanding atmospheric processes. Water vapour is evaporated water—water as a gas. This means that individual water molecules are moving in the air. Water vapour that has been evaporated from oceans and rivers rises until it reaches the cooler parts of the atmosphere. Cold air cannot hold as much moisture as warm air, so the water vapour turns back into liquid water: condensation. These drops of water then form into **clouds**. The clouds may be carried onto land by winds and may be forced to rise when they reach a mountain barrier or another air mass. The colder air can no longer hold the condensed droplets and they fall as **precipitation**—rain, hail or snow. The precipitation eventually moves back to the world's lakes and oceans through rivers and streams (collection) and the process begins again.



→ Fig 3.22 The distribution of water on Earth and the water cycle.

NUMERACY LAB

Measuring humidity

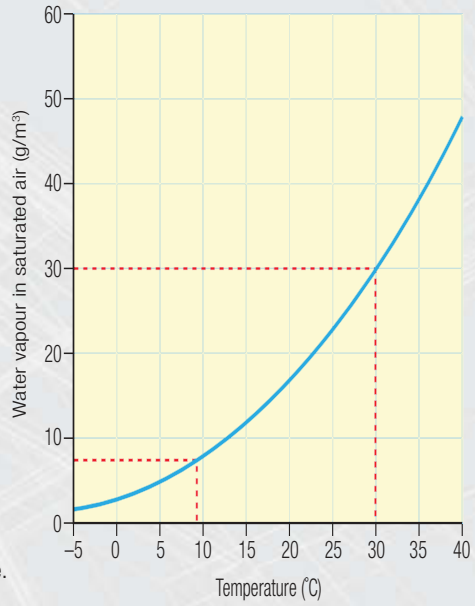
Humidity is a measure of how much water vapour is in the air. Warmer air can hold more water vapour, so it's common for humidity to be associated with tropical regions.

Questions to consider

1 Look at Figure 3.23. How much water vapour is in the air when it is 20°C? What about when it is 35°C?

2 When is there 20 g/m^3 of water vapour in the air? What about 45 g/m^3?

3 Where are you likely to find a more humid climate: Adelaide or Darwin? Explain.



→ Figure 3.23 Changes in the amount of water vapour in saturated air with temperature.

CYCLING OXYGEN

Oxygen is the essential ingredient in cellular respiration, the process by which most organisms obtain energy for life. The Earth has a fixed supply of 'useful' oxygen even though it can be found everywhere. There are three reservoirs of oxygen:

1 the atmosphere (0.49%)

2 the Earth's crust or lithosphere—rocks and the oceans (99.5%)

3 living organisms—the biosphere (0.01%).

In the atmosphere, oxygen exists as the molecules O_2 and O_3 (ozone) and in compounds such as water (H_2O) and carbon dioxide (CO_2). Oxygen is able to dissolve in the oceans, where it is available for uptake by marine organisms.

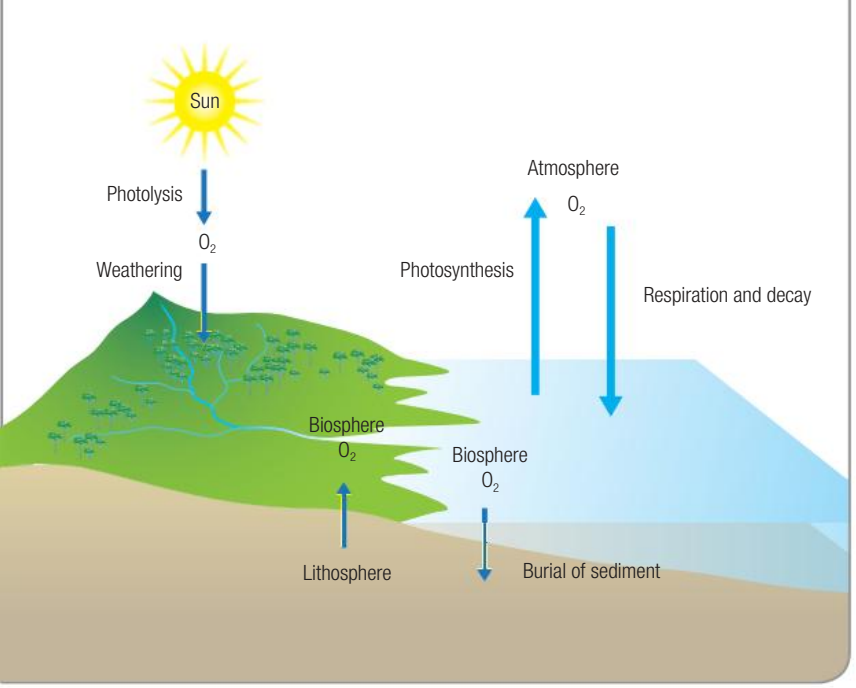
The oxygen cycle is influenced heavily by processes in the biosphere and atmosphere. In the biosphere, photosynthesis releases oxygen and cellular respiration absorbs oxygen. In the atmosphere, oxygen is formed through UV light converting water to oxygen and hydrogen in a process known as **photolysis**.

Photolysis: $2\ H_2O + \text{energy} \rightarrow 4\ H + O_2$

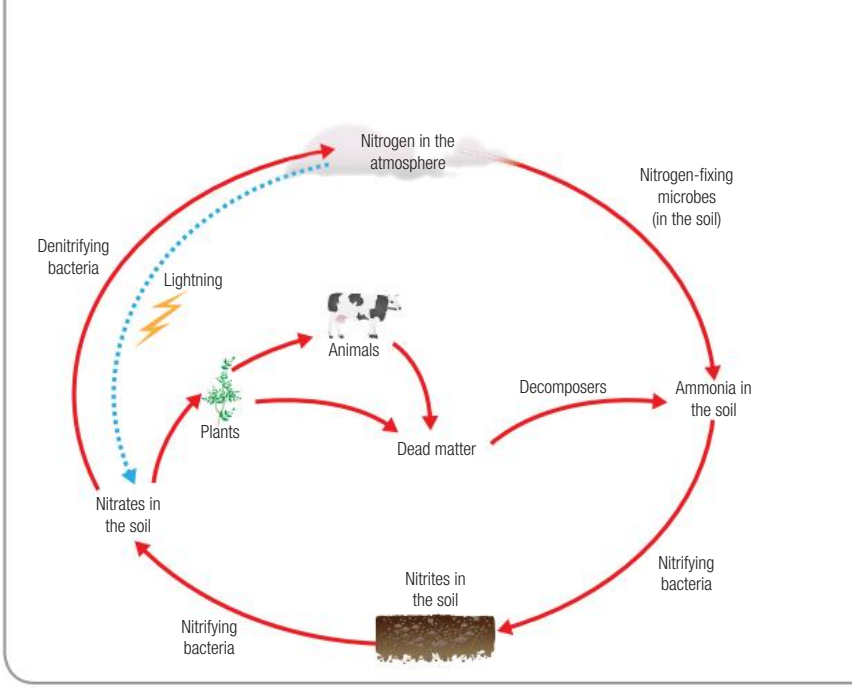
Oxygen is removed from the atmosphere through the process of cellular respiration, the decay of organisms and the weathering of exposed rocks.



→ Fig 3.24 Almost all the oxygen on Earth is locked in the compounds that make up the lithosphere.



→ Fig 3.25 The oxygen cycle.



→ Fig 3.27 The nitrogen cycle.



→ Fig 3.26 Legumes, such as peas and beans, have nitrogen-fixing bacteria living in the nodules on their roots. Consequently, farmers will often plant legumes between crops to maintain nitrogen levels in the soil.

CYCLING NITROGEN

Nitrogen is necessary for the synthesis (to make) proteins and nucleic acids, vital building blocks for all organisms. Although nitrogen makes up 78% of the gases in the atmosphere, making it the most abundant gas, it is not in a form that is usable for living organisms. Bacteria play an important role in changing nitrogen into usable forms—nitrate, nitrite and ammonium ions—and returning it to the atmosphere.

Nitrogen-fixing bacteria are able to 'fix' or convert nitrogen from the atmosphere (N_2) into nitrate (NO_3^-) ions, nitrite (NO_2^-) ions and ammonium (NH_4^+) ions. **Denitrifying bacteria** are able to return nitrogen back into the atmosphere.

Many human activities increase the amount of nitrogen in the atmosphere and lithosphere. These include fossil fuel emissions and run-off from fertilisers. Excessive use of nitrogen fertilisers in areas near coral reefs can result in the nitrogen being dumped on the reefs in times of flooding rains, which can lead to major bleaching of the reefs.

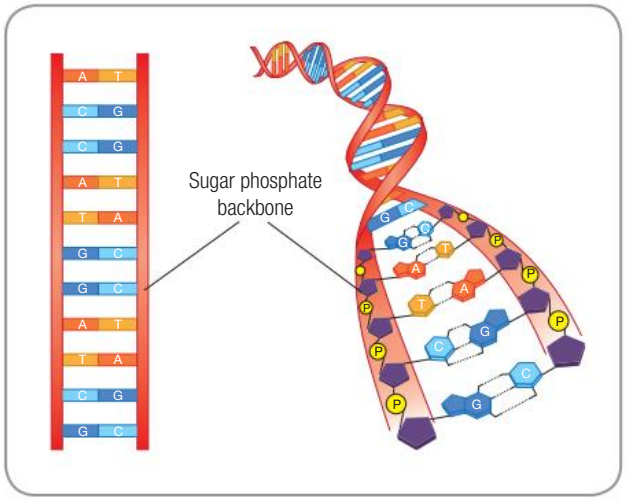
CYCLING PHOSPHORUS

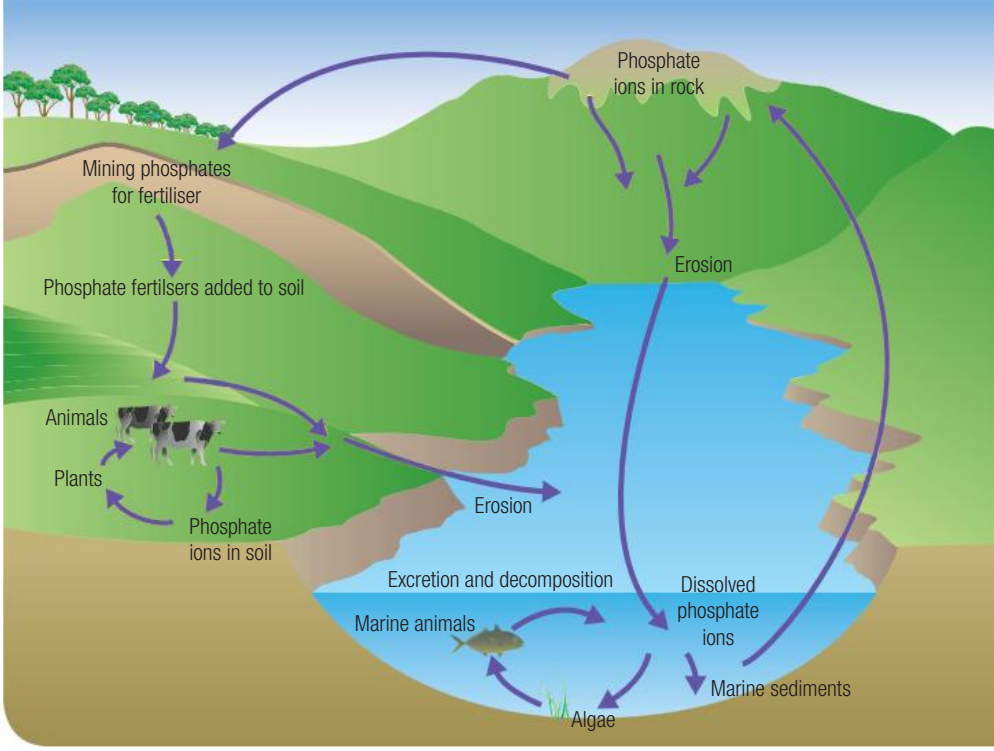
Phosphorus is an essential component of the energy molecule ATP (adenosine triphosphate), as well as the molecules DNA and RNA (sugar-phosphate backbones). Without phosphorus, an organism cannot use available energy-containing molecules. Approximately 80% of the phosphorus in humans is stored in our bones and teeth.

Most of the phosphorus available to living organisms comes from sedimentary rocks and soils. Unlike in the other biogeochemical cycles, phosphorus does not have a gaseous phase. Phosphorus is not a common element and its availability is often the limiting factor for plant growth. Farmers will often apply phosphate fertilisers to agricultural land or plant legumes between crops (see Figure 3.26).

The phosphorus cycle is the slowest of the biogeochemical cycles. Unlike photosynthesis and respiration, for example, weathering and decay are lengthy processes.

➔ Fig 3.28 The sugar-phosphate backbone of DNA is illustrated in red, as the sides of the ladder.





➔ Fig 3.29 The phosphorus cycle.



➔ Fig 3.30 The green may be misleading—algal growth is blocking sunlight from all other organisms that live in this irrigation channel.

In the phosphorus cycle:

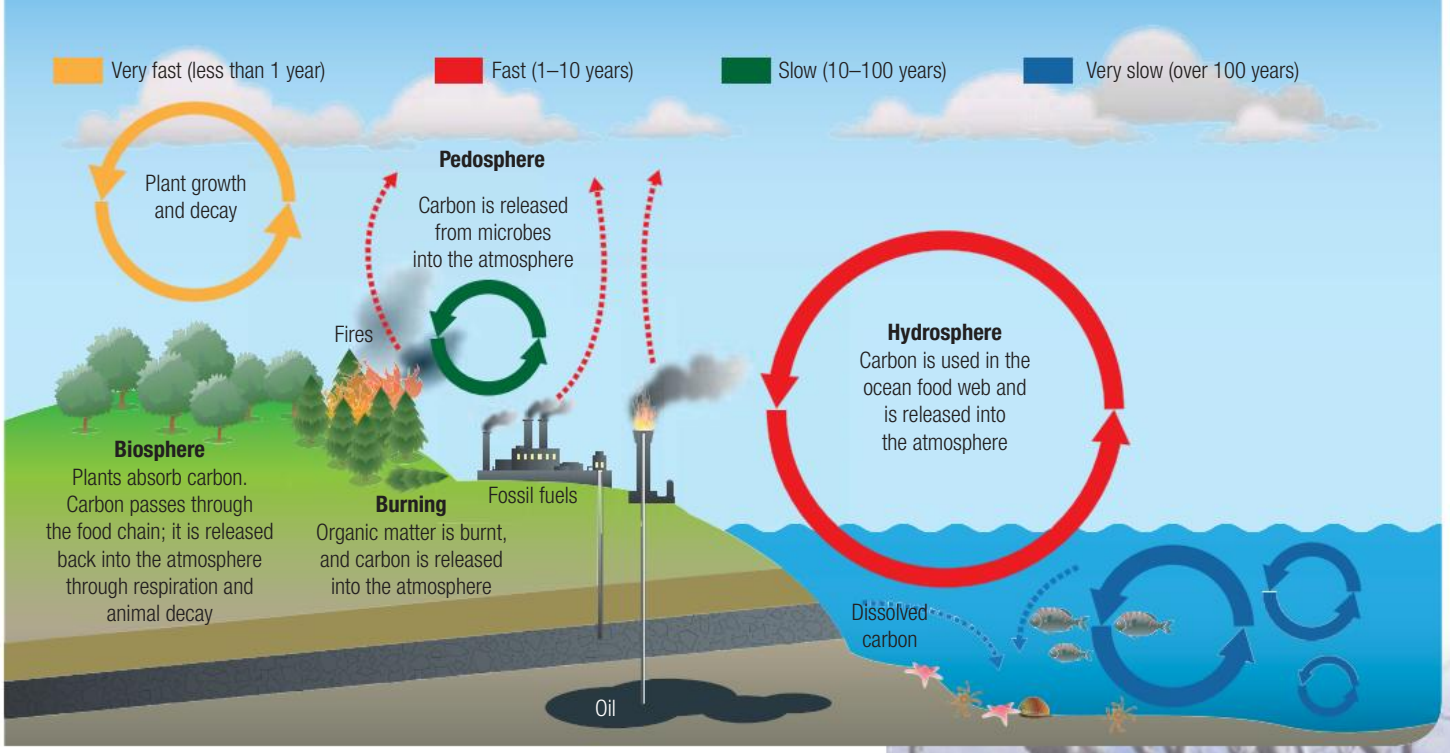
- rain weathers rocks, releasing phosphate ions into the soil
- plants absorb phosphate ions via their roots and thus phosphorus enters the food chain
- phosphorus absorbed by organisms returns to the soil through urine, faeces and the decomposition of an organism's body
- phosphorus is locked in sediments and rocks for millions of years before being released by weathering and erosion, thus completing the cycle.

Phosphorus is mined for use as a fertiliser. Run-off from agricultural land can lead to excessive levels of phosphorus in our waterways. Because phosphorus encourages plant growth, excess levels lead to the increased growth of plankton and other aquatic plants. This results in an increase in the consumption of oxygen within this environment, suffocating fish and other aquatic animals, as well as blocking sunlight from bottom-dwelling organisms. This process is known as **eutrophication**. To reduce this problem, phosphorus is no longer included in most detergents.

CYCLING CARBON

Carbon is the fourth most abundant element on Earth and is the basic component of all living organisms. It is the basis of carbohydrates, proteins and lipids. Carbon can cycle through the land, oceans and atmosphere over both the short and long term:

- geological carbon cycle—this is a long-term cycle that occurs over hundreds to millions of years and has resulted in the bulk of carbon being locked in rocks or in sediments as fossil fuels
- biological/physical carbon cycle—this is a short-term cycle that



→ Fig 3.31 The carbon cycle.

occurs over days, weeks, months and years and involves the cycling of carbon through photosynthesis and cellular respiration.

Humans tap into the geological carbon cycle by extracting oil, natural gas and coal, all of which are hydrocarbons, for use in cars and energy production. Large-scale extraction and the use of these fossil fuels has led to increased levels of carbon dioxide in our atmosphere. Coupled with an increase in deforestation, this increase in carbon dioxide has led to an enhanced greenhouse effect, altering temperature and rainfall patterns significantly.

Fire plays an important role in transferring carbon dioxide from the land to the atmosphere. Fires consume biomass and organic matter, producing carbon dioxide as well as methane, carbon monoxide and smoke (solid carbon particles).

Carbon is stored over the long term in the trunks and branches of trees. It is also temporarily stored in the bodies of other organisms, such as herbivores or carnivores. When these organisms die, carbon is returned to the atmosphere as carbon dioxide by decomposers.

Carbon is also stored in carbon 'sinks', such as:

- decomposed organic matter—coal, natural gas, petroleum, shale oil
- rocks, such as limestone, marble, dolomite, chalk and other carbonates
- organic matter in the soil
- dissolved carbon dioxide in the oceans and other waters
- the shells of marine organisms and some terrestrial organisms.



→ Fig 3.32 Bush fires are an important part of the carbon cycle, releasing carbon back into the atmosphere.

What do you know about natural cycles?

1. What are the three reservoirs of oxygen?
2. Phosphorus is very important to living things; where, in your body, is most of your phosphorus found?
3. Draw a concept map that shows the contribution of microorganisms to the cycling of nutrients in an ecosystem.
4. Explain how you are part of the carbon cycle.
5. What are the four parts of the water cycle?
6. What is the difference between *condensation* and *precipitation*?
7. Explain why the cycling of nutrients is referred to as a 'biogeochemical' cycle. Use an example to explain your answer.

Weather and climate systems

On the evening news you'll see a weather report that tells you what tomorrow will be like in terms of temperature, rain and other factors. **Weather**, therefore, is a snapshot of day-to-day changes. **Climate**, on the other hand, is more concerned with longer periods of time and involves the collection and analysis of large amounts of data. Weather predictions can be used to decide what to wear each day, whereas climate predictions may help farmers plan what types of crops to grow, governments to decide whether to invest in certain technologies or even households to decide whether they'll need to install an air conditioner.

Weather

Regions near the Equator are warmer than regions near the poles. Near the Equator, the Sun is directly overhead in the middle of the day. Because of this, the energy from the Sun is concentrated, so these regions are heated intensely. Near the poles, the Sun is lower in the sky, shadows are longer and energy from the Sun gets more spread out. This is because the Earth's surface is curved, so the Sun's rays come in at an angle.

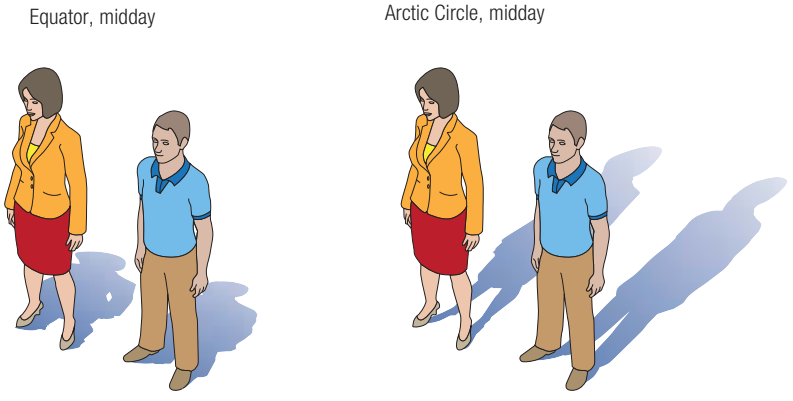
Air pressure differences cause air to move from areas of high pressure to areas of low pressure. So, warmer air near the Equator rises and heads towards the poles and colder air near the poles moves towards the Equator to fill the space left by the warm air. The movement of air is better known as **wind**. It is this unequal heating of the Earth's surface that generates most air pressure differences, so it can be said that solar energy is ultimately responsible for most wind. However, the patterns of air pressure movement illustrated in Figure 3.35 only show the beginning of the story.

Wind is the result of sideways or horizontal movements of air due to air pressure differences. The **Coriolis effect** is the influence of Earth's rotation on the direction of air or water movement. The Coriolis effect can cause winds to deviate from the path you may expect them to take. The surface of the Earth can also interfere with the speed and direction of wind. Rough and mountainous terrain will slow wind and significantly change the wind's direction.

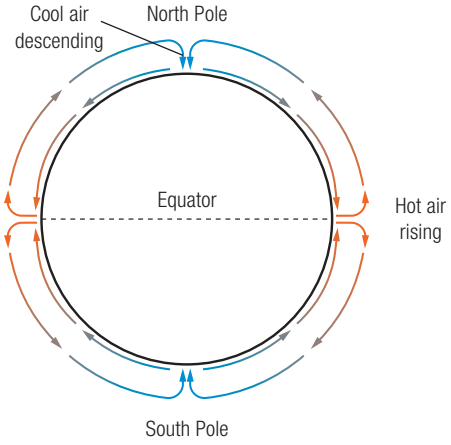


→ Fig 3.33 Flooding may result following torrential rain.

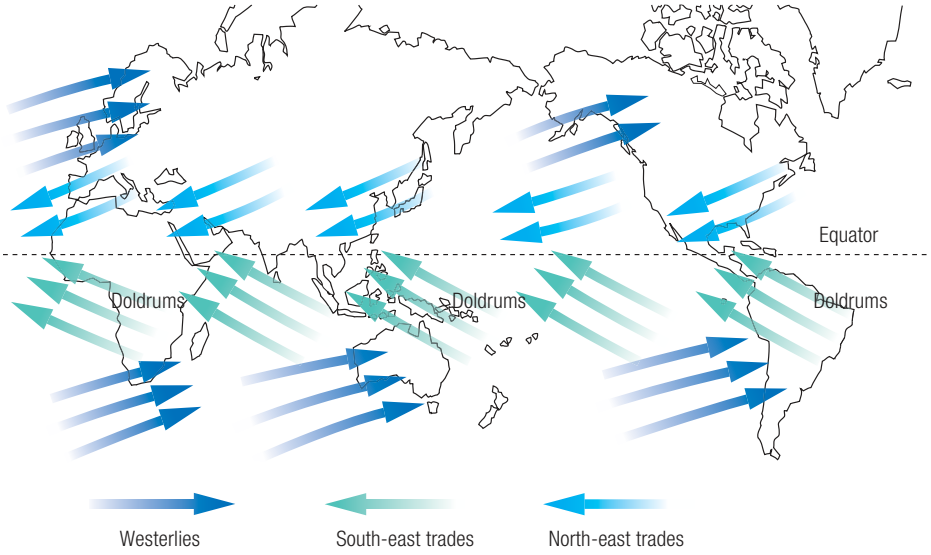
Local winds or breezes are the result of air pressure differences in the immediate area. Land heats and cools more quickly than water, therefore having a greater impact on the air above land than the air above water. Over warm seas, the air can rise rapidly, sucking in air quickly at its base and moving in a spiral motion. These intense low pressure systems are known as **cyclones** in Australia, **typhoons** in Asia and **hurricanes** in North America. Their strong winds and torrential rain can bring great destruction to any area they move over.



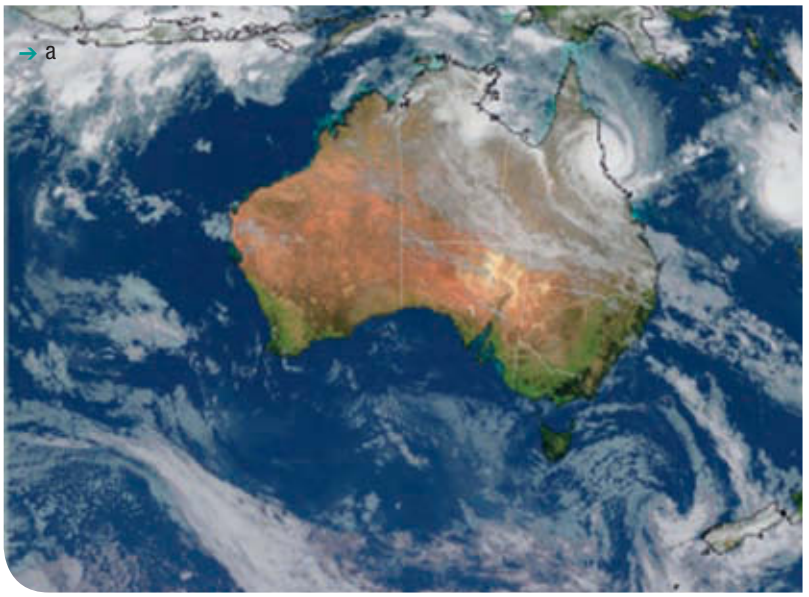
→ Fig 3.34 Shadows are longer the further you get from the Equator.

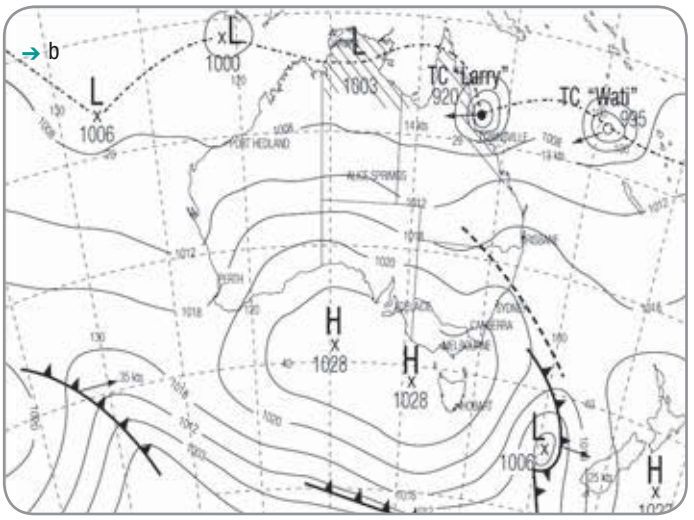


→ Fig 3.35 Movement of air at the Equator and at the poles.



→ Fig 3.36 Wind patterns over the Earth. The Doldrums are areas of low pressive where winds tend to be very calm.





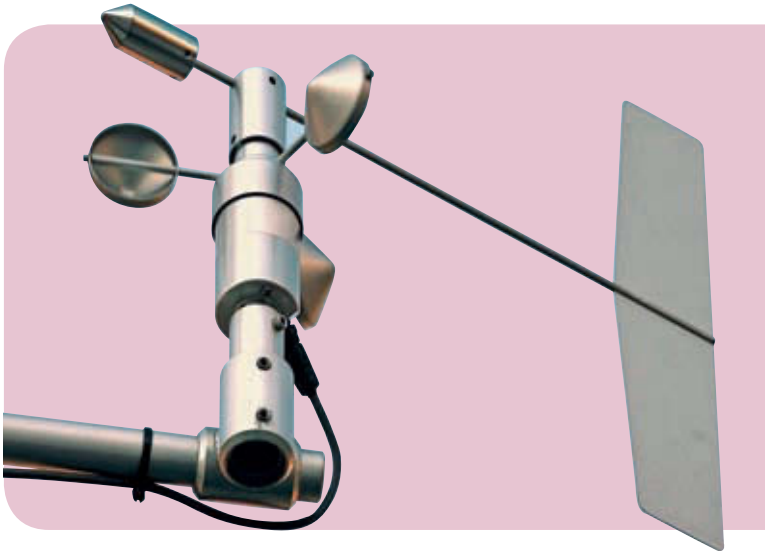
→ Fig 3.37 A satellite image (a) and a weather map (b) showing tropical Cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006.

Mapping wind

The unit for measuring air pressure is called the **pascal** (Pa) after the 17th century French scientist Blaise Pascal, who was the first scientist to develop the concept of pressure. Pressure is measured using a **barometer**.

Wind, on the other hand, is measured by a **wind vane** for direction and an **anemometer** for speed. Anemometers are like pin wheels or windmills that count the number of times they spin in a set period of time.

On a weather map, air pressure differences are shown as **isobars**; the closer the isobars, the greater the difference in pressure and the stronger the wind. Regions of high and low pressure are also shown on a weather map. Low pressure areas are frequently associated with clouds and precipitation, whereas high pressure systems bring clear blue skies.



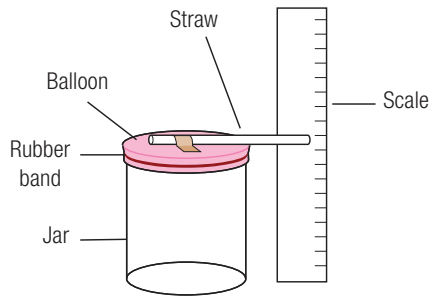
→ Fig 3.38 An anemometer measures wind speed.

PRACTIVITY 3.2

Making a simple barometer

What you need: glass jar, rubber balloon, rubber band, straw, sticky tape, sheet of thick paper with a scale marked on it

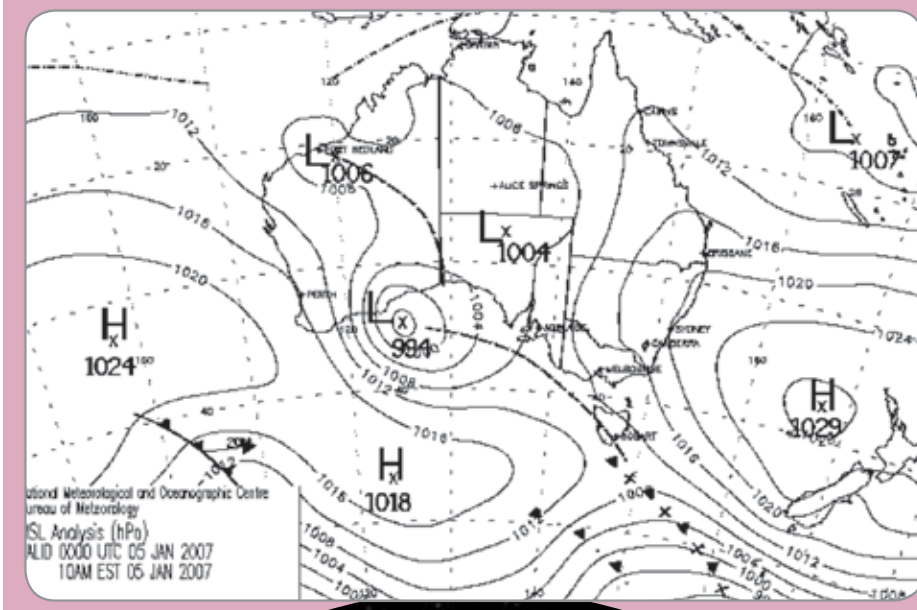
1. Cut a section from the balloon large enough to cover the opening of the jar.
2. Secure the balloon rubber over the jar with the rubber band.
3. Tape the straw onto the balloon.
4. Place the paper with the scale near the end of the straw and mark on the scale where the straw is.
5. Check the position of the straw on the scale over a few days. Mark each position of the straw.



- What happened to the rubber balloon as the outside air pressure changed?
- What happened to the position of the straw against the scale? Why was this?
- Use the particle model of air to explain why the rubber balloon gets pushed in or out of the jar by the surrounding air.
- This 'barometer' will also respond to changes in temperature in addition to changes in air pressure. Explain why.

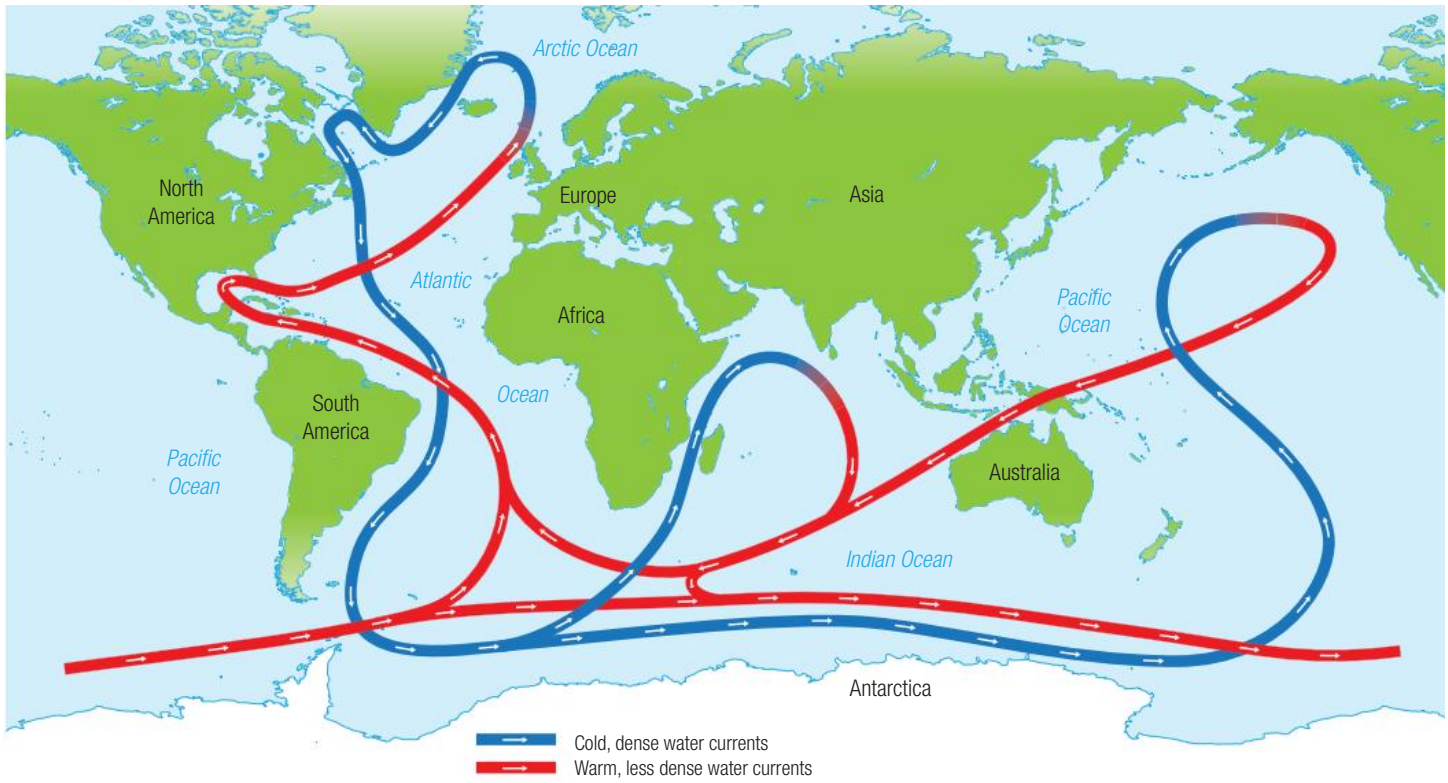
What do you know about weather and climate systems?

1. What is the difference between *weather* and *climate*?
2. What is meant by 'air pressure'?
3. What happens to the amount of air as you reach higher into the atmosphere?
4. What happens to the pressure of the air when it is heated?
5. What is an isobar?
6. How are winds related to rising air?
7. How do cyclones form?
8. What conditions must occur for water vapour in clouds to fall as precipitation?
9. Label the following weather map with as many of the terms listed in this section as you can.





→ Fig 3.39 The path of the ocean 'conveyor belt', in which differences in temperature and salinity drive the movement of large currents of water.



Deep ocean currents and climate control

When looking out at the ocean, the first thing that springs to mind for most people is probably not climate control (it's usually more about summer and holidays). There are actually large conveyer belt-like deep ocean currents that churn heat through various parts of the world and regulate temperature. A famous example of this is the Gulf Stream; there has even been a Hollywood movie about the Gulf Stream: *The Day After Tomorrow*. The movie depicts just how important the Gulf Stream is, heating a vast area of Europe. In the film the Gulf Stream shuts down and, in just a day, plunges most of Europe into a new Ice Age. Frozen birds fall from the sky and people freeze in the streets, with most becoming instant refugees in countries with warmer climates.

Scientists have explained that this can't happen in a day, but it would definitely happen within months of the Gulf Stean shutting down.

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water then cools and this colder water travels from the poles back to the warmer areas of the Earth. These large 'conveyer belts' of water are driven by the differences in temperature and salinity. Colder water is dense and heavy and moves downward in the ocean; warmer water is lighter and so moves up towards the surface, completing the conveyer belt-like movement. Less salty water is lighter and rises, whereas salty water is heavier and so sinks. Heat from the Sun evaporates the top-most layer of the ocean. The salt in the remaining water is therefore more concentrated.

What do you know about deep ocean currents and climate control?

1 Explain why deep ocean currents are like conveyer belts.
2 What type of water rises to the top and which drops to the bottom? What two factors control this movement?
3 Why are currents responsible, in part, for global temperature?
4 What is the Gulf Stream and why is it so important?

3.2

How does matter cycle on Earth?



Remember and understand

1 What input from the solar system has the greatest influence on our weather?
2 What is the Gulf Stream?
3 Will salty water sink to the bottom or come to the top of the ocean?
4 How would the shutting down of the Gulf Stream affect Earth?

Apply

5 What is the difference between water and water vapour? Would you find both in the air?
6 Why is it warmer near the Equator?
7 What factor has changed when water vapour condenses to fall as precipitation?

Analyse and evaluate

8 How are water currents similar to air currents? How are they different?
9 Why will a cool breeze blow from the land to the ocean?
10 What do 'H' and 'L' represent on a weather map? How are they formed and what type of weather are they associated with?
11 Find someone in your class that has seen the film *The Day After Tomorrow*—investigate how different the reality of the shut-down of the Gulf Stream is compared with what was portrayed in the movie.

Critical and creative thinking

12 The Sun is responsible for much of the weather and climate of Earth. Brainstorm all the impacts of solar energy and represent these effects, and their indirect effects, in a flow diagram.



CONNECTING IDEAS Dynamic Earth

13 Earth's climate and weather are the result of global interactions between systems and cycles. How does this support the argument that logging in any country is the concern of everyone else on the planet? What other human activities fit into a similar category? Discuss your thoughts with the class.

How do humans impact the environment?

3.3



Humans have inhabited the Earth for more than 100 000 years. In that time the Earth has undergone many changes as humans moved from a hunter–gatherer lifestyle to a subsistence lifestyle through agriculture and, eventually, to the industrial way of life we know today. In the 1800s scientists were investigating and writing about the human impact on our planet. Up to half of the Earth's land has been transformed by human actions, such as urbanisation and farming. Many of these changes have significantly altered the way energy and matter flow through the environment.

DISCOVERING IDEAS

Rising giants debate

Greenhouse gases increase the ability of the Earth's atmosphere to trap heat from the Sun. Significant warming of the planet could have detrimental effects for life as we know it. Should developing countries with massive populations, like India and China, be expected to reduce their greenhouse gas emissions?

According to recent reports, China's national greenhouse gas emissions may now exceed those of the United States. It is thought that greenhouse gas emissions from developing countries will result in a climate crisis within a generation—within 20 years these countries will be producing more greenhouse gases than the rich industrialised countries. For these developing countries, thinking about reducing their emissions is difficult, due to costs. They have incomes far below those in developed countries and have a need to grow and offer their people a better quality of life, like we experience here in Australia.

1. In groups of six to eight, split into two debate teams.
2. The first team is to argue against developing countries reducing their greenhouse gas emissions because it is their right to become fully industrialised, as well as to eradicate poverty, even at the cost of the environment.
3. The second team is to argue for developing countries reducing their greenhouse gas emissions. This team will argue that environmental sustainability is the most important factor in the debate.

Further research will need to be conducted to ensure that the arguments being made are valid and based on evidence.

- Which team had the most convincing arguments?



Climate change science

The Earth's ecosystems are complex. They have developed over millions of years. Over the past 50 years the impact of humans on the Earth's ecosystems has been accelerating. The fastest changes are now happening in developing countries. One of the most significant changes to the energy flow through ecosystems comes from the manner in which humans make use of energy. As a consequence of these changes, the capacity of ecosystems to support a number of diverse organisms is greatly reduced.

Human impact

Ecosystems depend on the biogeochemical cycling of water, carbon dioxide and other nutrients. Our activities have affected these cycles in many ways. For example:

- we have reduced the total mass of fished species by as much as 90% in much of the world
- freshwater ecosystems have been altered through the building of dams for irrigation and hydroelectric power production, resulting in changed river flows
- agriculture and farming have converted more than half the world's many grasslands for human use.

Human activity has diverted or prevented 20%–30% of



the flow of energy that is fixed by natural ecosystems (e.g. carbon fixation). This is due to:

- maintaining crops (15%)
- establishing urban areas (1.8%)
- grazing livestock (2.3%)
- habitat degradation (e.g. desertification; 4%).

Climate change is being talked about nearly everywhere we go: from dusty farms experiencing drought in the outback to families fleeing their homes in the worst flooding we have ever seen. Changes to the climate as a result of natural and human influences are having many different effects on the face of the Earth.

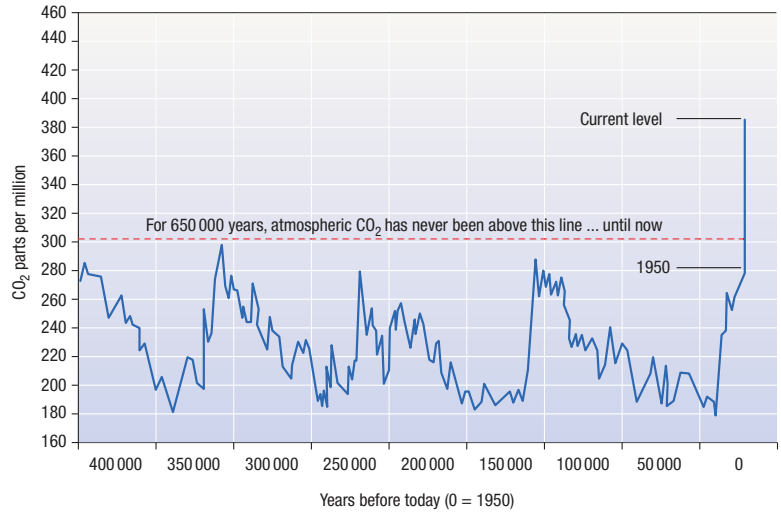
The greenhouse effect and the enhanced greenhouse effect

The greenhouse effect is critical for maintaining life on Earth. Solar energy passes through the atmosphere and warms the Earth's surface. Heat gradually leaves the Earth's surface and is radiated back into space. Some heat is trapped by a blanket of greenhouse gases. If heat were not trapped, the temperature would drop to –100°C each night and, in the day, would rise to 80°C.

Evidence from polar ice, among other sources, demonstrates that fluctuations in carbon dioxide and other greenhouse gas levels are natural. The main greenhouse gases are carbon dioxide, methane, nitrous oxide, water vapour and chlorofluorocarbons. Human activity has changed the proportions of these gases in the atmosphere to levels outside this natural fluctuation.

Since the Industrial Revolution, the level of greenhouse gases has been increasing, causing an *enhanced* greenhouse effect.

The concentration of carbon dioxide in the air has changed significantly, by approximately 34%, since 1750. The bulk of that increase has happened since 1959. The concentration of methane in the atmosphere has also risen dramatically over the past century, more than doubling.



→ Fig 3.40 Carbon dioxide levels in the atmosphere.

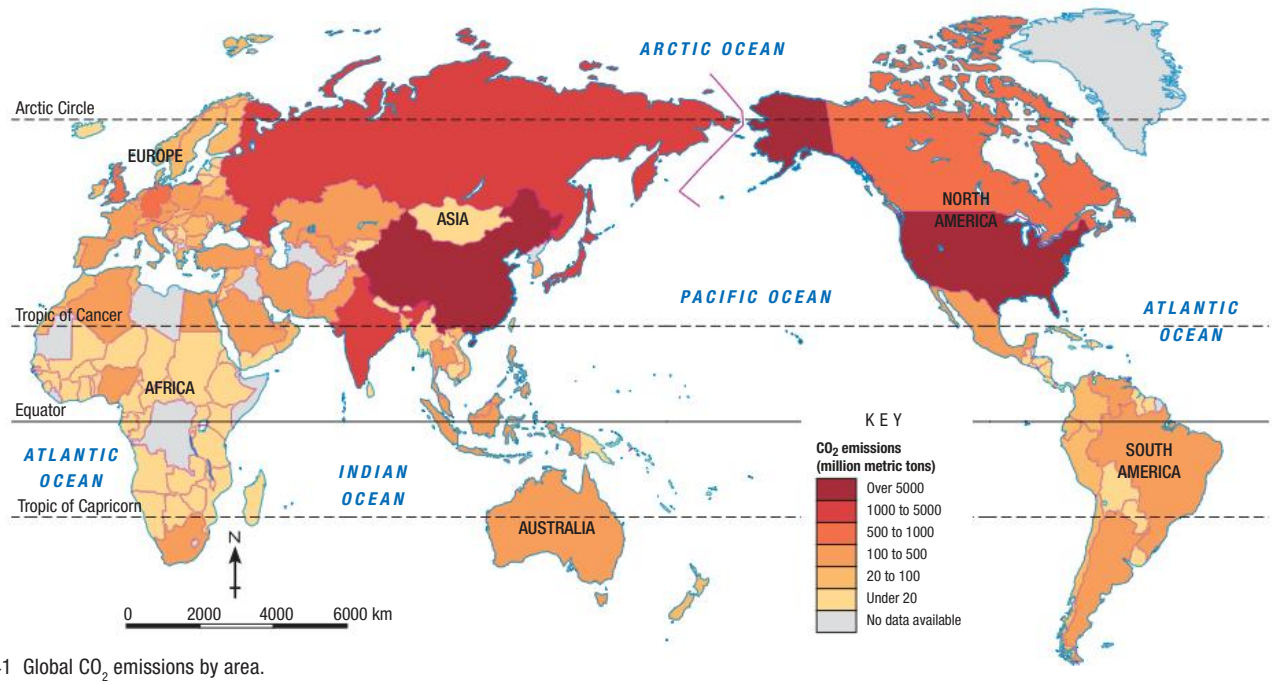
→ Table 3.2

Phenomenon and direction of trend	Likelihood that the trend occurred in the late 20th century (typically post 1960)	Likelihood of a human contribution to the observed trend	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	Very likely	Likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Likely (nights)	Virtually certain
Warm spells/heat waves; frequency increases over most land areas	Likely	More likely than not	Very likely
Heavy precipitation events; frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	More likely than not	Very likely
Area affected by droughts increases	Likely in many regions since the 1970s	More likely than not	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	More likely than not	Likely
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	More likely than not	Likely

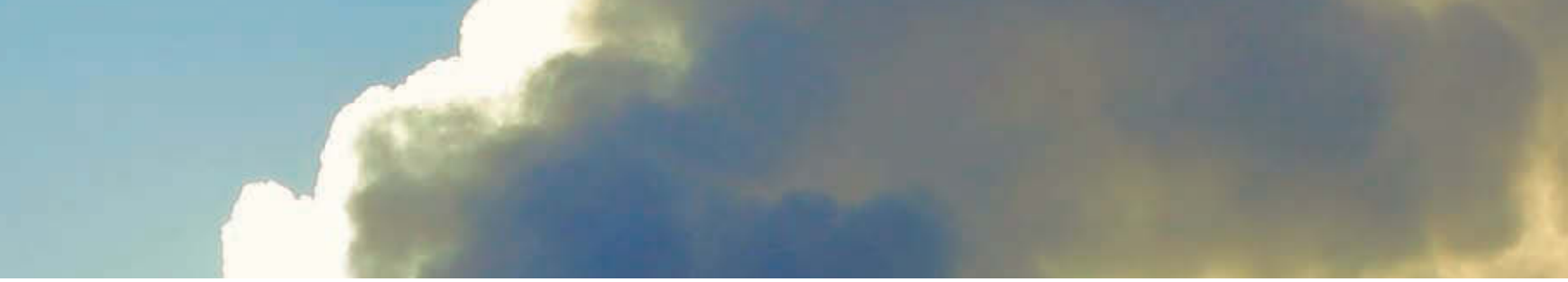
SRES, Special Report on Emissions Scenarios (from the IPCC: Intergovernmental Panel on Climate Change).

The main greenhouse gas is carbon dioxide. It is formed by the burning of fossil fuels, such as coal, petrol, oil and gas. The amount of carbon dioxide in the atmosphere has increased by 37% in the past 200 years due to the use of fuels by our society. We all use energy for heating, lighting, transport, industry and communications. Burning carbon-based fossil fuels, such as coal, gas and petroleum, releases energy, usually as heat, and produces carbon in the form of carbon dioxide, and sometimes carbon monoxide, or solid particulate carbon. Forests consume carbon dioxide in the process of photosynthesis. Massive deforestation for farming and urban land has also led to an increase in carbon dioxide levels because these forests are no longer available to absorb excess carbon dioxide.

Natural sources of methane in the Earth's atmosphere include the decay of organic materials in wetlands, termites, emissions from the oceans and the melting of methane hydrates, which are ices made of methane found in the ocean floor. Human activity also produces methane through energy production, increased emissions from livestock (e.g. cattle), landfill, biomass burning and waste treatment.



→ Fig 3.41 Global CO_2 emissions by area.





→ Fig 3.42 Human-induced climate change.

PRACTIVITY 3.3

Understanding the enhanced greenhouse effect

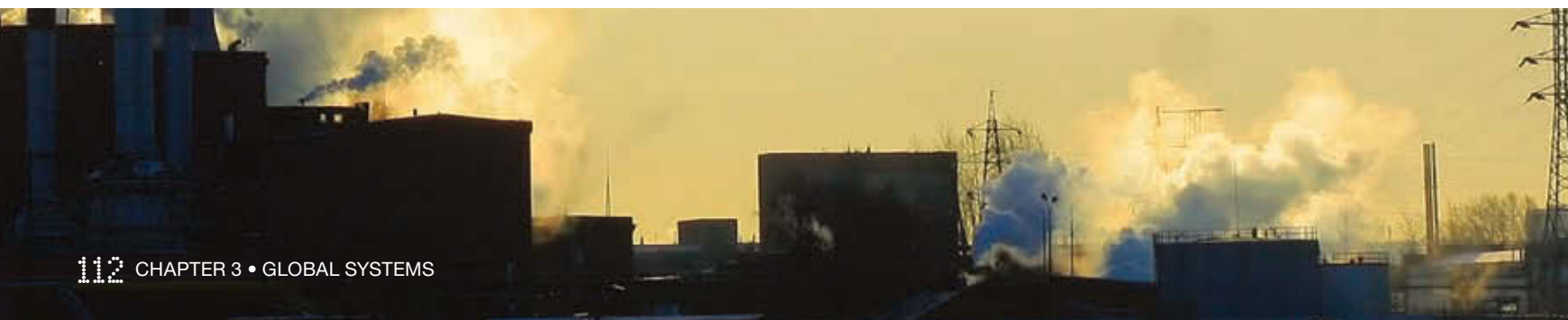
1 Working in small groups, brainstorm your understanding of the enhanced greenhouse effect

2 Use this knowledge to produce a poster that shows:

- **a** how the atmosphere works to protect the Earth from getting too hot or too cold
- **b** how human activities are warming the atmosphere
- **c** the impact changes to energy flow may have on ecosystems, animals and plants

Carbon sinks

A **carbon sink** is any feature of the environment that absorbs and/or stores carbon, keeping it from the atmosphere. Forests take in carbon dioxide, a major greenhouse gas, so they are a very significant example of a carbon sink. However, the ability of forests to absorb carbon has been reduced as a result of the large-scale clearing of forests throughout the world. The ocean is another important carbon sink, absorbing atmospheric carbon dioxide and consequently becoming more acidic.



EXPERIMENT 3.2

What factors affect a greenhouse?

Aim

To determine which surfaces of the Earth absorb energy and radiate it as heat and so are likely to contribute most to the warming of the atmosphere.

Materials

Six empty clear 600mL identical soft drink bottles

Six one hole rubber stoppers with thermometers inserted that fit securely into the bottle top or data logging equipment using long steel temperature probes with blue tack to secure the probe in place.

Six plastic containers at least 11.5 cm in diameter at the top (e.g. margarine containers)

White paint

Funnel

Three cups of dark soil

Three cups of white sand or perlite

Water

Sunlight or one 150 Watt floodlight bulb

Portable reflector lamp

Stand to support the lamp set up (burette stand and clamps)

Method

1. For each group, you will need six experimental chambers—empty bottles with the labels removed.
2. Label the bottles A, B, C, D, E and F. Paint the upper one-third of bottles B, D and F white to represent cloud cover.
3. Use a funnel to fill the base of bottles A and B with dark soil, bottles C and D with white sand or perlite, and bottles E and F with room-temperature water. Ensure that you use the same depth in each bottle—approximately 5–7 cm.
4. Put the thermometers inserted in the rubber stoppers into the bottle tops ensuring the bulbs are just above the top of the dirt, water, perlite/sand. If the bulbs are below the base, they may record the heat absorbed directly by the soil or water, which will affect your data. You want to measure the temperature of the air (atmospheric). If using a data logger temperature probe secure and seal into the top of the bottle with blu-tack.
5. Record the initial baseline atmospheric temperature of each bottle in a table.
6. If it is a sunny day take your bottles outside and record the temperatures of each bottle in a table every two minutes for at least 20 minutes. Alternatively, set up the 150 watt light source on a stand facing down. Place the bottles underneath the light source approximately 15cm away from the lamp. It is important that all bottles receive equal light. Depending on your light source you may be only able to do two bottles at a time. If this is the case ensure the two bottles have the same base for example, dirt.

Results

Predict which bottle will get hottest and justify your prediction. Draw a graph of time (in minutes) versus temperature to record your observations.

Discussion

1. Compare the graphs for the different bottles. Describe the differences. What do these graphs indicate?
2. Which situation produced the lowest temperature? Which situation would lead to the least heating of the atmosphere?
3. Suggest some possible explanations for your results.
4. Explain how this experiment demonstrates the effect of the oceans and dark and light surfaces on air temperature.
5. If the deserts are increasing and ice is melting, exposing dark soil, what effects would you expect these changes to have on atmospheric temperature?

Conclusion

Summarise your key findings from this experiment.

Tim Flannery awarded Australian of the Year

Friday, 26 January 2007(ABC/AFP)

Scientist, conservationist and bestselling writer Professor Tim Flannery has been named Australian of the Year.

Flannery was presented with the award from Prime Minister John Howard at a ceremony on the lawns of Parliament House last night.

'He has encouraged Australians into new ways of thinking about our environmental history and future ecological challenges,' the Prime Minister said.

Flannery's recent book, *The Weather Makers*, documents the role he believes human activity plays in causing climate change.

Flannery sees global warming as a calamitous crisis and argues Australia's drought-ravaged farmland, raging bushfires and dwindling city water reserves are textbook examples of its impacts.

'We are the worst, as a developed country. There is nowhere else that is getting the hammering that we are getting at the moment,' Flannery said before the award.

'That is not due to poor infrastructure planning or anything else,' he said. 'It's actually due to a natural cycle of water availability which is driven by greenhouse gas pollution.'

To avert biological disaster, Flannery argues the coal industry should be shunted aside and alternative power sources be used to establish a desert metropolis.

'We need to decarbonise the economy extremely rapidly,' he said.

Asked whether this approach would cripple the country's economy, currently riding a commodities boom thanks to North Asia's hunger for Australian resources, Flannery was unmoved.

'Won't the Australian economy collapse if climate change continues?' he said.

'There are a lot of ways to make electricity. Burning coal is just one of the more antique and stupid ways of doing it. We've got solar [energy], we've got wind, we've got geothermal.'

Flannery believes Australia has the best geothermal resource in the world in the Cooper Basin in the South Australian desert.

'If Australia is serious about this, we could build a major new city out there, link up with the north–south railway line, make it the centre of our electricity grid, and use that resource,' he said.

'It will provide enough electricity to run the entire Australian economy for 100 years.'

Nuclear: a forced choice

Flannery also argues the urgency of climate change demands the use of nuclear power in some parts of the world, despite the risks it poses.

'Here in Australia I believe nuclear power makes absolutely no sense because we have an embarrassing richness of renewable energy resources,' he told ABC TV, after receiving the award.

But he says places like China, the east coast of the United States and parts of Europe need nuclear power because they don't have the same choices.

'It's the lesser of two evils and for that reason I refuse to condemn uranium mining in Australia.'

But Flannery also stresses the dangers of nuclear power.

'Particularly nuclear proliferation … scares the hell out of me,' he said.

He says governments need to set up a good regulatory system to minimise the dangers of selling uranium.

'It could all go horribly wrong but, you know, we have to march into that future,' he says.

'I've thought long and hard about that and even at a personal level I think about the world I will leave my children,' says Flannery.

'They're going to be dealing with the problems of nuclear waste storage and of proliferation long after I'm too old to care about it and that's the future I've got to bequeath them, because this situation is so difficult.'

Flannery, a field zoologist by training, has also written on topics including the demise of Australia's megafauna, the discovery of new species of mammals and water management.

1 Summarise this article in your own words.

2 Tim Flannery's book is called *The Weather Makers*—who do you think he means the 'weather makers' are?

3 What techniques did the author use to include scientific information in an appealing way?

4 Why do you think the author used quotes from real people?

5 What did Tim Flannery mean when he said 'we need to decarbonise the economy', and how would this affect climate change?

6 In what other types of ways does Dr Flannery suggest we make electricity?

What do you know about climate change science?

1 Name the two most significant carbon-containing greenhouse gases.

2 Explain why these gases are called greenhouse gases.

3 Explain why the greenhouse effect is actually a good thing for life on Earth.

4 What are fossil fuels? What can be used instead of fossil fuels?

5 Copy and complete Table 3.3, showing the direct uses of fossil fuels you make in a 24-hour period.

→ Table 3.3

Activity	What did I use/ do?	What fossil fuel provided the energy?
Transport		
Heating or cooling		
Cooking		
Communication		

Effects of climate change

The main effects of climate change on ecosystems are:

- changes in the distribution and abundance of species—the migration of species southwards or northwards, to higher levels or more suitable locations due to increasing temperatures
- species loss
- genetic changes as species adapt to new climatic conditions
- changes in the composition of ecosystems (e.g. due to species competition for resources or invasion of weeds/pests)
- increased weeds and other invasive species (i.e. pests)
- changes in life cycle events (e.g. breeding, migration)
- changes in metabolic processes (e.g. cellular respiration, photosynthesis, growth and tissue composition)
- increased coral bleaching, destruction of and/or changes to coral reefs
- flow-on effects, such as eutrophication and algal blooms
- a decrease in coastal mountain rainforests
- changes in river flows, sediment formation and nutrient cycles
- drying of ecosystems
- ocean acidification.



→ Fig 3.43 Stephens Island wren was thought to have been wiped out by a lighthouse keeper's cat in 1894. It is more likely that the species was hunted to extinction by feral cats on the island.



Fig 3.44 In Australia, blackberries are an invasive species and serious weed.

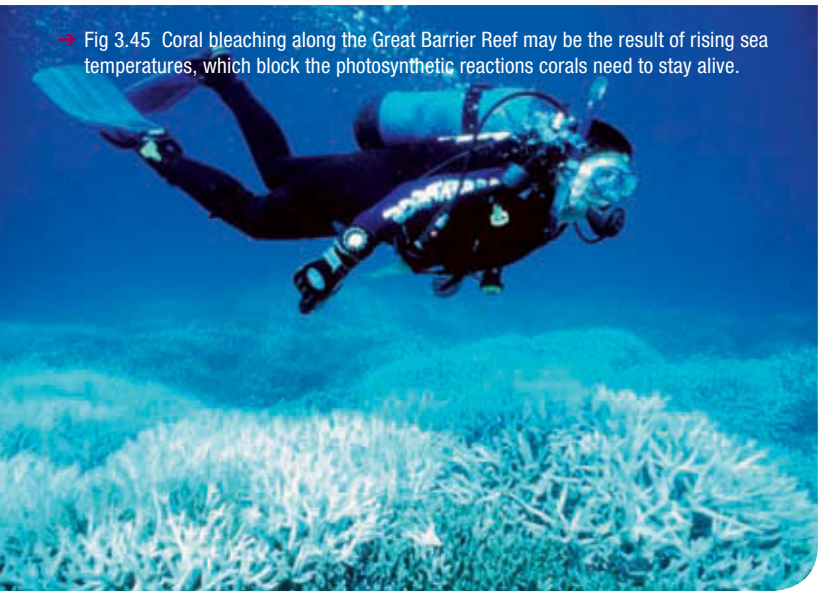


Fig 3.45 Coral bleaching along the Great Barrier Reef may be the result of rising sea temperatures, which block the photosynthetic reactions corals need to stay alive.

Increased global temperature

Due to increasing concentrations of greenhouse gases, we have seen the ten hottest years ever recorded all occurring between 1990 and now. The average global temperature has increased by 0.6°C during the past century. Although 0.6°C may not sound a lot, we are already seeing the effects of this on our environment. This increase in temperature has led to an increase in the temperature of the oceans, causing a loss of glaciers and sea ice and a rise in sea level of approximately 10–20 cm.

Evidence that climate change is actually occurring will include:

- melting of the polar ice caps
- rising sea levels
- increasing intensity and frequency of storms
- changes to weather patterns that will alter agricultural productivity, as well as affect snowfall and associated recreational and tourism activities.

If all these changes occur as a result of human activity, major changes will occur in our ecosystems. Temperature changes will affect the survival of plants and animals in certain habitats, the carrying capacity (number of organisms) of an ecosystem, the amount of light available for photosynthesis and the rate of biogeochemical cycling of nutrients.



Fig 3.46 The mouth of the Murray River near Goolwa in South Australia. Recent years have seen a decrease in the amount of water flowing into the river and an increase in salinity, which affects plant and animal life.

Melting sea ice

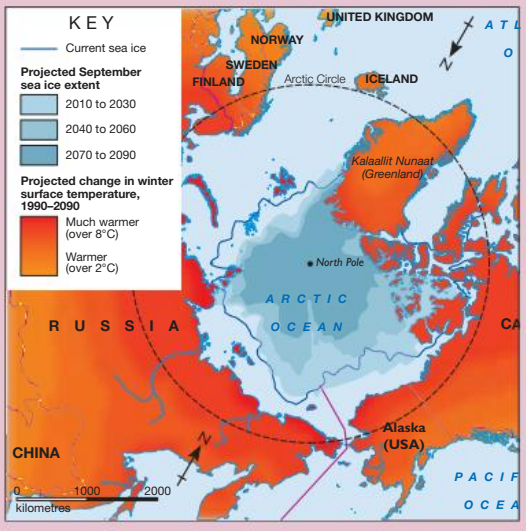
The ocean is very important in the regulation of global temperatures. It is a carbon sink, absorbing carbon, but it also absorbs up to 90% of the solar radiation that hits the ocean. Imagine if it didn't—it would certainly be a lot warmer on Earth! Unfortunately, with all the changes occurring to the Earth, the ocean is losing its capacity to regulate global temperature. It is starting to warm up.

Warmer water in the ocean results in a reduction in the ocean's ability to absorb solar radiation. The warmer water also causes sea ice to melt. If you have ever seen pictures of sea ice, it is vast, shiny and bright white—in fact, it acts as a big mirror that reflects the Sun's radiation back out to space, once again keeping the Earth cooler. When this ice melts, more heat is absorbed by the water, increasing its temperature. The warmer water heats the atmosphere above it, and so a cycle has begun that increases global temperature.

The warming ocean water is resulting in melting of ice in the Arctic—ice which is home to many species. For the first time ever, scientists are finding drowned polar bears. After swimming for days and days without rest, trying to find ice to climb on to, exhausted polar bears are drowning out in the ocean.

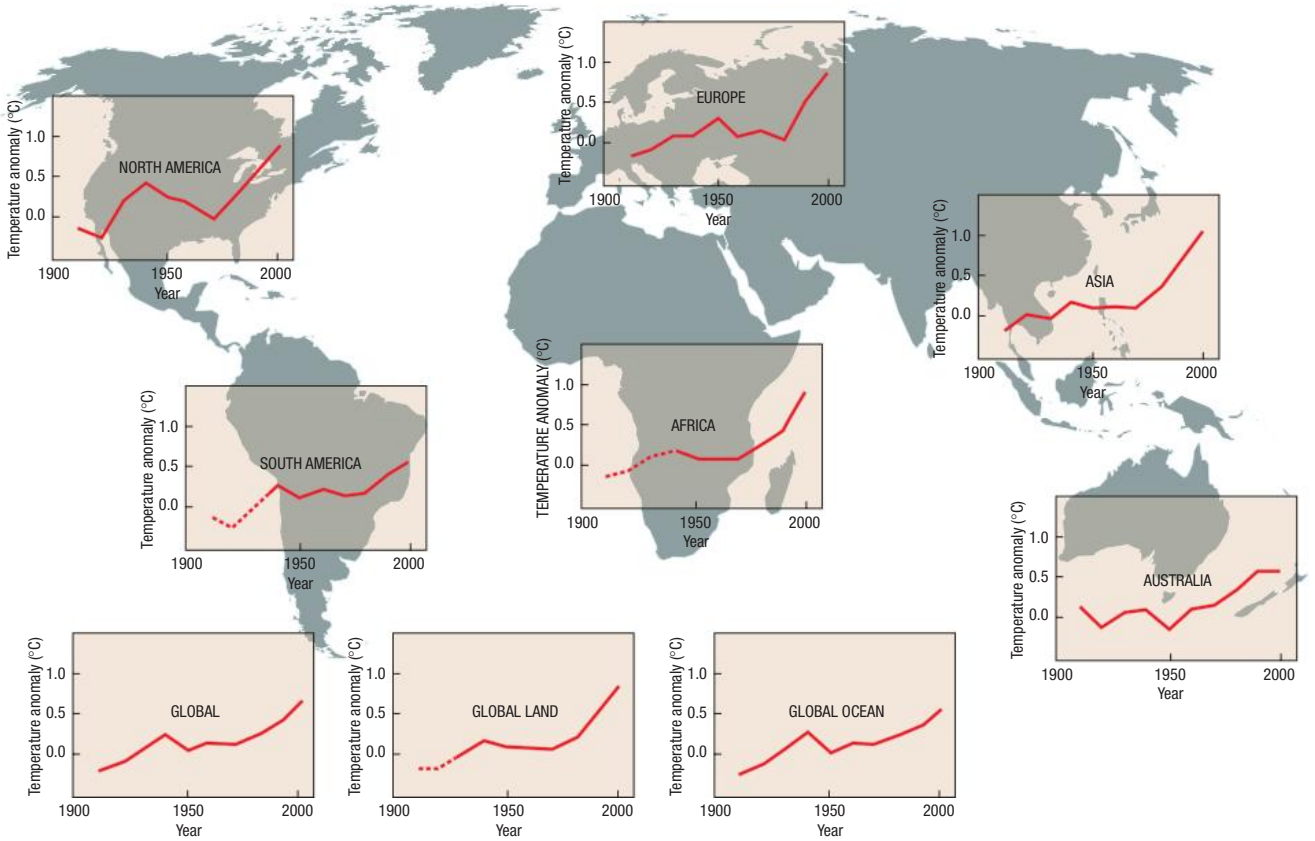


→ Fig 3.48 Arctic sea ice.



→ Fig 3.49 There was an 8% decrease in Arctic sea ice between 1995 and 2000. This trend is expected to speed up in coming decades.

→ Fig 3.47 Global changes in temperature since 1900.

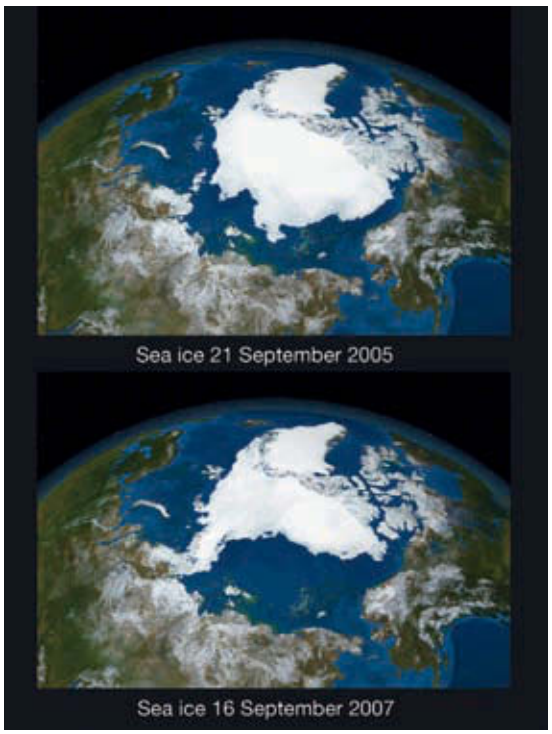


PRACTIVITY 3.4

The Gulf Stream

1 Re-read the information on deep ocean currents on page 107. These natural deep sea currents can be disrupted; such an event occurred 12 800 years ago when a huge lake created from melting glaciers at the end of the last Ice Age overflowed and poured into the north Atlantic, blocking the Gulf Stream.

2 Research the Gulf Stream and where it is positioned now. Consider any water sources nearby that may disrupt the Gulf Stream. What would have to happen for these to interact with the Gulf Stream? Is this likely to occur and to what effect?



→ Fig 3.50 Changes in sea ice from 2005 to 2007.

EXPERIMENT 3.3

Melting ice and its effect on sea levels

Aim

To observe the effect of melting sea and sheet ice on global sea levels.

Part A: sea ice

Sea ice is floating ice, like the ice found in icebergs or glaciers. Design an experiment that shows the effects of melting sea ice on the water level (e.g. an ice cube floating on water).

Part B: sheet ice

Sheet ice is ice resting on land. Approximately 98% of Antarctica is covered by sheet ice and the Antarctic ice sheet is one of two polar ice sheets. Design an experiment that shows the effects of a melting ice sheet on the water level (e.g. an ice cube resting on clay).

Results

Present your results for each experiment in an appropriate format.

Discussion

1 How did the water level change as the sea ice melted?

2 How did the water level change as the sheet ice melted?

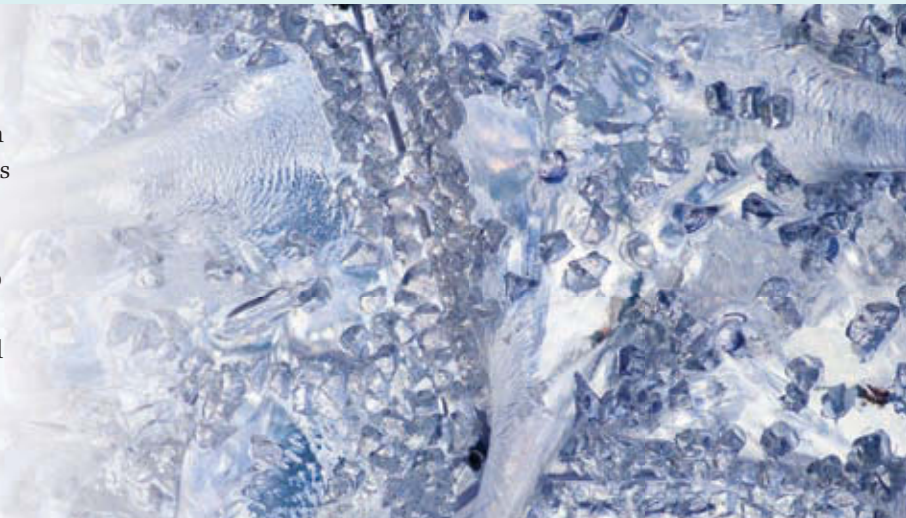
3 Provide an explanation for any differences you observed.

Conclusion

Will melting sea ice or melting sheet ice have the greatest effect on sea levels? Why?

Melting permafrost

Permafrost is permanently frozen ground that stores carbon from plant material frozen during the last Ice Age. Scientists believe that as much as two-thirds of the Earth's permafrost could disappear by 2200. If the Earth's permafrost does melt, it will release thousands of years worth of carbon into the atmosphere. This would equate to roughly as much as half of all fossil fuel emissions to date from when the world became industrialised.



What do you know about the effects of climate change?

1. Which type of sea ice increases water levels if melted? Explain this process.
2. How much has the temperature on Earth risen over the past century?
3. In what way will climate change affect the temperature on Earth?
4. What is permafrost and why does it add to emissions if it melts?
5. Consider the list of effects on ecosystems caused by climate change on page 115. List these in order from what you think is the most to least critical. Explain your answers.



→ Fig 3.51 The aftermath of a cyclone.

Other impacts on global systems

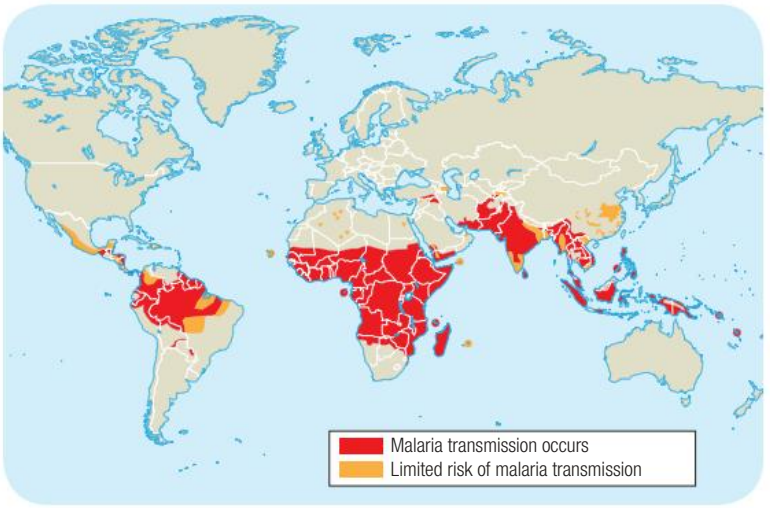
It is difficult to separate out the impacts that humans have on the natural environment. This is because all the systems and cycles of Earth are connected in some way. Some relationships are complex and some more straightforward. Many of the effects of climate change have a 'flow-on effect' to other cycles or systems.

Extreme weather events

The number of extreme weather events around the world is on the rise. Scientists predict that storms will have greater maximum wind speeds and more sudden and extreme rainfall. More intense tropical cyclones will cause flooding, landslides and damage to buildings. Worldwide, the number of cyclones reaching category 4 or 5 has risen by 15% over the past 20 years. Cyclones intensify over warm ocean waters, another consequence of increasing global and ocean temperatures. We can also expect to see an increase in the loss of human lives due to these occurrences.

Health and disease

Higher temperatures in summer have increased heat-related deaths. A heat wave in Europe in 2003 was estimated to have killed between 22 000 and 35 000 people. Global warming is also thought to extend the zones for infectious diseases, such as dengue fever and malaria, which thrive in warm, moist conditions. In cities like Beijing, in China,



→ Fig 3.52 Countries or areas at risk of transmission of malaria, 2010.

stagnant weather conditions can trap both warm air and pollutants, leading to smog, which results in serious respiratory problems.

Decreasing water supplies

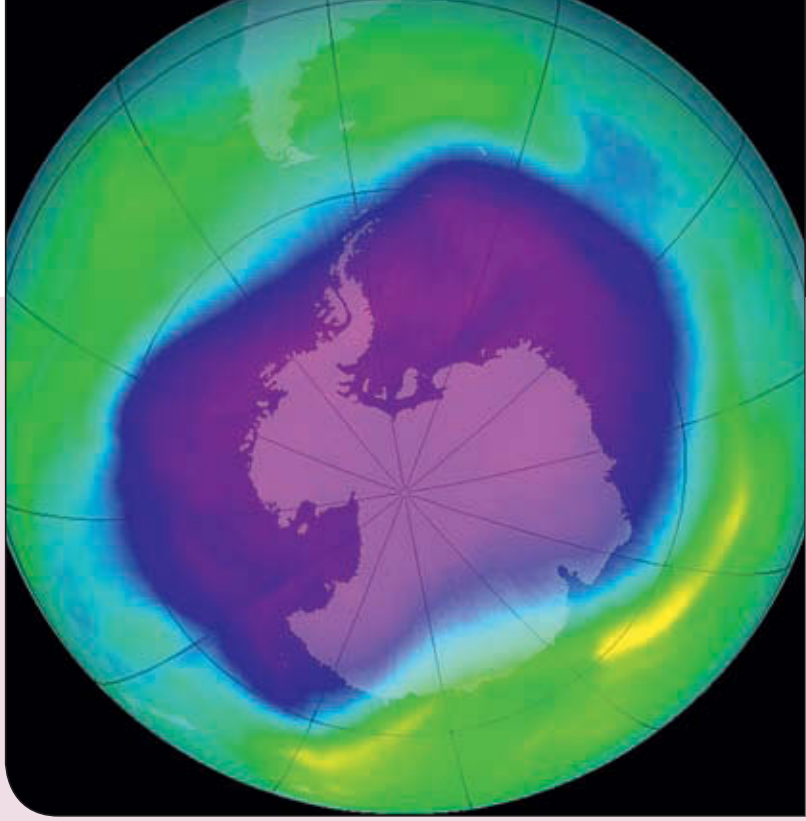
Scientists from the CSIRO predict a lot less rainfall for much of Australia, declining up to 60% by 2070 in the south-west. In Perth, surface water supply has decreased by 42% since the mid-1970s due to a 15–20% decrease in rainfall. The increased temperatures will also lead to increased evaporation, which will reduce the amount of water in our reservoirs.

Stability and change

Aerosol cans and the ozone layer: a case study

The protective ozone layer in the stratosphere becomes much thinner over Antarctica during August–October each year. This is a natural process caused by seasonal temperature change. Figure 3.53 shows the low values of ozone (referred to as a 'hole'), in blue and purple, over Antarctica. Scientists first began noticing a thinning in the ozone layer in the 1970s. Each year, less and less ozone was being regenerated to restore the natural balance of ozone in the atmosphere. A thinner ozone layer allows more harmful UV light to reach the Earth. The UV rays are responsible for skin cancers in people and animals, and also damage plants.

The main cause of the thinning of the ozone layer over Earth was the use of chemicals known as CFCs, or chlorofluorocarbons. These chemicals were used in aerosol spray cans and refrigeration units. Scientists discovered that the CFCs were actually reaching the ozone and destroying it. This was a big issue for the whole world because so many people use aerosol cans in their daily lives. The issue became widely talked about and was reported extensively in the media. In the late 1980s, ninety-three countries came together to bring about a halt in the use of CFCs and to help developing countries do the same. Now, fewer than 2% of aerosol cans in the United States contain CFCs—it looks like countries really can work together to save the world!

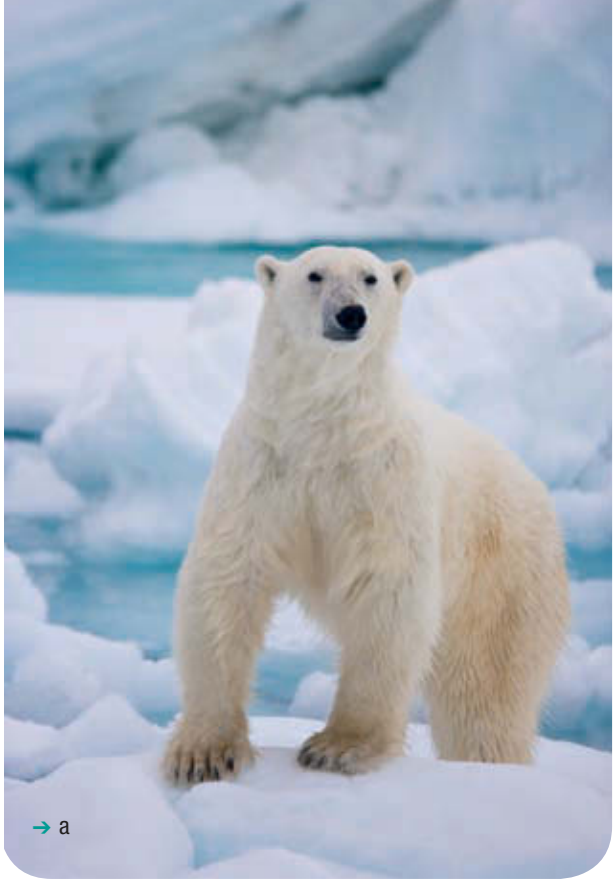


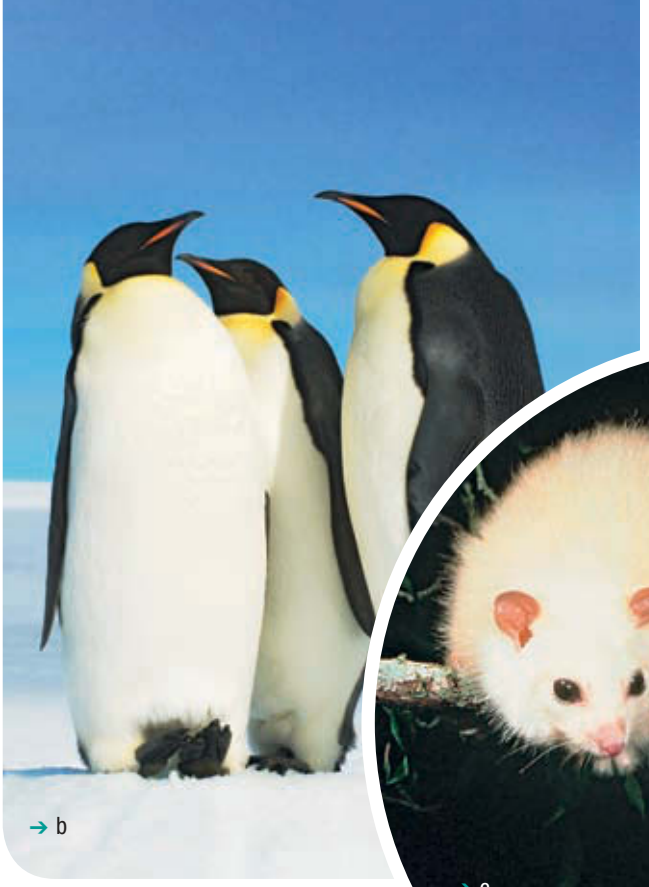
→ Fig 3.53 The hole in the ozone layer over Antarctica in 2006.

1 Describe how the ozone layer varies in thickness depending on the time of the year.
2 Compare yearly natural changes to the ozone layer with longer-term changes caused by human influences.
3 The media had a big part to play in getting CFCs banned. Why is the media so important in communicating environmental issues?
4 What are some of the issues that can impact on whether countries can come together to bring about change, like in the case of CFCs or the Kyoto Protocol?
5 How is limiting the use of CFCs different to limiting the release of greenhouse gases?

Loss of biodiversity

Climate change over the past 30 years has resulted in many changes to the distribution and numbers of species, and is thought to have caused extinctions. Many of the species at risk are Arctic and Antarctic animals, like polar bears and emperor penguins, which live on the ice. Other species, like the white lemuroid possum, which is only found in high-altitude areas in north Queensland, can only live within certain temperature ranges. The white lemuroid possum has been named as the first mammal species to have possibly been made extinct as a result of global warming. These possums cannot survive extended temperatures over 30°C, which occurred in 2005. The possum has not been seen for over 3 years.







→ Fig 3.54 Many animals are at risk of extinction as a result of climate change, including (a) polar bears and (b) emperor penguins, which live in cold climates, and (c) the lemuroid possum, which can only live within a certain temperature range.

Australia is one of the most biologically diverse countries. Species that are found only in Australia (i.e. are endemic to Australia) include:

- 85% of our flowering plants
- 84% of our mammals
- 89% of our temperate zone fish
- 45% of our birds.

Australia's biodiversity is already under stress from human impacts, such as land use change, changing river and stream flows, soil salinity, invasive species, overharvesting of commercially valuable species and changes to fire regimens. Climate change is an additional stress.

Australian native plants and animals are well adapted to year-to-year climate fluctuations, such as floods and droughts, but often they can only survive within a narrow range of temperatures. This means that many species and ecosystems could be highly vulnerable to the rapid and sustained increase in long-term average temperatures of 1–2°C that are anticipated as a result of global warming. For example, climate change modelling indicates that the extent of highland rainforest ecosystems of tropical north Queensland may decrease by up to 50% with a 1°C increase in temperature.

What do you know about other impacts on global systems?

1. Why is a change of only 1–2°C sometimes enough to cause problems to species of life on Earth?
2. Explain why more intense cyclones may be a result of global warming.
3. Describe how the hole in the ozone layer is dangerous to humans.
4. What extreme weather incidents have you heard about over the past 3 years? How many of these do you think could be linked to global warming?
5. Why are species becoming extinct due to climate change?



➔ Fig 3.55 Many changes are happening to the Earth and its climate.


The temperature of oceans to depths of 3000 metres is increasing. Warmer water expands leading to a rise in sea levels. Sea levels rose by about 17 centimetres last century.
Mid-latitude westerly winds have strengthened in both the northern and southern hemispheres. Together with the increase in ocean temperatures, this leads to larger storms and cyclones happening more often.
There is a change in ocean salinity: increased saltiness near the Equator and decreased saltiness closer to the poles, possibly due to changing evaporation and precipitation patterns.
Extreme temperature events have changed, with fewer cold snaps and frosts and more heat waves and hotter nights.

3.3

How do humans impact the environment?



Remember and understand

1 Make a list of the ways that increasing industrialisation, particularly since the 19th century, has affected ecosystems.

2 Describe the most significant way in which humans have affected ecosystems.

3 List some of the predicted outcomes of climate change.

4 Construct a chart or table that describes environmental carbon sinks and carbon producers.

5 Explain how humans are shifting the distribution of energy in an ecosystem.

Apply

6 The northern bettong is a very small, endangered nocturnal marsupial. It is an omnivore that eats small invertebrates, herbs, grasses and a species of fungus, which makes up approximately 45% of its diet. Northern bettongs were once widely distributed throughout Queensland. However, there are now only three populations left along the western edges of the wet tropics of north Queensland. Research the northern bettong on the Internet. What human activities do you think are contributing to the northern bettong being listed as endangered?



→ Fig 3.56 The northern bettong.

7 The glaciers on Mt Kilimanjaro are disappearing eight times faster than 20 years ago due to global warming. Explain how cloud cover can affect the atmospheric temperature and hence the melting of glaciers.

Analyse and evaluate

8 The human population was fairly stable until about 1 CE. Then it started to grow, accelerating its growth until almost reaching an exponential rate. In the past century, the human population has almost quadrupled. What are the likely effects of the population increase on world ecosystems?

9 Find out about biomass as an alternative source of renewable energy. Discuss whether you think this would be a good alternative to fossil fuels.

Critical and creative thinking

10 Imagine you had to reduce your energy impact on the environment. Look at all the appliances and gadgets you use in your home. Which one of these could you absolutely not bear to have to give up? Create an A4 page outlining why this one item is 'essential' to you and then make a list of appliances and gadgets that you could live without.

CONNECTING IDEAS Dynamic Earth

11 Over 80% of the Earth's energy resources are non-renewable and declining. In the 20th century, most energy use has been concentrated in a few nations, which make up only a small proportion of the Earth's population. The seven largest economies at the end of the 20th century (with 10% of the global population) used approximately 45% of the total primary energy supply. Yet, approximately 2 billion people on Earth do not have access to electricity. In a group, discuss this concept and form an opinion. What actions could you take to improve this situation?

>>ZOOMING OUT<<

Research

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

Peak oil

Our society runs on fossil fuels. Find out about the concept of peak oil and what implications it will have for our lives in the not-too-distant future.

Carbon capture and storage

One measure that has been proposed to decrease the amount of carbon dioxide we are adding to the atmosphere is to capture and store it. What does this mean? How will it work? Explain some of the options being considered for storing carbon dioxide.

Responding to climate change

The Kyoto Protocol is an agreement between 181 countries that aims to stabilise greenhouse gas emissions in the atmosphere at a level that would prevent danger to the Earth's climate system. In late 2007, Australia's newly elected Prime Minister Kevin Rudd ratified (fully agreed to) the Kyoto Protocol. Australia has set a target to reduce greenhouse gas emissions by 60% on 2000 levels by 2050. However, to date, the United States, the world's largest emitter of greenhouse gases, has not ratified the agreement. What does this mean for the effectiveness of the agreement? Which other countries are also not assisting and what might their motives be?

Global warming or Ice Age?

Like our Earth, the Sun demonstrates cycles of behaviour. One such pattern that has been identified is a period during which sunspots are absent. The next predicted period of sunspot absence is around 2020 and could last a couple of decades. The lack of sunspots would likely result in a global temperature decrease for Earth, potentially sending us into an Ice Age. Find out more about the potential impact of this solar cycle on Earth's future climate.

Reflect

Me

1 What new science laboratory skills have you learned or improved on in this chapter?
2 What was the most surprising thing that you found about the flow of energy and matter in ecosystems?
3 What were the most difficult aspects of this topic?

My world

4 Why is it important to understand the role of energy in ecosystems?

My future

5 Why is changing the way humans interact with ecosystems and how humans use energy important for the future of the global ecosystem?

Review

Key words

anemometer
atmosphere
barometer
biosphere
carbon sink
climate
climate change
Coriolis effect
cryosphere
denitrifying bacteria
earthquake
ecologist
eutrophication
geologist
greenhouse effect
greenhouse gas
hydrosphere
isobar
lithosphere
magma chamber
nitrogen-fixing bacteria
permafrost
photolysis
tectonic plate
volcano
weather

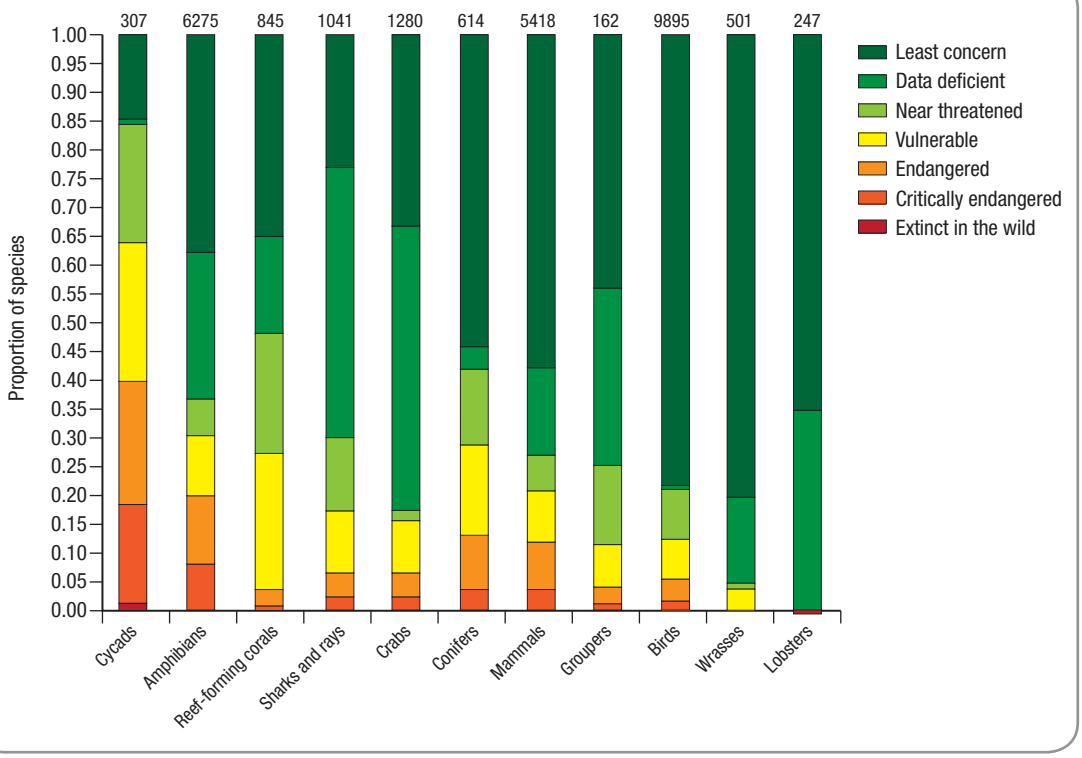
3

It would be a fair comment to suggest that the greatest concern regarding the effects of climate change would be the impacts on humans. Many populations will be forced to relocate, or perish, and standards of living will shift sideways and down for most as resource availability decreases. The impacts on biodiversity are far greater and are not just the consequence of climate change, but direct human impact also. The graph shown in Figure 3.57 highlights the plight of a range of species, including plants, from the International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

Your task

1 Critically analyse the species in the graph, thinking about the reasons for the proportions displayed by each taxa. Global cycles, human impact and other causes should be considered.

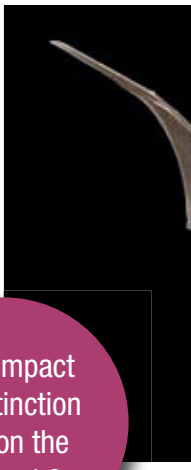
2 Select a taxon or species to investigate in greater detail. Present your research and critical analysis in a format that will engage your intended audience and promote thought and behavioural change.



→ Fig 3.57 The proportion of extant (i.e. excluding extinct) species in the IUCN Red List of Threatened Species, Version 2011.1, assessed in each category for the more comprehensively assessed groups. Taxa are ordered according to the horizontal red lines, which show the best estimate for the proportion of extant species considered critically endangered, endangered or vulnerable. The numbers above each bar represent the total number of extant species assessed for each group.



→ Fig 3.58 Spear tooth shark.



What impact will extinction have on the food web?



→ Fig 3.59 Orange-bellied parrot.

Why is it endangered?



Who cares about an endangered stick insect?



→ Fig 3.60 Lord Howe Island phasmid.



→ Fig 3.61 Port Davey skate.



→ Fig 3.62 Leaf-scaled sea snake.



→ Fig 3.63 Glenelg spiny freshwater crayfish.

Which species are more likely to be saved?



→ Fig 3.64 Western swamp tortoise.

How are humans responsible?



→ Fig 3.65 Southern bent wing bat.



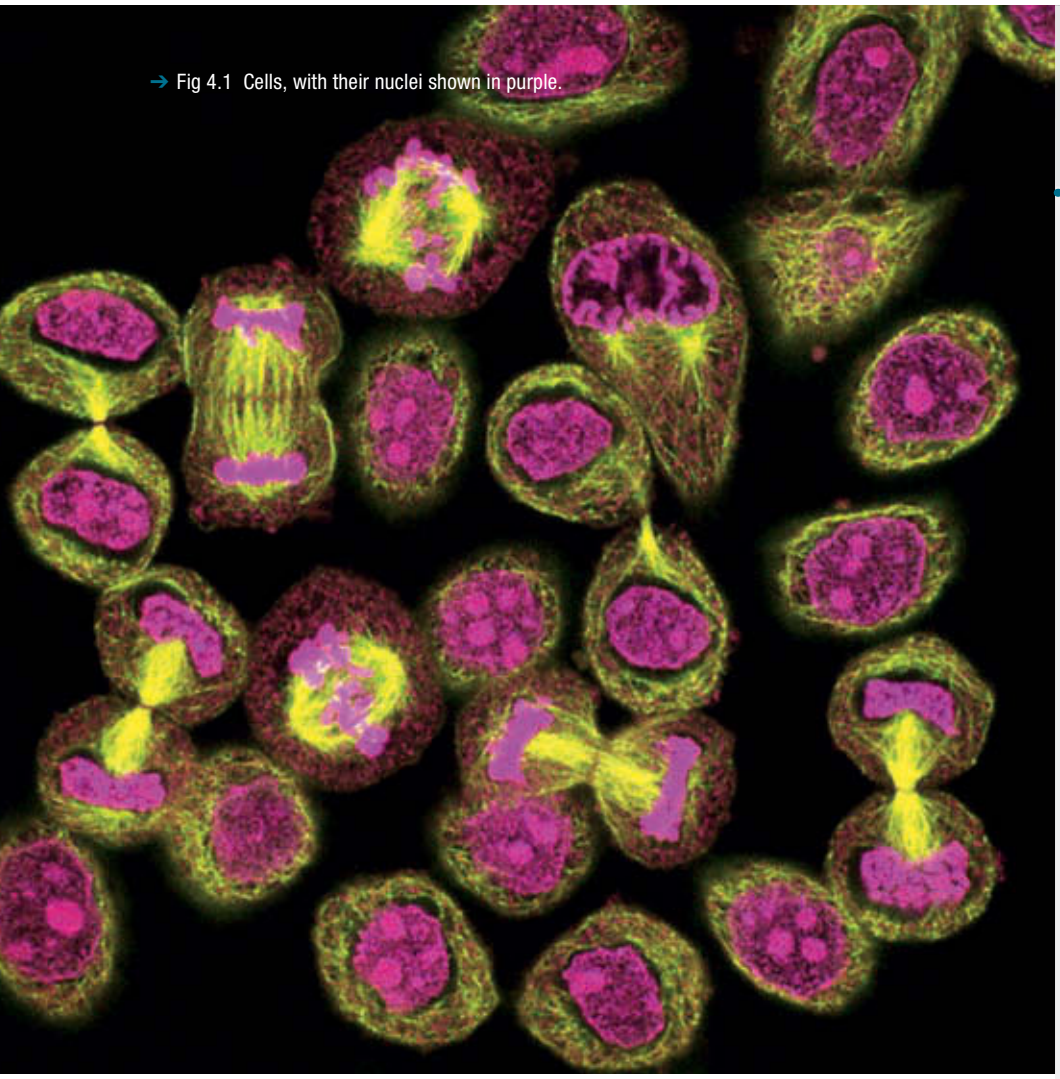
→ Fig 3.66 Oxeylan pygmy perch.

How is climate change responsible?



→ Fig 3.67 Gilbert's potoroo.

4 Genetics



→ Fig 4.1 Cells, with their nuclei shown in purple.

4.1 What is DNA?

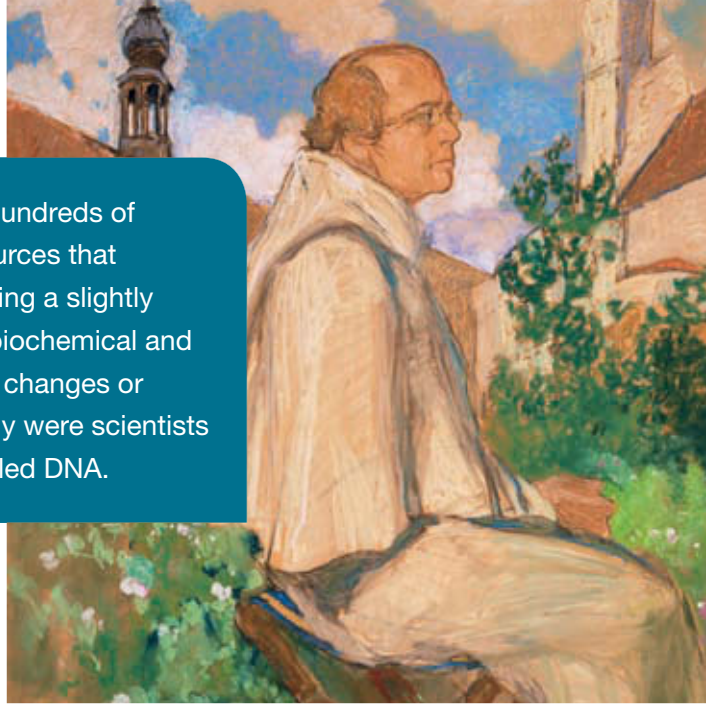
The year 1953 was an interesting one: climbers reached the summit of Mount Everest for the first time, a new queen was crowned in England and the structure of **DNA** was determined by James Watson and Francis Crick. DNA is deoxyribonucleic acid—it controls all the characteristics of life with its unique double-helix structure.

DNA has been functioning since life began, yet no human knew much about it until 1869, when the German chemist Miescher extracted a white, slightly acidic phosphorus-containing substance from the nuclei of cells. But this was far from knowing that DNA is a double helix. Between 1869 and 1953, experiments were performed to find out more about the structure and function of DNA. Increasingly more information was found, but the structure and function of DNA remained unclear.

1 Does every type of cell contain a nucleus?
2 What is inside a cell nucleus?
3 What is the role of the nucleus in a cell?
4 Is the role of the nucleus the same in all cell types?
5 What discoveries have been made that relied on an understanding of cell nuclei?



An incredibly diverse range of living things has evolved on Earth over hundreds of millions of years. This variety enables each organism to share the resources that the Earth has to offer in a sustainable way, with each organism occupying a slightly different niche in the environment. Variation in physical, physiological/biochemical and behavioural adaptations exists between and within species, with slight changes or mutations occurring as one generation flows into the next. Only recently were scientists able to identify the 'code' for these features—an amazing molecule called DNA.



→ Fig 4.2 Gregor Mendel.

4.2 How is DNA inherited?

Gregor Mendel, an Austrian monk and scientist, was the first person to make accurate conclusions about how genes work. He lived in Brno, which is in the modern Czech Republic. Mendel taught Maths, but he loved experimenting with peas—and he did many experiments in his garden.

In the mid-1800s, Mendel accurately concluded that genes come in pairs (one from each parent) and that they can separate and form pairs again in the next generation.

Mendel did not use the word 'gene'. He used the word 'factor' and said that a factor is something in the cell that controls a characteristic. Mendel's work was not recognised for its importance until several decades after his death. All our current knowledge and understanding of genetics begins with Mendel's work and develops from it.

1 Find some of your own characteristics that are more similar to your (a) mother and (b) father. List them in a table.

2 Are there some characteristics that are not similar to either parent? Can you think of any reasons for this? Work in a group to discuss your ideas.

3 Research and summarise the life story of Gregor Mendel. What aspects of his personality helped him achieve his status in the scientific world?



4.3 How do humans use their understanding of genetics?

With an increasing understanding of the structure and function of DNA, modern technologies are now being developed to manipulate DNA in various ways. From the treatment of genetic diseases in individuals using gene therapy to the production of genetically modified crops that are designed to feed an increasing world population with limited resources, the possibilities are only just beginning to be realised. Such technologies inevitably attract much enthusiasm, controversy and criticism.

1 What sort of diseases do you think might be helped by gene therapy?

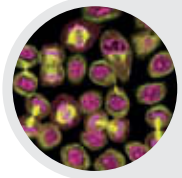
2 The use of stem cells is highly controversial. What do you know about stem cells and this 'controversy'?

3 Genetically modified (GM) crops are already included in some of our foods. What are some of the advantages and disadvantages associated with GM foods?

→ Fig 4.3 A human ear being grown on a mouse.

4.1

What is DNA?



DNA is like a blueprint for every structure and function in an organism. It contains a code unique to the individual that can be passed to offspring, generation after generation, with little or no change. Each cell within a single organism contains DNA molecules with the same general structure. Each species has its own unique DNA that defines the species. However, individuals within a species have differences in their DNA also. In individuals within a species, there may be some very fine variations in the structure of the DNA molecule and therefore in the code that it carries. An understanding of the structure of DNA enables us to explain not only the similarities that exist between and within species, but also the differences.

DISCOVERING IDEAS

Zooming in on DNA

1 Work in small groups to produce a concept of what a helix is and then what a double helix is.
2 Create a simple model of the double helix using common materials, such as ribbon, string, toothpicks and sticky tape. The model can lie flat on the bench or table.
3 Research some of the events that occurred in the 'search for DNA' between the time of Miescher and that of Watson and Crick. Prepare a time line to show the sequence of events.
4 Did Watson and Crick receive a Nobel prize for their work and, if so, when?
5 What aspects of reproduction pass DNA from parents to offspring?

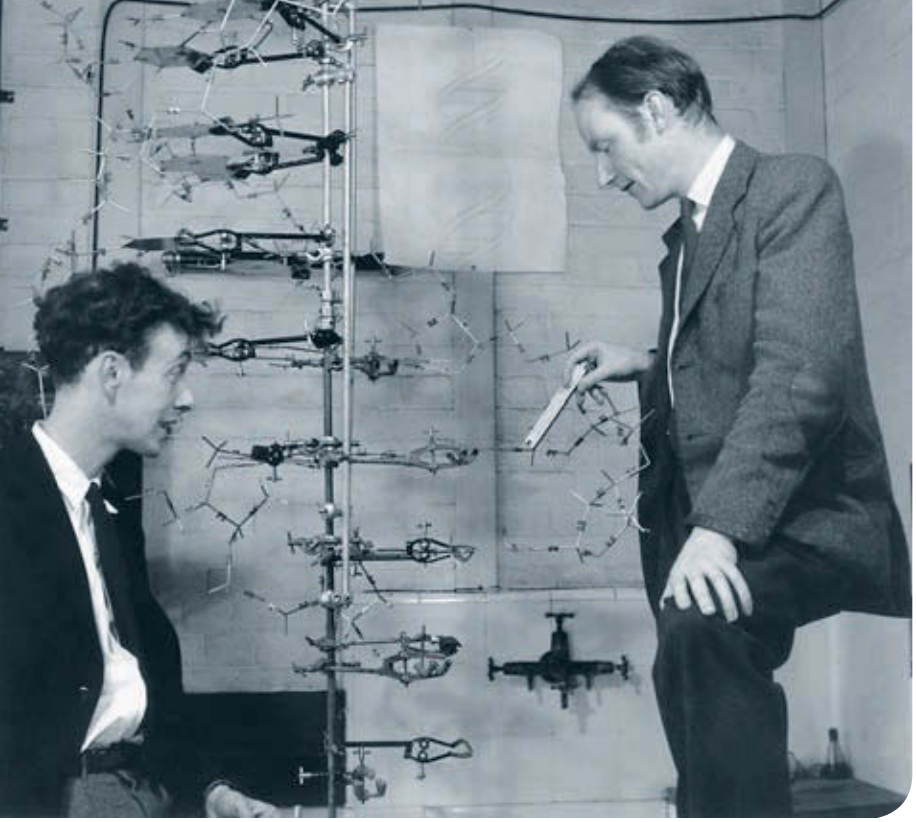


Watson and Crick's double helix discovery

James Watson, a young chemist from the United States, went to the University of Cambridge, in the United Kingdom, to meet Francis Crick, an Englishman, who was a physicist. They worked as a team to unravel the secret of the DNA structure. However, they performed no experiments themselves; their talent lay in interpreting the experimental results of others. Watson and Crick made frequent trips to the local pubs—close to the university—to thrash out their ideas.

The information available on DNA when Watson and Crick began their investigation was:

1 DNA was known to be a large, long, thin molecule and to be composed of nucleotides containing the nitrogenous bases adenine (A), guanine (G), cytosine (C) and thymine (T).
2 A Russian biochemist, Phoebus Levene, thought that the bases were arranged in order A, T, G and C in a repeating pattern.



→ Figure 4.4 Watson and Crick with their DNA model.

3 Based on his work with proteins, the American biochemist Linus Pauling believed that DNA had a helical structure.

4 X-ray diffraction pictures of DNA (see Figure 4.5) from the laboratories of Maurice Wilkins and Rosalind Franklin of King's College, London, showed markings that almost certainly indicated the turns of a giant helix.

5 Also crucial were the data of the American biochemist Erwin Chargaff that indicated that the amount of adenine is the same as the amount of thymine and that the amount of guanine is the same as the amount of cytosine (see Table 4.1).

→ Table 4.1 The composition of DNA in different species

	Purines (%)		Pyrimidines (%)	
	Adenine	Guanine	Cytosine	Thymine
Human	30.4	19.6	19.9	30.1
Ox	29.0	21.2	21.2	28.7
Salmon sperm	29.7	20.8	20.4	29.1
Wheat germ	28.1	21.8	22.7	27.4
Escherichia coli	24.7	26.0	25.7	23.6
Sea urchin	32.8	17.7	17.3	32.1

Watson and Crick attempted to put together all the information that was available to create models of possible structures of the DNA molecule. In February 1953, they built a model that established the general structure of DNA.

The structure of a nucleotide

Nucleic acids are polymers (chains) of nucleotides. A **nucleotide** is a complex molecule composed of three smaller molecules:

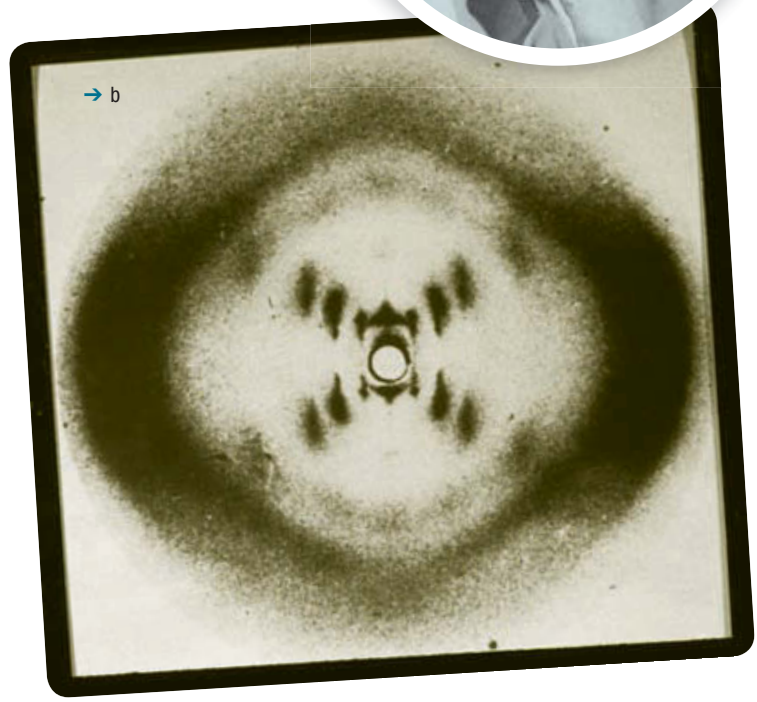
- a cyclic nitrogenous **base**
- a five-carbon sugar (either ribose or deoxyribose)
- a phosphate group.

DNA contains the sugar deoxyribose and the four bases **adenine** (A), **guanine** (G), **cytosine** (C) and **thymine** (T).

Another nucleic acid, RNA, contains the sugar ribose and the four bases adenine (A), guanine (G), cytosine (C) and **uracil** (U).



→ a



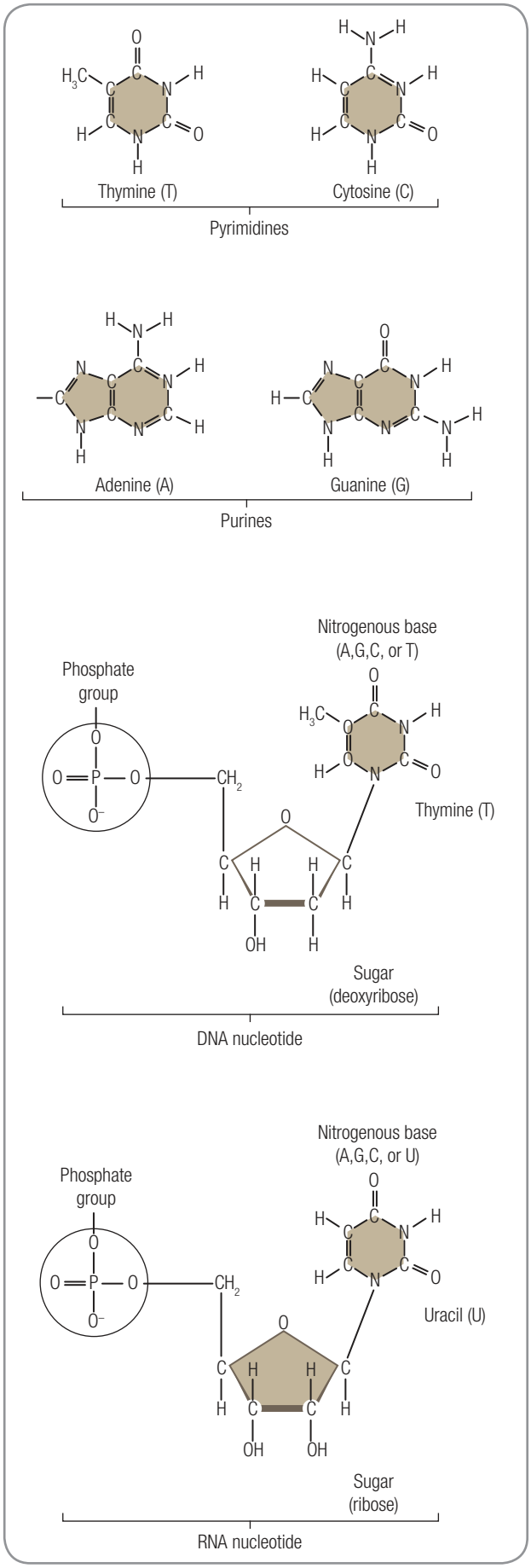
→ b

→ Figure 4.5 (a) Rosalind Franklin and (b) X-ray crystallography of DNA (taken by Rosalind Franklin).

The structure of a nucleic acid

Nucleotides are joined together by their sugar and phosphate groups. This forms a **sugar–phosphate backbone**. The bases are attached to the sugars and are at right angles to the sugar–phosphate backbone, like the steps in a ladder. This makes a polynucleotide chain.

➔ Figure 4.6 The structure of a nucleotide.



The double helix

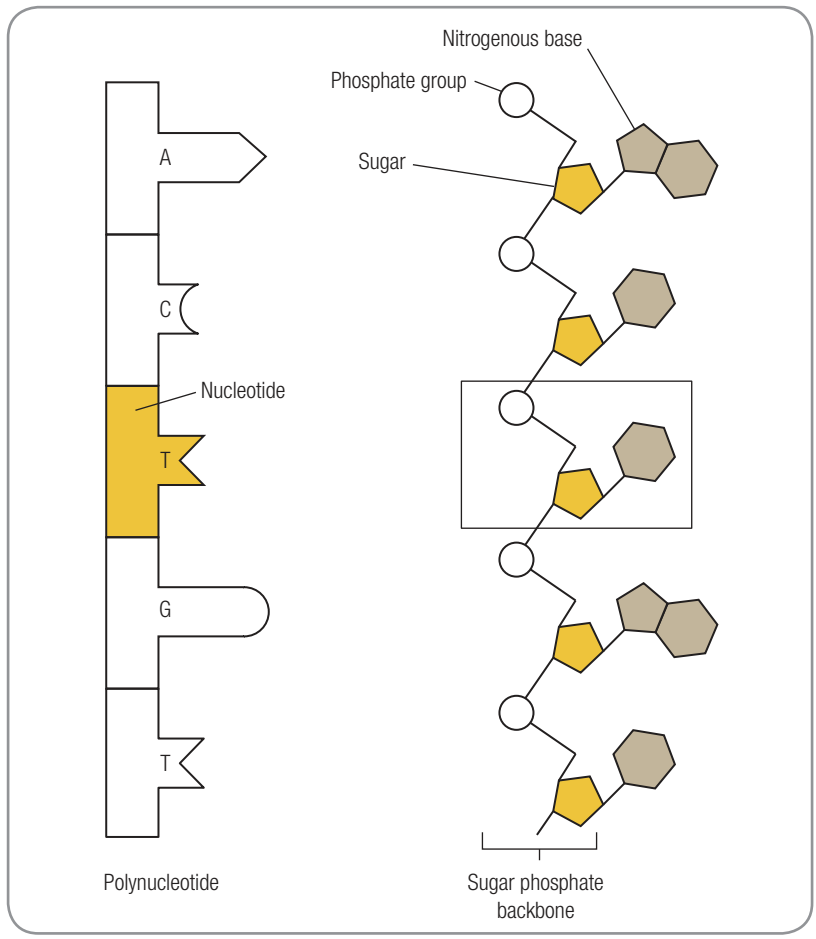
Two polynucleotide chains, or strands, are attached together by **hydrogen bonds** (relatively weak bonds) between the bases. This is important for the easy 'unzipping' of the ladder during replication. A large base (adenine or guanine) is always bonded to a small base (thymine or cytosine) because this gives just the correct amount of space between the strands.

One of the greatest achievements of Watson and Crick was their realisation that bases on one polynucleotide strand are bonded to bases on the other strand, with A opposite T and G opposite C: the results of Chargaff now became understandable. These base pairs are called **complementary bases** or complementary base pairs. The two polynucleotides then wind into a **double helix**—the twisted ladder.

DNA replication

Watson and Crick wrote a one-page paper on their model of DNA that was published in the journal *Nature*. This paper opened the eyes of the scientific world to the new field of molecular genetics. The model also suggested to Watson and Crick that, because of its structure and base pairing, DNA could make copies of itself. They published a second paper in *Nature* with their mechanism for DNA replication.

➔ Figure 4.7 Nucleic acids are composed of 'polynucleotides' so called because there are many joined together in a chain.

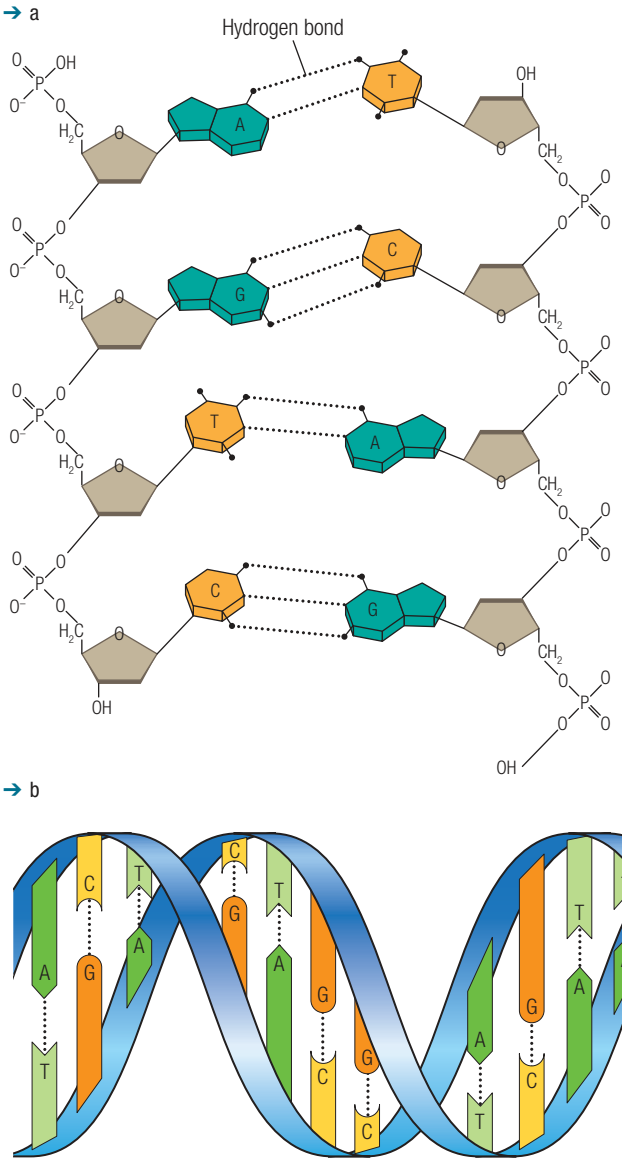


They wrote as follows:

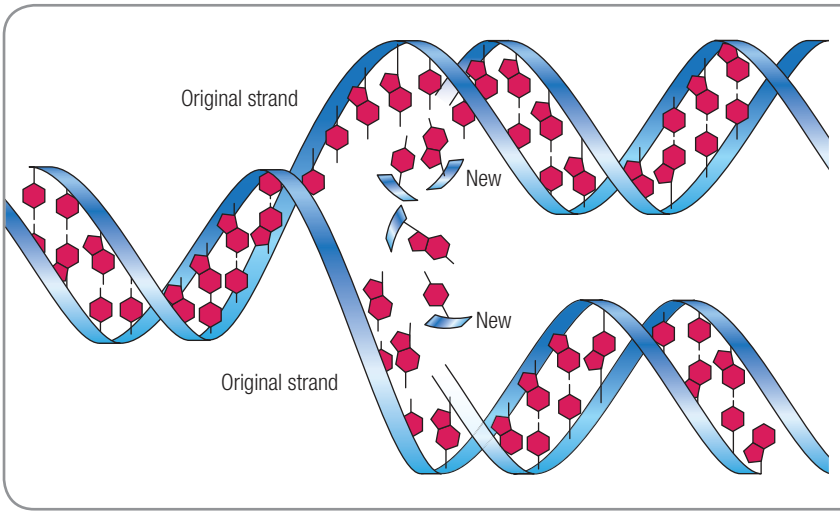
'Now our model for deoxyribonucleic acid is, in effect, a pair of templates, each of which is complementary to the other. We imagine that prior to duplication the hydrogen bonds are broken and the two chains unwind and separate. Each chain then acts as a template for the formation onto itself of a new companion chain so that eventually we shall have two pairs of chains where we only had one before. Moreover the sequence of the pairs of bases will have been duplicated exactly.'

Therefore, the unique double-helix structure of DNA, with its two complementary strands, allows it to replicate by a simple mechanism so that more identical DNA can be made.

→ Figure 4.8 (a) Two polynucleotide strands. (b) The two polynucleotide strands wind into a double helix.



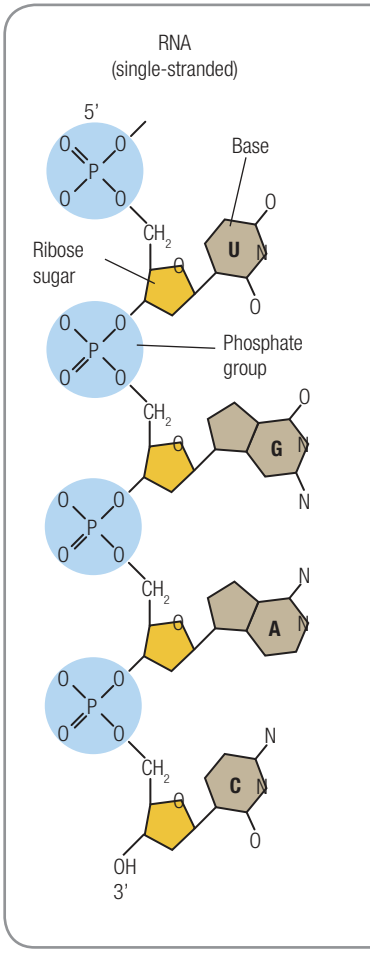
→ Figure 4.9 DNA replication. The double helix unwinds and each polynucleotide strand acts as a template for new nucleotides to bond by complementary base pairing. Two double helices (molecules of DNA) that are identical to the original molecule are formed.



RNA

Another nucleic acid, ribonucleic acid or RNA, is a single polynucleotide containing the sugar ribose with the nitrogen base uracil instead of thymine. RNA plays a key role in protein synthesis.

→ Figure 4.10 The structure of RNA.



PRACTIVITY 4.1

A beautiful model

What you need: coloured card, scissors, sticky tape, paper clips

Use the materials provided, or other craft materials available, to construct an accurate representation of the DNA double helix. Features that must be represented are pairing between the complementary bases, the structure of the sugar–phosphate backbone and the hydrogen bonding between strands.

EXPERIMENT 4.1

Extracting DNA

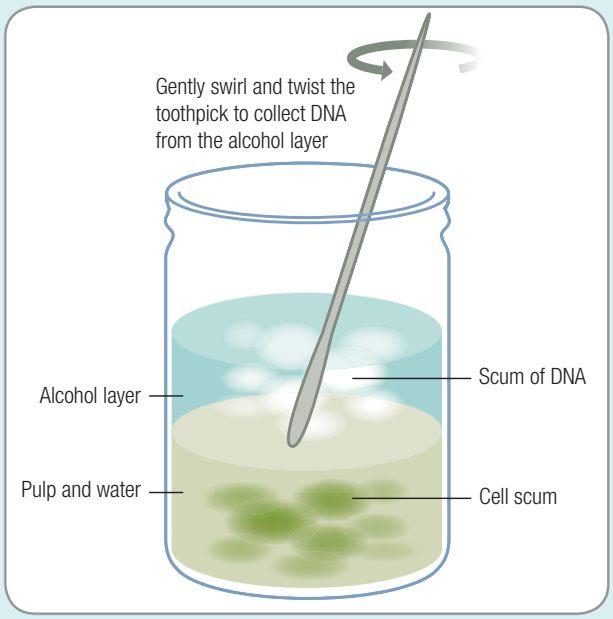
Part A

Materials

100 g (½ cup) dried peas or frozen peas (thaw first)
200 mL (1 cup) water
6 g (1 tsp) table salt
20 mL dishwashing liquid
1 g (⅛ tsp) meat tenderiser
Blender
1L beaker
Sieve
Stirring rod or spoon
Timer

Method

1. Dissolve the salt in the water.
2. Combine the peas and salty water in a blender. Mix for 15 seconds to form a lumpy liquid in which the peas are only just broken up. Do not overblend.
3. Pour the contents through a sieve into the 1L beaker. Discard the pulp in the sieve.
4. Add the dishwashing liquid and stir gently to avoid making bubbles. Stir for 8 minutes.
5. Add the meat tenderiser and continue to stir gently for another 2 minutes.
6. This is your prepared DNA source.



→ Figure 4.11 Procedure for collecting DNA from the alcohol layer.

Part B

⚠ Ethanol is flammable.

Materials

Test tubes and test tube rack or 50 mL glass vials
Ice-cold ethanol (stand a sealed bottle containing 200 mL ethanol in a metal bowl of ice water for an hour prior to using)
Skewer, glass stirring rod (toothpick for vials)
Microscope
Clean microscope slides and cover slips
Methylene blue stain

Method

1. Pour 15 mL of the DNA source into a test tube or a 50 mL glass vial. There should be enough of this mix for eight test tubes or vials, which can be shared in the class.
2. Dribble 15 mL ice-cold ethanol down the side of the test tube or vial—there should be equal amounts of filtrate and ethanol in the test tube or vial.
3. Leave the test tube or vial to separate into layers. This will take at least 10 minutes. The alcohol will eventually settle on top of the watery pea mixture. DNA is less dense than water and should float up into the alcohol layer, leaving the other cellular components behind.
4. When the mixture has separated completely, use a stirring rod to gently twirl and twist the DNA to collect it from the alcohol layer. DNA looks white in colour.
5. Put a small amount of the DNA sample onto a glass slide. Gently spread the DNA mixture. Add 1 drop of methylene blue stain to the DNA mixture. Place the cover slip on the edge of the methylene blue and allow it to fall into place. This should eliminate any air bubbles.
6. Look at your sample under ×10 magnification. Once focused, you can then try the higher magnifications using the fine focus knob to focus. You will not see the double helix strands, but you should see clumps of DNA material that may look like a tangled mass of strands.

Results

Present your results as a labelled diagram, with several short statements or labels explaining your observations.

Discussion

1. Briefly describe the appearance of the DNA.
2. Do you think human DNA will look the same as the DNA from dried peas?
3. What role does each of the additives (dishwashing detergent, meat tenderiser and alcohol) play?
4. What materials remain in the watery layer?

Conclusion

Summarise the outcomes of this experiment.

LITERACY LAB

An incredible woman

Rosalind Elise Franklin – Pioneer molecular biologist (© Merry Maisel and Laura Smart, San Diego Supercomputer Centre, University of California, San Diego)

Born: London, England, July 25, 1920 • Died: London, England, April 16, 1958



There is probably no other woman scientist with as much controversy surrounding her life and work as Rosalind Franklin. Franklin was responsible for much of the research and discovery work that led to the understanding of the structure of deoxyribonucleic acid, DNA. The story of DNA is a tale of competition and intrigue, told one way in James Watson's book, *The Double Helix*, and in quite another in Anne Sayre's study, *Rosalind Franklin and DNA*. James Watson, Francis Crick and Maurice Wilkins received a Nobel Prize for the double-helix model of DNA in 1962, four years after Franklin's death at age 37 from ovarian cancer.

Franklin excelled at science and attended one of the few girls' schools in London that taught physics and chemistry. When she was 15, she decided to become a scientist. Her father was decidedly against higher education for women and wanted Rosalind to be a social worker. Ultimately he relented, and in 1938 she enrolled at Newnham College, Cambridge, graduating in 1941. She held a graduate fellowship for a year, but quit in 1942 to work at the British Coal Utilization Research Association, where she made fundamental studies of carbon and graphite microstructures. This work was the basis of her doctorate in physical chemistry, which she earned from Cambridge University in 1945.

After Cambridge, she spent three productive years (1947–1950) in Paris at the Laboratoire Central des Services Chimiques de L'Etat, where she learned X-ray diffraction techniques. In 1951, she returned to England as a research associate in John Randall's laboratory at King's College, London.

It was in Randall's lab that she crossed paths with Maurice Wilkins. She and Wilkins led separate research groups and had separate projects, although both were concerned with DNA. When Randall gave Franklin responsibility for her DNA project, no one had worked on it for months. Wilkins was away at the time, and when he returned he misunderstood her role, behaving as though she were a technical assistant. Both scientists were actually peers. His mistake, acknowledged but never overcome, was not surprising given the climate for women at the university then. Only males were allowed in the university dining rooms, and after hours Franklin's colleagues went to men-only pubs.

But Franklin persisted on the DNA project. J. D. Bernal called her X-ray photographs of DNA, 'the most beautiful X-ray photographs of any substance ever taken'. Between 1951 and 1953 Rosalind Franklin came very close to solving the DNA structure. She was beaten to publication by Crick and Watson in part because of the friction between Wilkins and herself. At one point, Wilkins showed Watson one of Franklin's crystallographic portraits of DNA. When he saw the picture, the solution became apparent to him, and the results went into an article in *Nature* almost immediately. Franklin's work did appear as a supporting article in the same issue of the journal.

A debate about the amount of credit due to Franklin continues. What is clear is that she did have a meaningful role in discovering the structure of DNA and that she was a scientist of the first rank. Franklin moved to J. D. Bernal's lab at Birkbeck College, where she did very fruitful work on the tobacco mosaic virus. She also began work on the polio virus. In the summer of 1956, Rosalind Franklin became ill with cancer. She died less than two years later.

1 Discuss (in groups and then as a whole class) the following aspects of Rosalind Franklin's life:

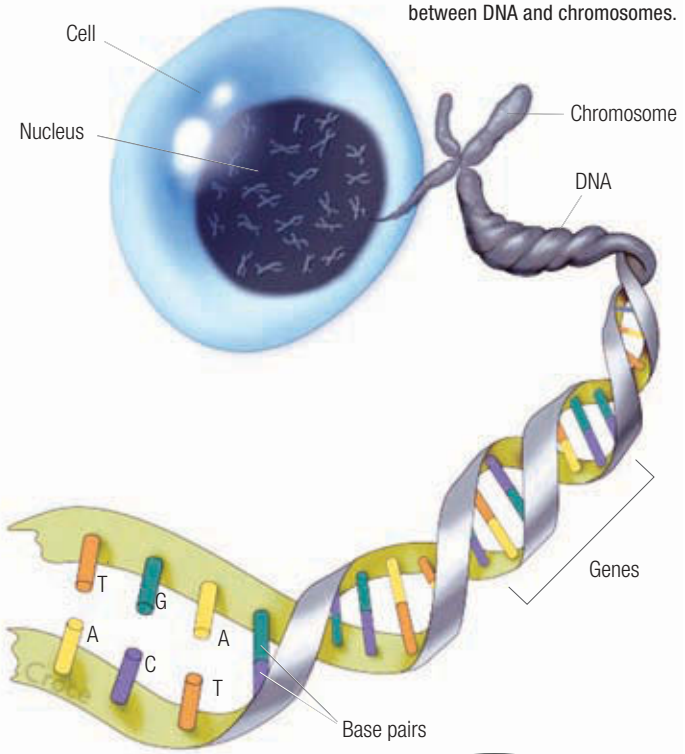
- **a** The controversy surrounding her role in the discovery of DNA.
- **b** Her impact on science.
- **c** The language in the article above—is it intended for the general public or the scientific community? Explain.

What do you know about Watson and Crick's double helix discovery?

1. Describe a nucleotide.
2. Explain how nucleotides join together to form polynucleotides.
3. Explain how two polynucleotides can twist helically around each other to form a double helix of DNA.
4. What part of the DNA molecule varies? What part remains constant?
5. How does the order of the bases on one polynucleotide chain determine the order of the bases on the other chain?
6. Briefly describe the roles of Chargaff, Pauling, Franklin, Wilkins, Watson and Crick in the discovery of the structure of DNA.
7. Briefly explain how DNA replicates.

The relationship between DNA, chromosomes, genes and characteristics

Take an imaginary trip across one of your own living cells—through the membrane and across the cytoplasm to the nucleus. Inside the nuclear membrane are the chromosomes. There are forty-six chromosomes in a human nucleus: twenty-three of them come from mum and twenty-three come from dad. Along the length of each chromosome, in specific positions, are the genes.



→ Figure 4.12 The relationship between DNA and chromosomes.

How do we relate chromosomes to DNA?

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

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

A single-stranded chromosome =
a molecule of DNA (a DNA double helix)

Chromosomes may be single or double stranded. The double-stranded chromosome is the 'X' you may be familiar with. The two strands of a double-stranded chromosome are identical. Double-stranded chromosomes are formed during DNA replication so that two identical copies—one for each of the two cells formed during cell division (**mitosis**)—can be produced. Each strand of a double-stranded chromosome is called a **chromatid**.

So, a second equation can be written:

Single-stranded chromosomes → double-stranded chromosomes = DNA replication

that is:

One molecule of DNA → two molecules of DNA

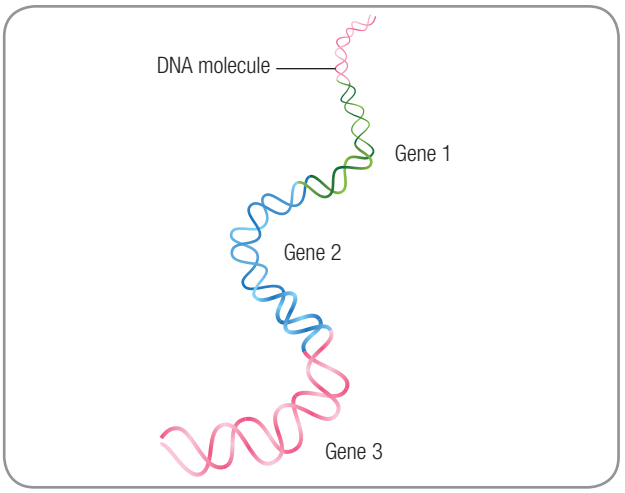


→ Figure 4.13 A double-stranded chromosome is made up of two sister chromatids joined at the centromere.

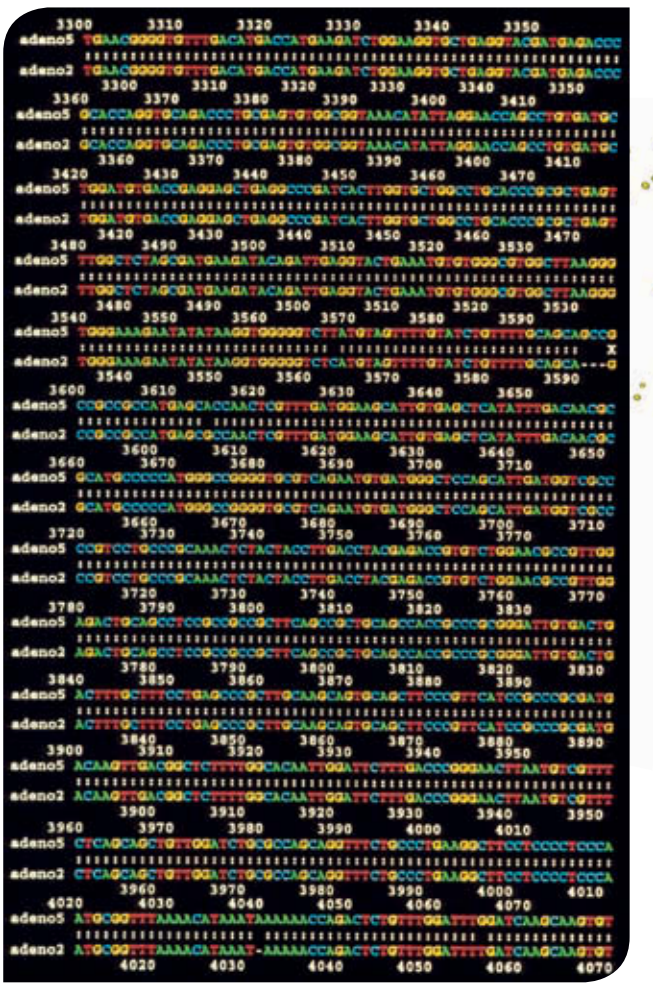
How do we relate genes to DNA?

Genes are sections of a DNA molecule. The base sequence of each gene contains information for one characteristic. For example, a gene may have information for making the pigment melanin, which tans our skin. So a chromosome, which contains many genes, is like a recipe book!

➔ Figure 4.14 The relationship between DNA and genes.



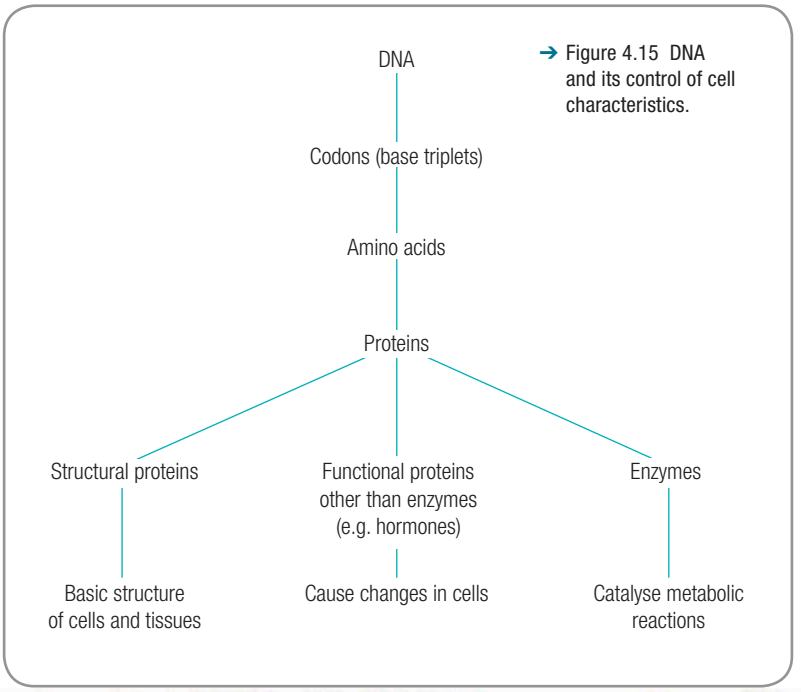
➔ Figure 4.16 The sequence of bases on the DNA is the coding system. For example, the sequence here shows adenovirus type 5 and 2. Recombinant adenoviruses are used in gene therapy.



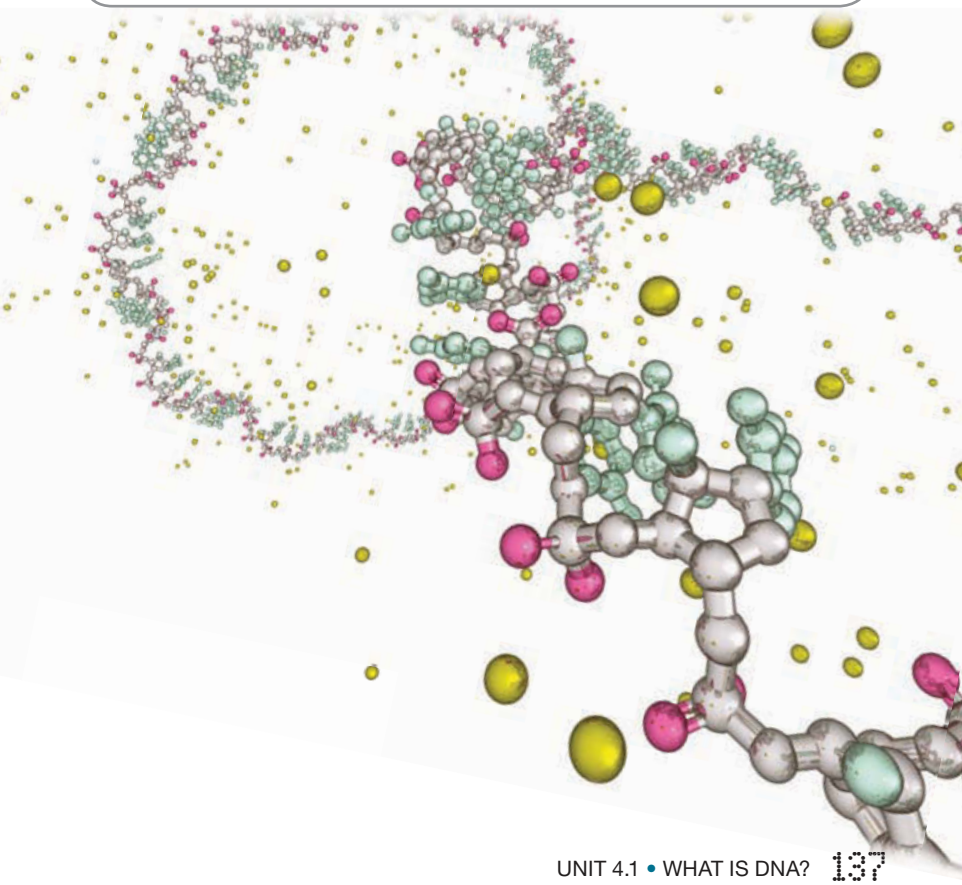
The genetic code

One major feature of DNA is its ability to replicate; the other is that it carries a genetic coding system for making proteins. It is the sequence of bases on the DNA strands that is the **genetic code** for an organism.

The genetic code specifies the structure of proteins. Some proteins are the major structural components of cells, whereas other proteins drive cellular metabolic reactions.



➔ Figure 4.15 DNA and its control of cell characteristics.



Coding for what?

Because genes act by coding for proteins, and proteins are polymers of **amino acids**, genes must be able to code both the *type* and *sequence* of amino acids in protein molecules. There are approximately twenty amino acids that occur naturally in proteins and each amino acid requires a specific code. The code symbols must be the bases A, T, C and G.

The individual amino acids are coded for by a triplet of bases called a **codon**. Four bases can be arranged as triplets in 4 × 4 × 4 = 64 different ways. This is more than enough for twenty amino acids. Hence, there is usually more than one codon for each amino acid (this is called 'degeneracy of the code').

The types of amino acids in a protein are coded for by the triplets of bases that make up the particular codons on the DNA molecule.

The sequence of amino acids in a protein is coded for by the sequence of codons along the DNA molecule.

→ Figure 4.17 The entire genetic code was deciphered by 1966 and scientists now understand which amino acid is coded for by each codon. There are three stop codons and one start codon.

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met/Start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

SKILLS LAB

Sequencing genes

A section of the mRNA sequence made from a particular gene is shown below.

G A G A A U C U C C G A G A C C U C

1 Write down the sequence of the template DNA strand.

2 Using the genetic code on Figure 4.17, write down the amino acids that the above sequence codes.

3 What would occur if a change to the DNA causes a stop codon to appear in the mRNA?

How are proteins synthesised?

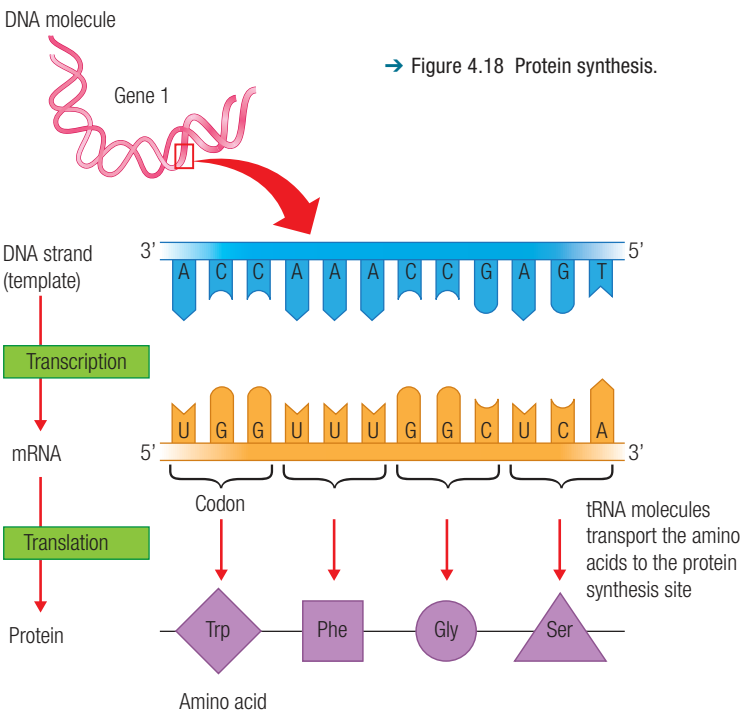
The DNA double helix unwinds and one strand acts as a template to form a molecule of **messenger RNA** (**mRNA**). The mRNA leaves the nucleus and attaches to a ribosome in the cytoplasm. The nucleotide sequence on the mRNA now acts as a template for amino acids to line up and bond together to form a protein.

DNA → mRNA is called **transcription** and takes place in the nucleus

mRNA → protein (or polypeptide) is called **translation** and occurs on the ribosome

The genetic code (the codons for the amino acids) is stated in terms of the mRNA rather than DNA.

Two other types of RNA are now involved: **ribosomal** and **transfer** RNA (**rRNA** and **tRNA**, respectively). Each tRNA transports a different amino acid to the ribosome for protein synthesis (see Figure 4.18).



→ Figure 4.18 Protein synthesis.

What do you know about the relationship between DNA, chromosomes, genes and characteristics?

1. Draw a flow diagram showing the relationship between DNA, chromosomes, genes and characteristics.
2. What type of role does mRNA play in the conversion of DNA information into characteristics?
3. How is a protein like a string of beads?
4. What type of molecule is the key to the cell's characteristics? Hint: The DNA (via mRNA) determines its structure.
5. If part of a base sequence on one polynucleotide strand on DNA reads ACTGGCATTCAG, what is the base sequence of the corresponding part of the other polynucleotide strand? What is the base sequence of the mRNA for which this strand acts as a template?
6. Why is a codon three bases and not one or two bases?

Passing DNA to offspring

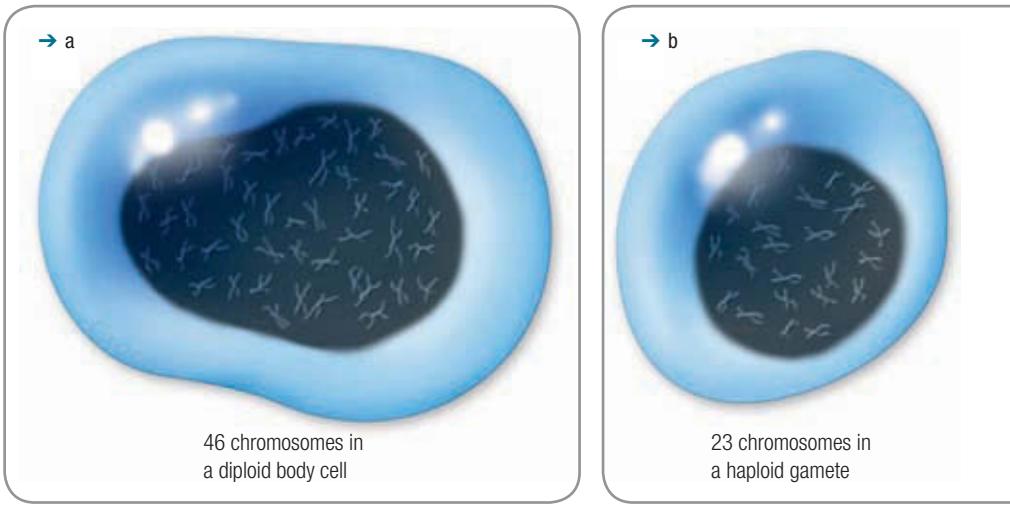
A **gamete** is a sex cell. In animals, the male gamete is a **sperm** and the female gamete is an **ovum**. In flowering plants the male gamete is contained in a pollen grain and the female ovum is located in the flower's ovary. The male and female gametes of a species join to form the first cell of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

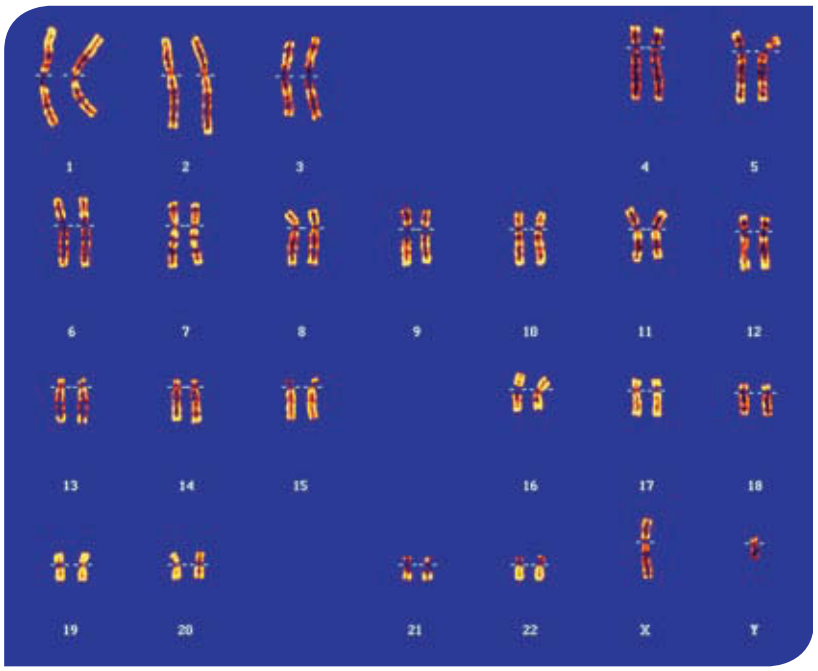
Gametes differ from all other body cells because they contain half the number of chromosomes of body cells—they are **haploid**. Gametes have twenty-three chromosomes, so the chromosomes are not in pairs. The nuclei of **somatic** (body) human cells contain forty-six chromosomes arranged into twenty-three pairs. One member of each pair has come from the female parent and the other from the male parent via the gametes. We can also say that the somatic cells contain two sets of chromosomes and that they are **diploid** (in pairs or two sets).

When gametes are produced (by a process called **meiosis**), it is likely that the one set of chromosomes in the gametes consists of a mixture of the maternal (mother's) and paternal (father's) chromosomes in that person's cells.

The only destiny for a gamete is to meet with another gamete and fuse or join with it to make a new cell called a **zygote**. This is called **fertilisation**. The zygote will be diploid because it contains two sets of chromosomes, one from each gamete. Therefore, the original number of chromosomes is restored again in the body cells of the new organism (offspring).

→ Figure 4.19 (a) A diploid body cell and (b) a haploid gamete.





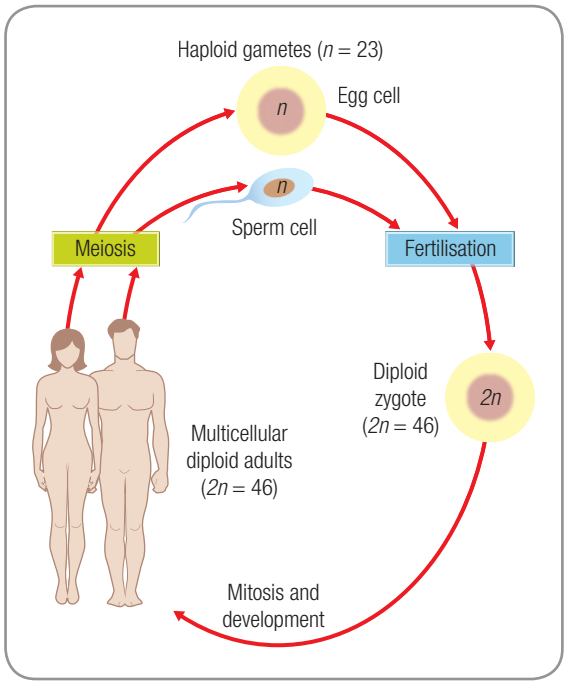
→ Figure 4.20 Pairs are often referred to by numbers according to their size—the largest pair is number 1. When the chromosomes are ordered in their pairs, the finished display is called a **karyotype**.

Chromosomes and the genes situated on them are made of DNA. Thus, fertilisation involves the passing of DNA from parents to offspring. Because DNA carries the instructions for life, fertilisation involves the passing of genetic characteristics from one generation to the next.

What do you know about passing DNA to offspring?

1. What is fertilisation and why is it important for a species?
2. We all commenced our lives from our first cell, the zygote, which then grew into an embryo. What type of cell division is involved in the growth of a zygote into an embryo? Explain your answer.
3. What is the difference between a haploid cell and a diploid cell? Give an example of each.
4. Are the offspring of sexually reproducing organisms identical to their parents?
5. What is asexual reproduction? Are the offspring produced asexually identical to their parents? Why or why not?
6. 'Your parents had nothing to do with each other genetically. You represent the combination of their genes.' Do you agree with this statement? Discuss.

→ Figure 4.21 The human life cycle, involving mitosis and meiosis.

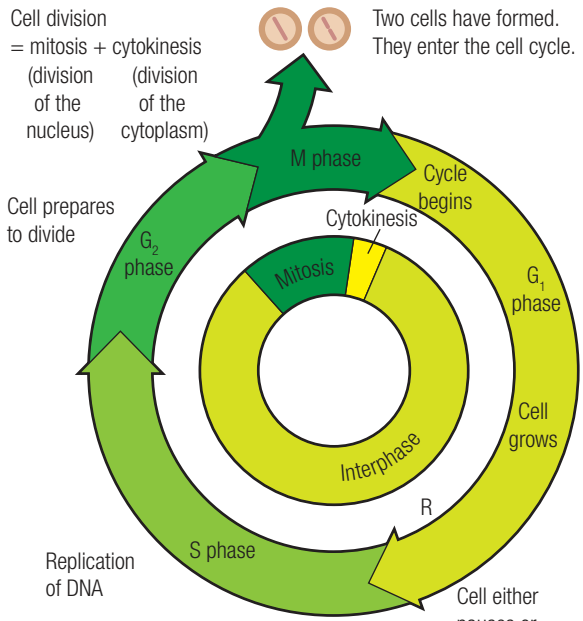


Mitosis and meiosis

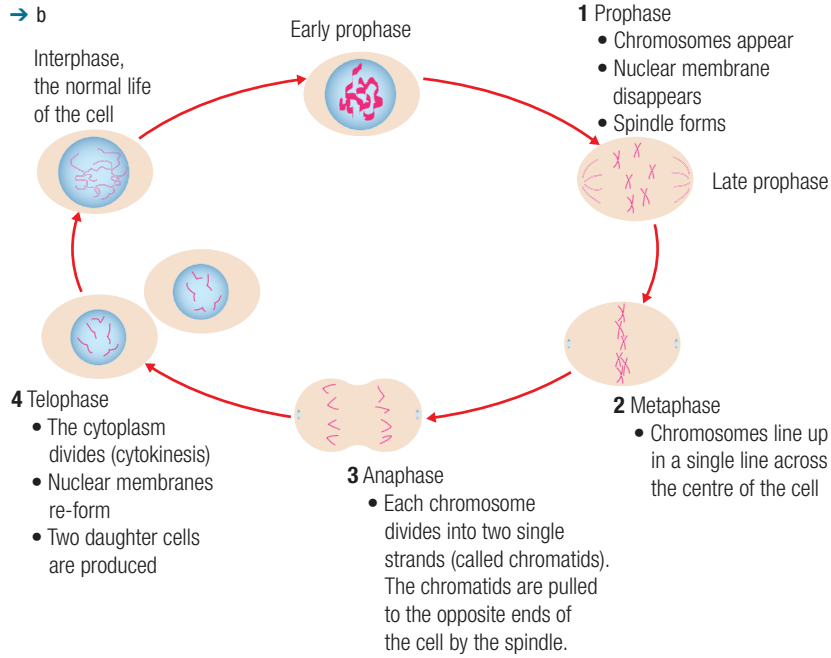
Mitosis is a type of cell division that does not involve a change in the number of chromosomes. Mitosis occurs during the growth and repair of cells and in asexual reproduction (reproduction without gametes and fertilisation). In mitosis, the cell divides into two, so one cell (**parent cell**) becomes two cells (**daughter cells**). The daughter cells are identical to the parent cell. Every cell in your body, except sex cells or gametes, arises through this process.

→ Figure 4.22 Mitosis. (a) The cell cycle. (b) Interphase and the phases of mitosis.

→ a



→ b



Meiosis is a special type of cell division in which the number of chromosomes is halved. Meiosis occurs only when gametes are being made. It is sometimes called **reduction division** and occurs in two stages, known as meiosis I and meiosis II.

PRACTIVITY 4.2

Cell division in action

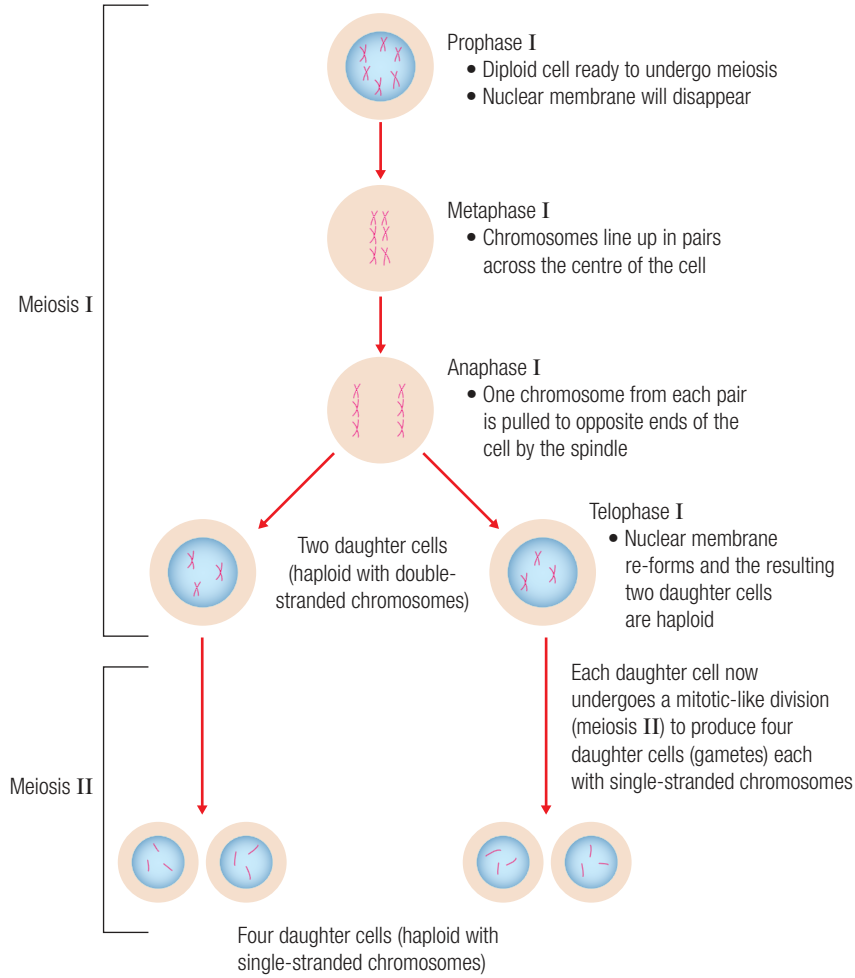
What you need: prepared microscope slide/s showing a tissue that is in the process of growth and development, light microscope

Alternatively, you could prepare your own slides from the growing root tips of a plant, such as garlic or spring onion.

1. View a prepared slide under the microscope at the greatest magnification possible.
2. In your field of view, identify the cells that are in interphase and those that are undergoing the other phases of mitosis.
3. Estimate the proportion of cells that are undergoing mitosis compared with those in interphase. Express this as a percentage and record it in your workbook.
4. Sketch at least four cells undergoing different stages of cell division. Remember the conventions for drawing biological images under the microscope. Clearly label all the components within the cell that you can identify correctly.

- DNA is visible under the microscope during interphase but not as individual chromosomes. Find out what DNA is called in this less tightly wound form.
- What might be an advantage for DNA being tightly wound during mitosis?
- Describe the possible consequences for a cell if errors occur during the process of DNA replication that occurs during interphase.
- Find out the actual time for a typical cell (e.g. a skin cell) to undergo the process of cell division.
- Explain the significance of mitosis for an organism.
- Explain the significance of meiosis for an organism.
- Suggest whether the cells you viewed under the microscope were likely to be undergoing mitosis or meiosis. Justify your answer.

➔ Figure 4.23 Meiosis consists of prophase II, metaphase II, anaphase II and telophase II, and is similar to mitosis, as shown in Figure 4.22. If a gamete is fertilised, the chromosomes of the zygote will become double stranded again so that it can grow (by mitosis) into an embryo.

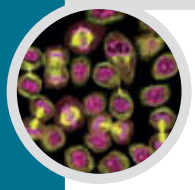


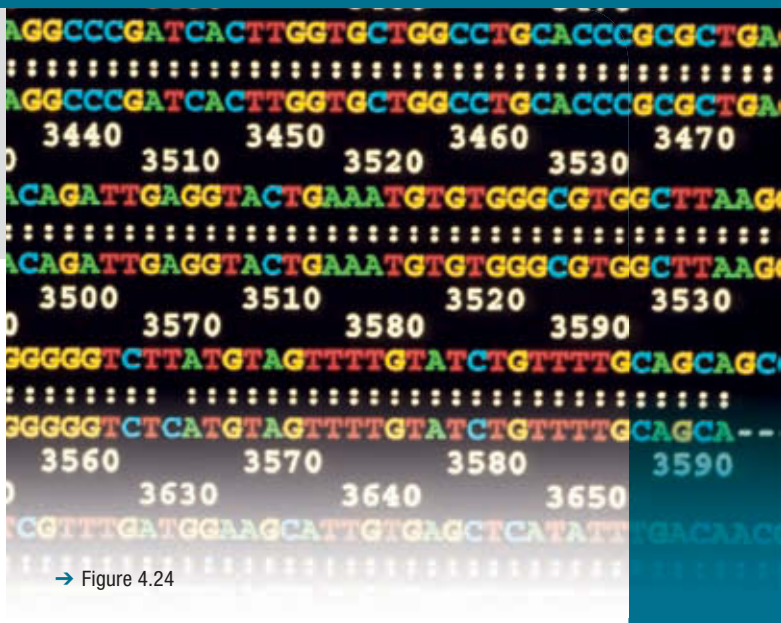
What do you know about mitosis and meiosis?

1. Prepare a table showing the similarities and differences between mitosis and meiosis.
2. Which of the following organisms will have meiosis as part of their reproduction? (Research, if unsure, and give reasons for your choices.)
   - **a** frog
   - **b** bacterium
   - **c** whale
   - **d** yeast
   - **e** fish
3. Interphase is the 'normal' life stage of the cell—the stage between one mitotic division and the next. Interphase also occurs between meiotic divisions. What important process involving DNA occurs during interphase and why does it occur?
4. Why is it essential that the number of chromosomes is halved during meiosis?
5. Research when scientists first saw chromosomes (during cell division) under the microscope. Write a short report.

4.1

What is DNA?





→ Figure 4.24

Remember and understand

1 What do the following abbreviations stand for?
- **a** DNA
- **b** mRNA
- **c** RNA
- **d** tRNA

2 Name the four nucleotides found in:
- **a** DNA
- **b** RNA.

3 Use the terms ‘gametes’ and ‘fertilisation’ to explain how DNA is transferred from one generation to the next.

4 Relate a chromosome to a molecule of DNA and explain how the replication of DNA is important for both mitosis and meiosis.

5 Describe three differences between the structure or function of DNA and RNA.

6 Use words and/or diagrams to explain the differences between each of the following pairs of terms:
- **a** base and codon
- **b** diploid and haploid.

Apply

7 If a gene contains 600 nitrogenous bases, how many amino acids would be incorporated into the resulting protein?

8 Which of the following is not a function of mitosis?
- **a** replenishing the epithelial cells of the small intestine that are shed daily
- **b** forming new red blood cells to replace those that are worn out
- **c** forming cells for sexual reproduction
- **d** repairing cuts and abrasions of the skin.

Analyse and evaluate

9 Does a chromosome or a gene provide the most information about the make-up of an individual? Explain the reasons why.

Critical and creative thinking

10 Create a teaching resource that could be used to teach a Year 7 student about the process of cell division.

CONNECTING IDEAS Diversity and evolution

11 Haemoglobin is a protein that plays a crucial role in the functioning of the human body. Conduct some research to answer the following questions about this vital molecule.
- **a** In what type of cells would you find haemoglobin?
- **b** Describe the role of haemoglobin within the body.
- **c** How many polypeptide chains make up a single haemoglobin molecule?
- **d** Draw a labelled diagram of the structure of a haemoglobin molecule.
- **e** What is the significance of the iron-containing groups within the molecule?
- **f** Suggest five ways in which haemoglobin is different from myoglobin, another important human protein.

How is DNA inherited?



Just how significant is our genetic code? Which characteristics of our make-up are determined by genes and their DNA code? When the relationship between DNA and the genes on chromosomes was established, it paved the way for a greater understanding of genetics. That, combined with the genetic crosses pioneered by Gregor Mendel, has answered many questions. Scientists now have a greater understanding of how our genes function and can also make inferences about the influence of our environment on genetically determined characteristics.



<DISCOVERING IDEAS>

Genes versus the environment

It is often said that successful gardeners have a 'green thumb', but what difference does the right type of plants make? If you obtain healthy plants with genes suited to the environment, will such plants grow regardless of how they are treated?

Challenge

Your task is to design an experiment to investigate the effect of the environment on a plant's growth.

Questioning and predicting

Select a plant, such as a geranium, where a new plant can be easily generated from a cutting from the parent plant. This process is known as propagation and is, essentially, asexual reproduction.

- How many parents are involved?
- How does the parent plant compare with the offspring?
- What other factors need to be considered when selecting a plant for investigation within the science laboratory?
- Which factors within the environment are you going to investigate (e.g. amount of water, quality of water, amount of light, type of light, soil quality, soil additives, levels of oxygen and carbon dioxide in the air)?
- How many plants will you test? What effect will this have on the reliability of your results?

Planning and conducting

- Write a list of all the equipment required.
- What method will you use? Consider details such as how long the investigation will run and how the results will be collected and presented. The design of the experiment should enable you to draw some conclusions about the significance of a plant's genes and environment.
- Which factor will be the independent variable and which factor will be the dependent variable in the experimental design?
- How will you present your results?

Processing, analysing and evaluating

1 What have you learned about the effect of genes and the environment on your plant's growth? How did these affect its appearance?

2 Can you extrapolate these conclusions to a wider variety of organisms?

Communicating

Present your experiment in an appropriate format.

Gregor Mendel's contribution to genetics

Gregor Mendel was a monk and a mathematics teacher whose hobby was performing scientific experiments on the pea plants in his garden. Most of his experimental work was done in the 1850s. His success in obtaining results that he could analyse and use to make predictions was because:

- he studied a large number of characteristics in the plants
- he carried out a large number of crosses
- he used pure breeding lines.

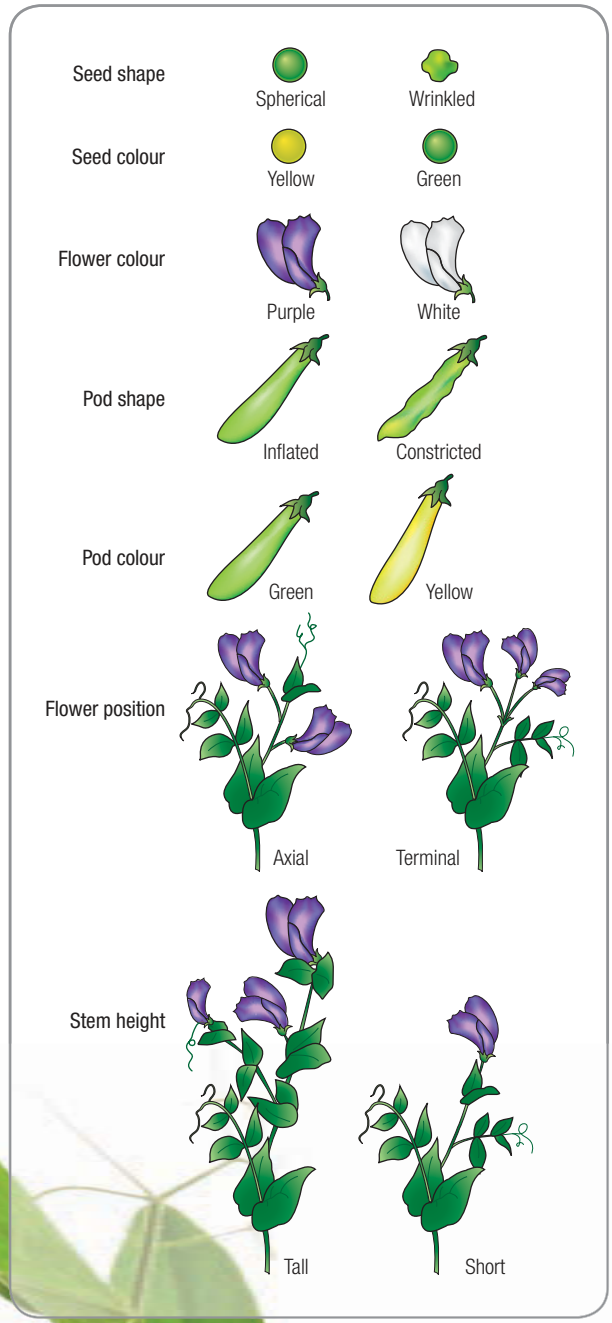
What did Mendel do?

Mendel obtained pure breeding lines for each of seven characteristics he noted could be easily recognised in the pea plants and occurred in only one of two forms (Figure 4.25). He continuously interbred these pure breeding plants and they always produced offspring that were identical to the parents. ('Pure breeding' means that an organism contains only one type of gene for a characteristic and will always produce identical offspring when interbred.)

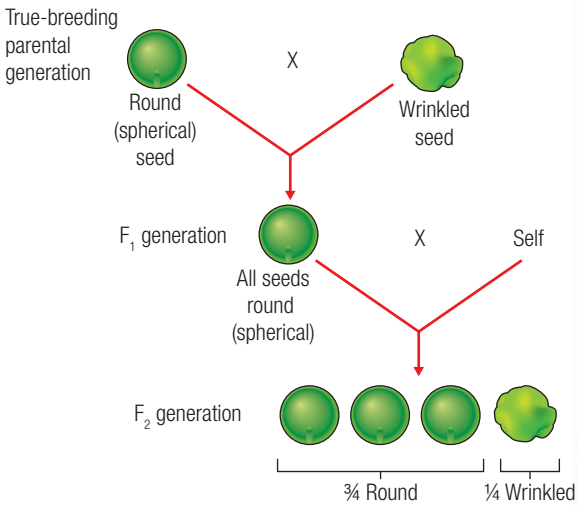
Take the characteristic of pea seed shape: either round or wrinkled.

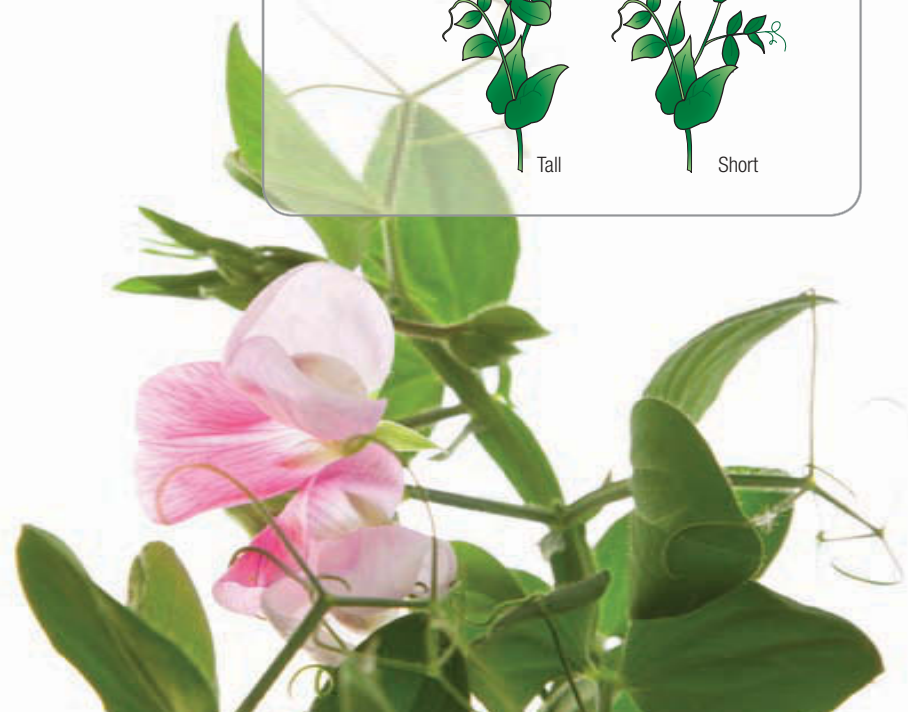
1. Mendel bred two groups of pure breeding pea plants, one with the gene for round seeds and the other with the gene for wrinkled seeds. These he called the P or parental generation.
2. He crossed the pure breeding plants for round seeds with the pure breeding plants for wrinkled seeds. He did this by manually transferring the pollen grains from one flower to another. The offspring were all round (spherical) pea plants. They were known as the F_1 or first generation.
3. Mendel then allowed the round F_1 plants to interbreed to produce an F_2 generation. In the F_2 generation, Mendel obtained both round and wrinkled offspring at a ratio of three round to one wrinkled. His ratios resulted in something like 296 round and 103 wrinkled, which is close to 3 : 1.

→ Figure 4.25 The seven traits, or characteristics, of pea plants studied by Mendel. Mendel focused on these seven pairs of traits and isolated each as a pure breeding trait before he began studying various crosses.



→ Figure 4.26 Mendel's experimental results using pea seed shape.





How did Mendel explain these results?

Mendel's explanations were amazingly accurate. With no microscope work and very few colleagues with whom to discuss the results, he made the following conclusions:

- two factors (we call them genes today) control each characteristic: one from the male parent and the other from the female parent
- each factor separates from the other factor before fertilisation and they recombine at fertilisation, but they do not blend.

He also made statements about the segregation (separation) of the factors with respect to each other. These conclusions became two fundamental laws of genetics.

The law of segregation

There are two factors, or units, in all sexually reproducing organisms that control each characteristic. During reproduction these two factors segregate, one factor appearing in every gamete (e.g. in the ovum/egg and in the sperm/pollen). These factors recombine at fertilisation—they do not blend, but match together.

The law of independent assortment

When the pairs of factors separate/segregate they do so independently of other pairs of factors.

We now know that the second law applies in all cases except when the pairs of factors (genes) are linked (i.e. they are situated on the same chromosome). Mendel, by chance, did not study any linked genes and he did not know that genes are situated on chromosomes. We also know now that it is the chromosomes, with the genes on them, that segregate and not the individual genes.

Mendel's results and conclusions remained dormant until Sutton, Punnett and others revisited them about 50 years later. Using microscopic examination of the cell nucleus and modern genetics, this later generation of geneticists provided new insights into Mendel's earlier work.

What do you know about Gregor Mendel's contribution to genetics?

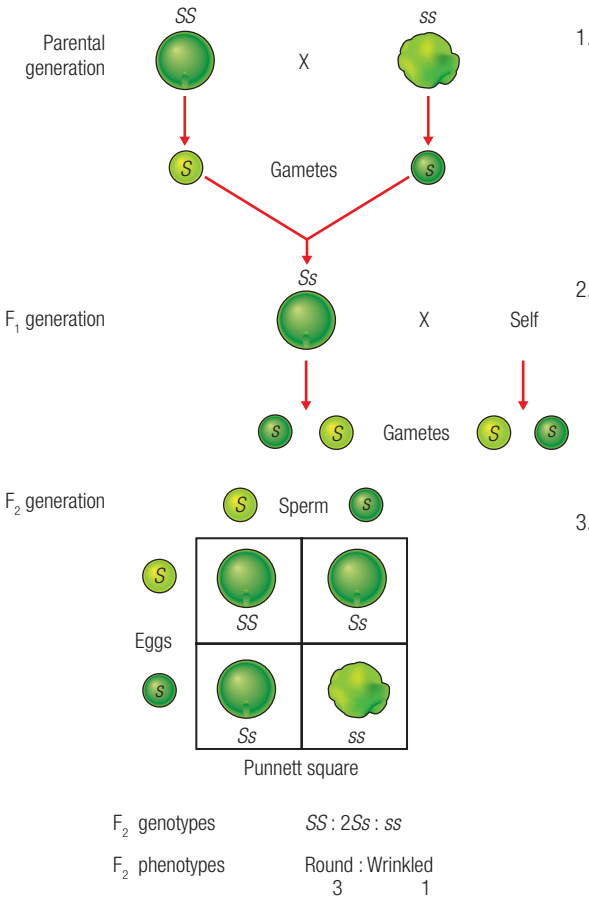
1. What are pure breeding organisms and how did Mendel produce them?
2. According to Mendel, how many genes, or factors, for a characteristic are present in the cells of each organism? Where do these genes, or factors, come from?
3. Name the process in the cell that segregates the genes (and the chromosomes).
4. When do the genes recombine?
5. Why did Mendel have such an influence on genetics?





Definitions in genetics

- A **gene** is a piece of a chromosome (DNA molecule) that codes for (contains information for) a characteristic. Genes can also be called pieces of chromosomes that control the synthesis of proteins or polypeptides.
- **Alleles** are corresponding members of a pair of genes (i.e. they are different types of the same gene for a particular characteristic). For example, for the gene for hair colour, one allele could be the gene for brown hair and the other allele could be the gene for red hair (there are other alleles, of course, for hair colour). Hence, alleles code for the same characteristic (in this case hair colour), but they may have different information for the characteristic. In the example given, one allele specifies brown hair and the other specifies red hair. So, alleles are different forms of a gene.
- **Homologous chromosomes** are corresponding pairs of chromosomes. Alleles are found on homologous chromosomes. One member of each pair is maternal (from the mother) and the other is paternal (from the father).
- A **gene locus** is the position of a gene on a chromosome.
- A **dominant trait** is a trait that only requires a single allele to be expressed. If the allele for brown eyes is dominant over the allele for blue eyes, it will always be expressed when it is present. This allele will always be shown by a capital letter.
- A **recessive trait** is only expressed if there are no alleles for the dominant trait present. If the allele for blue eyes is recessive to the allele for brown eyes, it will only be expressed when the allele for brown eyes is absent. This allele will always be shown by a lowercase letter.
- The **genotype** is the symbolic representation of the pair of alleles controlling a characteristic. For example, if the allele for brown eyes is *B* and the allele for blue eyes is *b* then a genotype for a brown-eyed individual could be *Bb*.
- The **phenotype** is the physical characteristic, such as black hair, or it could be an internal characteristic, such as a low level of insulin in the blood (as in a diabetic person).



1. Both parents are homozygous (*SS* and *ss*) and produce only one type of gamete (either all *S* from *SS* or all *s* from *ss*).
2. When a cross is made, it is the gametes that fuse. So, all the F_1 individuals will be *Ss*. Because spherical (round) is dominant to wrinkled, all the F_1 individuals will have spherical (round) peas.
3. When the F_1 individuals are crossed, it will be *Ss* crossed with *Ss* and both parents will produce two types of gametes, *S* and *s*. These gametes fuse to produce the F_2 generation and the genotypes of the offspring (F_2) can be obtained conveniently using a square developed by the geneticist Punnett, called a Punnett square. The gametes are placed on the Punnett square vertically and horizontally, as in the figure. The possible crosses, and resulting genotypes, are then found by putting the gametes together . In this way, the different phenotypes and their ratios can be easily determined.

➔ Figure 4.27 An explanation of Mendel's results in terms of genotypes, phenotypes, dominance and recessiveness. Note: *Ss* and *sS* are the same—it does not matter if it is the sperm or the egg that supplies the allele.

Monohybrid crosses

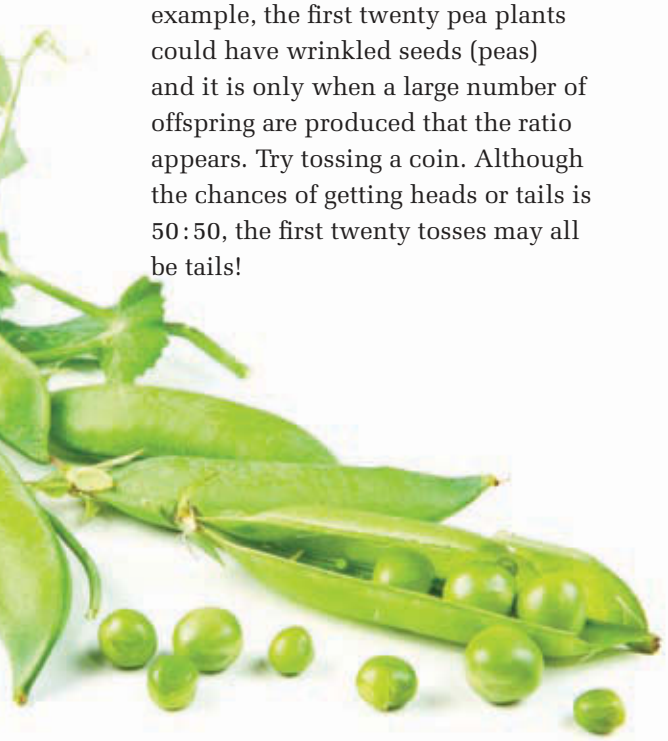
Many areas of study have their own jargon. For example, computers have brought many new terms into our vocabulary, such as 'software', 'hardware' and 'database'. Genetics has its jargon too. Consult the box of genetics definitions before moving on.



- **Homozygous** is the term used when the alleles are the same and is also known as 'pure breeding'. For example, the genotypes *BB* and *bb* are homozygous.
- **Heterozygous** is the term used when the alleles are different. For example, the genotype *Bb* is heterozygous.
- A **hybrid** is an organism containing heterozygous alleles for a characteristic being studied.
- A **monohybrid cross** is a genetic cross between two hybrid individuals when one (mono) characteristic is being studied. The cross of F_1 with F_1 individuals to produce the F_2 generation, which Mendel did, is a monohybrid cross.

We will now revisit Mendel's cross of round and wrinkled peas and show the genotypes and phenotypes. (Figure 4.27)

Note that these ratios only show the possibilities and not the order in which the offspring appear. For example, the first twenty pea plants could have wrinkled seeds (peas) and it is only when a large number of offspring are produced that the ratio appears. Try tossing a coin. Although the chances of getting heads or tails is 50:50, the first twenty tosses may all be tails!



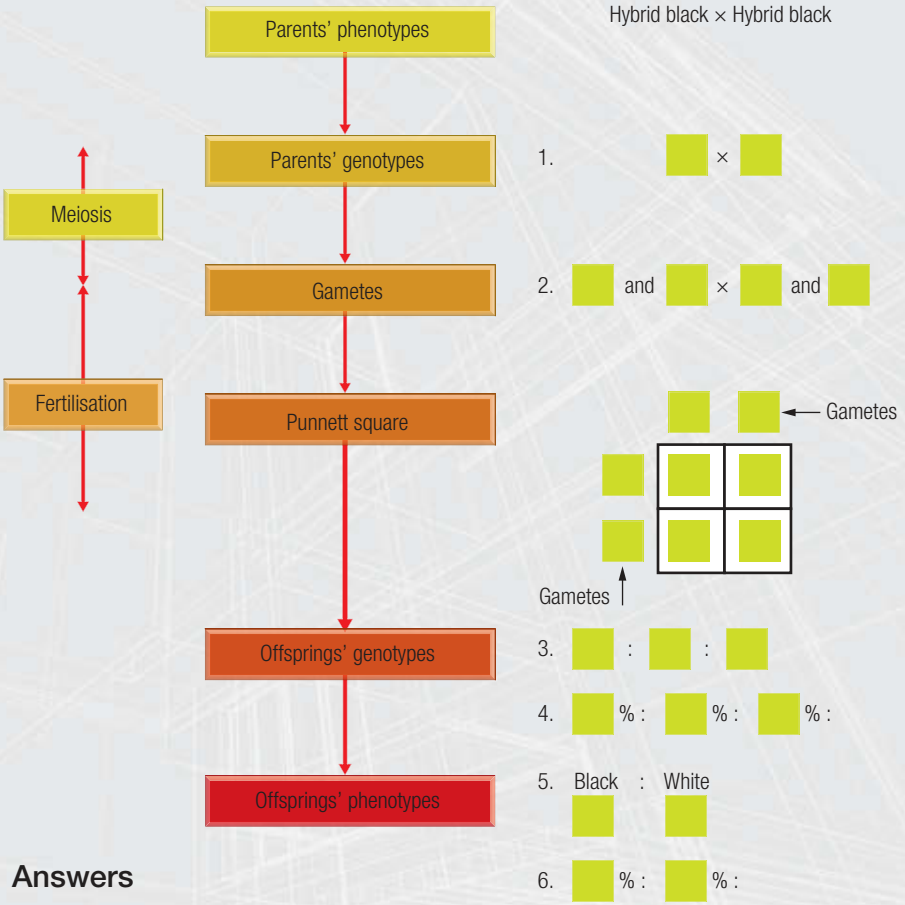
LITERACY LAB

Monohybrid crosses

Another example of a monohybrid cross is shown in Figure 4.28 for two guinea pigs heterozygous for black fur. The layout of the cross shown in this figure is considered the scientific convention.

Complete the following monohybrid cross, using Mendel's example in Figure 4.27 to assist you.

→ Figure 4.28 Monohybrid cross for hybrid black guinea pigs.



Answers

1. $Bb \times Bb$
2. *B* and *b* × *B* and *b*
3. *BB*: *Bb*: *bb*
4. 25%: 50%: 25%
5. 3:1
6. 75%: 25%

PRACTIVITY 4.3

Making more rabbits!



What you need: monohybrid cross problems and data below

Either alone or in a group of two, solve the problems and present your working clearly.

Problems and data

Rabbits on a small island are known to have the following alleles for genes:

B = big ears
b = small ears
H = hairy feet
h = smooth feet
Y = yellow fur
y = white fur
S = soft paws
s = sharp paws

1 Define 'genotype' and 'phenotype'.
2 Which alleles listed above are dominant and which are recessive?
3 Write possible genotypes for a rabbit that has: (a) big ears; (b) small ears; (c) hairy feet; (d) white fur.
4 Write phenotypes for the following genotypes: (a) *hh*; (b) *Yy*; (c) *SS*; (d) *ss*; (e) *Ss*.
5 Determine the possible genotypes and phenotypes of offspring born to parents that have the following genotypes:

	Father	Mother
a	*BB*	*BB*
b	*YY*	*Yy*
c	*Hh*	*Hh*
d	*ss*	*Ss*

6 For each of the answers to question 5, state the percentage chance of each genotype and phenotype occurring in the offspring.

PRACTIVITY 4.4

Investigating variation

What you need: several counters with stickers to simulate heterozygous genotypes

1 Consider the following traits:
   a eye colour
   b ability to roll tongue
   c left- or right-handedness
   d ear lobe shape
   e hairline shape

   Describe the variation that exists for each of these traits and record the allele symbol for each (use Table 4.2).
2 Copy and complete the table below by recording your own genotype and phenotype for each of the five traits. If you display the dominant trait, can you determine whether you are homozygous or heterozygous? If you are unsure, assume that you are heterozygous.
3 Working with a partner, determine the possible offspring that may result from a combination of your genotypes for each of the five traits. If both of you are homozygous for a trait, only one possible type of allele can be inherited from each parent. If either individual is heterozygous, you will need to flip a counter to determine which of the two alleles is inherited.
4 Use the counters to determine a second offspring with the same partner. Are the results the same or different? Can you suggest why?
5 Find a second partner and repeat steps 3 and 4. Are the results the same or different from those with your first partner? Can you suggest why?

Your trait	Eye colour	Tongue roll	Handedness	Ear lobe shape	Hairline shape
Genotype					
Phenotype					

- Provide an example of a genotype for which you (or another member of the class) were: homozygous dominant; heterozygous; and homozygous recessive.
- If you display a recessive trait, such as blue eyes or left-handedness, there is only one possible genotype. Can you explain why?
- One of the limitations of this activity is that, in reality, there are often many more variations of particular traits. Eye colour is a good example of this. Can you suggest why there are variations beyond just 'blue' or 'brown'?
- What does the percentage chance of a characteristic in offspring mean?
- What is the difference between a dominant characteristic in the phenotype and a recessive characteristic in the phenotype? For which of them is it possible to state the genotype?

What do you know about monohybrid crosses?

1 Dimples (*D*) is dominant to no dimples. Write the genotypes for individuals who are:
   - **a** homozygous for dimples
   - **b** heterozygous for dimples
   - **c** have no dimples.

2 If a right-handed man marries a left-handed woman and all their children are left-handed, does this mean that right handedness is dominant? Discuss.

3 A girl wants to check if her grey cat is heterozygous or homozygous. Assuming breeding was ethical and time efficient, what cross should she carry out? What results would she obtain if the cat is:
   - **a** homozygous?
   - **b** heterozygous?

4 The allele for blue eyes is recessive to the allele for brown eyes. What are the chances that two blue-eyed parents will have a brown-eyed child? What are the chances of two brown-eyed parents having a blue-eyed child?

5 Wavy hair in humans is dominant to straight hair. A wavy-haired man married a straight-haired woman and they had two children. The first child had wavy hair and the second child had straight hair. State the genotype of all four individuals and use suitable symbols to show your working.

6 Table 4.2 lists the alleles for a variety of common human characteristics. Use the table to list the genotypes of five individuals that are homozygous for a particular dominant trait, five that are homozygous for a recessive trait and five that are heterozygous for a trait. For each individual, state their genotype and phenotype in your list.



→ Table 4.2

Dominant trait		Recessive trait	
Description	Allele symbol	Description	Allele symbol
Brown eyes	*B*	Blue eyes	*b*
Right-handedness	*R*	Left-handedness	*r*
Ability to roll tongue	*T*	Cannot roll tongue	*t*
Rhesus positive (Rh^+) blood	*D*	Rhesus negative (Rh^-) blood	*d*
Free ear lobes	*F*	Attached ear lobes	*f*
Peaked hairline (widow's peak)	*W*	Straight hairline	*w*
Not red hair	*R*	Red hair	*r*
Mid-digital hair present	*G*	Mid-digital hair absent	*g*
Normal skin pigmentation	*A*	Pigmentation lacking (albinism)	*a*

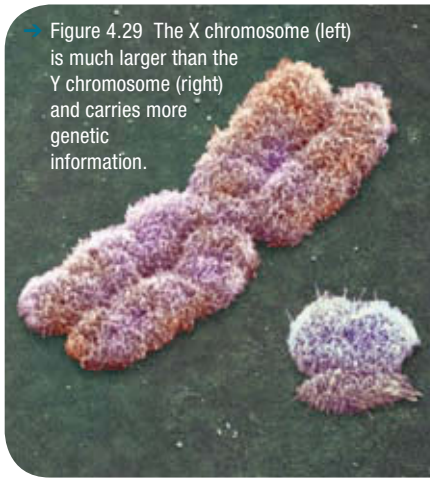
Sex linkage

In humans, there are twenty-two pairs of chromosomes that are not sex chromosomes (called **autosomes**). The twenty-third pair of chromosomes is the **sex chromosomes**. The genotype for the sex chromosomes in a female is XX and the genotype for a male is XY. These chromosomes contain the genes with information for sexual characteristics.

The X chromosome is larger than the Y chromosome. In addition to carrying genes for sexual characteristics, it contains information for non-sexual characteristics, such as blood clotting and red–green colour vision. Characteristics (and the genes that determine them) that are carried on a sex chromosome are said to be **sex linked**. Males show deficiencies in these genes more commonly than females because they only have one X chromosome.

In general, when investigating the pattern of inheritance for a particular trait (characteristic), it is useful to consider each trait as one of the following four:

- autosomal dominant
- autosomal recessive
- X-linked dominant
- X-linked recessive.



→ Figure 4.29 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.



→ Figure 4.30 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes, such as hairy ears. So only males have hairy ears!



→ Figure 4.31 A male gets his X chromosome from his mother and his Y chromosome from his father. A female gets one of her X chromosomes from her mother and the other from her father.

→ Table 4.3 The four patterns of inheritance

	Dominant	Recessive
Autosomal	• Males and females affected equally over a large sample size. • Affected offspring have at least one affected parent (i.e. does not skip a generation).	• Males and females affected equally over a large sample size. • Affected offspring may have unaffected parents (i.e. parents may be carriers).
X-linked	• Generally, more females than males are affected. • Affected offspring have at least one affected parent (i.e. does not skip a generation). • An affected father will pass the trait to all daughters, but not to any sons. • An affected mother has a 50% chance of passing the trait to any son or daughter.	• Generally, more males than females are affected; females are carriers. • Affected offspring may have unaffected parent/s (men cannot be carriers, but women may be). • A carrier mother has a 50% chance of passing the trait on to each son. • Daughters of an affected father will all be carriers.

Sex-linked conditions

Two conditions that are caused by defective sex-linked genes are red–green colour blindness and haemophilia.

Red–green colour blindness is an X-linked recessive trait (characteristic). The colour receptors in the retina of the eye are controlled by a gene on the X chromosome. When the gene is defective, the receptors do not function properly and the person cannot distinguish red from green. Approximately 8% of males and less than 1% of females have red–green colour blindness. It is very rare for a female to have two defective genes, but not so rare for them to be 'carriers' (heterozygous) of the defective gene.

Haemophilia is a disease that prevents the blood from clotting. This is because the X-linked gene that controls one of the clotting factors is defective. Even a small injury to a haemophiliac can result in prolonged bleeding. It is possible to treat this disease today because the clotting factors can be produced from blood donations or made in the laboratory. These clotting factors are given by injection.

In the past there was no treatment for haemophilia. Queen Victoria, the English queen, appears to have had a spontaneous mutation in the gene on the X chromosome for making a blood clotting factor. She passed this defective gene on to some members of her family.

Communicating sex-linkage

When writing genotypes for sex-linked crosses, it is important to show the allele as being attached to either the X or Y chromosome because the gender of the offspring is important in determining phenotype.

For example, in colour blindness, using X for normal and X^c for colour blindness, the genotype for a colour blind female is X^cX^c, the genotype of a carrier female is XX^c and the genotype for a colour blind male is X^cY.

In Queen Victoria's family, her granddaughter Alexandra was a carrier of the haemophilia gene and she married the last Tsar of Russia, Nicholas. They had four normal daughters and a haemophiliac son, Alexis. Alexis's disease caused great stress to the family. Alexandra even called in the monk Rasputin to pray over him, but there was no cure for haemophilia in the early 20th century.





➔ Figure 4.32 A person with colour blindness will have a very different view of the world.



➔ Figure 4.33 Queen Victoria's granddaughter Alexandra, her husband Nicholas (the last Tsar of Russia) and their haemophiliac son Alexis.

Key: *H* = normal gene and ***h*** = gene for haemophilia

Queen Victoria *Hh* × *HY* Albert

↓

Carrier daughter *Hh* × *HY* Her husband

↓

Alexandra (carrier granddaughter) *Hh* × *HY* Nicholas (last Tsar of Russia)

↓

Alexis (haemophiliac son) ***h****Y*

Note, X^H and X^h can also be used to symbolise the alleles on the X chromosome.

➔ Figure 4.34 Genotypes in the family tree of Queen Victoria leading to Alexis.

What do you know about sex linkage?

For the following questions, assume that the sex-linked gene is X-linked and recessive.

1. Why does a defect in a sex-linked gene affect males more than females?
2. A man and a woman, both of whom had normal sight, married and had three children, two boys and a girl. One of the boys had normal sight and the other was red–green colour blind. The girl had normal sight. Write the genotypes for this family.
3. The girl from the family in question 2 married a normal-sighted man and produced a son who was colour blind. Write the genotypes for this family.
4. The colour blind son from the family in question 3 married a normal-sighted woman and had a son with normal sight and a colour blind daughter. Write their genotypes.
5. What is the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia?
6. Who will be affected by a Y-linked gene? Explain.

Pedigree construction and analysis

Although each of your parents contributes to your genotype, the genotypes of other family members (e.g. grandparents, aunts and uncles) can all be important in explaining who you are. Inheritance of characteristics is often traced through families using family tree diagrams or **pedigrees**. There are specific symbols used in constructing pedigrees:

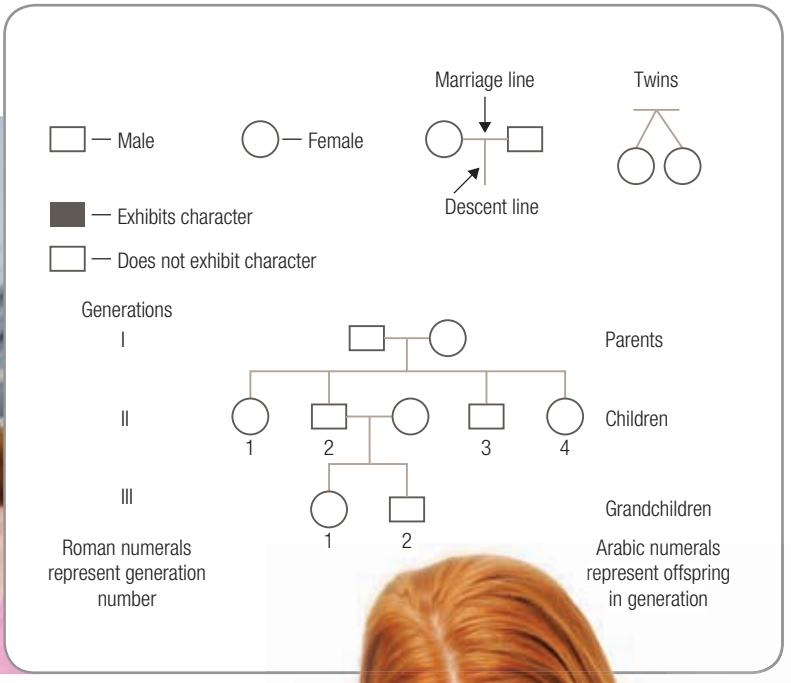
- males are represented by squares and females by circles
- a marriage is shown by a horizontal line; a vertical line leads to the offspring
- the characteristic being studied is shown by shading
- generation numbers are represented by Roman numerals and individuals by Arabic numerals.

When analysing a pedigree to determine whether an allele is dominant or recessive, the following rules can be used:

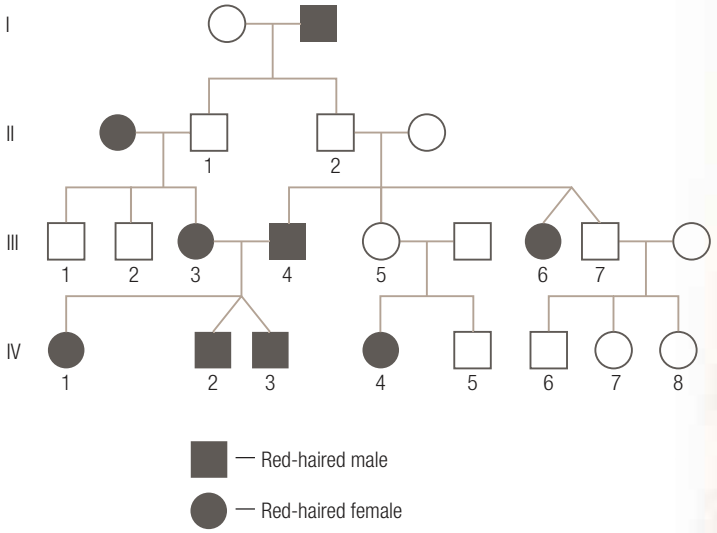
- If neither parent has a characteristic and some of their offspring have it, then it is recessive (i.e. both parents are carrying the recessive allele but not expressing it).
- If both parents have a characteristic and some of their children have it, then it is dominant (i.e. both parents are heterozygous).
- If both parents have a characteristic and none of their children has it, then it is dominant (because, if both parents have a characteristic and it is recessive, then all of their children will have it).

Hence, for the pedigree in Figure 4.36, red hair is recessive because individual II2 and his partner do not have red hair and some of their children have it. They are both carrying the allele for red hair, but not expressing it. They both contribute their allele for red hair to some of their offspring.





→ Figure 4.35 Some symbols used in family tree diagrams.

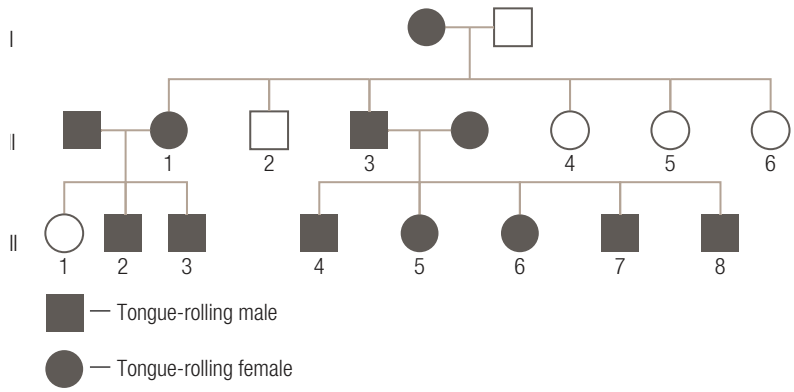


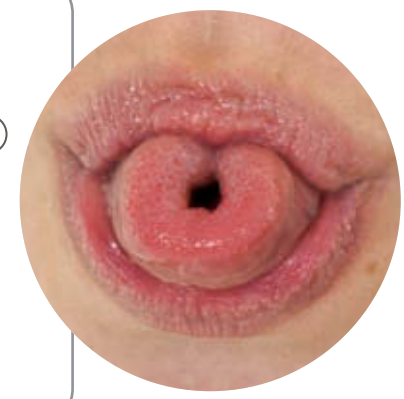
→ Figure 4.36 A pedigree for red hair.



→ Figure 4.37 A pedigree for tongue rolling.

In the pedigree shown in Figure 4.37, tongue rolling is dominant. This is because individual II1 and her partner are able to roll their tongues and some of their offspring can and some cannot. The parents are both heterozygous for tongue rolling.





ZOOMING IN

Dwarfism



Achondroplasia is the most common form of dwarfism and is inherited as an autosomal dominant trait (although spontaneous mutations can also arise with no prior family history). The gene is located on chromosome 4 and it controls the production of a growth factor receptor. Therefore, individuals with a defective gene will have dwarf stature. Most people with achondroplasia have normal intelligence and can lead independent and productive lives, although they may face potential medical problems that are dealt with as they arise.

Because the defect is dominant, those affected by achondroplasia have at least one affected parent. If one parent is affected, there is a 50% chance of the children being affected.

→ Figure 4.38 Achondroplasia is the most common form of dwarfism.

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Analysing pedigrees

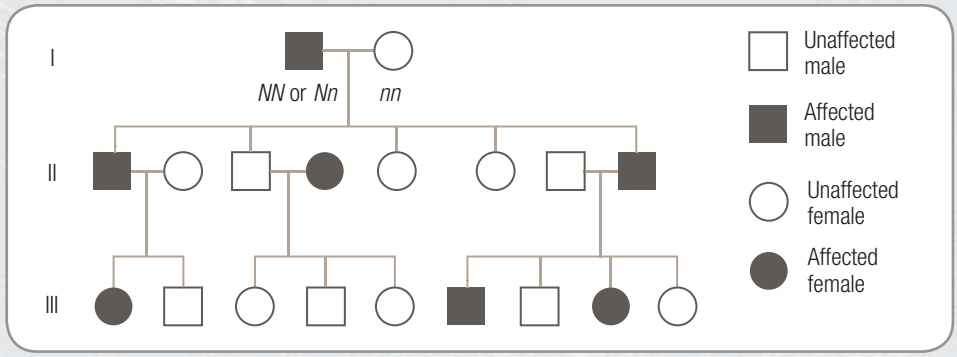
Pedigrees can be analysed to determine whether an individual will inherit a disease. Look at the family pedigree for the autosomal dominant disease achondroplasia shown in Figure 4.39. The father's genotype is either *NN* or *Nn* because he is affected, but the mother's genotype is *nn* because she is unaffected.

1 Based on the pedigree, is the father's genotype *Nn* or *NN*?

2 What is the chance that the parents (generation I) will have a child of normal stature?

3 What is the chance that the parents (generation I) will have a child with a dwarf stature?

→ Figure 4.39 The pedigree chart of a family affected by achondroplasia. Some of the children could be unaffected.

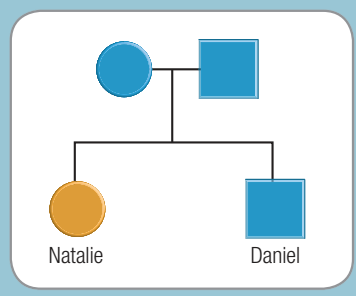


What do you know about pedigree construction and analysis?

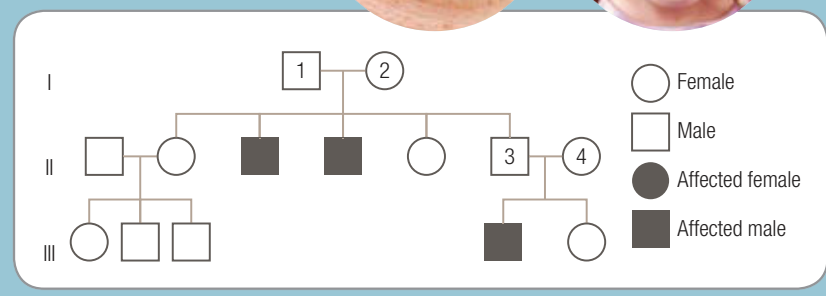


1 Some people have ear lobes that hang free and some people don't. Natalie has attached ear lobes but both Natalie's parents and her brother, Daniel, have free-hanging ear lobes (Figure 4.40).

→ Figure 4.40



→ Figure 4.41



a Is the characteristic of free-hanging ear lobes a dominant trait or a recessive trait? Explain your choice.

b Use suitable symbols to represent the alleles for the ear lobe gene, then write the genotypes of:

i Natalie

ii Natalie's parents.

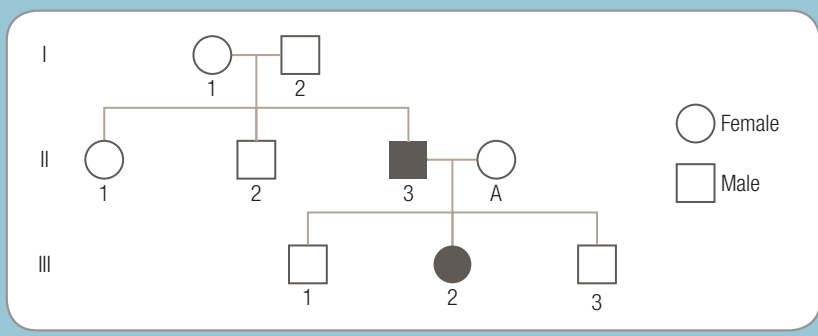
c What are the possible genotypes for Daniel?

2 A particular X-linked disease causes weakening of the muscles and loss of coordination. This often leads to death in childhood. A pedigree for this disease is shown in Figure 4.41.

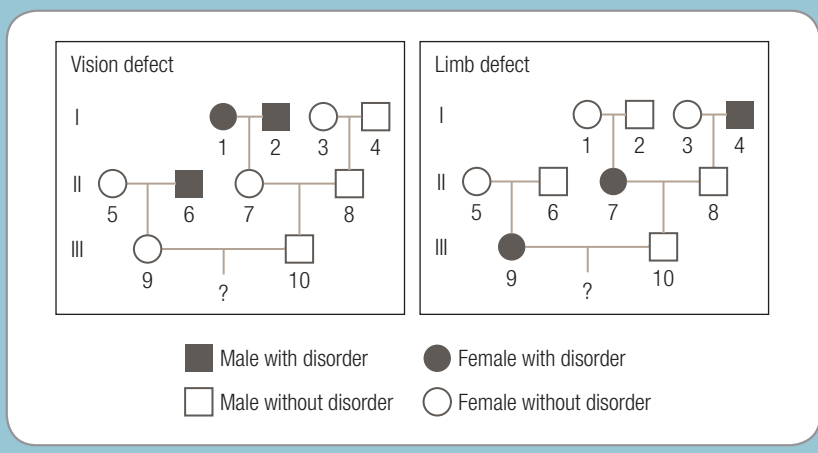
a Using this pedigree and suitable symbols, what is the genotype of individuals 1, 2 and 3? What must be the genotype of individual 4?

b What is a carrier? Identify one carrier in the pedigree shown in Figure 4.41.

→ Figure 4.42



→ Figure 4.43



3 Look at Figure 4.42.

a In this family pedigree, is the characteristic indicated by shading dominant or recessive? Explain.

b If *R* represents the allele for the dominant trait and *r* represents the allele for the recessive trait, write the genotypes for I1, I2 and person A.

c If A and her partner had another child, what is the chance of the child having the characteristic indicated by shading? Show your working.

4 The pedigrees shown in Figure 4.43 show the inheritance of two genetic disorders (vision and limb defects) in the same family.

a Is the allele responsible for the vision defect dominant or recessive? Explain your choice.

b Is the allele responsible for the limb defect dominant or recessive? Explain your choice.

4.2

How is DNA inherited?



Remember and understand

1 What is a monohybrid cross?

2 What were Mendel's conclusions from his work on breeding peas?

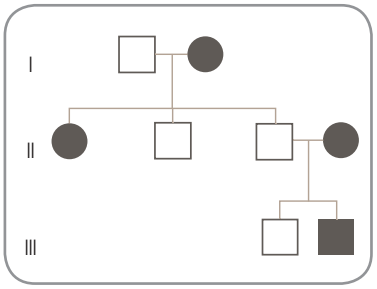
3 What is the difference between the following pairs of terms?

- **a** *autosome* and *sex chromosome*
- **b** *gene* and *allele*
- **c** *heterozygous* and *homozygous*

4 Explain in your own words what is meant by the following formula:

Phenotype = genotype + environment

→ Figure 4.44



Apply

5 What sort of information can be determined from the pedigree shown in Figure 4.44? List as many points as possible.

Analyse and evaluate

6 A newborn baby shows distinct facial abnormalities. A karyotype (Figure 4.45) was prepared to determine whether there were any chromosomal abnormalities.

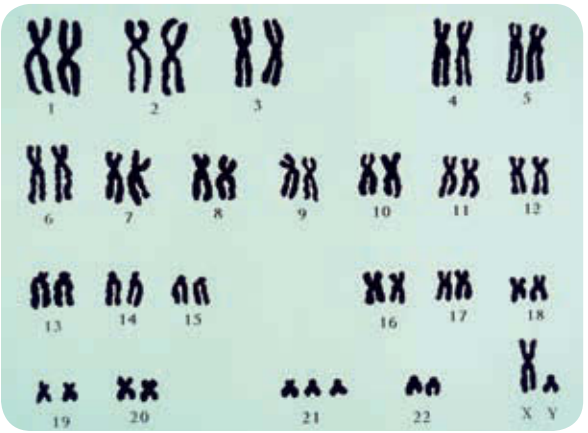
- **a** What is the total number of chromosomes shown?
- **b** Is the child male or female? How do you know?
- **c** As the geneticist, what would you advise the parents about the health of their baby?

7 If both parents have achondroplasia, what are the chances of their children being unaffected?

8 Find out about a genetic trait that is inherited as an autosomal recessive trait. Investigate the following:

- **a** the name and location of the gene responsible
- **b** the frequency of the disease in the population
- **c** diagnosis
- **d** symptoms
- **e** treatment.

→ Figure 4.45



Critical and creative thinking

9 Select a genetic disease and create a pamphlet for display in the reception area of a doctor's surgery. The pamphlet should outline information about the cause of the disease (gene or chromosomal abnormality), pattern/s of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.

CONNECTING IDEAS Diversity and evolution

10 Bowel cancer is a significant public health concern.

- **a** What sort of lifestyle choices may contribute to bowel cancer?
- **b** How does a family history of the disease affect an individual's chances of developing bowel cancer?
- **c** Which group of individuals are most at risk of developing bowel cancer?
- **d** Does genotype or environment play a greater role in developing bowel cancer?

4.3

How do humans use their understanding of genetics?



There has been an explosion of knowledge and understanding of genetics during the past 50 years—from the discovery of the structure of DNA to the ability to cut and paste it to suit ourselves. A key step has been the completion of the Human Genome Project in the early 21st century. A **genome** is the full set of genes in a species. The Human Genome Project determined the number of all human genes and their location and some of their base sequences. The genomes of other species have also been determined. Many genes have been found to produce more than one protein through mechanisms such as cutting and pasting of the mRNA before protein synthesis. The analysis of genomes from humans and other species, and the base sequencing of the genes, has been made possible by the development of fast computers. Other discoveries have also helped the new science of genetic engineering to take off.

DISCOVERING IDEAS

Genetics in your world

You have no doubt heard many stories in the media about aspects of genetic engineering. **Genetic engineering** is basically modifying genes in some way. It usually involves moving genes from one organism to another.

In small groups, brainstorm all the different examples you can think of in which genes have been modified for a particular reason. Consider the reasons why this work may have been done: was it to save lives? Or were the scientists more interested in simply seeing what was possible? Was there an element of entertainment to some of the examples? Did they only help the wealthy? Did they only affect humans? Did all the genetic engineering take place in a science laboratory?

Some images have been provided to get you started.

Share your group's thoughts with the class and keep the examples in your mind while you continue through this chapter.

→ Figure 4.46 Animals and foods can be genetically engineered to look a certain way.



The genetic revolution

In the past 150 years we have moved a long way from a world in which people believed that an entire human being inhabited an ovum or a sperm and the other gamete only kick-started it to develop. Nowadays nobody would believe these early attempts to clarify life. Mendel was the first investigator to make conclusions that identified what was 'really going on' in the nuclei of cells. His conclusions were considered amazing because he had so little equipment.

So what has changed? More equipment and dramatic developments in technology have had a major impact. There is also the cumulative effect of scientists working to decipher the events that occur at the microscopic level in living cells. Scientists build on the work that has been done by those before them and eventually the 'jigsaw' begins to make sense.

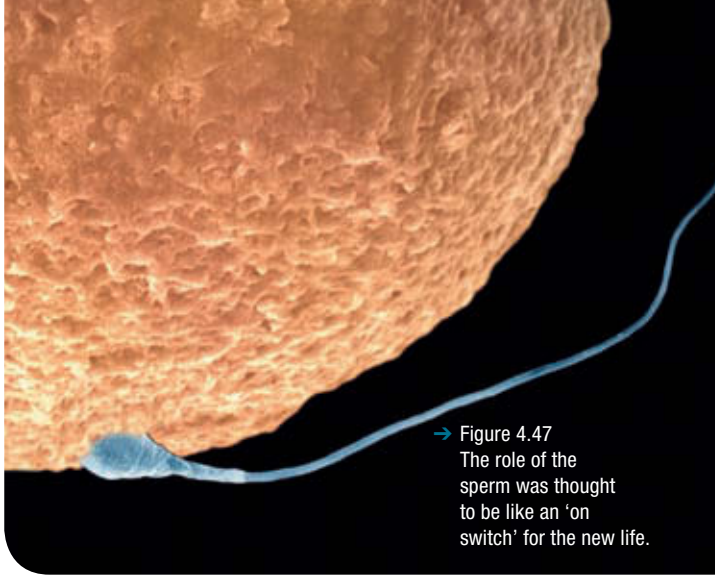
People like Sutton, Boveri, Punnett, Morgan and others in the 1920s made progress in understanding the location of genes on chromosomes. Where Mendel used the pea plant, Morgan used the fruit fly (*Drosophila melanogaster*) and his studies resulted in the discovery of sex linkage (see Figure 4.48). He and his team also spent numerous hours anaesthetising the flies and checking their eye colour and other characteristics. The result was that he established the relative position of many genes on the chromosomes. This is called gene mapping.





In one way, the fruit fly was not a convenient organism to research because it had to be put to sleep before it could be studied, but it was very convenient in another way because it only has four pairs of chromosomes (one pair are the sex chromosomes) and it breeds prolifically, producing a new generation every 2 weeks or so.

Work continued to determine whether it was the protein or the nucleic acid component of nuclei that made up the genetic material: the experiments of Griffith and Hershey and Chase established that it is the nucleic acid (DNA). Yet, despite some elegant work (such as the X-ray diffraction pictures of DNA by Rosalind Franklin), the exact structure of DNA remained elusive. Using the experimental results of others,



→ Figure 4.47 The role of the sperm was thought to be like an 'on switch' for the new life.



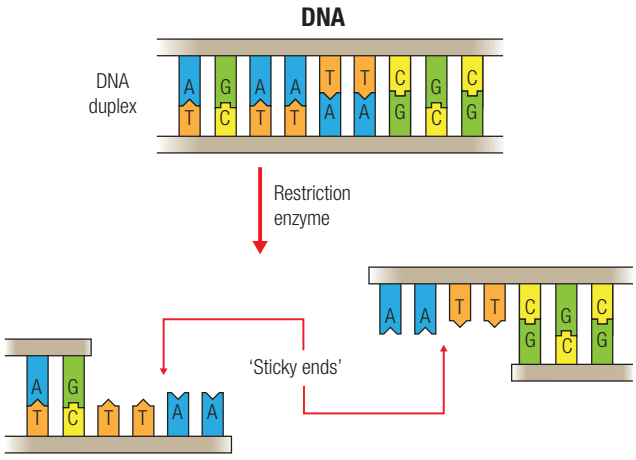
→ Figure 4.48 The fruit fly, *Drosophila melanogaster*.

Watson and Crick proposed the structure of DNA in 1953. This opened the door to the understanding of the genetic code and protein synthesis. At this stage, humans had not been able to manipulate genes by cutting and pasting them or transferring them between organisms (genetic engineering). This depended on one more big discovery—the restriction enzymes.

Restriction enzymes were first extracted from bacteria in the 1960s. Restriction enzymes are enzymes that can cut the DNA molecule at specific sites. Their natural role is to protect bacteria from foreign DNA (which they cut up and destroy). The bacteria's own DNA is protected from the enzymes by methylation (the attachment of methyl groups, which stops the restriction enzymes acting). These enzymes are called restriction enzymes because they restrict the growth of other organisms by destroying their DNA.



➔ Figure 4.49 Thomas Hunt Morgan in his fly room.



➔ Figure 4.50 Different restriction enzymes cut at different 'recognition' sequences.

Scientists saw the potential of the restriction enzymes for cutting DNA and removing genes. They used them with another group of enzymes called **DNA ligases**. The ligases attach or 'link' pieces of DNA together. Hence, scientists now had the tools—the scissors (restriction enzymes) and the glue (the DNA ligases)—for cutting and pasting genes from the chromosomes of one organism into another (and this could be between species). Genetic engineering had begun!

Impact of gene technologies

Genetic engineering and allied technologies have had a huge impact on life on Earth. Nowadays we can obtain many genetically engineered products, including:

- genetically modified (GM) tomatoes that can resist frost
- genetically engineered microbes that can clean up toxic waste
- genomic libraries (stored genes)
- human insulin produced by bacteria
- DNA fingerprinting to identify criminals or solve paternity cases
- gene therapy to insert a healthy gene to replace a defective gene (e.g. in cystic fibrosis).

There are also disadvantages of genetic engineering, some of which include:

- ethical issues around the source of some material (e.g. the use of human embryos)
- privacy issues resulting from access to human genomes (e.g. predisposition to a disease as determined by genome analysis)
- the potential spread of genetically modified crops to non-modified crops
- the drama of patents for discoveries and the argument that genes are not discoveries.

It is important for us all to be aware of these innovations because it is likely that they will have an impact on most of our lives at some time or another.



LITERACY LAB

Clarifying terms

What is 'genetic engineering'? It is the manipulation of genes by transferring them from one organism to another. The genes are cut out of the chromosomes of the donor organism and inserted into the chromosomes of the receiver organism. The two organisms may or may not be members of the same species. This area of genetics is sometimes spoken of under the general term **gene technology**.

The organisms with the new genes are called **transgenic organisms** and the genetic engineers are no longer working with natural genotypes. The transgenic organisms have artificially created genotypes.

What is **biotechnology**? It is the selection of specific organisms to make products that are beneficial to humans. These organisms may be entirely natural or produced by artificial selection (bred by humans) or produced by genetic engineering.

Define the bold terms above in your own words. You might like to construct a mnemonic or rhyme to help you remember them.

What do you know about the genetic revolution?

1. Distinguish between *biotechnology* and *genetic engineering*.
2. What are the 'scissors' and the 'glue' that are used in genetic engineering? How are they used?
3. Discuss the discovery or innovation you consider to be a key step in the development of genetic technology—and why.

Mutations and mutagens

A **mutation** is a heritable change in the structure or amount of the genetic material (DNA). A mutation is therefore a change in the DNA and it may be in one gene or in a number of genes (part or all of a chromosome). '**Heritable**' refers to the change being passed to offspring or 'inherited'.

If the change is in a single gene, then it is called a **genic** or **genetic mutation** and if it is in a chromosome it is called a **chromosomal mutation**.

Because DNA replication (and other similar genetic events) is a copying process involving huge numbers of base pairs, there are occasional mistakes and these are natural mutations. The base sequence (order of bases) in DNA is critical—a tiny change in the sequence changes the amino acids being coded for, which, in turn, may change the protein produced. This may then impact on the normal functioning of the organism. Although the aim of genetic copying is to preserve that order, occasional errors can occur. On many occasions these changes can be corrected or they do not cause a change in an important part of the protein that is coded for by the DNA. But on other occasions the results can be detrimental or even fatal.

There is a continuous low rate of natural mutations. However, environmental factors called **mutagens** can increase the frequency of mutations. Mutagens include chemicals, radiation and ultraviolet (UV) light.

Genetic mutations

There are two types of genetic mutations: (i) point or substitution mutations; and (ii) frame shift mutations.

A **point mutation** occurs when one base substitutes for another.

Consider the base sequence in DNA:

TAC ATG GCC GTG AAG

This sequence transcribes into the base sequence in mRNA:

AUG UAC CGG CAC UUC

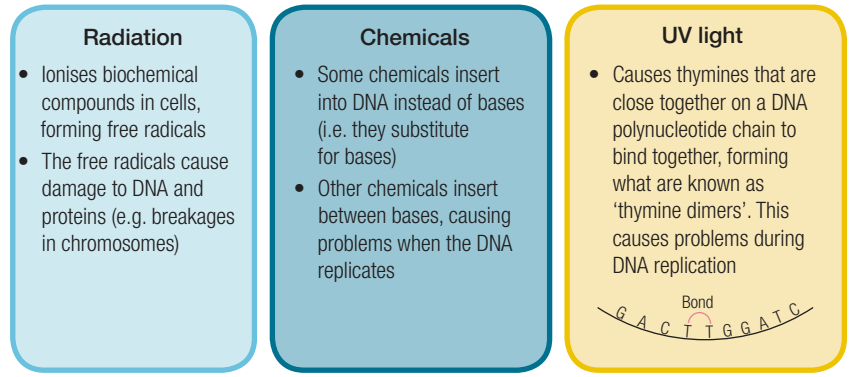
producing the amino acid sequence:

methionine–tyrosine–arginine–histidine–phenylalanine

One amino acid difference in a protein usually does not have major consequences. But there are a few exceptions, such as the disease sickle cell anaemia.

A **frame shift mutation** involves the addition or deletion (removal) of one or more bases from a base sequence.

→ Figure 4.51 The effect of mutagens.



→ Figure 4.52 The genetic code.

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gin	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gin	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met/Start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

➔ Figure 4.53 Haemoglobin and sickle cell anaemia—an example of the effects of a point mutation.

Let's take the same DNA sequence:

TAC A**TG** GCC GTG AAG

If the first two TG bases are removed (shown in bold) then the sequence will read:

TAC AGC CGT GAA G

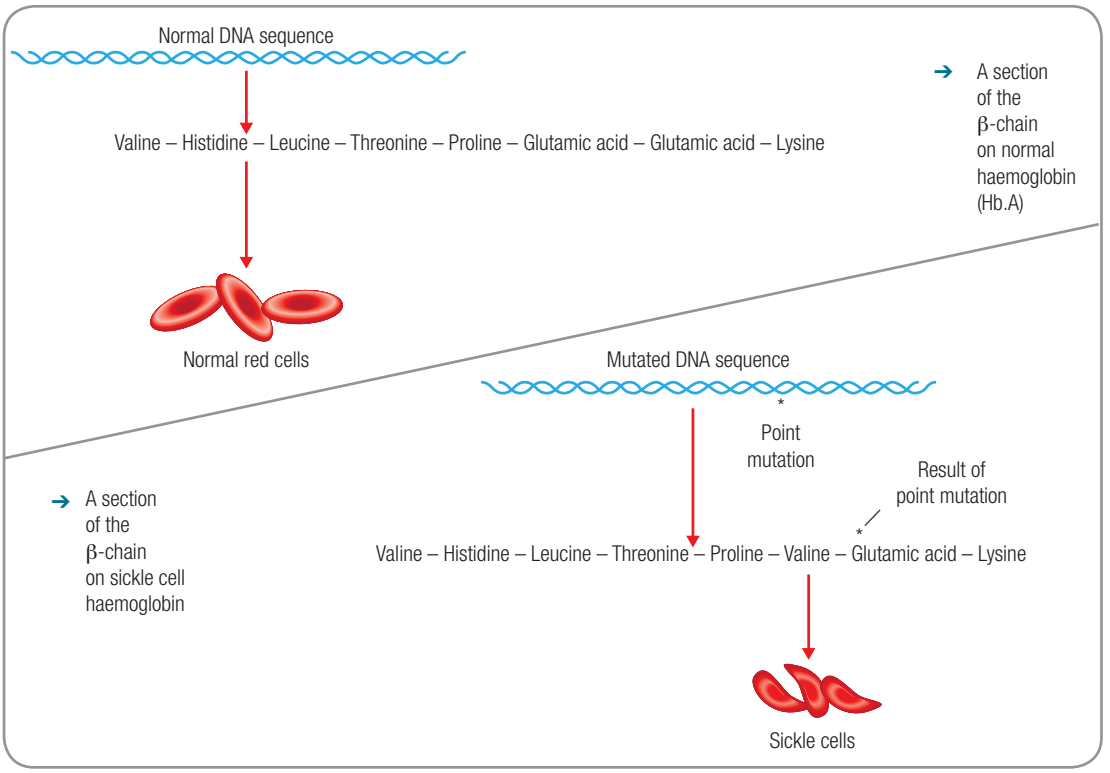
Then, the mRNA will be:

AUG UCG CGA CUU C

giving the amino acid sequence:

methionine–serine–arginine–leucine

This is different by more than one amino acid from the original and is therefore less likely to function properly in the cell.



Frame shift mutations have more damaging effects than point mutations because they change the entire reading frame of the DNA and RNA, producing quite a different protein. If the mRNA sequence reads UAC after the mutation, then this is a 'stop codon' and the polypeptide/protein synthesis will stop at that location, resulting in a shorter molecule that is very unlikely to be viable.

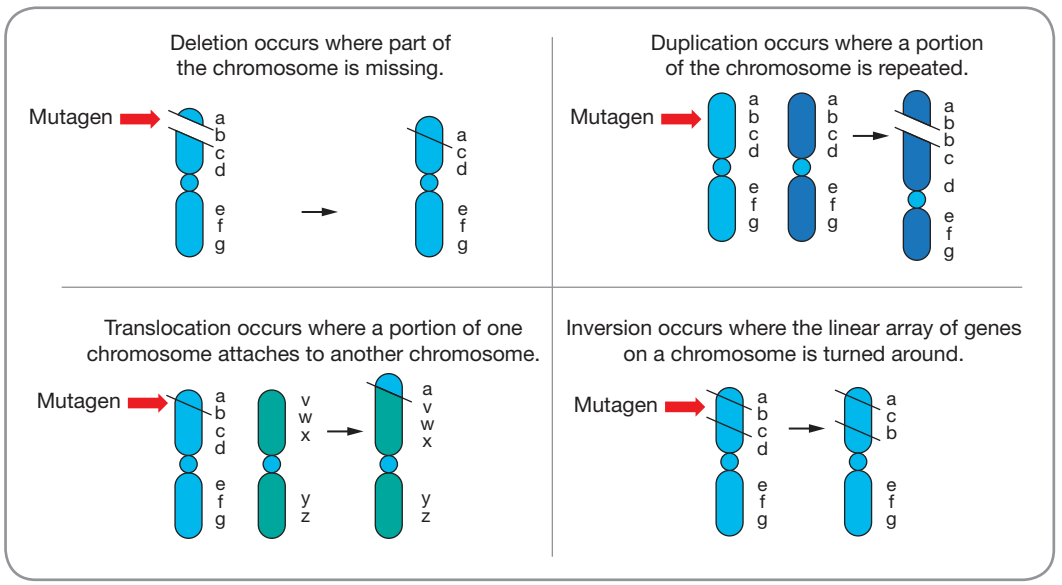
Chromosomal mutations

Chromosomal mutations are grouped according to changes in *structure* or changes in *number*.

Mutations involving chromosome structure

Four major alterations in chromosome structure may occur (Figure 4.54).

➔ Figure 4.54 Mutations involving changes in the structure of chromosomes: four major alterations may occur.

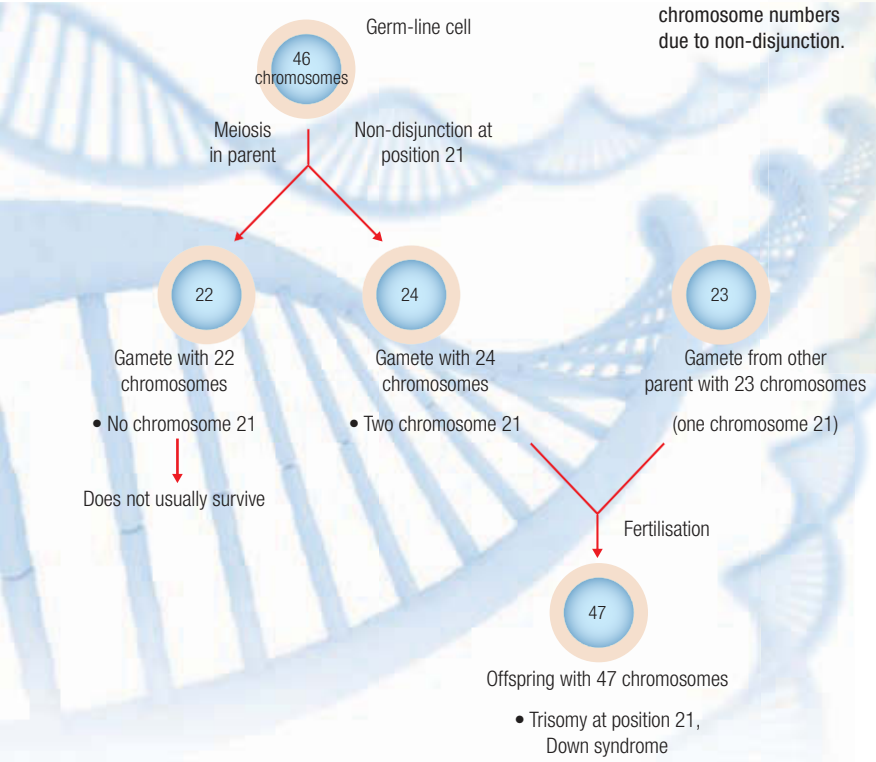


Mutations involving chromosome number

This type of mutation is usually the result of **non-disjunction**—the failure of a chromosome pair to separate during metaphase I in meiosis. In such cases, one of the daughter cells (gametes) will have too many chromosomes and the other will have too few chromosomes. If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

Down syndrome is the result of non-disjunction in chromosome pair 21 during the formation of the gametes in one parent (frequently the mother).

Klinefelter's syndrome and Turner's syndrome are caused by non-disjunction in the sex chromosomes.

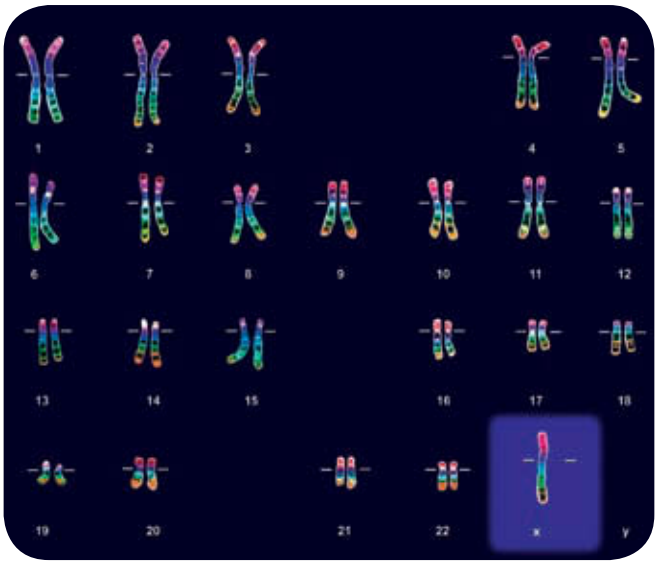


➔ Figure 4.55 Changes in chromosome numbers due to non-disjunction.



➔ Figure 4.57 An individual with Down syndrome.

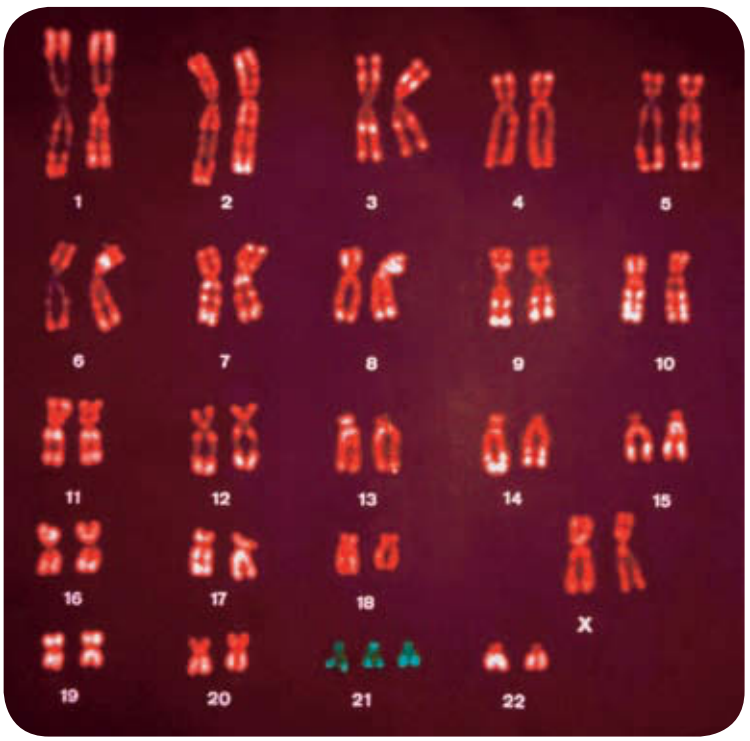
➔ Figure 4.58 Females with Turner's syndrome have only one X chromosome.



➔ Figure 4.59 Turner's syndrome can cause lymphedema (a swelling of the hands and feet).



➔ Figure 4.56 Individuals with Down syndrome have three copies of chromosome 21.



SKILLS LAB

Identifying mutations

1 A normal mRNA sequence is shown below, together with two different genetic mutations.

- Normal AUG ACG CAG AAU UGG GAU CCU ACG
- Mutation 1 AUG ACA CAG AAU UGG GAU CCU ACG
- Normal AUG ACG CAG AAU UGG GAU CCU ACG
- Mutation 2 AUG AGC AGA AUU GGG AUC CUA CGC

a Name the type of mutation represented in each case. Explain your answer.

b Describe the outcome of mutation 1 on protein synthesis. You may wish to consult the genetic code in Figure 4.52.

c Describe the outcome of mutation 2 on protein synthesis.

2 Genetic Creutzfeldt–Jacob disease (CJD) is caused by an abnormal protein called PrPc. This protein is formed because of a mutation in the *PrPc* gene on chromosome 20 and occurs in DNA base triplet 200 in the gene's sequence.

DNA base triplet number	199	200	201
Normal gene	TGG	CTC	CAA
Mutated gene	TGG	TTC	CAA

a What type of mutation is this?

b Describe the amino acid change that would occur in the PrPc protein.

c Distinguish between natural and induced mutation.

What do you know about mutations and mutagens?

1 How would you define a mutation?

2 What is a mutagen? Give some examples of mutagens and how they act to cause mutations.

3 What is a trisomy? Give an example of a trisomy in humans.

4 Do some research: find out about Klinefelter's syndrome and Turner's syndrome. Discuss your findings in small groups or in the class.

5 Can mutations ever be advantageous? Discuss.

Gene technologies in medicine

With the discovery of restriction enzymes and the use of DNA ligases, the enormous potential for genetic technologies became apparent. Genetic technologies use the cutting power of the restriction enzymes and the sticking power of ligases to remove genes from one organism and insert them into another. Therefore, new **transgenic organisms** can be produced, such as pigs that can produce more muscle or bacteria that produce a human protein that can be extracted and used to treat illnesses.



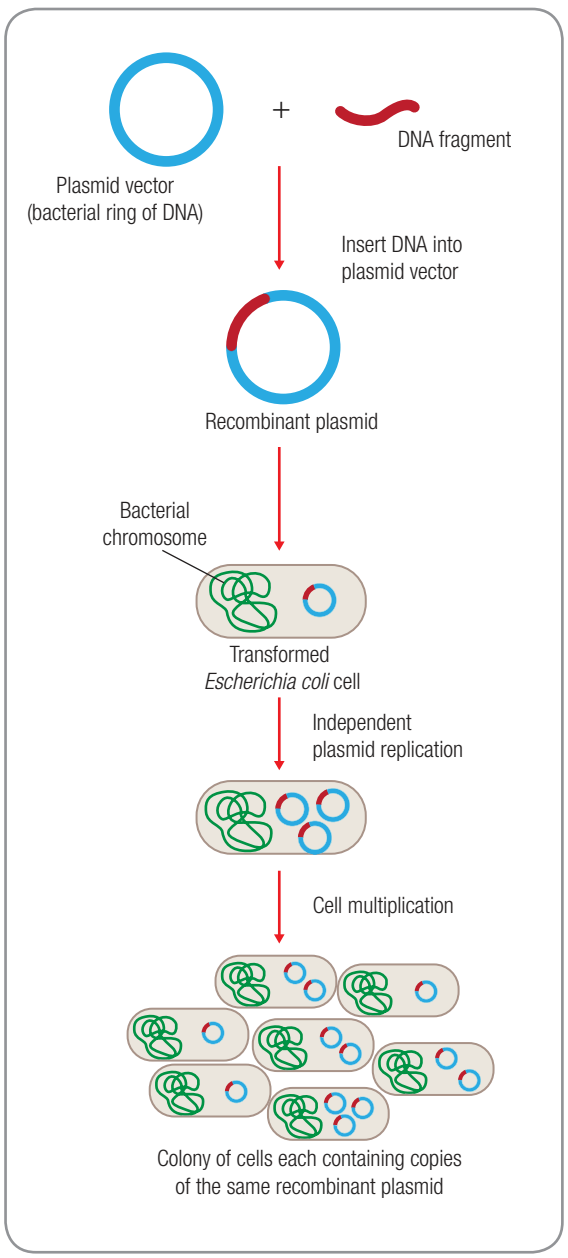
→ Figure 4.60 These transgenic pigs produce a human protein that is really important for blood clotting.

The scope of this work is enormous. Genes from other organisms can be cloned (copied) inside bacteria and then cut out of the bacterial chromosomes. The genes can then be purified and used to treat diseases, a process called **gene therapy**.

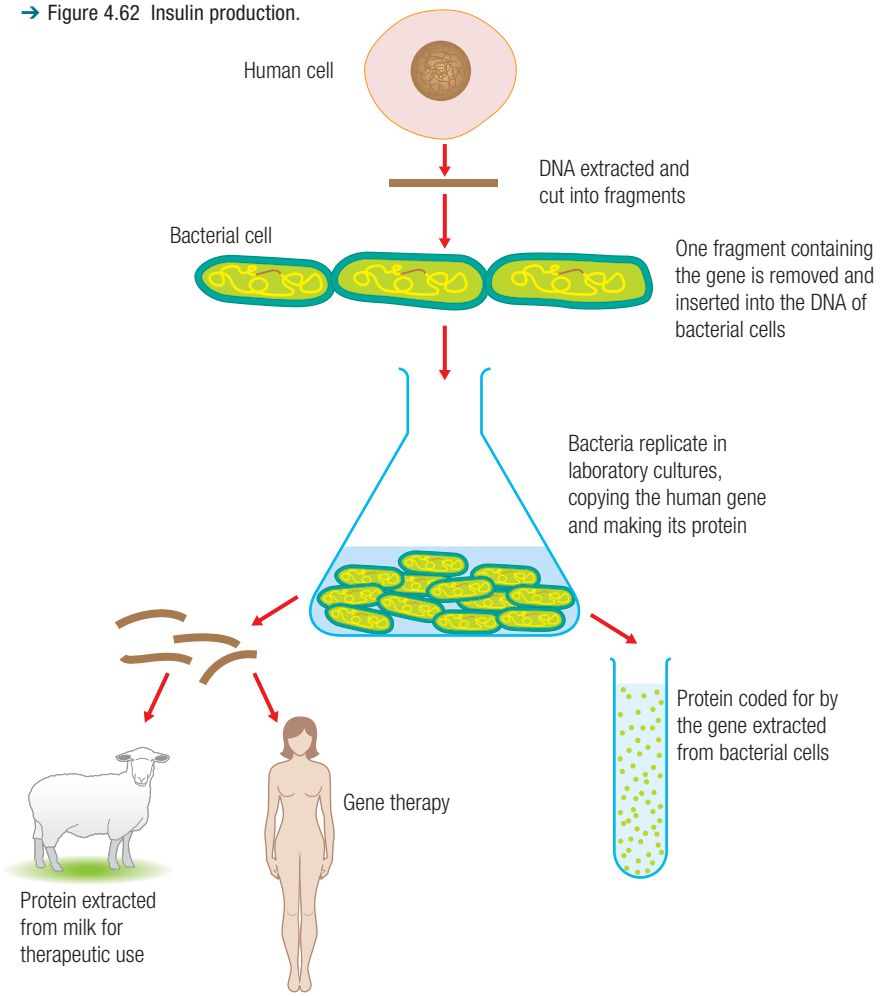
Another application of genetic engineering is for a gene, for example a human gene, to be expressed (activated) in bacteria so that the bacteria now produce a human product that can be purified and used to treat a human disease. This method avoids the rejection issues faced by using similar products from animals, such as pigs or sheep. An example is the production of human insulin by bacteria.

The use of fast, sophisticated computers has enabled scientists to determine the base sequence of DNA (**gene sequencing**). This knowledge can be applied to diagnose and treat disease because the location of the defective genes can be found quickly.

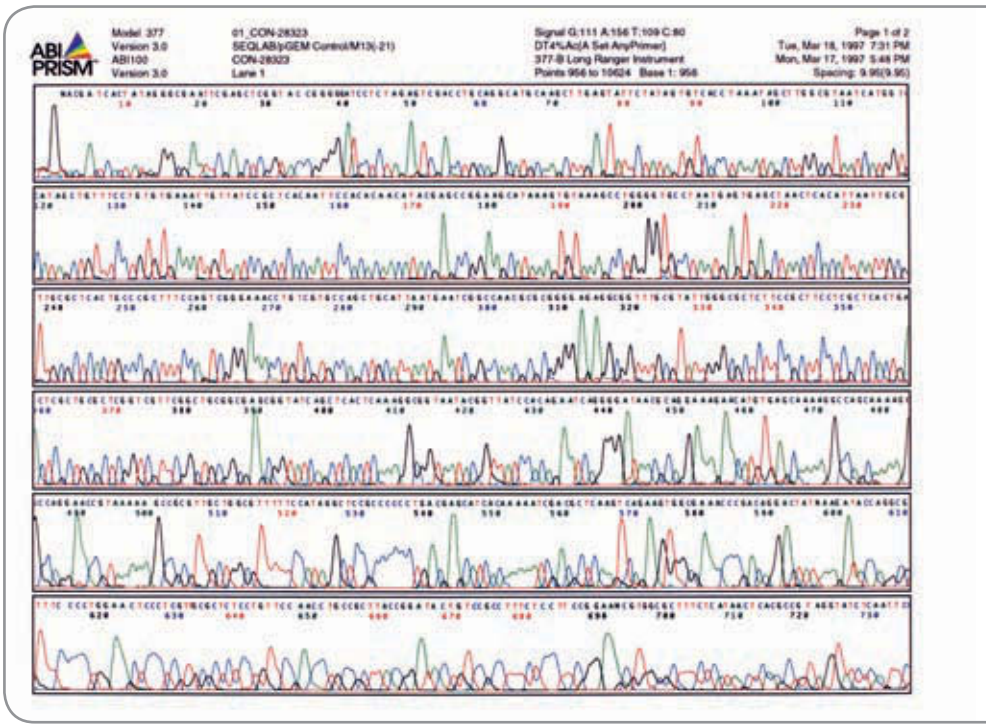
➔ Figure 4.61 Gene cloning.

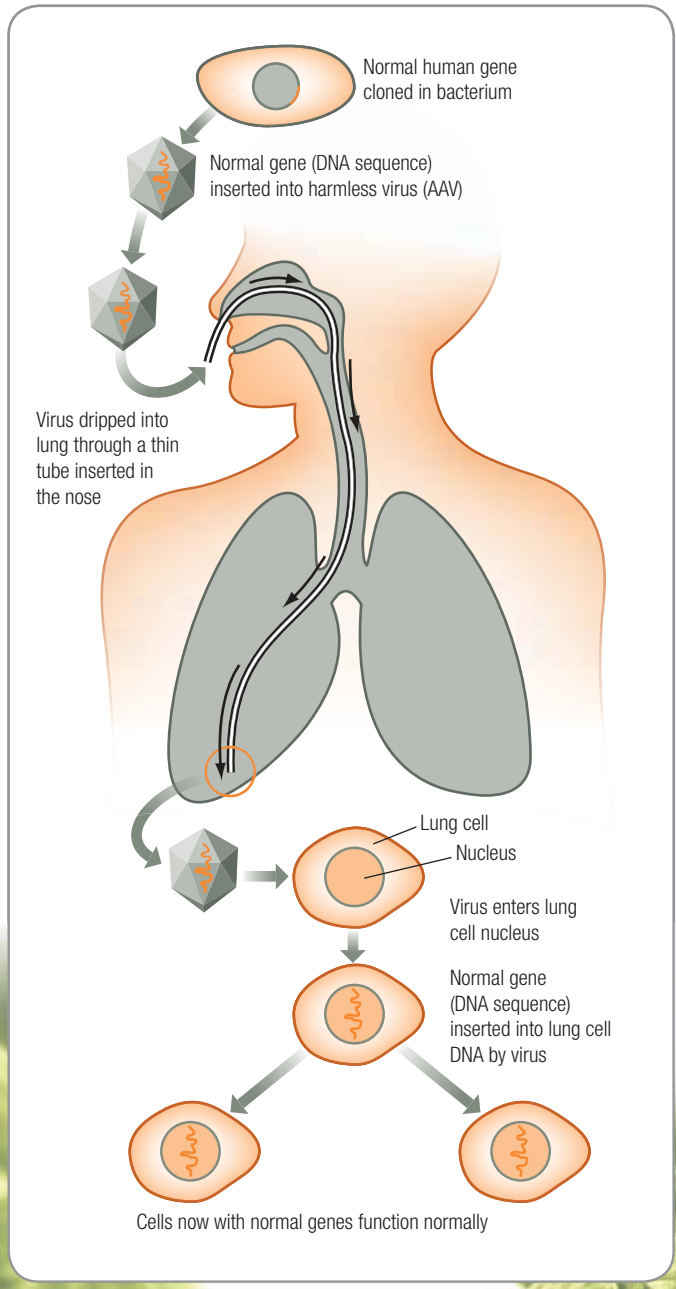


➔ Figure 4.62 Insulin production.



➔ Figure 4.63 To obtain a DNA profile of a person's genome, a sample of his/her DNA is placed in a DNA analyser and the sequence of bases is determined. The result appears as a series of peaks for each base, which is produced by a microcomputer within the analyser. This is called an electropherogram.





Gene therapy has been quite successful in the treatment of cystic fibrosis (CF). Patients with CF have a deficiency in a gene that controls the production of a protein that regulates the movement of ions across cell membranes.

A major symptom of CF is the accumulation of a thick mucus that can damage lung tissue. This reduces life span significantly.

Medical scientists have been able to clone the healthy gene in bacteria. The purified gene is then attached to a carrier molecule called a vector. The **vector** is a harmless virus and it is added as a drip through the nose of patients. The viruses enter many of the lung cells and insert into the DNA in the nucleus. When the lung cells divide, the new cells contain the healthy gene.

A controversial type of gene therapy involves the insertion of a healthy gene into an embryo. Parents who are known carriers of a defective gene can have test tube fertilisation (*in vitro* fertilisation) and the defective gene can be replaced shortly after fertilisation—even at the zygote stage. As the embryo develops, the cells will have the normal gene. The controversy arises because some people believe that any alteration of an embryo is unethical. However, this research is in its early stages. If it is successful, it may become more accepted.

→ Figure 4.64 Gene therapy.

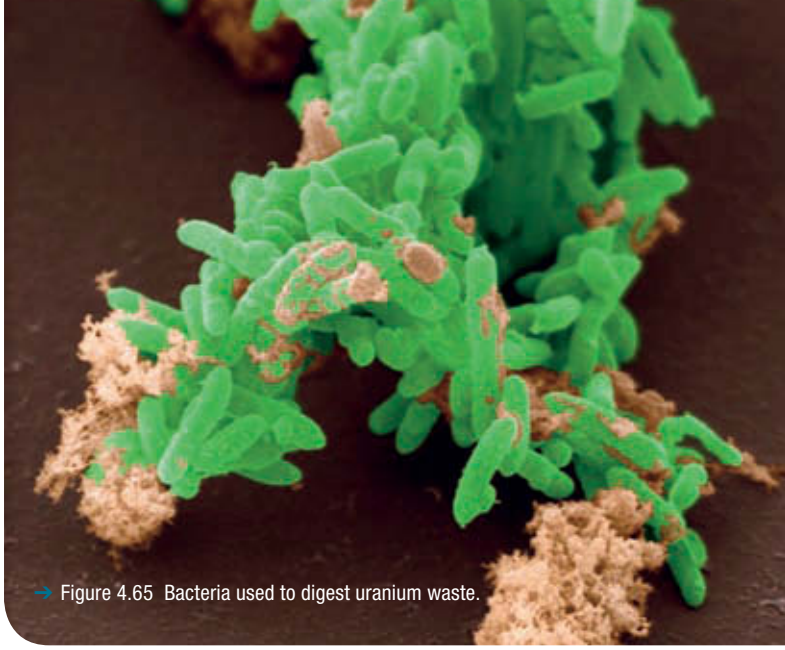
What do you know about gene technologies in medicine?

1. What is recombinant DNA and how does its production depend on restriction enzymes and DNA ligases?
2. What are the reasons why scientists choose bacteria to clone human genes?
3. Give an example of a successful gene therapy treatment for a disease.
4. State two uses of DNA sequencing. Are there any ethical issues involved in DNA sequencing?
5. What technology has made it possible to sequence the genome of an individual? Give a brief description of it.

Genetic technologies in other fields

Genetic technology has wide applications. In addition to medicine, it has impacts on the law, agriculture, the environment, world hunger problems and the economies of many countries. For example, the technique of DNA fingerprinting has become established as a major tool in solving criminal cases and in determining paternity (identifying the father of a child).

Some of the problems surrounding environmental oil spills and waste products from mines have been reduced by the development of bacteria containing genes that produce proteins to break down oil deposits and mining wastes. Other microbes are able to extract heavy metals, such as copper and lead, from deposits. This is particularly useful when the amounts of metals in the earth become too low for large-scale mining.



→ Figure 4.65 Bacteria used to digest uranium waste.

Agriculture has been significantly affected by the introduction of transgenic animals and genetically modified crops and foods (GM foods), including plants that are resistant to herbicides and pesticides. There are also 'pharm' plants and animals that produce pharmaceutical proteins required by humans.

Crops that have been engineered to resist disease mean that poorer farmers can grow them without the extra expense of spraying. Crops that contain genes to resist the effects of herbicides and pesticides are also of great use in preventing malnutrition.

Because lower amounts of pesticides and herbicides are necessary when growing these crops, production costs and environmental pollution are reduced. Plants have even been developed with genes that control the production of vitamins. Golden rice contains genes from daffodils that produce larger amounts of vitamin A.

Examples of plants that have been genetically engineered in this way include those shown in Figures 4.66–4.69.

→ Figure 4.66 Transgenic varieties of cotton, corn and potatoes that are pest resistant. Genes from the bacterium *Bacillus thuringiensis* have been introduced into the chromosomes of these plants that specify a protein that is toxic to many serious insect pests. The protein is called Bt (*Bacillus thuringiensis*) toxin and the plants are called Bt plants. The toxin produced in the plant only becomes active in the alkaline environment of the insect gut, whereas in vertebrate animals it is destroyed by the acid in the stomach.



→ Figure 4.67 Transgenic papaya plants in Hawaii are resistant to a virus that attacks papayas (the ring spot virus). The genetic engineering of the papaya in this way has saved the papaya industry. The technology has also been exported to other countries where ring spot virus is damaging papaya plants.



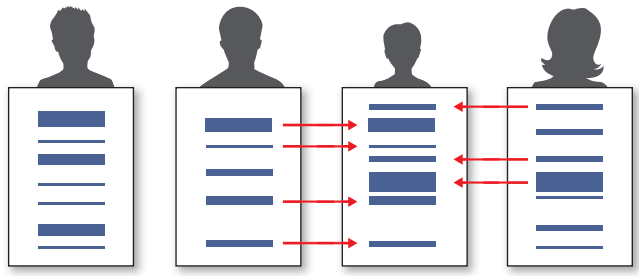
ZOOMING IN

DNA fingerprinting

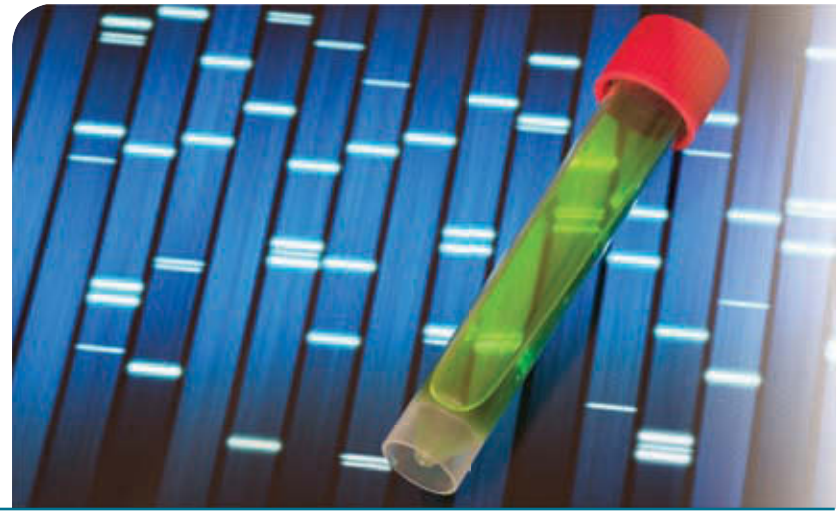
Your DNA fingerprint is unique to you. Certain regions of chromosomal DNA are known to be highly individual. Because of this, the identity of criminals (using samples found at crime scenes) has been made easier and more accurate. DNA fingerprinting is also very useful in paternity cases, in which there is more than one possible father.

In criminal cases, DNA samples are obtained from all suspected individuals and the victim. In paternity cases, DNA samples are usually obtained from the mother, child and possible fathers.

All the samples are treated in the same way. Each DNA sample is broken up into fragments using the same restriction enzyme. The fragments are then separated on an electrophoresis gel. The fragments are visualised using either a fluorescent dye or radioactive tags. The fragments appear as bands in different positions. The bands of DNA from different individuals can then be compared (see Figure 4.70).



➔ Figure 4.70 DNA fingerprinting can reveal a child's biological father.



➔ Figure 4.68 Genetically engineered soy plants that are resistant to the herbicide glyphosate have had a bacterial gene inserted into their DNA. The gene controls the production of an enzyme and is from the bacterium genus *Agrobacterium*. The bacterial enzyme is active in the presence of glyphosate. The corresponding plant enzyme is inactivated by glyphosate. Therefore, the plant cannot make its aromatic amino acids in the presence of glyphosate and the plant dies. But the transgenic soy beans have the bacterial gene (and therefore the enzyme) and can continue to synthesise their amino acids in the presence of glyphosate.





➔ Figure 4.69 Golden rice has had genes inserted from daffodils. These genes control the production of a chemical that is converted into vitamin A, making this rice much richer in vitamin A than non-transgenic rice. Without adequate amounts of vitamin A, people's eyesight can be severely impaired, even leading to blindness. This has actually occurred. Many people in south-east Asia, the great rice-consuming area of the world, are blind or severely sight impaired due to vitamin A deficiency. Therefore, this high-nutrition rice is most valuable in parts of Asia.

SKILLS LAB

DNA matching

The DNA fingerprint below shows how 'matches' can be made. The more bands that two individuals have in common, the more likely they are to be related. In a criminal case, you would expect the bands from a crime scene specimen to completely match the suspect before a guilty verdict is pronounced.

1 The forensic DNA fingerprint analysis in Figure 4.71 shows the DNA profiles of a blood sample taken from a crime scene and blood samples obtained from four suspects.

a Explain which suspect has been incriminated by the DNA analysis.

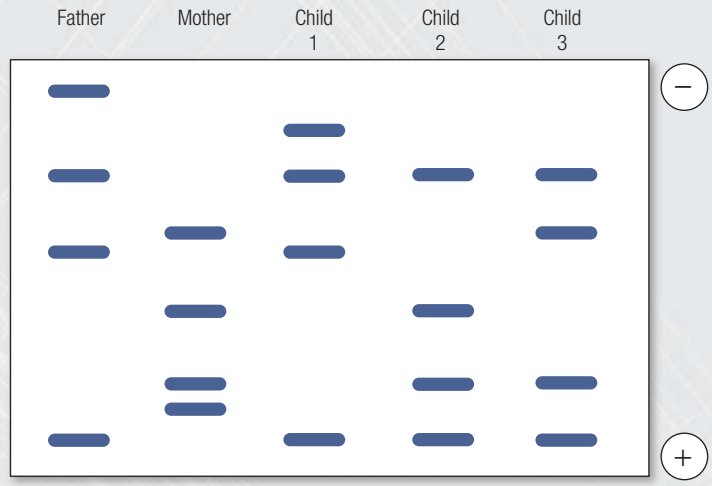
b Describe the part played by gel electrophoresis in the production of the DNA profiles.

c Other than forensic DNA fingerprinting, state one other application of this DNA profiling technology.



→ Figure 4.71

2 Figure 4.72 shows a small section of the gel electrophoresis results from a family's DNA fingerprint analysis. Which of the children is least likely to be the offspring of both parents? Explain your choice.

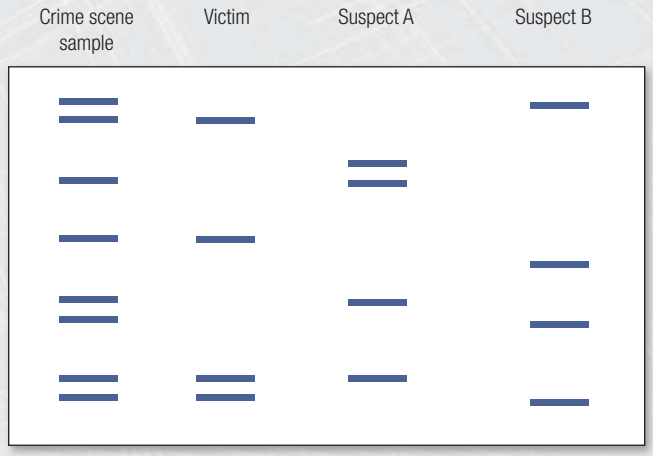


→ Figure 4.72

3 Figure 4.73 shows DNA fingerprints from four sources—a sample removed from a crime scene and samples from the victim and two suspects, A and B.

a Do these DNA fingerprints give conclusive proof that either of the suspects were involved in the crime? Support your argument with evidence.

b List two steps that are taken in the production of DNA fingerprints.



→ Figure 4.73

What do you know about gene technologies in other fields?

1 What is DNA fingerprinting? What is it used for?

2 Give an example of an organism that has been genetically engineered for use in agriculture. How has it been useful?

3 Briefly describe a method that is used to insert 'new' genes into plant cells.

4 What are some reasons for genetically engineering plants?

5 Vectors are used in genetic engineering technologies. What is a vector? Give an example.

Gene ethics

Ever since humans began to domesticate plants and animals approximately 10 000 years ago, they have been interfering with nature. The artificial selection of plants and animals for breeding became common about 200 years ago. Some of the results include cattle with good muscle mass, all types of domestic dogs, high-yielding rice and wheat and disease-resistant crops.

The discovery of DNA and the development of various gene technologies have enabled us to manipulate organisms even further. But along with all the great spin-offs there are ethical issues. How much is human interference affecting human welfare and the welfare of other species both positively and negatively? It is time for a review!

LITERACY LAB

Debating scientific issues

The media is constantly presenting contentious scientific issues. The ability to comment on and formulate an opinion requires some understanding of the process involved and an ability to critically analyse the evidence presented in relation to such issues.

The art of debating

A debate is essentially an argument with strict rules of conduct and quite sophisticated arguing techniques. Debating requires a topic and two teams of three members each, who make up an affirmative side and a negative side. The affirmative side begins, with a speaker from each team then alternating.

There is more than one side to any topic. The team that agrees with the topic is the affirmative team and the team that disagrees with the topic is the negative team. Often one of the most challenging components of taking part in a debate is being a member of the team for which you have to argue against what you believe in.

A debate may be judged on matter, method and manner. Matter is what you say, method is how you organise what you say and manner is how you present what you say.

Relevant scientific issues

Working in small groups, brainstorm some of the relevant scientific issues that have dominated the media over the past year. From your brainstorm, formulate some potential debate topics. Each topic should begin with the word 'That'—for example, 'That the government should collect and store a genetic fingerprint of all individuals at birth'.

Arguing your point

Form groups of six and then two groups of three. Randomly select a topic and a side (affirmative or negative). As a team of three, research as much evidence as you can about your issue and prepare to debate the topic accordingly.

Other members of the class will act as your audience and will be responsible for assessing your team in terms of matter, method and manner.

Genetic screening and testing

Genetic testing is carried out on people who are known to be at risk of a particular genetic disease or condition. This is usually evident from an individual's family history. **Genetic screening** refers to testing that is readily available to a cross-section of people within the community regardless of a previous family history of genetic disease.

Genetic screening and testing services available in Australia include:

- maternal serum screening (MSS)—offered to all pregnant women for the detection of Down syndrome and neural tube defects
- newborn screening—the screening of all newborn babies for genetic diseases, including phenylketonuria (PKU), hypothyroidism and cystic fibrosis
- early detection and predictive testing for adults—the screening of adults to detect existing disease, a predisposition to disease or to identify carriers with a reproductive genetic risk.

Genetic screening has the ability to increase the early diagnosis of and subsequent intervention in genetic diseases. Potentially, this will minimise the frequency of such diseases in subsequent generations; however, it sometimes involves some very difficult decisions. For example, for parents who are carriers of genetic mutations: should they have children? What are the risks of the tests and are they prepared to take them? Who should be screened, and for what? What is the impact of false positives? What options are available if it's not good news?

ZOOMING IN

Cloning

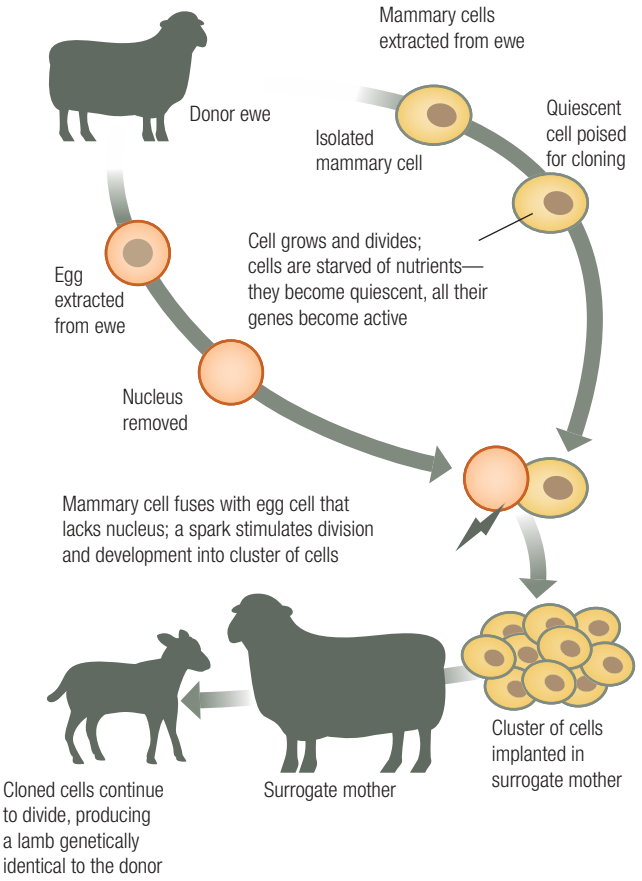
A **clone** is an exact copy of something else. It is possible to clone a gene using bacteria. It is also possible to clone an entire organism using the technique of **nuclear transfer**. This production of a new organism is called **reproductive cloning**.

Sometimes the embryo that is the result of using this technique is used to produce stem cells for medical treatments. This is **therapeutic cloning**. Because the embryo is effectively 'killed' for this to occur, some people are ethically opposed to this technology—which raises the issue 'when does life actually begin?'



→ Fig 4.75 Dolly the sheep.

→ Fig 4.74 Cloning Dolly.



Genetic counsellors can help clarify the situation, but they cannot make the decision for the people involved.

Privacy is another big issue. Information about a person's DNA (the base sequence of or other information on their genes with an indication of any defects likely to cause later development of a disease) can be misused. Insurance companies may make a DNA analysis part of an application for insurance. Such information can lead to discrimination against individuals whose DNA results indicate certain genetic health risks. Insurance companies may even refuse to insure some people.

The collection, storage and potential uses of genetic information raise many ethical questions, including access to and the possible misuse of such information.

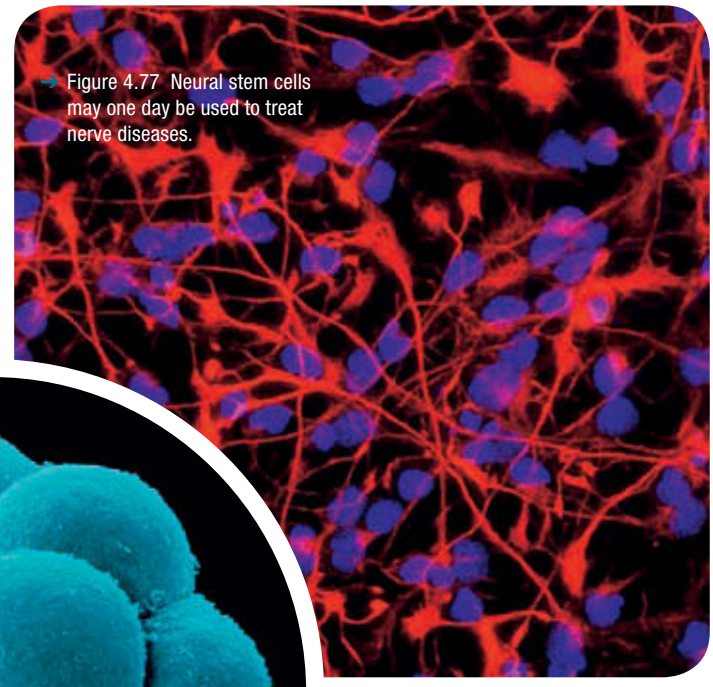


→ Figure 4.76 A blood sample is collected from a newborn infant to screen for phenylketonuria.

Gene therapy

Gene therapy involves the insertion of a healthy gene into the chromosomes of an individual with a defective gene. Gene therapy that involves the body cells (somatic cells) can be therapeutic only. This means that the mutation cannot be passed on to the next generation. At present, gene therapy targeting germ-line cells (cells destined to become gametes) is not legal in Australia.

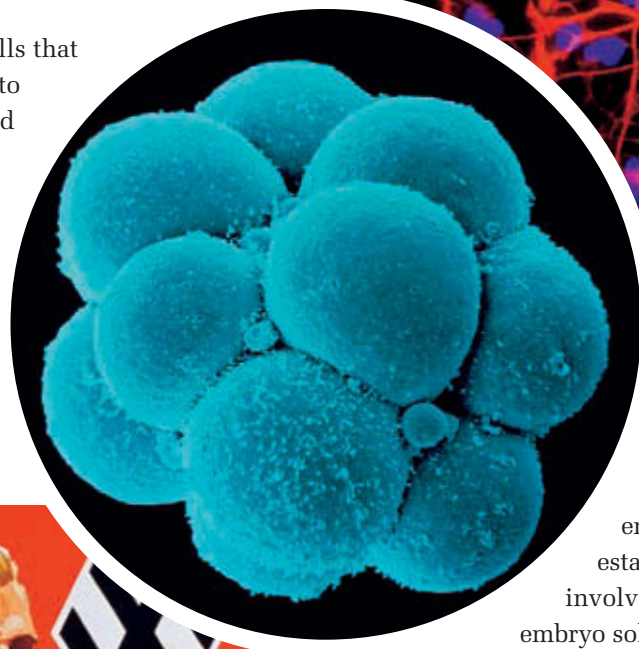
Apart from the success with cystic fibrosis and the great potential of gene therapy, limited progress has been made since the first clinical trials of gene therapy began in 1990. Human trials with gene therapy suffered setbacks with the deaths of several people as a consequence of the technique. The ethics of treating patients with a technique that involves significant risks to life have to be considered carefully.



→ Figure 4.77 Neural stem cells may one day be used to treat nerve diseases.

Stem cells

Stem cells are undifferentiated cells that have the ability to differentiate into many different types of specialised cell types, such as muscle, nerve, liver and blood cells. There are two types of stem cells. **Embryonic stem cells** are able to give rise to most cell types in the body, whereas **adult stem cells** can only give rise to certain cell types in the body.



→ Figure 4.78 Embryonic stem cells.

There are many ethical issues associated with the use of embryonic stem cells. The establishment of a stem cell line involves the artificial creation of an embryo solely for the purpose of collecting stem cells. This process results in the destruction of the embryo. At present, such procedures are illegal in Australia. The only embryos that are used for research are those classed as 'excess embryos', having been originally created for use in '*in vitro* fertilisation' (IVF). However, the use of these excess embryos is considered unethical by certain bodies in society. In their opinion, the embryos are potential life and their use in research represents the deprivation of life to these embryos. In the future, embryonic stem cells may be used to treat a variety of diseases, including cancer, multiple sclerosis (MS), Parkinson's disease, motor neurone disease and spinal cord injuries.

Some potential parents also want to choose certain embryos over others. For example, they may want a male child—or a female child. They may want a child with blue eyes and fair hair. They may choose a healthy embryo over one with, say, cystic fibrosis. This is a situation that has ethical implications. What if the embryo that has been created does not have these characteristics? What are the parents going to do with that embryo?



→ Figure 4.79 Hitler used propaganda such as this poster to portray the image of the 'perfect' human. Some people are concerned that embryonic stem cell technologies have the potential to be used for unethical purposes.

Genetically modified organisms

One of the most controversial developments in modern food production is the proliferation of genetically modified organisms, or GMOs. Genetically modified (GM) plants have been modified in the laboratory to enhance desired traits, such as increased resistance to herbicides or improved nutritional content. Although the enhancement of desired traits has traditionally been achieved through selective breeding, genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy. For example, geneticists can isolate a gene for drought tolerance and insert that gene into a different plant. The new GM plant will display a tolerance to drought. Not only can genes be transferred from one plant into another, but genes from non-plant organisms can also be used. Remember that transgenic organisms are those that contain a foreign gene inserted from another organism, usually a different species.



→ Figure 4.80 Corn has been genetically modified so that it produces a toxin to kill harmful insects.

GMO issues

GM crops pose a threat to biodiversity because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. The significant increase in GM plants has only occurred in the past decade or so.

The organic food movement is completely against the principle of GM foods, and public debate into the benefits and dangers of such foods is likely to continue well into the future. Some people believe that GM foods pose health risks, although there is no clear evidence for or against this.

A criticism of GM foods is the potential for accidental gene transfer to other species. GM plants may also contaminate non-GM plants of the same species when, for example, the wind blows the seeds from one farm to another if the plants are grown nearby. Another problem is that increased pesticide and herbicide resistance may develop in insects and other pests. The GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.



→ Figure 4.81 The first commercial GM plant to hit the supermarket shelves was the Flavr Savr tomato, in 1995.

What do you know about gene ethics?

1. Why are some genetic diseases screened for in the community but others are only tested in those with a family history?
2. What is the aim of cloning?
3. Identify some ethical issues associated with the use of embryonic stem cells.
4. Why is DNA profiling (fingerprinting) so reliable in identifying individuals?
5. What ethical issues do you think would be associated with DNA profiling?
6. As a consumer, do you think that food containing GMOs should be labelled to reflect this?
7. What factors would influence your decision to purchase or not to purchase food containing GMOs?

4.3

How do humans use their understanding of genetics?



Remember and understand

1 Define the following terms:
   - **a** GMO
   - **b** transgenic organism
   - **c** DNA profile
   - **d** clone.

2 Explain in your own words the process of:
   - **a** DNA profiling
   - **b** gene therapy
   - **c** therapeutic cloning.

3 Suggest why genetically modified (GM) plants are thought to present a greater risk to the environment than non-GM plants.

Apply

4 The process of DNA profiling is often used to analyse evidence in a crime.
   - **a** Explain why this technique is a more useful tool than sampling blood groups.
   - **b** Suggest why a DNA sample is often taken from the victim and included in the analysis.

5 Do large-scale genetic screening programs have the ability to reduce the prevalence of genetic diseases? Explain your response.

6 Gene therapy has been proposed as a treatment for a young boy suffering from Duchenne's muscular dystrophy, a degenerative disorder of the muscles. Describe three factors that should be considered by the child's health team prior to treatment.

Analyse and evaluate

7 Phenylketonuria is an autosomal recessive genetic disorder that results in the lack of production of an enzyme that is needed to metabolise the amino acid phenylalanine to the amino acid tyrosine. A diet low in phenylalanine and high in tyrosine is prescribed to people with phenylketonuria to avoid progressive mental retardation. Every child born in Australia is now screened for phenylketonuria within weeks of birth. What is the benefit of such genetic screening?

8 Investigate a high-profile case in which DNA evidence has been used to secure a conviction in Australia and present your findings to the class.

Critical and creative thinking

9 Select one of the issues raised in this section. Write a letter to the editor of a newspaper stating your viewpoint on the issue. Include evidence to support your stance.

10 Produce a brochure that promotes the benefits of purchasing organic and non-GM foods. Alternatively, produce a brochure promoting the benefits of GM foods.

CONNECTING IDEAS Diversity and evolution

11 The debate around embryonic stem cells is heated. What are the reasons for and against using embryonic stem cells? How have governments intervened in this area? Based on your findings, do you think that using embryonic stem cells could provide benefits to humans?

Research

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

Breast cancer

To what extent does a family history affect an individual's chances of developing breast cancer? How is breast cancer detected and treated?

A shrinking Y chromosome

The Y chromosome has been losing genes over the course of time so that it is now only a fraction of the size of the X chromosome. How has this happened? Will it disappear altogether? What is the future of the Y chromosome? What effect will this have on humans?

Cloning

What sorts of other animals have been cloned since Dolly the sheep in 1997? What are some of the arguments for and against cloning?

Stem cell survival technique

Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them. Why is this technique a breakthrough? What does the technique involve? What are the immediate uses of this technique?

Reflect

Me

1 What was the most surprising thing you found out about how DNA gives its instructions?
2 What were the most difficult aspects of this topic?
3 How has your understanding of genes changed?
4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know about how genes are inherited?
6 Why is it important to understand how genetics can shape our lives?

My future

7 How do you think genetic screening might be used in the future?

Review

Key words

adult stem cells
allele
autosomal trait
autosome
carcinogen
carrier
centromere
chromatid
chromosome
clone
co-dominant
codon
diploid
DNA profile
DNA replication
dominant trait
embryonic stem cell
eukaryotic cell
frameshift mutation
gamete
gene
gene sequencing
gene therapy
genetic code
genetic screening
genetic testing
genetically modified organism
genomics
genotype
germ-line mutation
haploid
heterozygous
homozygous
interphase
karyotype
meiosis
meiosis I
meiosis II
messenger RNA (mRNA)
mitosis
mutagen
mutation
nuclear transfer
nucleus
pedigree chart
phenotype
point mutation
polypeptide
protein synthesis
recessive trait
ribonucleic acid (RNA)
ribosomes
sex chromosome
sex-linked trait
sister chromatid
somatic mutation
stem cell
transcription
transfer RNA (tRNA)
transgenic organism
vector

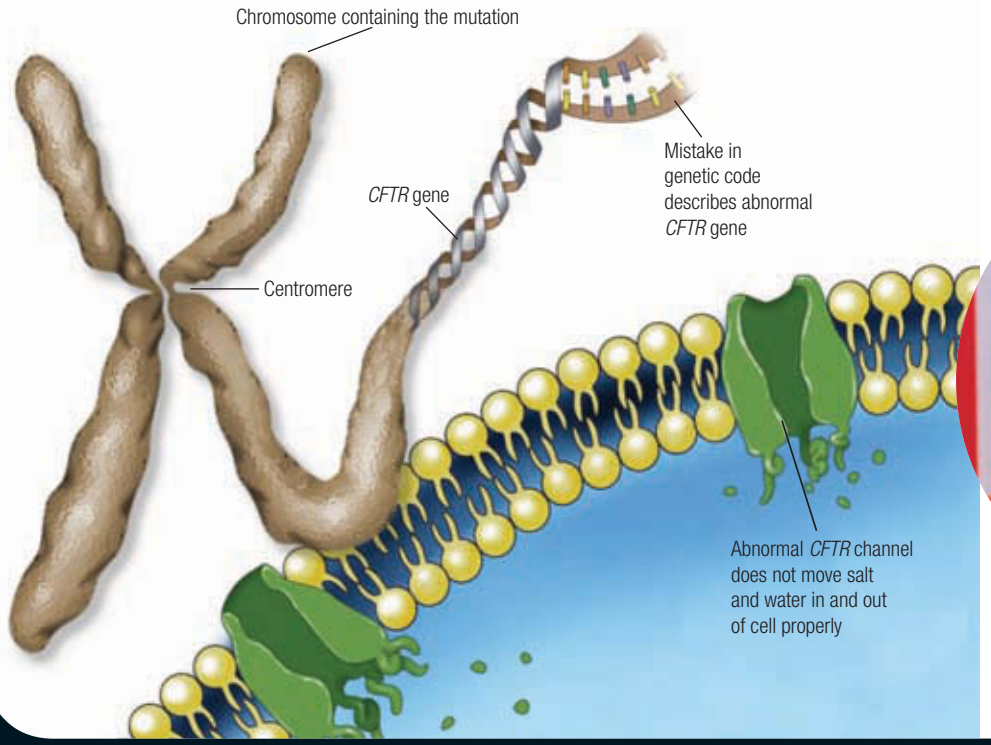
Cystic fibrosis

Cystic fibrosis, or CF, is a genetic disease that predominantly affects children. CF is inherited as an autosomal recessive trait so, in most instances, an affected child is born to two unaffected parents who may have no family history of the trait. Diagnosis is made shortly after birth from routine screening. A positive test result can often be devastating and confusing for the baby's parents. In such instances, the roles of the genetic counsellor and the associated team of health professionals are crucial in helping family members to understand the diagnosis and what the future holds for those affected by CF.

The mutation

In 1989, scientists identified the gene associated with cystic fibrosis—the *CFTR* gene on the number 7 chromosome. Various types of mutations have arisen in this gene, resulting in CF, but the most common type of mutation results in what is known as the delta F508 allele. This specific mutation is a deletion of three base pairs at position 508 in the *CFTR* gene. The deletion prevents the codon for phenylalanine from obtaining its normal position in the protein coded for by the gene. Having two copies of this mutation, inherited from both parents, is the leading cause of cystic fibrosis.

→ Figure 4.82 Instructions for moving water and salt in and out of cells come from the CFTR gene; when this functions abnormally, we get cystic fibrosis.



Effects of the mutation

The product of the *CFTR* gene is a protein that forms a chloride ion channel, which is important in creating sweat, digestive juices and mucus. People with CF have thicker than normal mucus and digestive secretions. Although most people without CF have two working copies (alleles) of the *CFTR* gene, only one is needed to prevent CF. CF develops when neither allele can produce a functional CFTR protein.



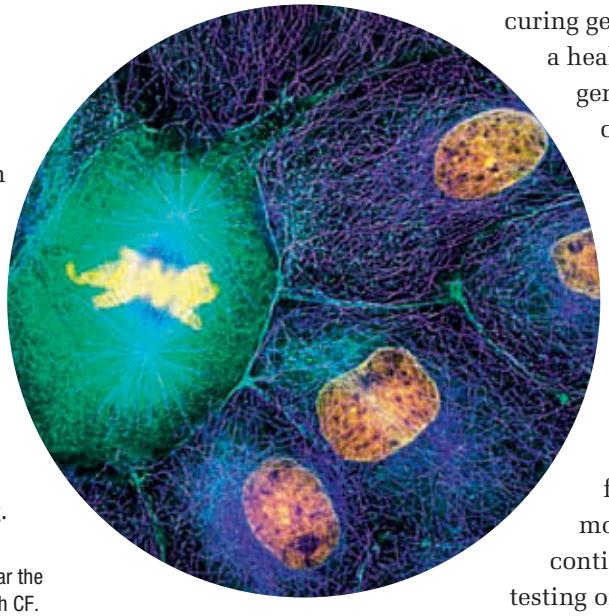
→ Figure 4.83 Cystic fibrosis affects the production of mucus in the lungs and people with CF may need help breathing.

Location, location ...

In Caucasian populations in Australia, America and Europe, one in twenty-five people are carriers for the CF allele. In other words, they are heterozygous at the *CFTR* gene and have the ability to transmit this mutation to subsequent generations. This proportion of carriers results in approximately one in 2500 children born being affected by CF. The frequency of carriers is much less in some other populations. For example, in Japanese populations, the proportion of those affected with CF is estimated to be as low as one in 300 000 births.

Treatment

There are many aspects to the treatment of people with CF. Traditional treatment involves the input, advice and expertise of various healthcare professionals, with regular check-ups and tests to monitor the condition and to keep a check on a child's growth, development and well-being.





→ Figure 4.84 Physiotherapy helps clear the thick mucus secretions in people with CF.

The future

CF is a lifelong condition. With improved treatment, life expectancy has increased from less than 10 years in the 1960s to an average of 30–40 years. With current treatment, most people with CF can live reasonably normal and productive lives.

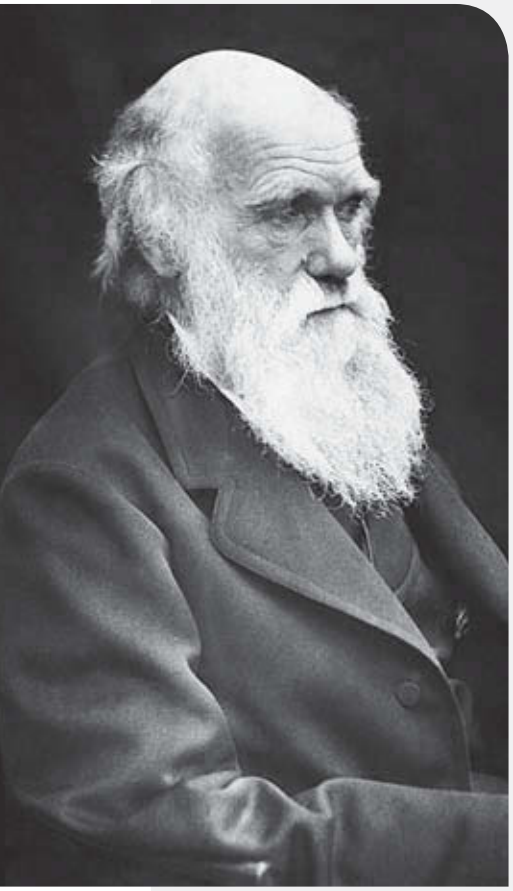
The discovery of the *CFTR* gene and further understanding of its function are now opening up new possibilities in terms of treatment. One such possibility is gene therapy. The field of genetics has proposed gene therapy as a plausible method for curing genetic disease. Through gene therapy, a healthy version of the defective *CFTR* gene could be inserted into the affected cells in the body, particularly those of the lungs. Such treatment does not just treat the disease symptoms, it cures the illness. To date, clinical trials involving gene therapy have produced disappointing results, with the effects short-lived and the benefits quickly reversed. However, gene therapy as a method of treatment does hold much promise for the future as research into the most effective methods of gene therapy continues. Carrier genetic testing (i.e. the testing of at-risk individuals for the presence of the gene before they have children) is currently available in Australia.

1 Why is CF considered an autosomal recessive disease?
2 How would a mutation arise in this gene?
3 Why does the deletion of the codon prevent phenylalanine from obtaining its normal position?
4 How does the genotype of a person with CF affect their phenotype?
5 How does being heterozygous for CF affect the phenotype?
6 Do you think CF will become more common in populations as time goes on? Why or why not?
7 How has modern technology benefited people with CF?
8 How do you think gene therapy could cure CF?
9 Why do you think clinical trials are conducted in new areas of research?

5 The origin of species

5.1 How do we explain biodiversity?

The world has recently celebrated the 200th birthday of one of the most influential biologists—some would say the most influential biologist—ever born. Charles Darwin revolutionised the way people think about how life on Earth came to be. It was a dramatic story of how a medical school drop-out and future clergyman transformed our picture of nature and our place in it. Darwin's work modelled the classical scientific method. He observed significant numbers of organisms, made inferences and proposed theories that were published for peer review. So considered were his theories that there was eventual acceptance of a unifying theory of evolution.



1 What do you think a 'unifying' theory might mean?
2 Why do you think Darwin's theory attracted a lot of criticism?
3 Why might some people not wish to believe in new scientific ideas and theories?

→ Fig 5.1 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism.

5.2 How do species evolve?

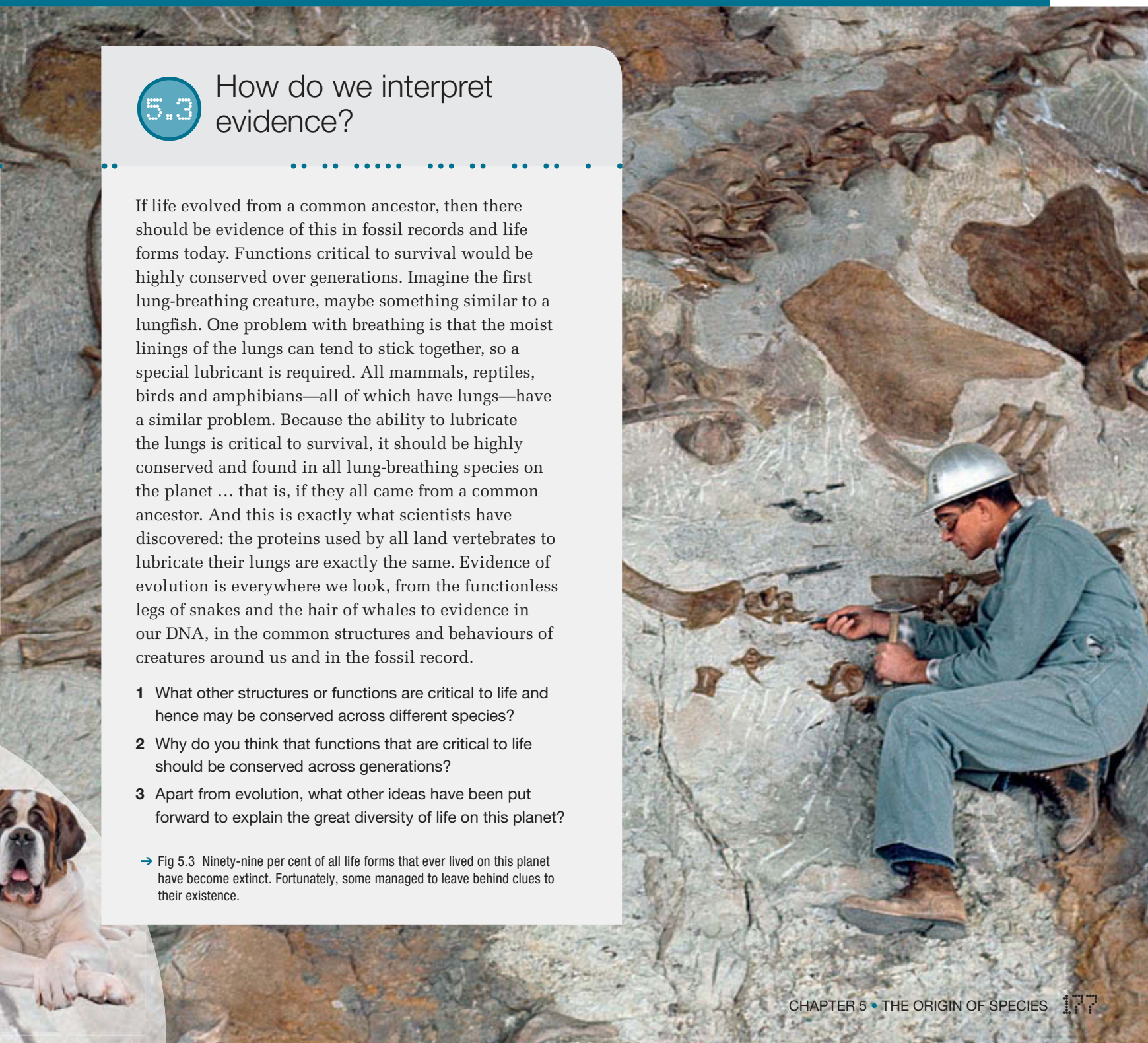
Molecular studies have shown that the different domestic dog breeds are all descended from one or more populations of grey wolf, *Canis lupus*, and still retain the ability to interbreed with wolves. There are literally hundreds of different dog breeds, all differing in behaviour, appearance or both. Humans have created a staggering diversity of dogs by selective breeding in only a few thousand years. It should be no surprise then that we are surrounded by such a diversity of life on this planet given that the Earth has been around for approximately 4.5 billion years.

1 What does 'selective breeding' mean?
2 How do you think selective breeding happens in nature?
3 What advantages might selective breeding offer?



→ Fig 5.2 The many different breeds of dogs are still the one species.

Change is inevitable. In every aspect of our lives and our world, change continues to occur whether we like it or not. The non-living world is constantly in a state of flux, in a small part influenced by the living world, particularly the actions of humans. Change is also occurring within the living world, with organisms adapting to changes in their environment over short- and long-term time scales. The ability to adapt is essential for the survival of individuals, with certain adaptations essential to avoid the extinction of the species.



5.3 How do we interpret evidence?

If life evolved from a common ancestor, then there should be evidence of this in fossil records and life forms today. Functions critical to survival would be highly conserved over generations. Imagine the first lung-breathing creature, maybe something similar to a lungfish. One problem with breathing is that the moist linings of the lungs can tend to stick together, so a special lubricant is required. All mammals, reptiles, birds and amphibians—all of which have lungs—have a similar problem. Because the ability to lubricate the lungs is critical to survival, it should be highly conserved and found in all lung-breathing species on the planet … that is, if they all came from a common ancestor. And this is exactly what scientists have discovered: the proteins used by all land vertebrates to lubricate their lungs are exactly the same. Evidence of evolution is everywhere we look, from the functionless legs of snakes and the hair of whales to evidence in our DNA, in the common structures and behaviours of creatures around us and in the fossil record.

1 What other structures or functions are critical to life and hence may be conserved across different species?

2 Why do you think that functions that are critical to life should be conserved across generations?

3 Apart from evolution, what other ideas have been put forward to explain the great diversity of life on this planet?

→ Fig 5.3 Ninety-nine per cent of all life forms that ever lived on this planet have become extinct. Fortunately, some managed to leave behind clues to their existence.

5.1

How do we explain biodiversity?



We know that there are many, many different types of animals across the planet, there are different types of plants, and we're only beginning to appreciate the diversity of bacteria, fungi and protists. Before travel across the seas was possible, many people believed the sum total of animals and plants on Earth to be those that existed in their immediate environment. As the 'New Worlds' were discovered—only a few hundred years ago—stories, illustrations and specimens told of new and amazing creatures and plant products. Can you imagine a world without chocolate or coffee? The development of the microscope brought yet another dimension to biodiversity: the world of microscopic organisms. Naturally, the eternal question 'where did life come from?' became all the more complex.

<<DISCOVERING IDEAS>>

Explaining biodiversity

Imagine you were living before the theory of evolution existed. You are influenced heavily by the teachings of the local religion—Christianity, Islam etc. Many men are returning from voyages across the seas with stories, illustrations and specimens that reflect a hugely diverse range of animals and plants.

Consider the following questions by yourself, then share your thoughts in small group discussions and eventually the whole class.

- What feelings would these discoveries of new creatures conjure up in the local community? Would everyone respond the same way?
- Do you think a system would be put in place immediately to record this new information? Who might control it if it happened?
- How do you think differences would be accounted for?
- How do you think similarities between local organisms and those from the New World would be explained?
- What types of information do we have today that would have been useful in answering these questions had they existed 200+ years ago?



→ Fig 5.4 In the 19th century, explorers travelled the seas, returning home with huge collections of plant and animal specimens.

Before evolutionary theory

Life was 'created' by gods—that was the generally accepted view for many thousands of years. In fact, even the events of the non-living world, such as volcanoes and earthquakes, were considered to be the consequences of the emotions of the gods. Depending on the geographical location and the people involved, there was one or more gods and they were either human or animal-like in appearance.

There was little thought given to whether organisms changed over time. The very idea of extinction was not proposed until the 1790s, when a young man named William Smith uncovered fossils while analysing the geology of a mine in England. Fossils were already known to be the remains of living organisms, but Smith identified organisms that had never been seen before and was able to 'date' them based on the layer of rock in which they were found. This later became known as relative dating.



➔ Fig 5.5 Rock strata seen along a cliff face.

Georges Cuvier, a French zoologist, was fascinated by these and other fossils that had been unearthed. He collected and examined as many as he could, eventually reaching the conclusion that many of the animals represented were remains of species now extinct. In a paper he wrote in 1796, Cuvier said:

'All of these facts, consistent among themselves, and not opposed by any report, seem to me to prove the existence of a world previous to ours, destroyed by some kind of catastrophe.'

Cuvier argued that life exists, is wiped out by some type of catastrophe, then new life is created. The very thought of evolution still had not infiltrated the minds of the public.



➔ Fig 5.6 Georges Cuvier.

Much of modern science has stemmed from European cultures' research and translations of other cultures. Evolutionary theory is no different. Charles Darwin and Alfred Russell Wallace, arguably the most important figures in the story of evolutionary theory, lived in times when Christianity governed the beliefs of the people in Europe. God was the Creator—responsible for all the good in the world and 'working in mysterious ways' when motives were unclear.



Fig 5.7 Byzantine icon from 1220 showing God as the Creator.

What do you know about before evolutionary theory?

1. One of the biggest questions asked by humans is 'Where did we come from?' How have different peoples answered that question?
2. Describe the role of religion and other belief systems in explaining life before evolutionary theory.
3. What do you understand 'relative dating' to mean? Use a diagram to explain.
4. Cuvier supported the idea of 'catastrophism'. How did this satisfy both the evidence (fossils) and the people of the day?

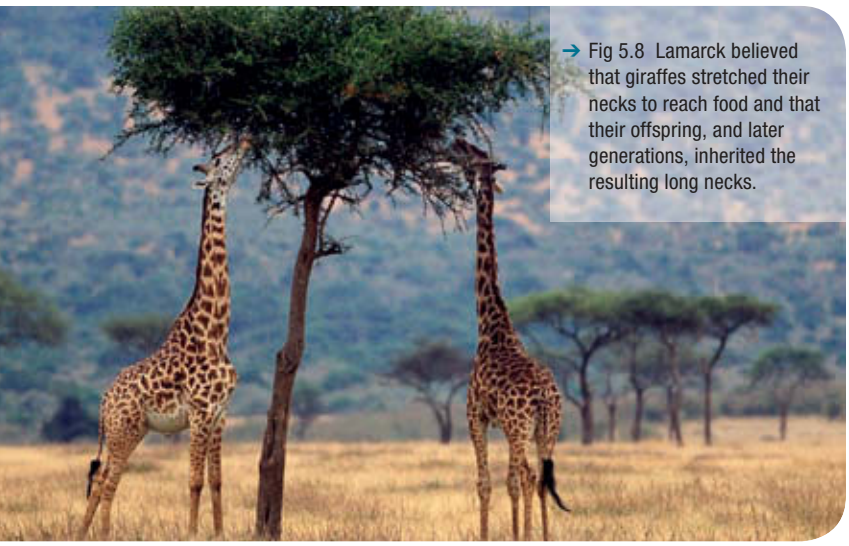
Early evolutionary ideas

It is important to remember that evolutionary theories were all proposed without any knowledge or understanding of DNA and genetic inheritance. Those theories that have stood the test of time were reinforced by the developments in genetics, making the following stories all the more remarkable.

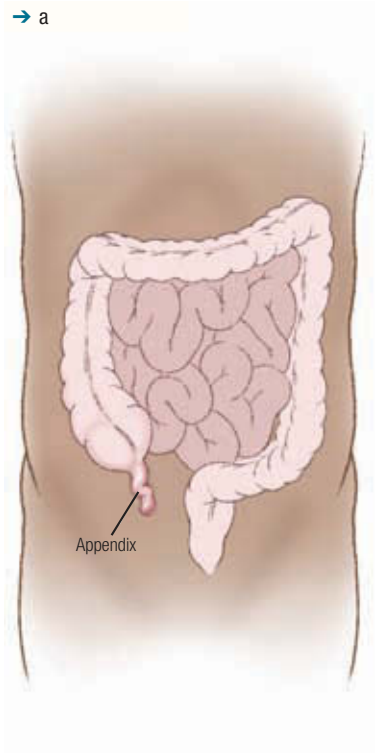
Lamarckian theory

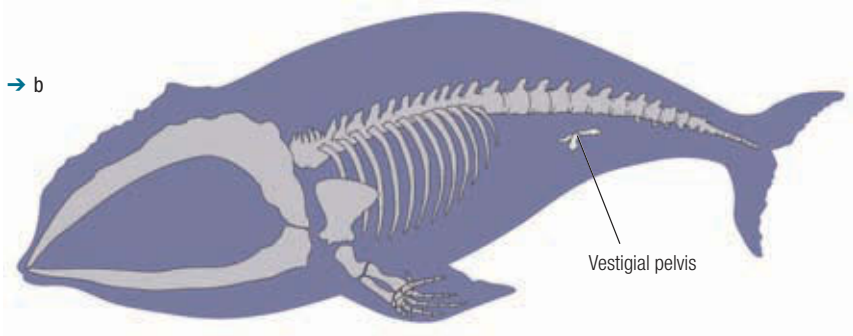
One of the first documented theories of evolution was by a man named Lamarck. Jean-Baptiste de Lamarck, a French naturalist, believed in evolutionary change—that organisms change over time due to changing environmental conditions. He is best known for his theory of inheritance of acquired characteristics, which was first presented in 1801. In this theory, Lamarck proposed that if an organism changes during its lifetime in order to adapt to its environment, those changes are passed on to its offspring. In other words, the change is made by what the organism wants or needs. Lamarck also stated that body parts that are not being used, such as the human appendix and little toes, are gradually disappearing, so that eventually people will be born without these parts.

Although Lamarck's ideas are based on valid questions about the nature of life and are supported by what he saw around him, they could not be tested or replicated and were attacked by the French scientific establishment.



→ Fig 5.8 Lamarck believed that giraffes stretched their necks to reach food and that their offspring, and later generations, inherited the resulting long necks.





→ Fig 5.9 Lamarck's theory identified 'shrinking' vestigial structures as those that were no longer useful, such as (a) the human appendix and (b) the whale pelvis.

Darwin sets sail

For Charles Darwin, explaining biodiversity was of great importance. Darwin was well educated and had been exposed to the sciences through his father and grandfather, who were both physicians. Darwin's grandfather had sought to explain life in evolutionary terms in a book he published in 1794: 'Would it be too bold to imagine that all warm-blooded animals have arisen from one living filament?' This was too bold a question for the day and lacked substantial evidence.

Darwin had also read the works of Lamarck. It is with this background of scientific thought and process that the young naturalist set sail on a 5-year world cruise as the unpaid naturalist aboard HMS *Beagle*. The year was 1832 and Darwin was just 23 years of age.

A DIVERSITY OF LIFE

Over the 5 years of the *Beagle*'s voyage, Darwin investigated the geology of the places he visited and collected all manner of wildlife and fossils, carefully recording the details before sending them by ship back to England. It was during this period of intense record keeping and observation of natural systems that Darwin questioned traditional views and developed his hypothesis for the natural selection of species. It was during the final stages of the voyage, when the *Beagle* headed westward into the Pacific to the Galapagos Islands, that Darwin made his most significant observations.



➔ Fig 5.10 HMS *Beagle*.



➔ Fig 5.11 Darwin collected a huge range of samples, and sent the specimens back to England.

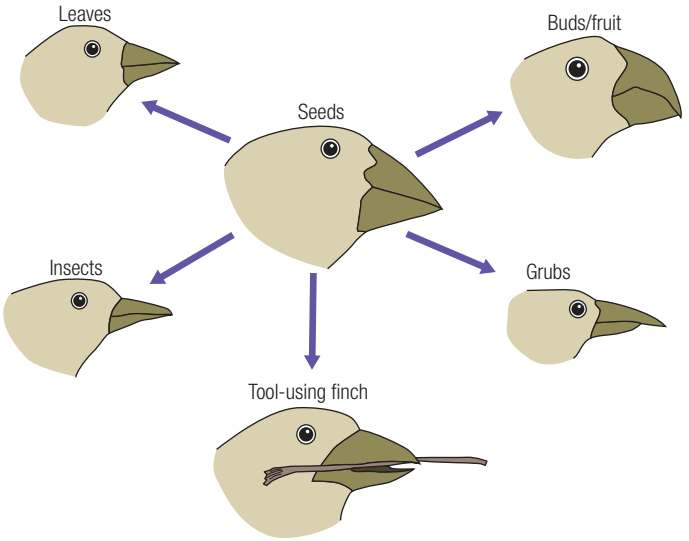
GALAPAGOS SPECIES

Darwin and his helpers went about the process of collecting specimens, seeking as usual to collect at least one of each species. Among the specimens collected were thirteen finches, all of which resembled one another in terms of the structure of their beaks, the form of their bodies and in their plumage. Yet each specimen represented a new species and most had been found on different islands. In his journal, Darwin noted that these creatures held a striking similarity to those found on the mainland and pondered why, if new and different beings had been placed on the islands at the time of Creation, did they look so much like those found in the Americas?

PRACTIVITY 5.1

Analysing beaks

Refer to Figure 5.12, the various finches that were identified by Darwin while in the Galapagos Islands. For each beak type, analyse and evaluate the size and shape of the beak to ascertain how it was suited to the food type consumed by that finch.





➔ Fig 5.12 Darwin's finches showed beak diversity because of the types of foods they ate and variations in their habitat.

The dry, volcanic Galapagos archipelago looked desolate and the only plants struck Darwin as 'wretched-looking weeds'. As he walked across Chatham Island's rugged lava surface, Darwin came across two huge tortoises ambling along a well-beaten path.

A few days before Darwin left the Galapagos Islands, the remark by the Islands' Vice-Governor that he could tell which island a tortoise came from by the shape of its shell provided Darwin with the inspiration he needed. Indeed, this is the main way in which the different types of tortoise on the Galapagos Islands differ: the shape of the tortoise's shell depends on its environment. Tortoises that live on dry islands, such as Hood Island, have shells that are raised at the front so the tortoises can reach up for vegetation; in contrast, tortoises that live on large islands with dense vegetation have domed shells to help them push through the shrubbery.





➔ Fig 5.13 The shape of a tortoise's shell varies according to its habitat on the Galapagos Islands.

What do you know about early evolutionary ideas?

1 Charles Darwin wasn't the first person to come up with the ideas of evolution and natural selection. What was Lamarck's idea about the way evolution worked?

2 What was it about the tortoises of the Galapagos Islands that helped Darwin develop his ideas about evolution and natural selection?

3 What features of the finches showed similarity in form?

Developing the theory of evolution

On 2 October 1836, the *Beagle* reached the shores of England. A year later, Darwin was finishing work on his journal, which became known as *The Voyage of the Beagle*, and arranging his Galapagos collections. Again, it struck Darwin that if each species had been created independently, why should some details have been repeated in the different tortoises and birds whereas other features were ignored?

The idea of species haunted Darwin and he thought that if he was ever to make sense of it, he needed to collect as many facts about variations in plants and animals as possible. This search led him to investigate the breeding of racehorses and pigeons.



→ Fig 5.14 In Darwin's time, pigeon breeding was a popular pursuit and many new forms of different traits were constantly being bred.

Artificial selection

Selective breeding has been a human pursuit for well over 10 000 years, when many human populations moved from the hunter–gatherer way of existence to more permanent settled communities. Selective breeding is essentially humans choosing breeding partners for animals and other organisms in an effort to 'select' certain traits for their offspring. Over many generations, the 'wild' traits are often lost and the species is considered 'domesticated'.

Darwin then wondered how, in nature, 'selection' occurred. The answer Darwin was seeking came from the work of Thomas Malthus, whose paper *An Essay on the Principle of Population* gave Darwin the insight he needed. Malthus argued in his paper that the human race would completely overrun the Earth if it were not held in check by war, famine and disease. Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last Darwin had a hypothesis to test. Yet, it would take another 20 years of painstaking hard work before he was convinced that his hypothesis had enough support to be developed into a theory. Alfred Russell Wallace, a naturalist who had worked in the East Indies, sent Darwin



→ Fig 5.15 Was the plague simply nature keeping the human population in check?

a copy of his manuscript, in which he had independently arrived at the same concept of natural selection. In 1858, Darwin and Wallace jointly published a paper and, in 1859, Darwin published his book *On the Origin of Species by Means of Natural Selection*.



→ Fig 5.16 Alfred Russell Wallace (1823–1913) arrived at the same theory as Darwin and at the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in Africa. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.



→ Fig 5.17 All living things vary. Darwin was struck by the almost infinite variety of life, even within a single species.

PRACTIVITY 5.2

Artifical selection in humans

In small groups, discuss the factors that determine how reproduction between humans occurs. For example, are there certain features of a person's physical, mental, intellectual or emotional make-up that tend to make them more attractive to the opposite sex? Do these factors change from one generation to another? Do these factors change from one culture to another? How might these choices impact the human species? Are there similarities with other animals?

Share your groups' thoughts with the class, then discuss whether you believe this to be 'artificial' selection.

On the origin of species

Darwin's book *On the Origin of Species by Means of Natural Selection* was largely one long argument that was based on three facts from which Darwin drew two major deductions:

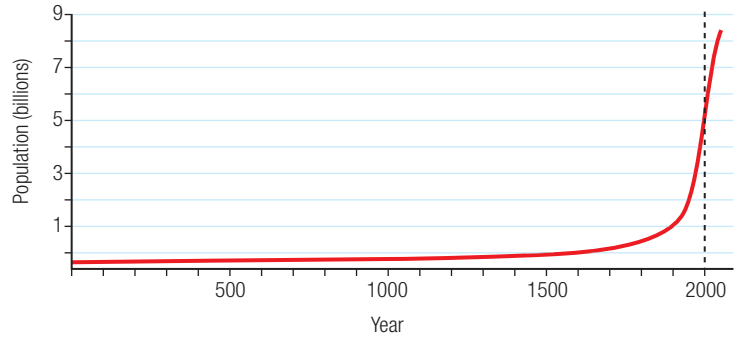
1 There is a struggle for existence.

2 In that struggle, the fittest survive.

Although these observations may seem relatively obvious to us, they were nevertheless a major conceptual challenge for many people, including many scientists, of Darwin's time.

The two basic ideas that flowed from Darwin's book are the concept of the *tree of life* and the theory of *evolution by means of natural selection*.

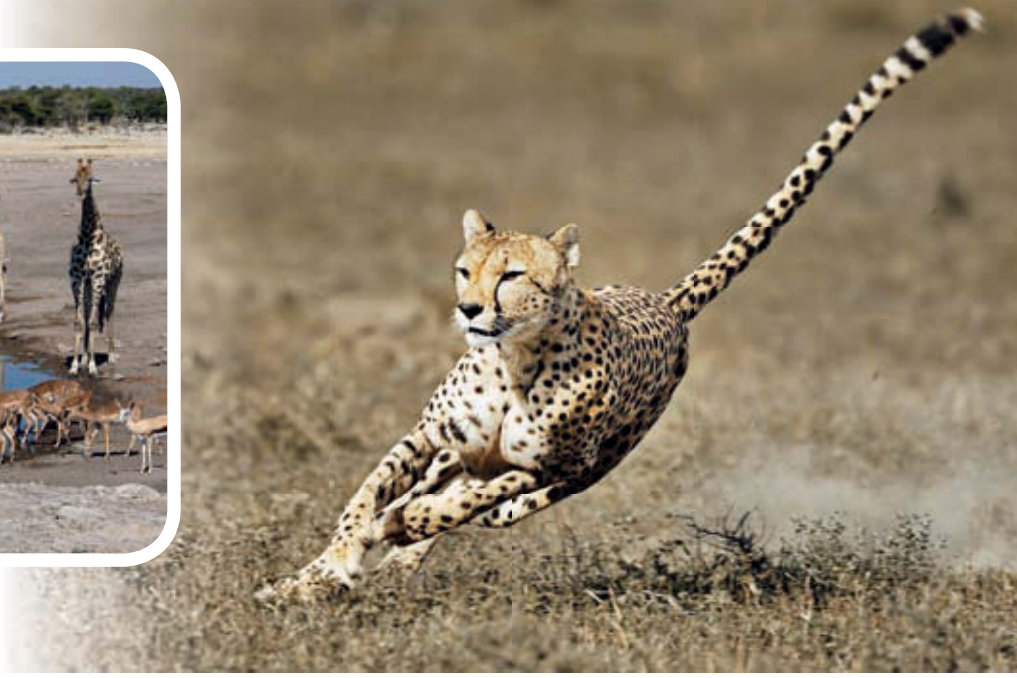
In his tree of life metaphor, Darwin depicted living organisms as being organised like the limbs of a great tree, with more general groups branching into less general ones.



→ Fig 5.18 All living groups tend to increase in geometric ratio. Human population growth in recent times is an excellent example of the geometric ratio that Darwin referred to. All species produce more young than are needed to replace the adults. Mathematically, this is sometimes modelled as exponential growth. Improvements in medicine and living conditions since the 1800s have significantly decreased death rates, resulting in a rapid explosion of the human population.



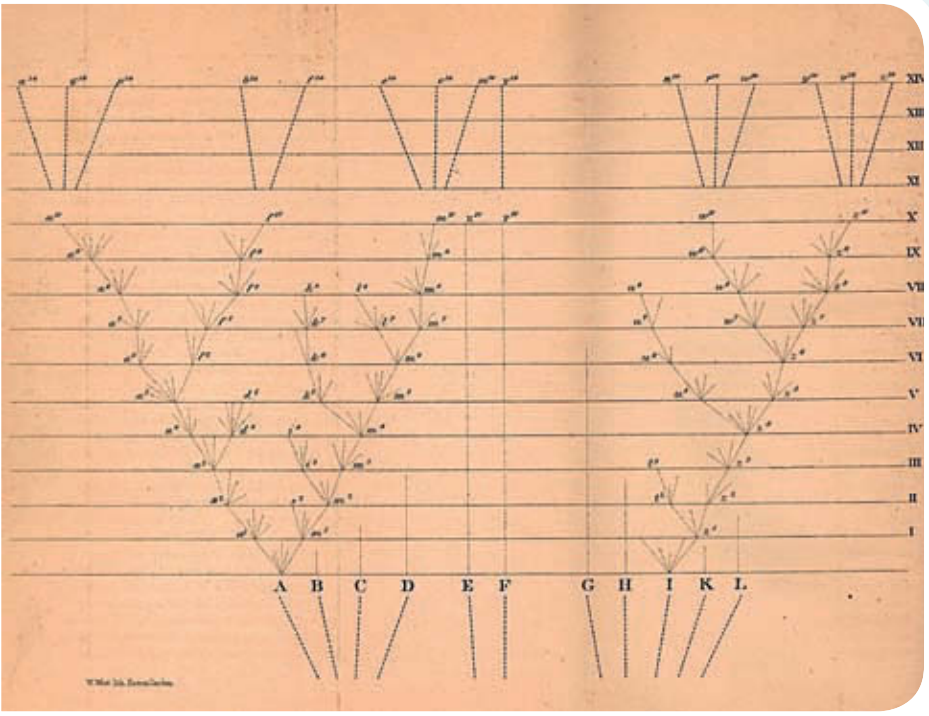
➔ Fig 5.19 The number of individuals in a population or species tends to remain constant in stable ecosystems. The numbers of organisms tend to remain fairly stable if the ecosystem they live in is also stable; that is, the birth rate matches the death rate and, as a consequence, equilibrium is achieved.



➔ Fig 5.20 'Survival of the fittest' doesn't refer to those animals that can run fast; it refers to any feature or characteristic of a species that will help it survive.

In his theory of evolution by means of natural selection, Darwin concluded that:

- species change over time—**transmutation**
- some species become extinct—**extinction**
- some species keep diverging, splitting eventually into multiple descendent species—**common descent**.





➔ Fig 5.21 Darwin's Tree of Life, from his publication *On the Origin of Species by Means of Natural Selection*.



→ Fig 5.22 Wallace's line—the flora and fauna are strikingly different on either side of the red line.

ZOOMING IN

Wallace's line

Alfred Russell Wallace (1823–1913) was a naturalist working at the same time as Darwin. Wallace collected specimens in the field in tropical regions, particularly the Malay Archipelago, which is now Malaysia and Indonesia. In his 8 years in the Archipelago, Wallace collected thousands of insects, shells and bird skins, as well as mammal and reptile specimens, many of which were new species to science at the time. One of his best-known discoveries was Wallace's golden birdwing butterfly.

During his time in the Archipelago, Wallace proposed the theory of natural selection as the mechanism of evolution. After corresponding with Darwin, both he and Darwin published papers in a journal of the Linnean Society of London.

Wallace is best known for his discovery of what is called Wallace's Line. Wallace found that the faunas of Asia and Australia, which are strikingly different, divide along a line that runs through Bali and Borneo, continues north through Lombok and Sulawesi, and then east of the Philippines. It has since been discovered that this line is approximately the collision zone between the Asian and Australian crustal plates.



What do you know about developing the theory of evolution?

1. Why do you think Darwin waited so long between arriving at his hypothesis and publishing his theory on evolution?
2. What are the three facts and two deductions Darwin arrived at in his publication *On the Origin of Species by Means of Natural Selection*?
3. Explain, in your own words, the concepts of the 'tree of life' and the 'struggle for existence'.

5.1 How do we explain biodiversity?





→ Fig 5.23 The Galapagos Islands.

Remember and understand

1 Was the 'big question' always about biodiversity? What was always the answer?

2 What are inferences and why are they important to the development of scientific theories?

3 What are the three basic facts cited by Darwin about the origin of species?

4 What is the difference between a *hypothesis* and a *theory*?

5 Explain how Wallace's Line may have formed.

Apply

6 Develop your own hypothesis about something you have observed in the animals or plants around you. How might you test this hypothesis?

7 Use other examples to illustrate the two critical deductions that Darwin made—the struggle for existence and the survival of the fittest.

Analyse and evaluate

8 What were the main steps Darwin followed to produce his theory of evolution?

9 Both Darwin and Wallace developed the theory of evolution while studying life in the tropics on islands such as the Galapagos (see Figure 5.23). Why was studying tropical islands so helpful?

10 Catastrophism was widely accepted in its time, particularly by Cuvier and those associated with Christianity. How does this theory support the Christian explanation of life? What are the limitations to this theory?

Critical and creative thinking

11 This chapter deals with some important events and dates around the development of the theory of evolution. Create a timeline of important scientific events leading up to the publication of Darwin's book about the origin of species.

12 Research the various explanations for changes in the natural world before evolutionary theories. Select one example and present your findings and analysis to the class in an appropriate and interesting format.

13 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. Prepare a three-part cartoon strip for each theory that clearly identifies the similarities and differences between these theories.

CONNECTING IDEAS Diversity and evolution

14 Speculate about how Darwin's theory may have been different if he had known about genetics, the age of the Earth and other related ideas.

How do species evolve?

5.2

Dogs have been bred for centuries in all human cultures. Dogs were originally bred for qualities such as hunting, herding, companionship and protection, but since the 1850s have also been bred for their looks. It's possible to interbreed most types of dog, although physical traits would make it awfully difficult for a Chihuahua to give birth to a litter fathered by a Great Dane. When organisms reproduce sexually, and the resulting offspring are able to survive and continue reproducing, then the original parents are considered to be of the same species. This idea of 'species' is relatively recent and a crucial aspect of evolutionary theory.



<DISCOVERING IDEAS>

Generational change

What you need

Different tools (e.g. spoons, forks, chopsticks or straws)

Lollies

⚠ Make sure you check for food allergies and avoid using lollies that present a risk of anaphylaxis.

What to do

This is a whole-class activity.

Each different group of students has a different type of eating utensil, such as spoons, forks, straws and chopsticks. Each group has the same mix of lollies. Using only the tool provided, try and collect as many of the lollies as possible into a bowl.

Questions to consider

- Which of the eating utensils was the most successful at gathering lollies?
- Which of the eating utensils was the least successful at gathering lollies?
- Over time, what might happen to the numbers of each lolly type?
- If a new tool that enabled certain lollies to be gathered much more easily was introduced, what effect could this have on the numbers of each lolly type?
- How could this simulation be used to analyse the changing features of populations over several generations?

Natural selection

To date, the theory that best explains the diversity of life forms and the evidence of change over time is Darwin's theory of evolution by natural selection. Darwin argued that it was entirely possible for one species to evolve gradually into a separate species, with its own unique traits, over many generations.

As Charles Darwin and Alfred Russell Wallace pointed out, an individual doesn't evolve; rather, populations do. A **population** is considered to be a group of interacting individuals of a species living in a particular area, whereas a **species** is defined as organisms that can reproduce sexually to create offspring that are both viable (able to survive) and fertile (able to reproduce).



→ Fig 5.24 Darwin's theory doesn't apply to acquired traits. Tattoos are acquired, just like scars and other lifestyle-related traits.

Natural selection is the principal mechanism for evolution. Darwin proposed four means by which natural selection works:

1. Not all individuals that are produced in a population survive to produce offspring.
2. Variation exists between individuals in a population.
3. Those individuals in a population that are 'fitter' contribute more to the next generation than those that are less fit. This is known as **survival of the fittest**.
4. The differences between individuals in a population are inherited.



→ Fig 5.25 It's sometimes possible for organisms of different but similar species to reproduce; however, their offspring are often unable to live a normal, healthy life and are certainly not able to reproduce. The animals above are the result of crosses between (a) a zebra and a horse (zorse) and (b) a zebra and a donkey (zonkey).

→ Fig 5.26 In this population of elephants, which features are inherited? Which are acquired? Which features may help the animal survive? Are there certain environmental conditions that would make some features better than others?



Mental and physical gymnastics

What you need: a gymnasium with various stations set up for different gymnastic or similar activities and several stations on the sidelines set up for different mental challenges, such as calculations or even origami. Students could be responsible for planning and setting up the stations.

1 All members of the class are to complete each station in a 'round robin' style, recording their results for each station in a previously agreed format.

2 Where members are unable to complete the activity, either for time or health reasons, this should be noted as 'unable to complete'.

3 Once complete, merge the data into a single class set for analysis.

- Who was the best at each activity? Were these people the same for every activity?
- How does this series of activities simulate 'survival of the fittest'?

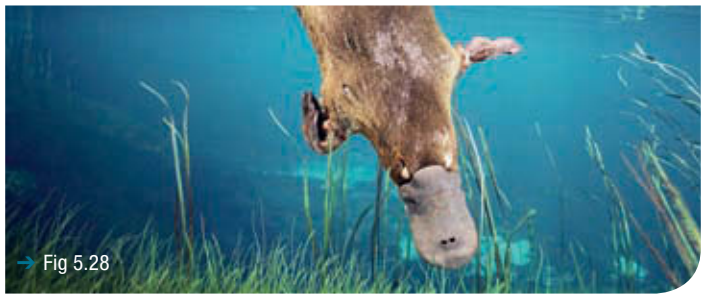
Variations in populations

Natural selection depends on the variation of traits within a population, but where does this variation come from? All members of a species share a set of common traits that help define them as a species. For example, *Homo sapiens* (i.e. humans) are identified, for purposes of classification, as:

- an animal (kingdom Animalia)
- with a backbone (phylum Chordata)


→ Fig 5.27

- with a segmented spinal cord (subphylum Vertebrata)


→ Fig 5.28

- that suckles its young (class Mammalia)


→ Fig 5.29

- that gestates its young with the aid of a placenta (subclass Eutheria)


→ Fig 5.30

- that is equipped with five-digit limbs, a collarbone and a single pair of mammary glands on the chest (order Primates); and

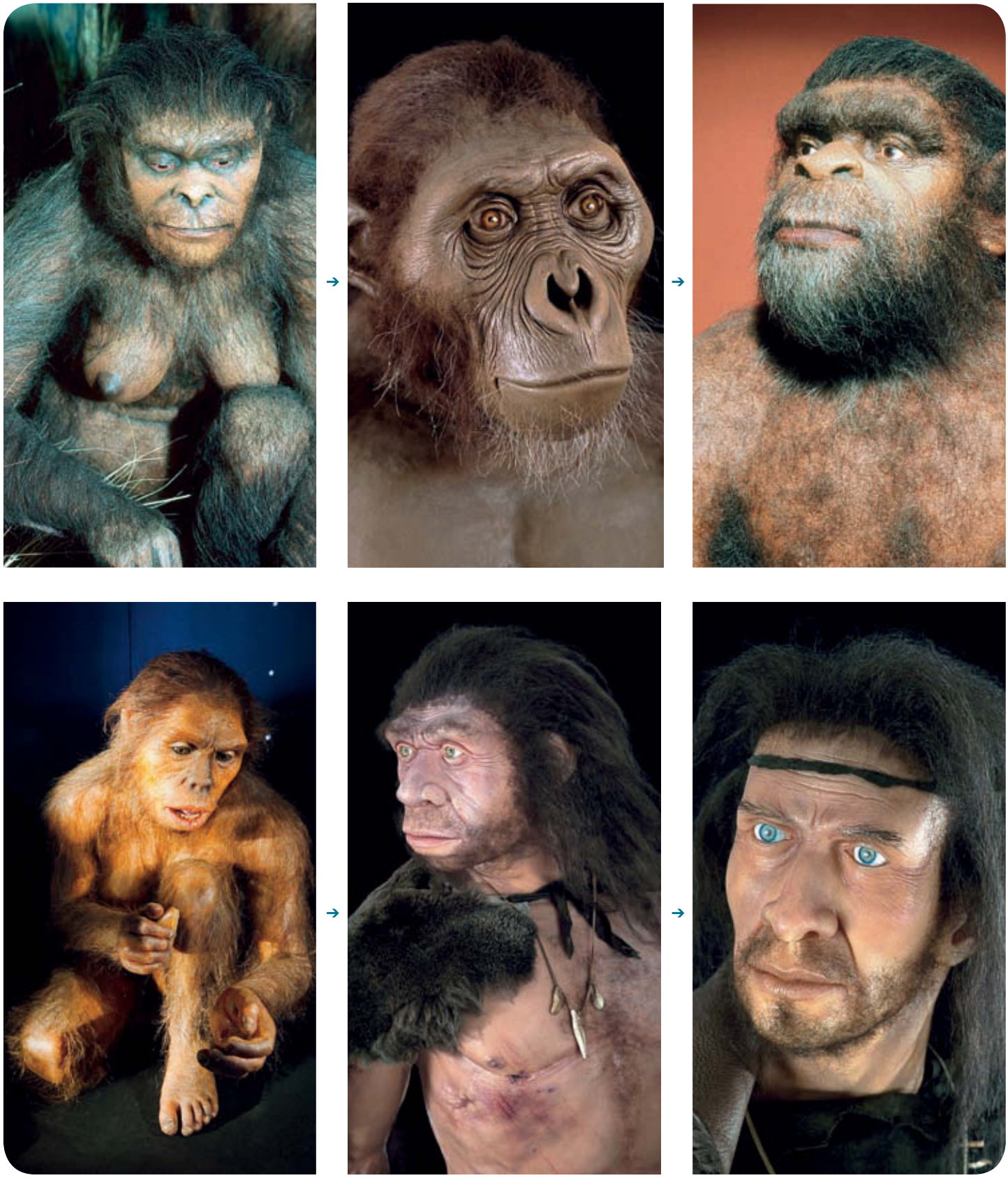

→ Fig 5.31

- that has eyes at the front of the head, stereoscopic vision and a proportionately large brain (suborder Anthropoidea).


→ Fig 5.32

Our species belongs to the family Hominidae and the genus *Homo* (larger-brained hominids that appeared approximately two million years ago) and is characterised by a higher and more vertical forehead, a round skull, small face and teeth, a prominent chin and a longer, more slender skeleton.

→ Fig 5.33 The evolution of man.



Despite these unifying traits, no two people (except for identical twins) look the same. Most traits differ from one individual to another, especially in sexually reproducing species.

Much of the variation between individuals is due to genetic differences that can be inherited—something that Darwin and his contemporaries observed but did not understand.

Individuals of the same population generally have the same number and types of genes, but different alleles (variations of the genes). For example, all humans will have the gene for eye colour, but the alleles they have for this gene may be blue, brown or even hazel.

All the genes in the entire population can be thought of as a **gene pool**—a pool of genetic information. The gene pool includes all the alleles for all the genes in the population: all the variations possible without mutation.



→ Fig 5.34 These Siberian huskies have the gene for eye colour, but different versions, or alleles, of the gene.

Mutations

A human gamete (sex cell) can have one of 10 600 possible combinations of alleles. Consequently, it is extremely unlikely that another person with your exact genetic make-up has ever lived or ever will (unless you have an identical twin). Only alleles that already exist in parent DNA can be inherited, unless a mutation creates new alleles.

Mutations can occur at the gene level or at the chromosome level. Some mutations may be lethal, having a drastic effect that results in its death. Others may be neutral, neither helping nor harming an individual. Natural selection does not increase or decrease the frequency of these neutral mutations in a population because they do not influence an individual's chances of surviving or reproducing.



→ Fig 5.35 Gametes contain all the genes, and therefore alleles, of new life. Mutations that arise from gamete production (meiosis) are the only possible way for new alleles to be passed on to the offspring.



→ Fig 5.36 Polydactyly is the presence of an extra digit. Polydactyly can occur by itself or, more commonly, as one feature of a syndrome of congenital (inherited) anomalies. When it occurs by itself, it is associated with autosomal dominant mutations in single genes. The condition occurs in one in every 500 live births and is generally considered to be a neutral mutation.



→ Fig 5.37 Syndactyly is webbing between the fingers and toes. It is quite common because a foetus actually has webbing that undergoes 'programmed cell death', or apoptosis, to remove it prior to the baby being born. Syndactyly is biologically neutral, but there are certainly situations in which it may be beneficial. Imagine a career as an Olympic swimmer!

A mutation may also give an individual an advantage. Even if the advantage is small, chance events or natural selection may preserve the mutated gene and ensure its representation in the next generation.

Beneficial mutations, and neutral ones, have been accumulating in different lineages for billions of years. Through all that time they have been the raw material for evolutionary change—the basis for the staggering range of biological diversity, past and present, as environmental conditions change and favour them.

Allele frequencies

In the real world, populations are always evolving. How common an allele is within a population is considered to be its frequency—often referred to, confusingly, as the *gene frequency*. The allele frequency changes according to the environmental conditions, which affect whether the allele is passed on to the next generation.



→ Fig 5.38 Many variations have no impact for organisms until an environmental change occurs; then, they may be good, bad or remain neutral.

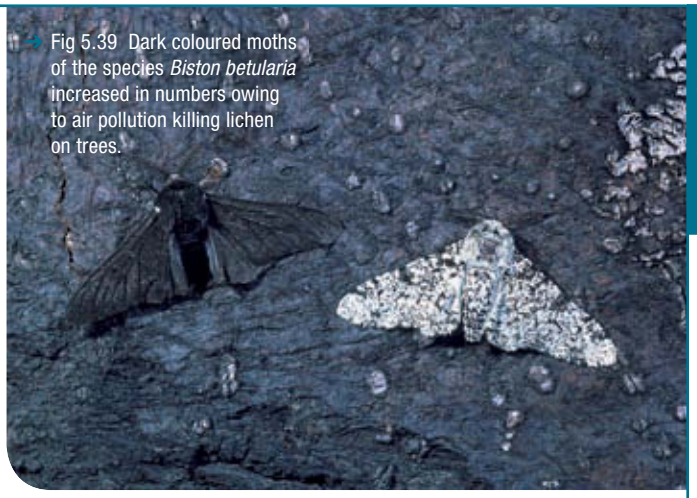
ZOOMING IN

Mutating moths?

In the 1950s, scientists in England documented changes in the colour of the moth species *Biston betularia*. These moths range in colour from light grey to nearly black. During the day the moths rest motionless on tree trunks. In unpolluted areas, tree trunks are covered with light grey lichens, against which the light grey moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so the tree trunks are lichen-free and dark, exposing lighter moths to predation from birds.

It seemed to researchers that, as areas became more polluted, dark moths increased in frequency—natural selection seemed to be changing allele frequencies in the population. This was selection in favour of the 'dark' allele.

In 1952, strict pollution controls went into effect so that the lichens returned and the tree trunks became free of soot, for the most part. As may have been predicted, selection started to operate in the reverse direction. In areas where levels of pollution declined, the frequency of dark moths also declined.

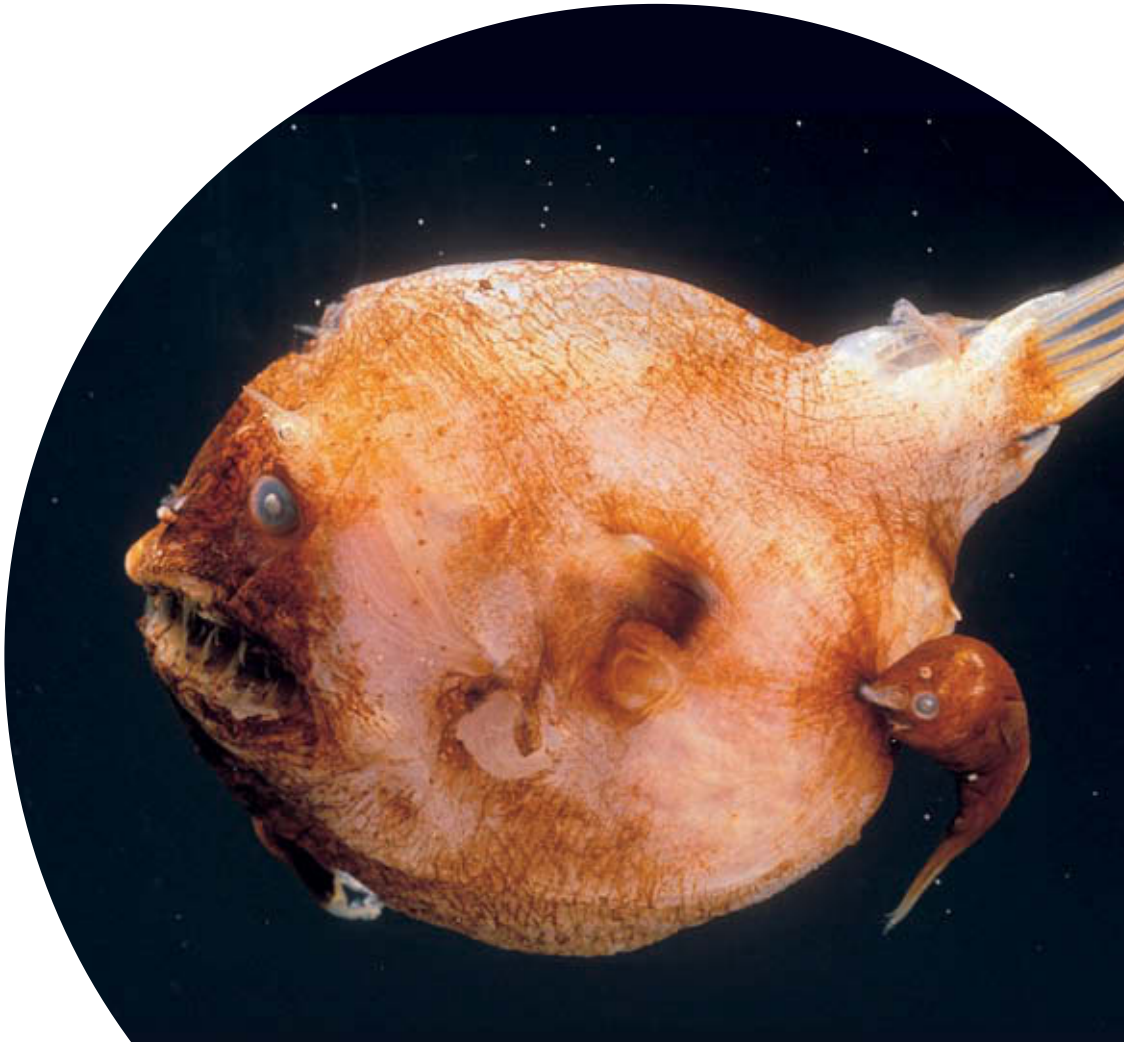


→ Fig 5.39 Dark coloured moths of the species *Biston betularia* increased in numbers owing to air pollution killing lichen on trees.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of chemicals (i.e. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

Sexual selection

Evolution by natural selection occurs as a result of competition between individuals in a population with different traits. This competition may be for food, shelter or mates. Selection for traits that provide an advantage with regard to mating is called **sexual selection**. **Sexual dimorphism** is the term that describes the male and female of the same species being different in appearance (dimorphism = two (di) shapes (morph)). This is particularly common in the invertebrate world.



→ Fig 5.40 The devil angler (*Linophryne indica*) fish is an example of extreme sexual dimorphism. The female is approximately 51 mm long, whereas the male attaches himself as a parasite to the female and is only 15 mm long!

What do you know about natural selection?

1 **1** Variation in individuals can occur in different ways, but there is only one way in which new alleles can be created. What is this process called?

2 **2** Natural selection cannot increase or decrease the frequency of neutral mutations in a population. Why is this?

3 **3** In many species, females are larger than the males because they carry the reproductive burden. However, there are exceptions to this. What could be the cause of these exceptions?

4 **4** In your own words, describe the mechanism by which natural selection can influence the frequency of alleles in a population.



→ Fig 5.41 Extreme events can also result in **physical** or **geographical isolation**. In the summer of 1995, Hurricane Luis, followed by Hurricane Marilyn, ripped through the northern Lesser Antilles in the Caribbean. Fifteen green iguanas survived on a raft of uprooted trees for nearly a month, floating over 300 km before reaching the northern-most island of Anguilla. These few individuals were the first recorded of their species, *Iguana iguana*, to reach the island. The iguanas have since established themselves as an independent breeding colony on the island and, in time, natural selection may operate on this isolated group to the point that they become a new species.

Speciation

When a variation is favoured by the environmental conditions, it is referred to as an **adaptation**. Variations within a species provide 'options' for the species in the face of changing environmental conditions. Although individual organisms may be wiped out, some members of the population will continue the species gene pool.

Along the way, some entire species will become extinct and new species will emerge. Under normal conditions, genes in a given population are exchanged through breeding, so that even if some variation occurs, it is limited by this **gene flow**. But the gene flow is interrupted if the population becomes divided into two groups—**isolation**. If there is no exchange of genes between the two groups, then they may begin to look and behave differently from each other. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding should they ever come together again: a new species has been created (**speciation**).

Speciation can occur in a variety of ways.

Allopatric speciation occurs when one species divides into two or more through some form of isolation, each experiencing very different environmental pressures. In their separate niches (habitats and lifestyles), the groups go their own



→ Fig 5.42 Temporal isolation occurs when individuals of divergent populations reproduce at different times. For example, periodical cicadas mature underground. One species emerges and reproduces every 17 years. A 'sibling' species, which is almost the same morphologically, emerges every 13 years to reproduce. At this rate, the two species would release gametes at the same time only once every 221 years!



➔ Fig 5.43 **Behavioural isolation** prevents gene flow between related species living in the same territory through differences in behaviour. Many animals have elaborate species-specific courtship rituals that must occur before individuals can mate. For example, female birds use colour, song and displays to identify potential mates, whereas female fireflies identify the pattern of blinking lights put out by the males.

➔ Fig 5.44 **Mechanical isolation** occurs when there is a physical incompatibility between the body parts of potential mates or pollinators. For example, the flowers of some plants vary in size and shape, or they may have spiny barriers, thus excluding certain pollinators.

evolutionary ways, accumulating different gene mutations and being subjected to different selective pressures.

In **sympatric speciation**, new species arise within an existing species. This form of speciation is much more common in plants than in animals. It may occur as a result of the failure of chromosome separation during meiosis or it may be the result of a cross between two (plant) species. The resulting new species cannot mate with the parent species, but, in the case of plants, may be able to reproduce asexually. The gene mutations that occur as a result of sympatric speciation are significant enough for the species to show very different responses to environmental changes. Sympatric speciation is rare due to gene flow within a population.

The third mechanism of speciation, **parapatric speciation**, is even

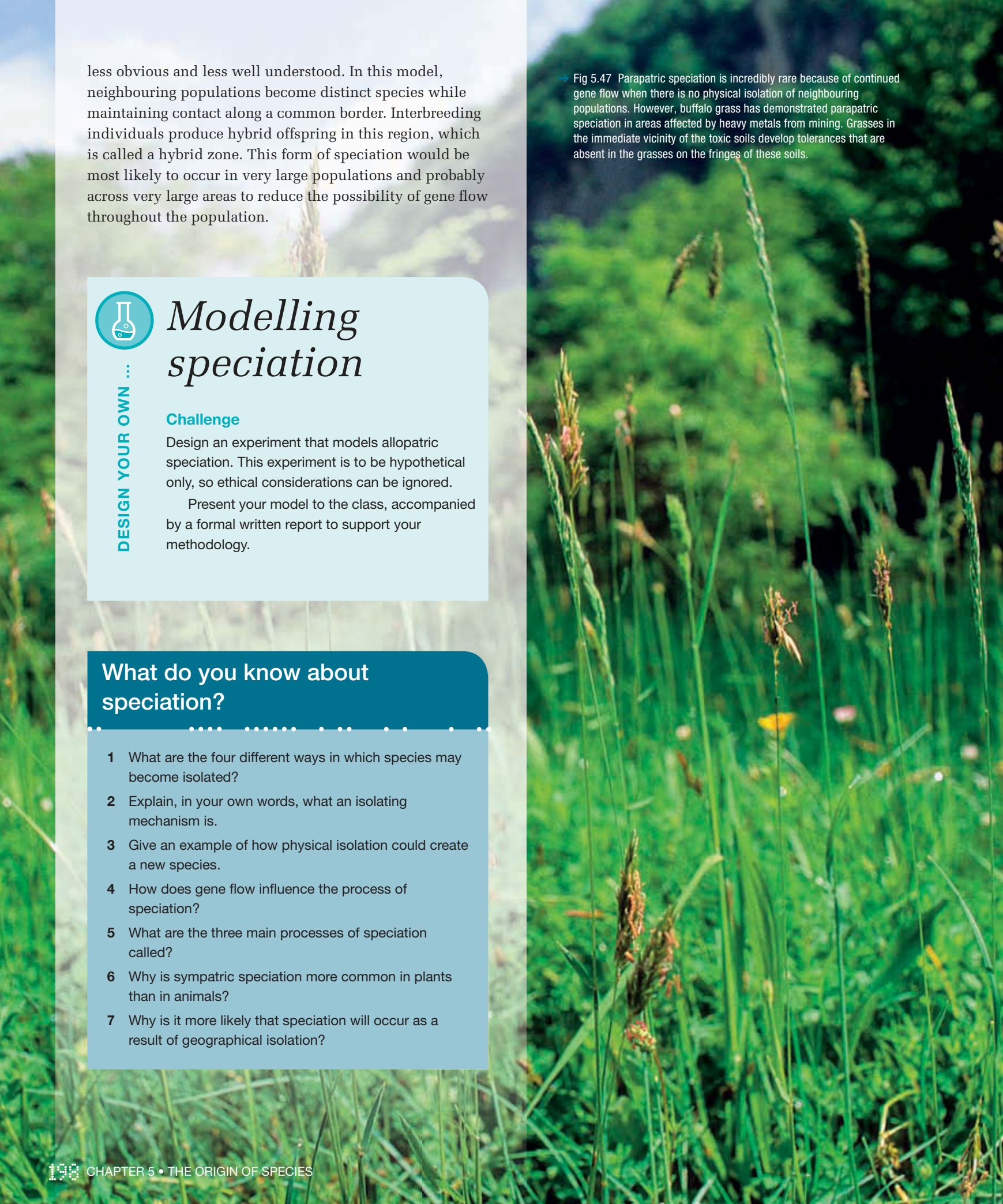


➔ Fig 5.45 Allopatric speciation is thought to have occurred among rock wallabies in Australia. Rock wallabies live in rocky outcrops, which are often separated by long distances, resulting in their geographical isolation from each other. There are approximately twenty different genetically and chromosomally different forms of rock wallaby in Australia, of which sixteen are classified as different species.



➔ Fig 5.46 Sympatric speciation may explain the diversity of Cichlid fish in some African lakes. Here, the competition for resources is so great that the isolation of populations without a physical barrier may have occurred.

less obvious and less well understood. In this model, neighbouring populations become distinct species while maintaining contact along a common border. Interbreeding individuals produce hybrid offspring in this region, which is called a hybrid zone. This form of speciation would be most likely to occur in very large populations and probably across very large areas to reduce the possibility of gene flow throughout the population.



→ Fig 5.47 Parapatric speciation is incredibly rare because of continued gene flow when there is no physical isolation of neighbouring populations. However, buffalo grass has demonstrated parapatric speciation in areas affected by heavy metals from mining. Grasses in the immediate vicinity of the toxic soils develop tolerances that are absent in the grasses on the fringes of these soils.

DESIGN YOUR OWN ...

Modelling speciation

Challenge

Design an experiment that models allopatric speciation. This experiment is to be hypothetical only, so ethical considerations can be ignored.

Present your model to the class, accompanied by a formal written report to support your methodology.

What do you know about speciation?

1. What are the four different ways in which species may become isolated?
2. Explain, in your own words, what an isolating mechanism is.
3. Give an example of how physical isolation could create a new species.
4. How does gene flow influence the process of speciation?
5. What are the three main processes of speciation called?
6. Why is sympatric speciation more common in plants than in animals?
7. Why is it more likely that speciation will occur as a result of geographical isolation?

5.2

How do species evolve?





→ Fig 5.48

Remember and understand

1 What is natural selection and what are the four essential factors?

2 What is the difference between sexual selection and directional selection?

3 What are the three processes of speciation?

4 Explain the difference between incorrectly suggesting an organism has evolved as opposed to correctly suggesting that a population of organisms has evolved.

5 Define the term 'gene pool' in your own words.

6 Isolation usually refers to physically being away from others. Is this the case for all forms of isolation that apply to speciation?

Apply

7 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers. Instead, the stem keeps growing out past the old flower. Consequently, a mature plant may contain the ripe seed of numerous years in its branches. How has this adaptive feature enabled *Callistemon* to exploit the current Australian environment?

8 Connect the terms 'allopatric speciation' and 'gene flow'.

Analyse and evaluate

9 The tortoises of the Galapagos Islands either have a domed shell with short neck—in islands with significant rainfall—or a shell with the front flared up and a long neck—in islands that are more arid. The tortoises feed on prickly pear cactus. On islands with no tortoises, the prickly pear plant is low and spreading, but on islands with long-necked tortoises, the prickly pear plant is tall and has harder spines protecting it.

- **a** Why might the tortoises have two very different phenotypes?
- **b** Would the tortoises that originally reached the islands be likely to resemble any of the tortoises that live there today?
- **c** Using the terms 'variation' and 'survival of the fittest', explain why the prickly pear plant is so different on islands with long-necked tortoises compared with those plants growing elsewhere.
- **d** What type of speciation is occurring on these islands?

Ethical behaviour

10 Through selective breeding, humans are able to make speciation occur. Discuss the various scenarios in which this may occur now, in the past and in the future. Provide three examples of human intervention being positive and three examples of detrimental intervention. Support your choices.

Critical and creative thinking

11 Describe a range of scenarios in which a population of a species becomes (naturally) reproductively isolated from other populations.

CONNECTING IDEAS Diversity and evolution

12 In what ways are the terms *diversity* and *evolution* linked? How does one rely upon the other? Can evolution occur without diversity? Can diversity occur without evolution?

5.3

How do we interpret evidence?



A scientific theory is a well-substantiated (but not proven) explanation of some aspect of the natural world, based on a body of facts that have been confirmed repeatedly through observation and experiment. Evidence is needed to support a theory and, initially, this evidence may be tentative and limited. There is no magic number of pieces of evidence that 'prove' a theory. Scientists seek out evidence from a range of sources, which must be critically examined to ensure that it does support the theory. So, what evidence do we have to support the theory of evolution by natural selection?

<DISCOVERING IDEAS>

Fossils as evidence

In small groups, discuss what you already know about fossils. You have no doubt heard of them before and have most likely studied their formation when examining the rock cycle.

1. What is the difference between a rock and a fossil?
2. Are all fossils rocks?
3. How is a fossil formed?
4. Are there different types of fossils?
5. What might a fossil be able to tell you about the past?
6. How might the age of a fossil be determined?



→ Fig 5.49 Insects preserved in amber.

Evidence for evolution

Support for any theory requires evidence from a range of sources that all points towards the same explanation. Evolution is certainly no different and is arguably one of the more controversial of the scientific theories.

Early evidence for evolution came from the discovery of fossils that identified extinct species. Evidence of large-scale extinctions reinforced the fact that life forms change with changing environmental pressures—even if that simply means that many die and only few survive.

William Smith's geological studies of mines in the 1790s led him to propose the theory that fossils existing in deeper layers were older than those laid down above: relative dating. Some estimation of the time frame in which organisms existed and/or became extinct added another dimension to the story of life on Earth.

The third big step forward in support of evolutionary theory came from the extensive database that was created, and continually added to, as curious observers travelled the globe and documented their sightings. Communicating what organisms were seen and where added to a pool of knowledge that has been critically analysed for over two centuries. This pool continues to expand, and so do the analyses.



→ Fig 5.50 *Triceratops horridus.*

→ Fig 5.51 William Smith did extensive geological studies of mines in the 1790s.

OVERARCHING IDEAS PATTERNS, ORDER AND ORGANISATION

Biodiversity Heritage Library (BHL)

Kate Chmiel, 14 July 2011, Museum Victoria Blog

The Australian node of the Biodiversity Heritage Library (BHL) is now live!

BHL is a project started by a consortium of American and English museums and herbaria that wanted to make historical biodiversity texts available online. These important books and journals are scanned, uploaded to the Internet Archive, and made available through the first BHL website. It's especially useful to scientists needing historical information about species, distributions and taxonomy, but it's also a fascinating site for anyone interested in natural history or rare books. Museum Victoria is managing the Australian part of the project in conjunction with the Atlas of Living Australia.

At present, the 34 596 227 pages in the BHL-Australian node come from libraries in US institutions, so there is plenty of Australian content yet to be added. First off the rank in this national project [are] some of the in-house journals that have already been scanned by other museums, including those of the Queensland Museum and the Western Australian Museum. Museum Victoria, with new book-scanning equipment, will be leading the development of new scanning projects, starting with the complete archive of *Memoirs of Museum Victoria* containing the first scientific descriptions of many Victorian animal species. This will be very handy for biologists worldwide who don't have ready access to hard copies of this journal. Later on, rare books from [Museum Victoria] and the libraries of other Australian institutions will be scanned and uploaded.

The high-quality scans are not just useful, but often quite beautiful. You get the whole book—covers, library labels, marbled endpapers and marks of age—not just the text within. BHL puts these wonderful books in the hands of anyone.

1. Why is communication between scientists so important?
2. How has the Internet changed the way scientists communicate?
3. How would a database of biodiversity-related information be useful for classification?
4. How would such a database be useful for evolutionary biologists?

What do you know about evidence for evolution?

1 Will the theory of evolution ever become fact? Explain.
2 Two crucial leaps were made through certain fossil discoveries: extinction and relative dating. How are these 'crucial' to the theory of evolution?
3 How might observations of extant (living) organisms contribute to the evidence for evolution?

Analysing the dead

Fossils are the remains or traces of organisms from a past geological age embedded in rocks or other substances by natural processes. They are extremely important for understanding the evolutionary history of life on Earth because they provide direct evidence of evolution and detailed information on the ancestry of organisms.

Palaeontologists study fossil records and determine their relationships with different geological time periods.

Fossilisation requires the organism, or its traces, to be buried quickly so that weathering and total decomposition do not occur. Skeletal structures or other hard parts of the organisms that resist weathering and are slower to decompose are the most commonly occurring form of fossilised remains. **Trace fossils** show moulds, cast or imprints of some previous organisms.

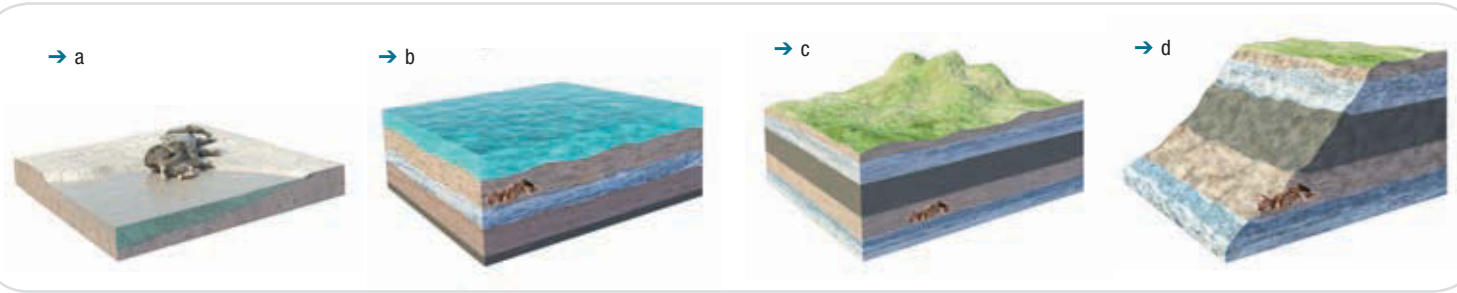


Fig 5.52 Formation of a fossil. (a and b) If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. (c) Over millions of years, more sediment is deposited and the remains are transformed gradually into sedimentary rock. (d) Years of geological movement, weathering and erosion may eventually expose the fossil.



Fig 5.53 Fossilised megafauna (giant animal) footprints.

PRACTIVITY 5.4

Examining bones

What you need: selection of real and/or cast bones

1 Examine the bones carefully.
2 Using your understanding of the musculoskeletal system and your experience of cutting meat off bones, identify features of the bones that could provide indications of muscle attachment, animal size, the entry and exit of blood vessels and nerves, the function of that bone etc.

How might analyses of the bones of modern animals be used to assist the analyses of fossils?

ZOOMING IN

Rare dinosaur footprints found in Victoria

by Becky Crew
Cosmos Online

Dinosaur footprints have been discovered in Victoria, adding to the four documented dinosaur tracks found in the State after more than 100 years of paleontological research.

The two sandstone blocks covered in tracks were found at Melanesia Beach, about 100 km from Melbourne. The 24 tracks represent 85% to 90% of the known dinosaur footprints in the State, and are considered to be an invaluable resource of information on dinosaur diversity and activity.

'What is significant about dinosaur footprints—as opposed to dinosaur bones or teeth—is the evidence of the presence of dinosaurs. The trace fossils tell us how the dinosaurs were living in the area at the time,' said Thomas Rich, senior curator of vertebrate palaeontology at Museum Victoria in Melbourne and lead author of the paper published today in *Alcheringa: An Australasian Journal of Palaeontology*.

'This is the most significant dinosaur track discovery in Victoria. There are at least 24 dinosaur tracks made by a variety of dinosaurs within the two sandstone blocks,' he added.

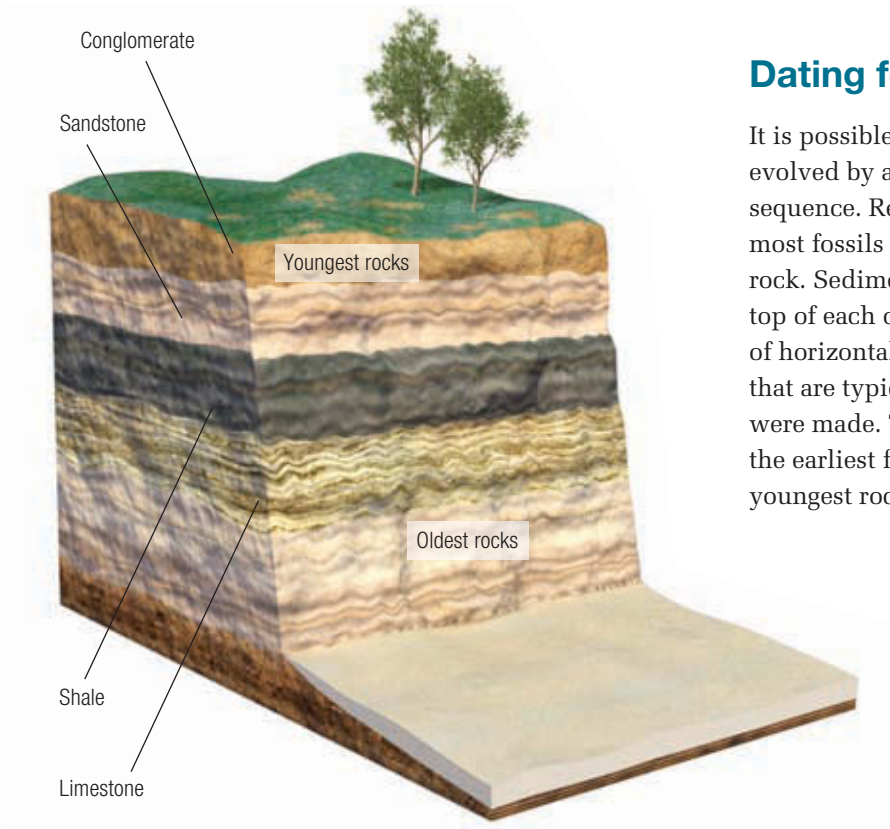
PRACTIVITY 5.5

Examining fossils

What you need: selection of fossils

Examine each fossil, making careful observations of the structures you can see.

- What do you definitely know about the organism responsible for the fossil?
- What can be inferred from the structures you have observed in the fossil? Consider lifestyle, diet, reproductive behaviours etc.
- What further evidence would you require to support your inferences?

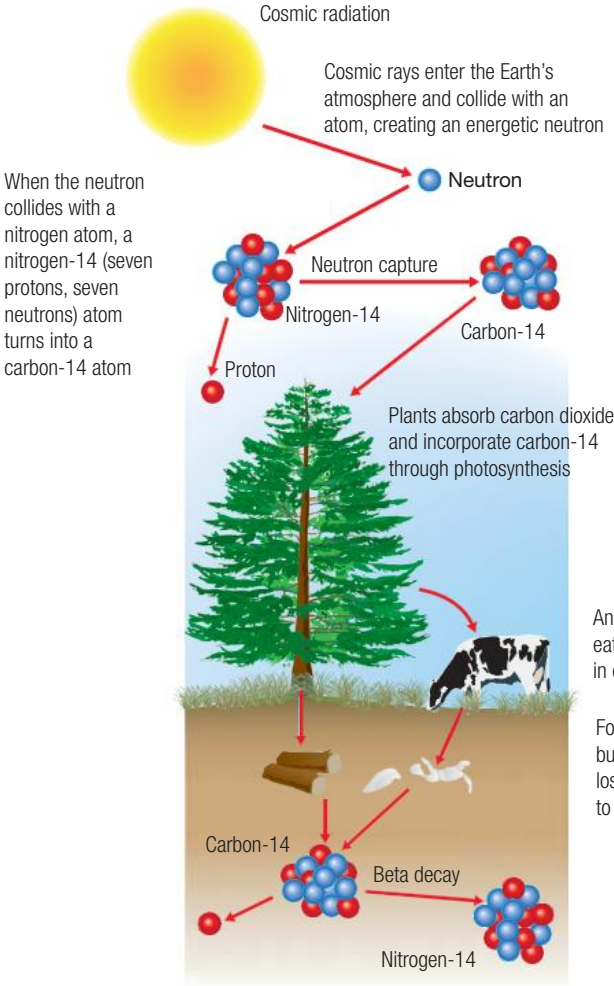


Dating fossils

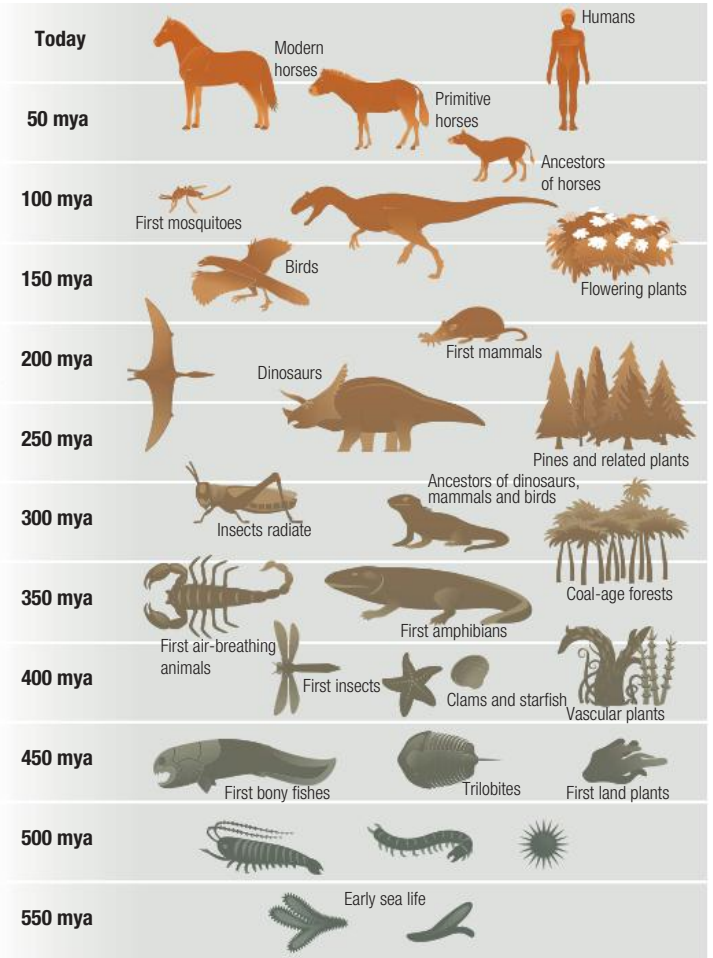
It is possible to find out how a particular group of organisms evolved by arranging its fossil records in a chronological sequence. Relative dating can provide approximate dates for most fossils because fossils are found mainly in sedimentary rock. Sedimentary rock is formed by layers of silt or mud on top of each other. Thus, the resulting rock contains a series of horizontal layers, or strata. Each layer contains fossils that are typical for a specific time period during which they were made. The lowest **strata** contain the oldest rock and the earliest fossils, whereas the highest strata contain the youngest rock and more recent fossils.

› Fig 5.54 Comparative dating is used to work out the age of rocks and fossils.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils. **Absolute dating** relies on the level of radioactivity detected in rocks containing radioisotopes. Certain radioactive isotopes are known to exist in living organisms, so the rate of decay of these isotopes indicates how long an organism has been dead.



➔ Fig 5.55 Absolute dating is used to calculate an approximate age. The process relies on the levels of radioactivity detected in rocks that contain radioisotopes.



➔ Fig 5.56 The history of living things, as determined by palaeontology.



Fishibians

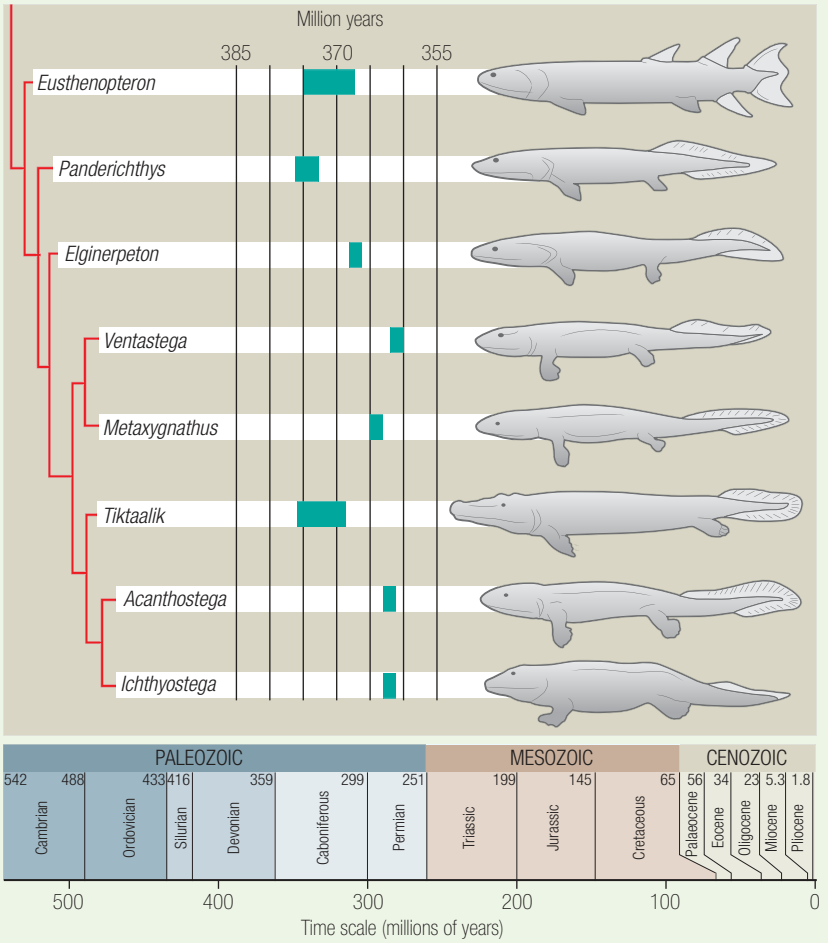
It's a lovely idea to suggest that life originated in the sea, crawled onto land and then took to the skies or grew fur. But what evidence links these stages? **Transitional fossils** show the intermediate states between the 'before' and 'after'. They are sometimes referred to as 'missing links', although the reality is a 'chain of missing links' is required over many generations.

When Darwin first published his theory, he stressed that the lack of transitional fossils was the most formidable obstacle to his theory because, at that time, very little was known about the fossil record. Since then, numerous excellent examples have been found, starting with the discovery of *Archaeopteryx* in the Solnhofen area of Germany just 2 years after Darwin's work was published.

Archaeopteryx is the earliest and most primitive bird known, displaying a number of features common to both birds and reptiles.

The 'fishibian' sequence is perhaps one of the most complete in the fossil record, providing insight into the steps that may have occurred to enable life to move from the sea to the land.

→ Fig 5.57 The 'fishibian' sequence.



Living fossils

According to fossil records, some modern species of plants and animals are found to be almost identical to species that lived in ancient geological ages. **Living fossils** are existing species of ancient lineages that have remained unchanged in form for a very long time.

Examples of living fossils include the coelacanth fish (Figure 5.58), the *Ginkgo* trees and *Metasequoia* conifers of China and the Wollemi pine, which was only discovered in New South Wales in 1994.



→ Fig 5.58 Unique in the animal kingdom, the coelacanth is a 400 million-year-old living fossil fish! The coelacanth pre-dates dinosaurs by millions of years and was thought to have become extinct with them. In 1938, the coelacanth was discovered living in caves off the continental shelf. This environment has changed little over the past 400 million years and, as a result, neither has the coelacanth.

EXPERIMENT 5.1

Building animals

Aim

To reconstruct an animal's skeleton from a pile of bones to simulate the processes undertaken by palaeontologists.

Materials

Whole roast chicken
Water
Washing liquid
Saucepan
Colander
Stove
Toothbrush
Newspaper
Diagram of a chicken skeleton

Method

1. Remove as much flesh from the bones of the roast chicken as possible.
2. Boil the bones in a saucepan of water for 20–30 minutes.
3. Strain the water from the bones using the colander.
4. Gently remove the rubbery pieces of cartilage from the bones.
5. Scrub the bones with a toothbrush and a small amount of washing liquid.
6. Rinse the bones and leave them to dry overnight on newspaper.
7. Use the diagram of a chicken skeleton to attempt to reconstruct your chicken. Your finished skeleton will be laid out on a piece of newspaper rather than as a three-dimensional model.

Hint: It may be helpful to group bones into long bones, flat bones etc.

Results

Include images showing your method and finished skeleton.

Discussion

Analyse how this process may be similar to the work of a palaeontologist.

1. What sorts of bones may palaeontologists be dealing with?
2. Would they be reconstructing entire skeletons?
3. Would palaeontologists attempt to reconstruct the layers of flesh that cover the skeleton?
4. What indicators on the bones may they be looking for?

Conclusion

Write a brief statement about the work of palaeontologists to reconstruct skeletons.



What do you know about analysing the dead?

1. What parts of organisms are most likely to be found in fossils? Explain.
2. How does comparative dating work? Why is it often used before absolute dating?
3. In your own words, describe a transitional fossil.
4. Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. How has this been possible?

Analysing the living

When you consider a family photograph, there are similar traits throughout, with more similarities shared between members of immediate family compared with extended family. The same applies to the non-human members of the animal kingdom and all other living organisms. Such observations of the living are considered an integral aspect of evidence for evolution.

Evolutionary theory is regularly supported by the analysis of similarities between organisms—both living and dead. These similarities can be in body parts, cells, biochemistry, embryos or even vestigial (functionless) structures. The evidence studied to date supports the theory that the greater the level of similarity, the more closely related two organisms are.

Comparative anatomy

Structures that are found across organisms and have a similar pattern but different function are known as **homologous structures**. The most commonly discussed homologous structure is the **pentadactyl limb**—the pattern of limb bones in all groups of tetrapods (i.e. four-legged vertebrates) that ends in five digits. This structure can be traced back to the fins of certain fossil fishes from which the first amphibians are thought to have evolved. Throughout the tetrapods, the fundamental structures of the pentadactyl limbs are the same, indicating that they originated from a common ancestor. But, during the course of evolution, these fundamental structures have been modified to serve different functions as a result of adaptations to different environments and modes of life.

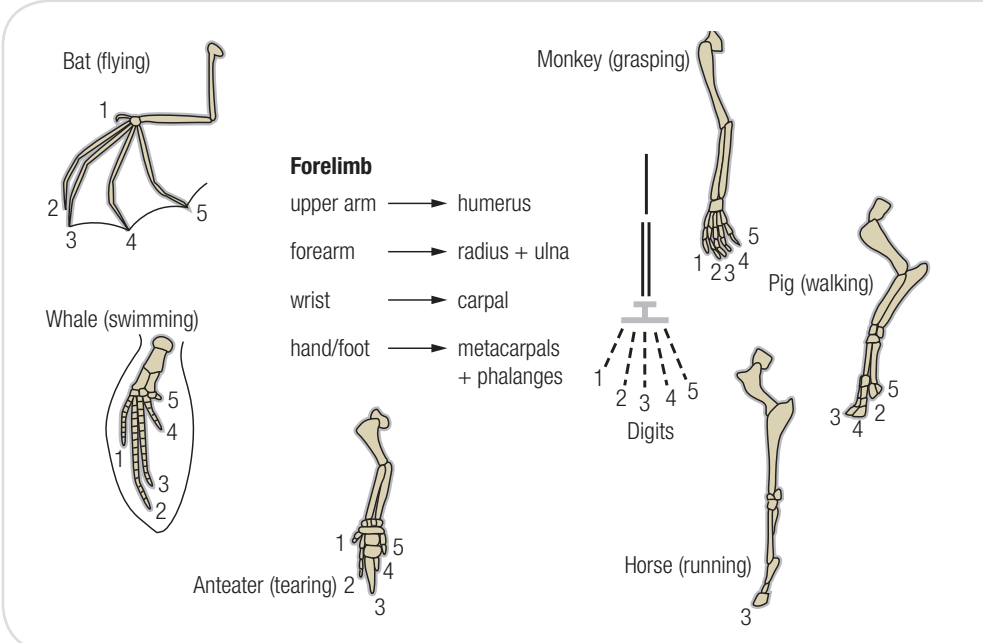
Structures in organisms that perform the same function but are structurally different are described as **analogous structures**. This absence of similarity in structure suggests there is no common ancestor in the recent past. When organisms become more similar with time due to similar environmental pressures, this is referred to as convergent evolution.



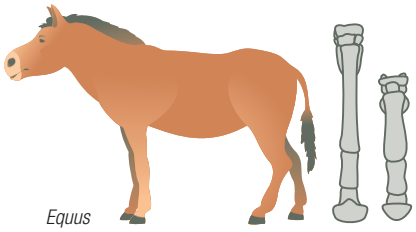
→ Fig 5.59 The appendix in humans appears to be getting smaller through the generations and has not been useful to human digestion for a very long time.

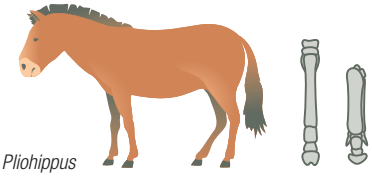


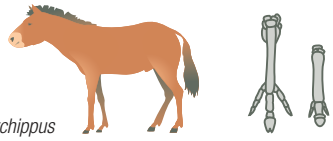
→ Fig 5.60 The rear legs on a snake (arrows) are an example of a vestigial structure.



→ Fig 5.61 The forelimbs of different mammals show the same basic structure, with five fingers that are adapted to different uses.











→ Fig 5.62 Combining fossil dating with comparative anatomy can provide a timeline of structural changes, such as those of the fossil ancestors of modern horses.





→ Fig 5.63 The wings of a bird (a) and the wings of a butterfly (b) are analogous structures: they perform the same function, but have significantly different structures. Birds and butterflies are an example of convergent evolution.

ZOOMING IN

Vestigial structures

Vestigial structures, functionless structures found in organisms, have perplexed naturalists throughout history and were noted long before Darwin first proposed the concept of common descent. We now understand that individual organisms contain, within their bodies, abundant evidence of their histories. Some of these structures are clearly designed to perform a certain task that they no longer do. Without the theory of evolution, the tiny wings of a cassowary are a puzzling structure. So, too, are the hindlimb buds of many snake species, which still carry vestigial pelvises hidden beneath their skin.

Vestigial structures are now interpreted as evidence of an ancestral heritage in which these structures once performed other tasks. The wings of a cassowary are a reminder that a distant relative of this organism once used its wings to fly. Similarly, snakes evolved from a four-legged ancestor. Humans, too, carry the evolutionary baggage of our ancestry. The ancestors of humans are known to have been herbivorous, and

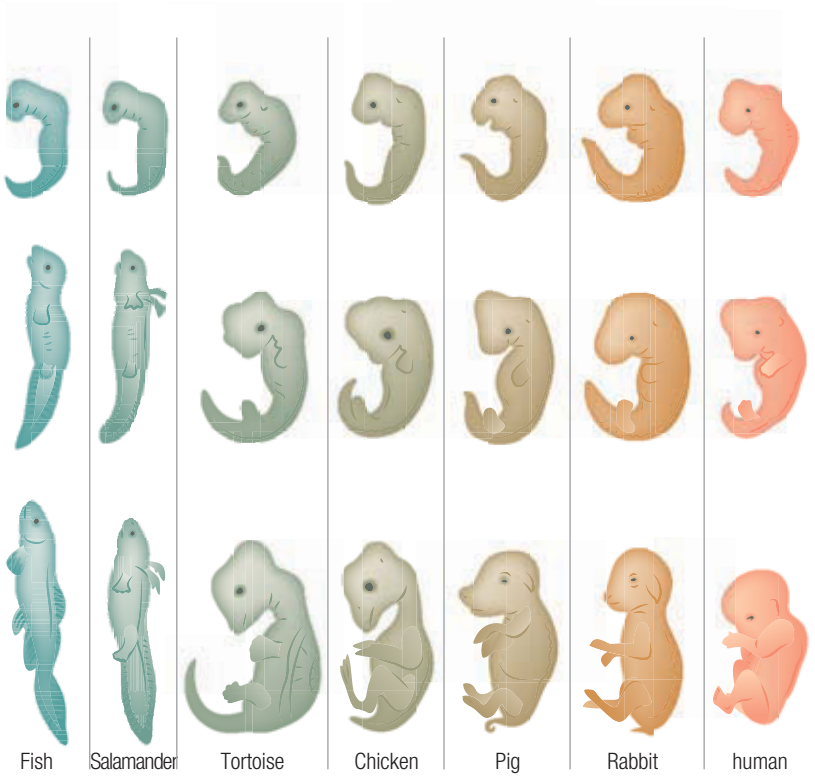


→ Fig 5.64 Cassowary wings.

Analysing embryos

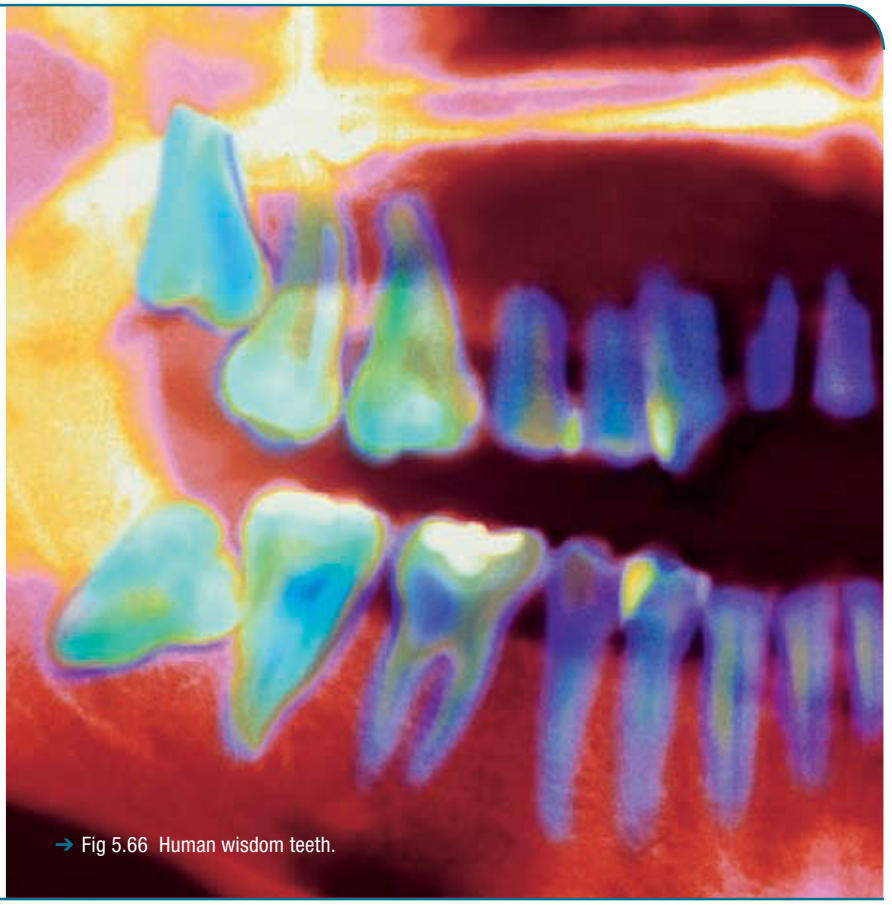
Scientists have noticed that, although adult vertebrates have certain differences, many embryos demonstrate huge similarities during the early stages of development. For example, a chicken and a human are very different when fully formed, but chicken embryos are very similar to human embryos. In fact, even reptile embryos are similar to human embryos. Embryos may also show many interesting features that are not seen in the fully developed animal. As the embryo develops, it goes through a variety of stages. Many of these stages show homologous structures with different species.

If the various life forms developed independently, one would think that their embryonic development would be distinct and reflect what the organism would look like when it was fully developed. Why should a bird's three-digit limb develop from a five-digit limb? This makes no sense if organisms developed independently. The embryological similarities are explained by inferring that these organisms all had a common ancestry. Whales develop teeth embryonically because they evolved from ancestors that had teeth. Birds develop their three-digit limbs as embryos from five-digit limbs because they evolved from ancestors with five-digit limbs.



→ Fig 5.65 Stages in the embryonic development of vertebrates.

molar teeth are required for chewing and grinding plant material. Over 90% of all adult humans develop third molars (otherwise known as 'wisdom teeth'). Usually these teeth never erupt from the gums and, in one-third of all individuals, they are malformed and impacted. These useless teeth can cause significant pain and an increased risk of injury, and may result in illness and even death. Another vestigial structure from our herbivorous ancestry is the appendix. Although this intestinal structure may retain a function of some sort, perhaps in the development of the immune system, it is a rudimentary version of the much larger caecum found in other mammals that is essential for the digestion of plants.



→ Fig 5.66 Human wisdom teeth.



➔ Fig 5.67 Bird embryos develop pentadactyl limbs, which then fuse in places to become three-digit limbs.

Comparing molecules

Advances in the understanding of the biochemical processes of life have provided a wealth of evidence in support of evolution. Biochemical homologies (similarities) provide some of the strongest evidence for evolution because of the detailed level of information they afford. Most biochemical evidence for evolution comes from comparative examination of genetics or proteins.



➔ Fig 5.68 In some toothless whales, teeth develop in the embryos, but these are absorbed later during embryonic development. Why should a toothless whale develop teeth that are later absorbed?

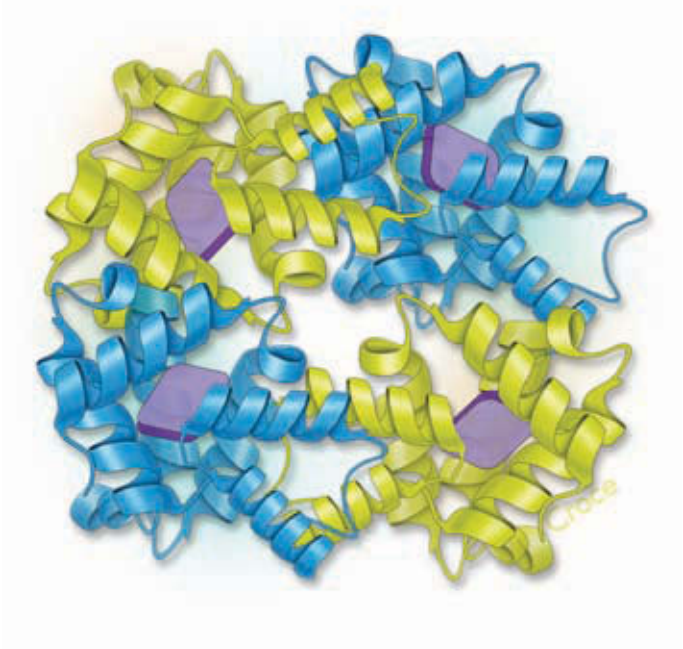
Comparing amino acids in proteins

Proteins are coded for by genes and are made up of a string of amino acids. Proteins range in size from approximately fifty amino acids to thousands and are among the most important chemicals in life, controlling metabolic processes and providing vital structural components. The characteristics of a protein are determined by the sequence of amino acids from which it is constructed.

All livings things use the same twenty amino acids to make proteins, even though approximately 250 amino acids occur naturally. If life evolved from a common ancestor with only these twenty amino acids, we may expect that these same twenty amino acids are always used.

Protein sequences also show remarkable similarities. A number of different codons can code for the same amino acid, and small changes in some of the amino acids that make up a protein can have little, if any effect, on the functioning of the protein. So, we can have a set of proteins that do essentially the same thing but are not identical.

Haemoglobin is one such example. Several types of haemoglobin molecules are found among different vertebrates and invertebrates. These haemoglobin molecules are all very similar in structure and all serve the function of binding oxygen in the blood, yet they differ in their amino acid sequences.



➔ Fig 5.69 There are so many different sequences of amino acids that could make a functional haemoglobin molecule. Why should these variations in haemoglobin exist? Convergent evolution provides a meaningful answer.

SKILLS LAB

Evolutionary relationships

Cytochrome *c* is a protein commonly used to identify evolutionary relationships because of its involvement in cellular respiration—a metabolic process common to most organisms.

Table 5.1 shows the number of amino acid differences in a homologous (common) sequence of cytochrome *c* from several species. The homologous sequence contains a total of 104 amino acids.

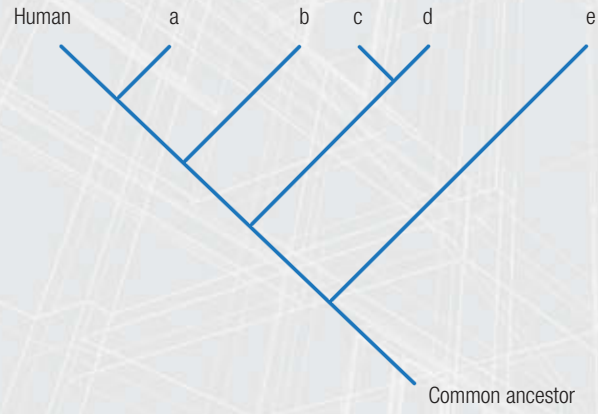
→ Table 5.1 Number of amino acid differences in cytochrome *c* between species

	Human	Penguin	Rabbit	Monkey	Duck
Human					
Penguin	14				
Rabbit	9	8			
Monkey	1	13	8		
Duck	11	3	6	10	
Tuna	21	18	17	21	16

From the information in Table 5.1, relationships can be identified between the species as comparisons between the species listed.

For example, there are fourteen differences between humans and penguins compared with only eight differences between penguins and rabbits; so, penguins and rabbits are more closely related than humans and penguins.

→ Fig 5.70



Your turn

1 Which are more closely related: penguin and duck or rabbit and monkey?

2 The relationship between species is considered to be an indication of how recently they shared a common ancestor. A tree diagram is often used to represent evolutionary relationships. Can you work out which species from Table 5.1 fits the labels in Figure 5.70?

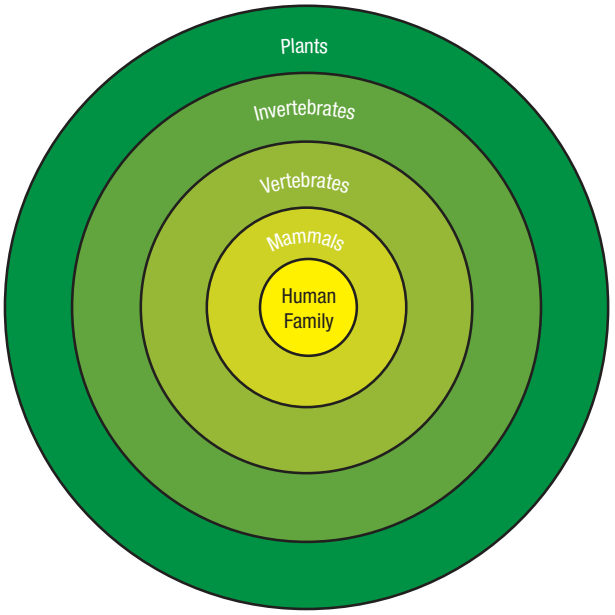
Answer

Penguin and duck, with only three differences between them.

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of gene sequences. Comparing DNA sequences examines the relationship between different species—more similarities indicate a closer relationship. Darwin's original hypothesis of common descent (all life evolved from a single life form) is reinforced by this evidence.

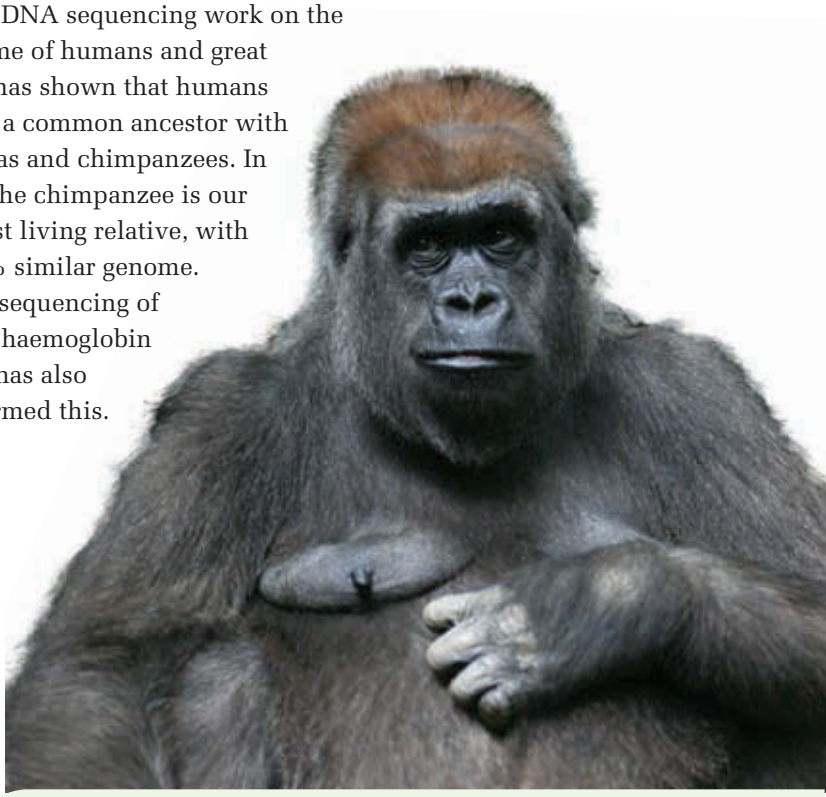
If the hypothesis of common descent is true, then species that share a common ancestor will have inherited that ancestor's DNA sequence. In addition, they will have inherited mutations unique to that ancestor. These specifics can be used to produce timelines that indicate roughly when speciation would have taken place and therefore can be used to create a 'family tree' similar to Darwin's tree of life.

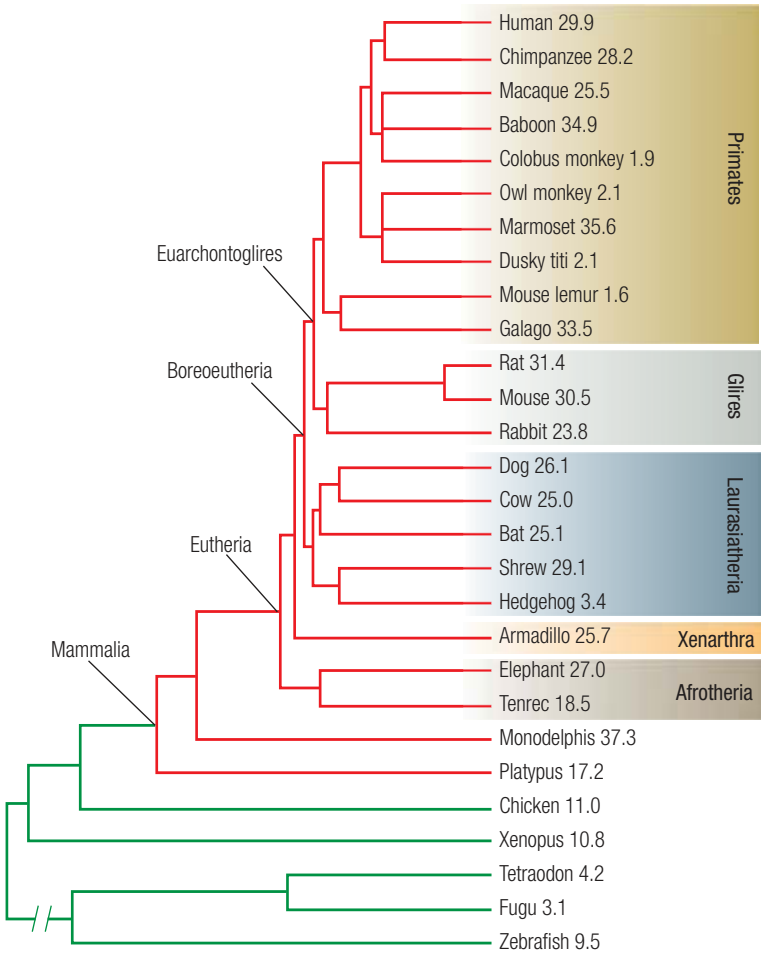


➔ Fig 5.71 Your DNA is going to be most similar to your immediate family, followed by your extended family, the rest of the human species and then other mammals.

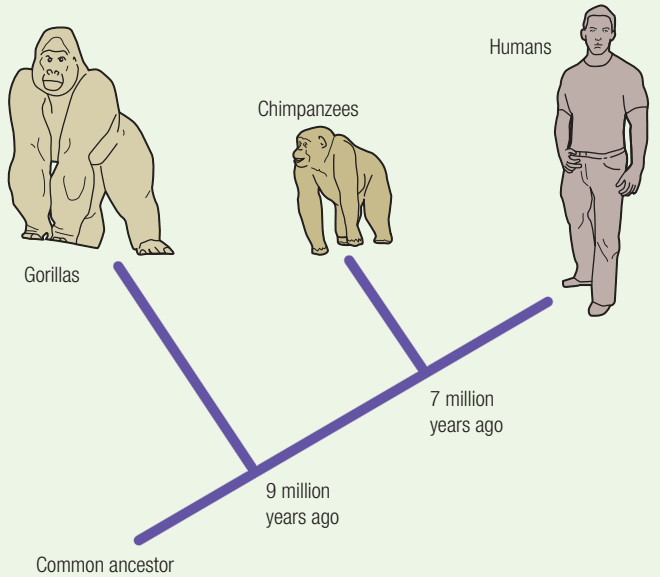
The most detailed DNA sequence reconstructions have been performed using the genomes of mitochondria, which are shared by all eukaryotic organisms and are short and easy to sequence.

Early DNA sequencing work on the genome of humans and great apes has shown that humans share a common ancestor with gorillas and chimpanzees. In fact, the chimpanzee is our closest living relative, with a 98% similar genome. DNA sequencing of the β-haemoglobin gene has also confirmed this.





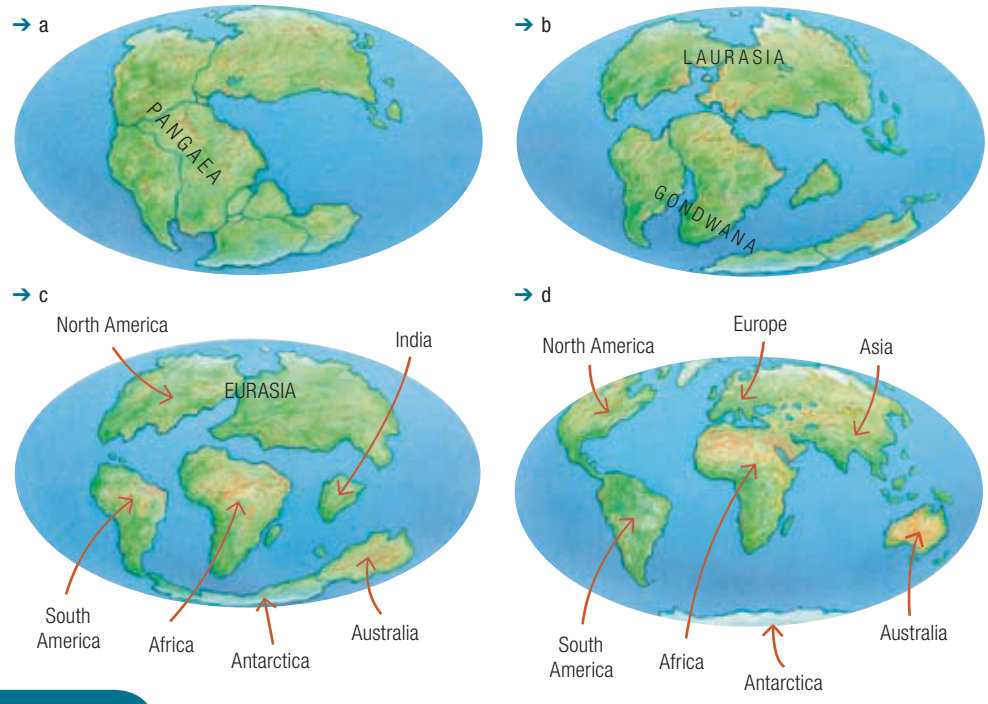
➔ Fig 5.73 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.



➔ Fig 5.72 Research comparing genomes has helped define relationships among vertebrate species. The lengths of the branches on this phylogenetic tree, which are based on DNA sequence comparisons, show how closely each animal is related. The numbers next to each species name indicate the amount of the sequence (in megabases) that was analysed.



→ Fig 5.74 Very distant relatives!



→ Fig 5.75 How the continents have drifted: (a) 220 million years ago; (b) 135 million years ago; (c) 65 million years ago; and (d) the continents today.

What do you know about analysing the living?

1. Define the term 'homologous structures' in your own words.
2. Give an example of a homologous structure.
3. How does the presence of vestigial structures support the theory of evolution?
4. Which two biomolecules are of most interest to biologists studying evolution?
5. How do the twenty amino acids used in protein synthesis provide evidence for evolution?
6. Explain in your own words how DNA sequencing supports the concept of evolution from a common ancestor.

Biogeography

At the beginning of the 17th century, the English philosopher Francis Bacon noted that the east coast of South America and the west coast of Africa looked as though they could fit together like pieces of a jigsaw. Since this time, detailed maps have been constructed of the Earth, geologists have developed our knowledge of the structure of the Earth and the theory of continental drift through plate tectonics continues to be supported by observations of various phenomena across the planet. It is now believed that at one time all the continents were connected in a single land mass—Pangaea. This supercontinent then broke in two to form Gondwana in the south and Laurasia north of the Equator.

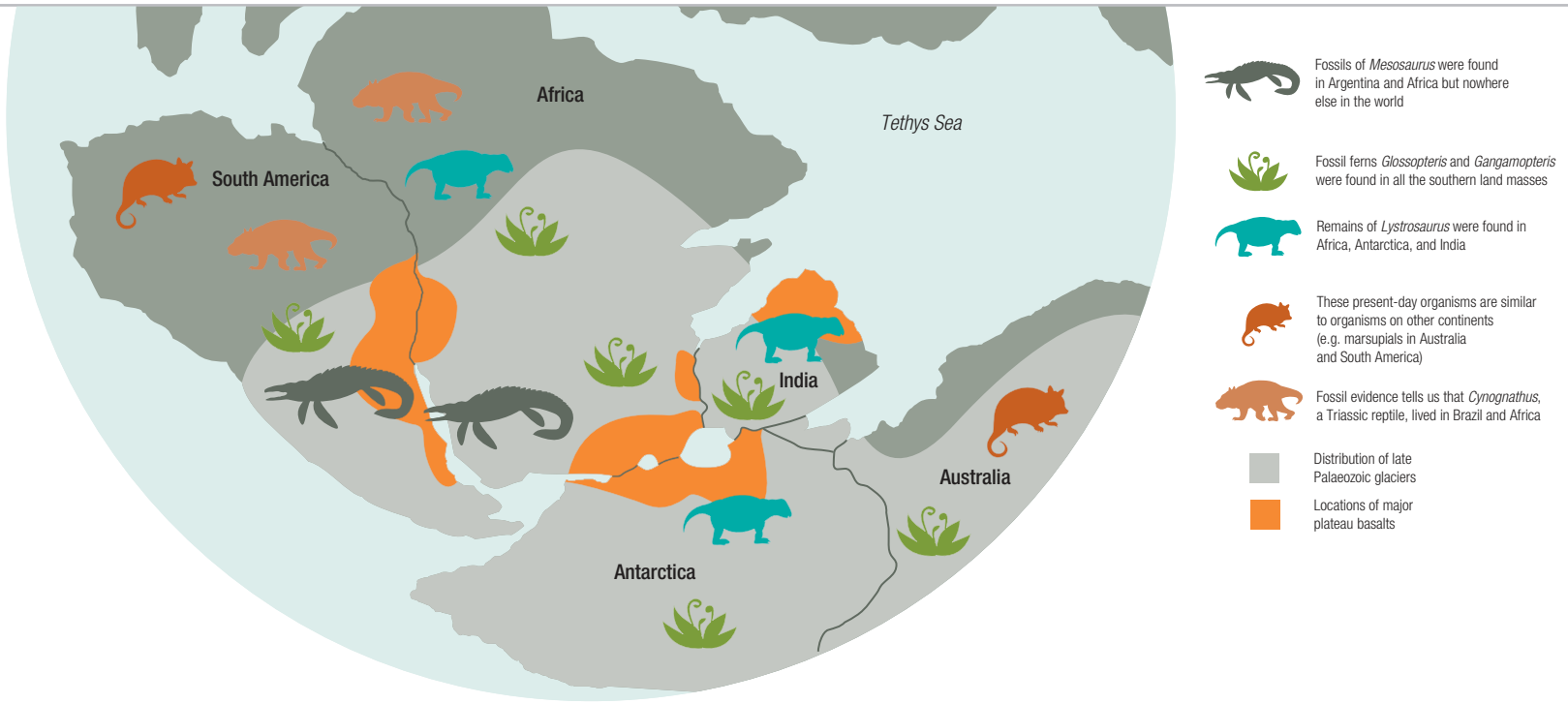
The theory of continental drift has had a major impact on evolutionary theory because living organisms were carried on the land masses.

The distribution of the fossils of extinct plants and animals, as well as modern-day species, supports the theory of continental drift. Some continents share very similar organisms even though they are separated by large stretches of ocean. For animals that are able to fly or swim, connections are less solid, but for the rest, continental drift is the only convincing explanation.

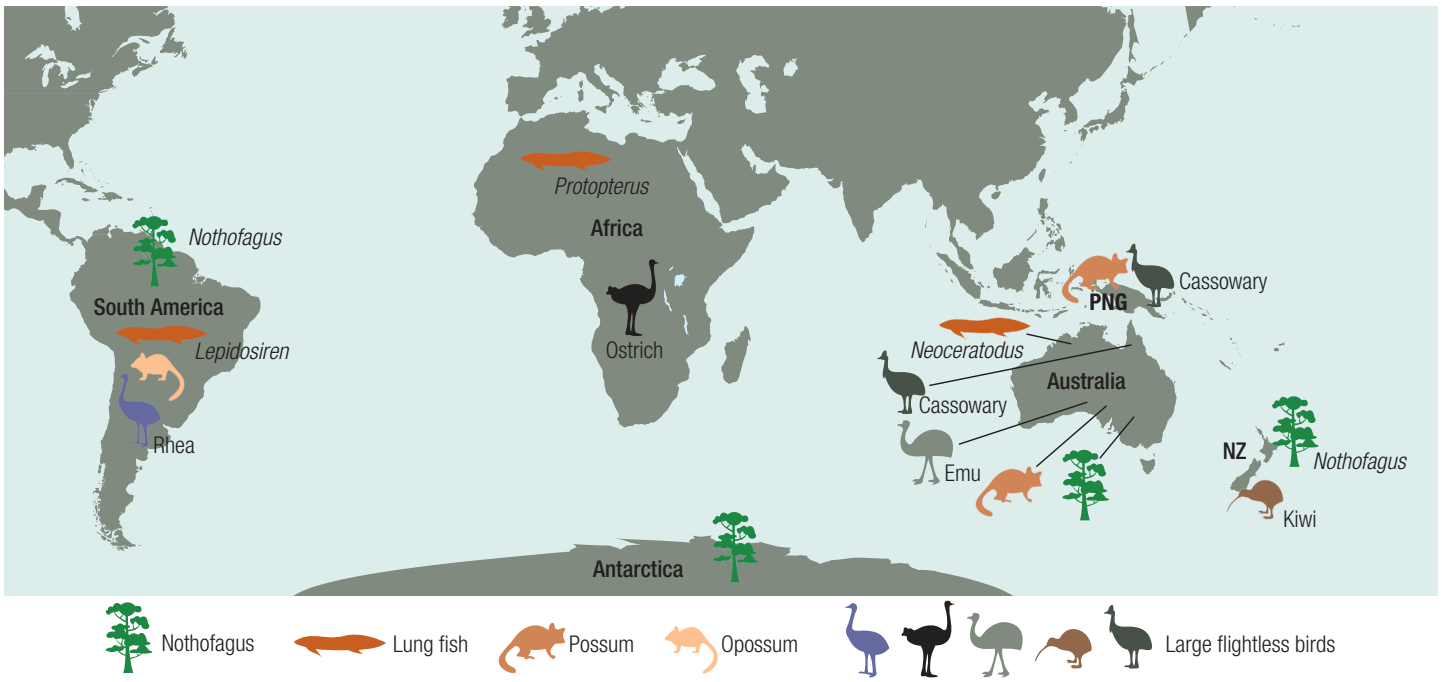


→ Fig 5.76 A jigsaw fit of Africa and South America.

Continental drift provides a well-supported explanation for the geographical isolation of species that eventually results in speciation—divergent evolution. Groups of similar species, such as the ratites (flightless birds), and the existence of marsupials on several continents, can be explained by biogeography. 'Coincidence' is simply not a scientific explanation.



➔ Fig 5.77 Evidence for the existence of supercontinent Gondwana.



➔ Fig 5.78 Similar lungfish are found in South America, South Africa and Australia. Similar marsupials are found in South America and Australia.

What do you know about biogeography?

1. The frogs of Australia show their closest evolutionary relationships to frogs in Africa and South America. How is this possible? Did humans carry them on boats?
2. Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years. How could this information be used to support the theory of continental drift? How could it impact the theory of evolution?
3. If marsupials were found in North America, would this disprove the theory of continental drift? Explain.

Origins of life

Like any good jigsaw puzzle with lots of pieces, the final image isn't revealed until all the pieces are locked in place. The story of evolution continues to be written and modified as new evidence is added to the mix, but an aspect of significant interest to many is determining the answer to one of the biggest questions of all time: where did life come from?

Early Earth

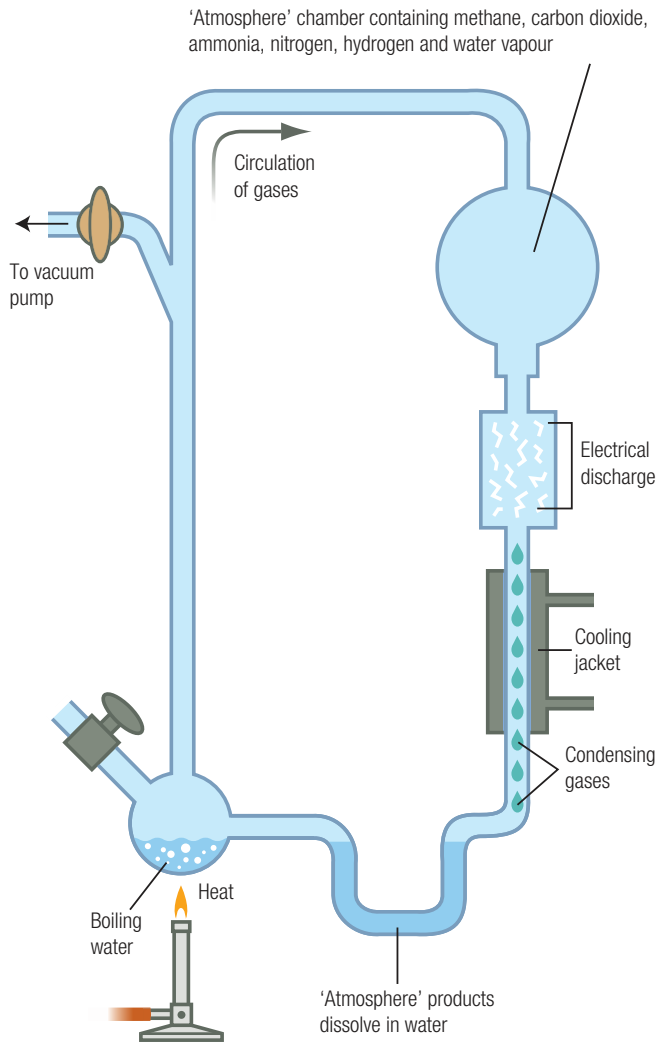
Geological evidence points towards a very different Earth 4.5 billion years ago to what we encounter today. Clouds of water vapour condensed to form hot oceans and seas; only one or two large land masses existed; volcanoes spewed ash and lava continuously; electrical storms and cosmic rays produced explosive energy bursts; and the atmosphere consisted of hydrogen, carbon monoxide, methane and ammonia, but no oxygen.



→ Fig 5.79 The warm oceans are considered by many to be a 'primordial soup', a mixture of non-living components capable of combining to form primitive life.

Urey-Miller experiment

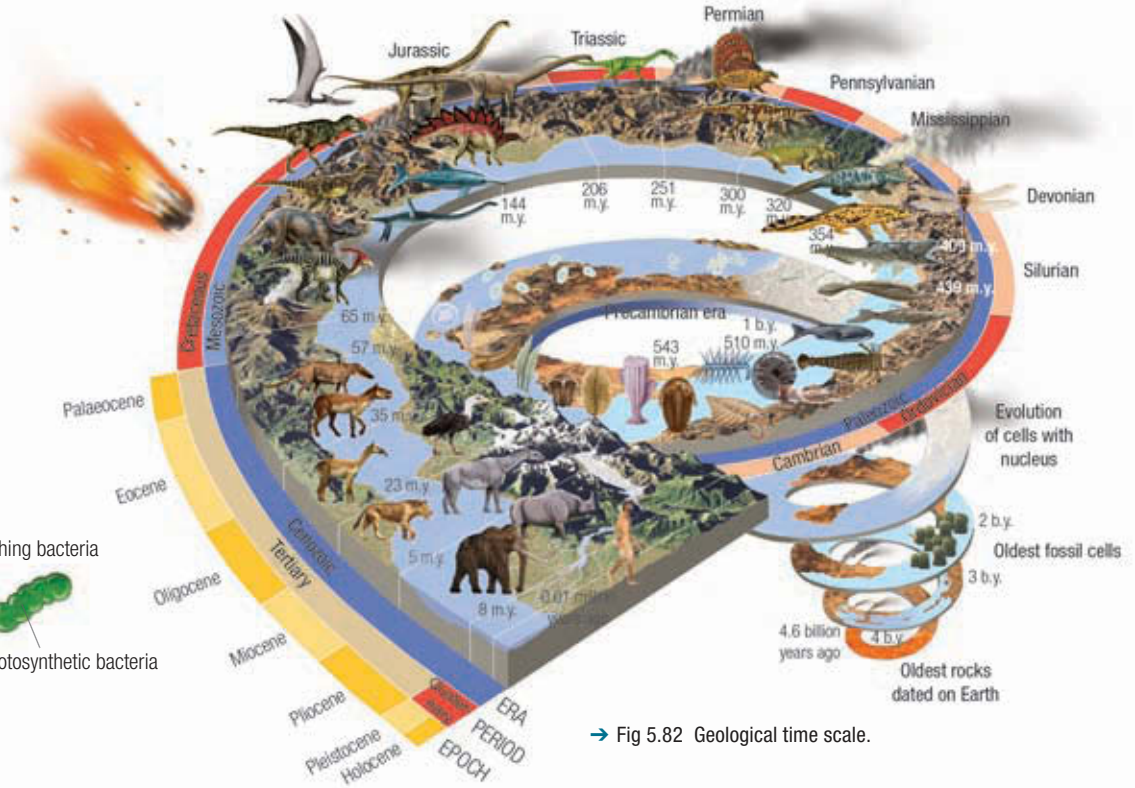
Despite the hostile nature of this early environment, it is believed that the first organic chemicals (carbon compounds present in living things) originated in it approximately 4 billion years ago. Once these biological chemicals were present, primitive cells emerged about 3.5 billion years ago. Over the past 200 years, scientists have attempted to simulate this 'spontaneous generation of life' in a science laboratory. All scientists agree that for living matter to evolve, the chemicals of life must first be present. Then, over a long period of time, these chemicals could become organised into living cells.



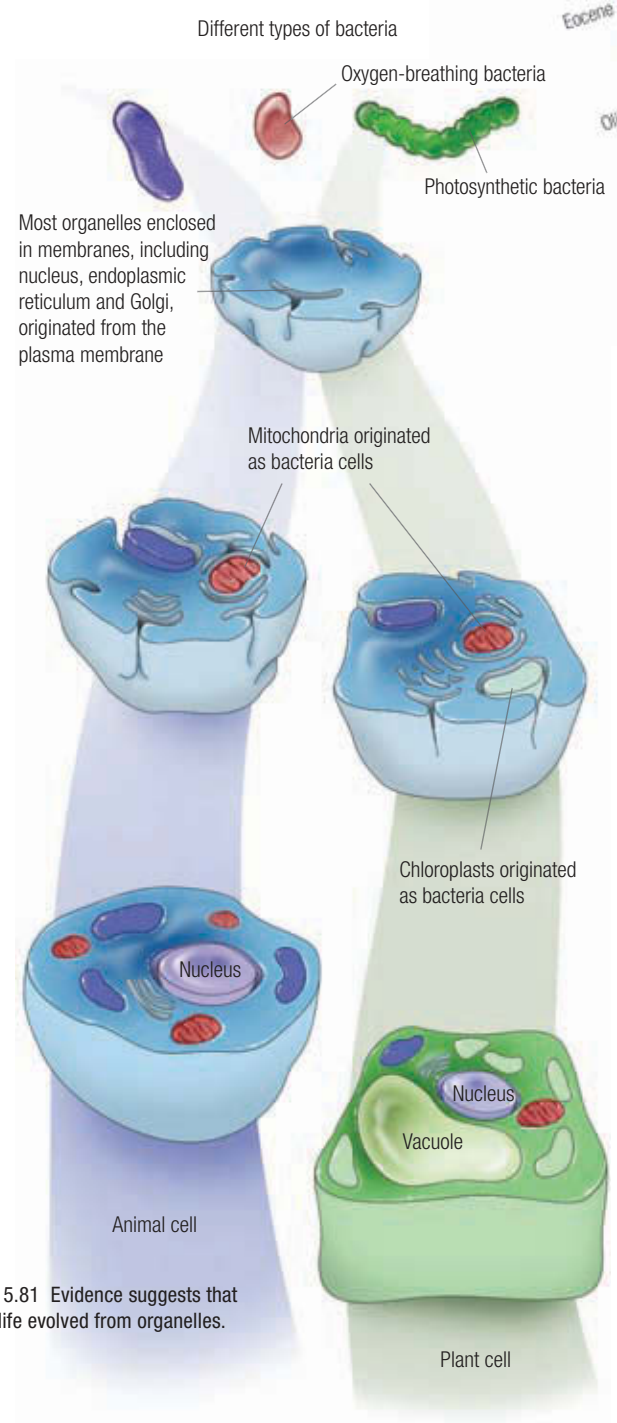
→ Fig 5.80 The Urey-Miller experiment, named after the two scientists responsible for it, attempted to simulate the early environmental conditions on Earth. Their experiment produced amino acids that provided some support to the theory of the spontaneous generation of life.

Life evolves

All forms of evidence now point towards organelles as the first life structures, eventually combining to form the first primitive cells—prokaryotes. Eukaryotes followed, first as unicellular organisms and then colonies; eventually, the multicellular organisms evolved.



→ Fig 5.82 Geological time scale.



→ Fig 5.81 Evidence suggests that all life evolved from organelles.

→ Fig 5.83 These structures, known as stromatolites, have been formed by massive colonies of cyanobacteria (blue-green algae) as they deposit layers of sediments such as calcium carbonate. Stromatolites are Earth's oldest fossils. Growing less than 5 cm every 100 years, these stromatolites in Shark Bay, Western Australia, are approximately 3000 years old—so they are only youngsters!



What do you know about the origins of life?

1 When did the first life forms appear on Earth?

2 What were the environmental conditions like when these life forms emerged?

3 What is the 'primordial soup' and how does this relate to Urey and Miller?

4 Construct a flow diagram using the following terms: *unicellular*, *multicellular*, *amino acids*, *organelles*, *primordial soup*

5 Methanogens (methane-breathing organisms), thermoacidophiles (heat- and acid-loving organisms) and halophiles (salt-loving organisms) are just three of the recently discovered extremophiles on Earth—they live in extreme conditions that were believed to support no life at all. How might the discovery of such organisms support the primordial soup theory?



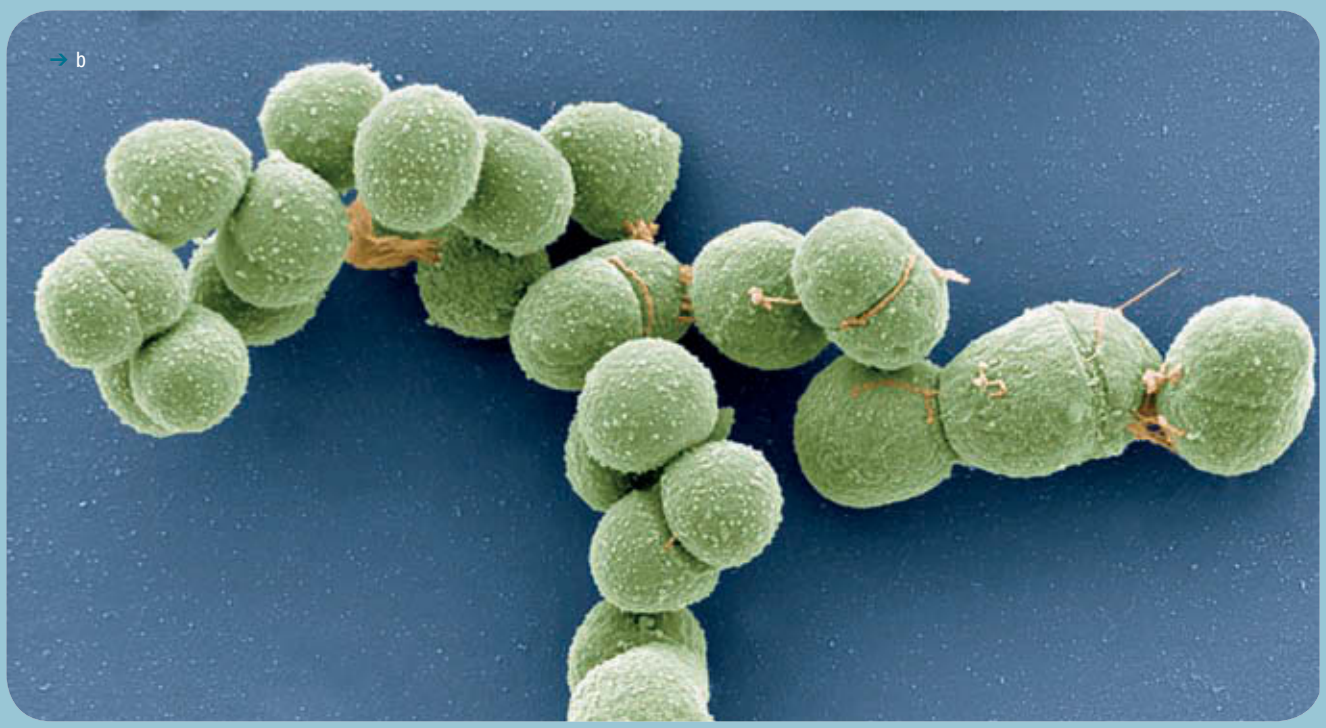


Fig 5.84 Archaea, single-celled microorganisms, were initially thought of as extremophiles, but are now known to live in a broad range of environments. (a) Archaea forming a pink mat around a hot spring. (b) Some Archaea, such as these methane-producing species, live anaerobically in the digestive tracts of animals.

5.3

How do we interpret evidence?



Remember and understand

1 What is the professional title for a person who studies the fossil record and geological time periods?

2 *Archaeopteryx* was part bird and part lizard. What term is applied to fossils that show the evolutionary progression between two very different forms?

3 What is or was Gondwana?

4 The layering of sedimentary rocks is useful in comparative dating. What is the basic principle of comparative dating?

5 Distinguish between the terms 'transitional fossil' and 'living fossil'.

6 Explain precisely how fossils provide evidence for evolution.

Apply

7 Suggest why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

Analyse and evaluate

8 How might you investigate the hypothesis that birds are more closely related to reptiles than to mammals?

9 Only two species of native non-marine mammals (both bats) existed in New Zealand before the Polynesians introduced the rat and dog some 1500 years ago. This unusually small number of mammal species, along with New Zealand's separation from Gondwana 60–80 million years ago, has led many to speculate on which land mass mammals originally evolved. The earliest known mammal-like fossil remains are over 160 million years old. Considering this information, explain whether a Gondwanan origin for mammals is likely.

10 How does the study of DNA sequences help in our understanding of evolution?

11 Imagine you could go back to the time when Darwin was formulating his theory on evolution. If you could pick only one of the pieces of evidence to convince him that his theory was right, which would it be and why?

12 The human appendix has been believed for many years to be shrinking and lacking any purpose. Recent studies suggest it may serve an immune function. Explain how scientists might be able to ascertain whether this immune function was a new purpose for the appendix, or simply a long-existing function that had not been identified.

Critical and creative thinking

13 To what extent is the theory of evolution testable?

14 Present the strengths and weaknesses of the various forms of evidence to support evolutionary theory in a clear and attractive format.

CONNECTING IDEAS Diversity and evolution

15 Scientists support the theory of evolution with few exceptions; however, several other theories exist to explain the origins of life and the changes that have occurred. Set up a classroom debate, with one team charged with the case of supporting Darwin's theory of evolution and the other team with rejecting it. Some research into alternative theories may be required.

ZOOMING OUT

Research

Modern-day evidence for evolution

There is evidence of current populations evolving by natural selection all around us. Research one of the following topics and see whether you can find evidence of evolution by natural selection occurring today.

- Can controlled breeding modify organisms?
- When fewer predators are present, how does brighter colouration evolve?
- How does natural selection lead to pesticide resistance?

Climate change and natural selection

How do you think climate change will affect species on the Earth? Which species do you think will be most affected? Why is this? What could these species do to avoid becoming extinct as a result of changing habitats? How could they do this? Would all species be able to avoid the effects of climate change? Do you think new species may evolve as a result of climate change?

Darwin and the Galapagos Islands

Much of Darwin's theory developed while he was visiting the Galapagos Islands. Which new species did he find there? What was so unique about these species? How did Darwin's findings help him develop his ideas? What was unique about the Galapagos Islands that helped Darwin develop his theories?

Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in general agriculture are monitored closely. Why are these examples important? Why do they need close monitoring? Why do these organisms demonstrate evolution at such a fast rate?

Reflect

Me

1 What new science skills have you learned in this chapter?
2 What was the most surprising thing you found out about evolution?
3 What was the most difficult aspect of this topic?
4 How has your understanding of how scientific theories are developed improved?

My world

5 Why is it important to understand evolution and natural selection?
6 What is being done in the world to better understand the process of evolution?
7 Which technologies have helped us understand the process of evolution?

My future

8 How do you think climate change may affect the natural selection of species?
9 What career paths could a study of evolution lead to?

Review

Key words

allopatric speciation
analogous structure
behavioural isolation
common descent
comparative dating
continental drift
convergent evolution
divergent evolution
evolution
extinction
fossil
gene flow
gene pool
homologous structure
isolating mechanism
living fossil
mechanical isolation
natural selection
niche
parapatric speciation
pentadactyl limb
physical isolation
plate tectonics
population
sexual dimorphism
sexual selection
survival of the fittest
sympatric speciation
temporal isolation
transitional fossil
vestigial structure

The rise of the bipedal ape

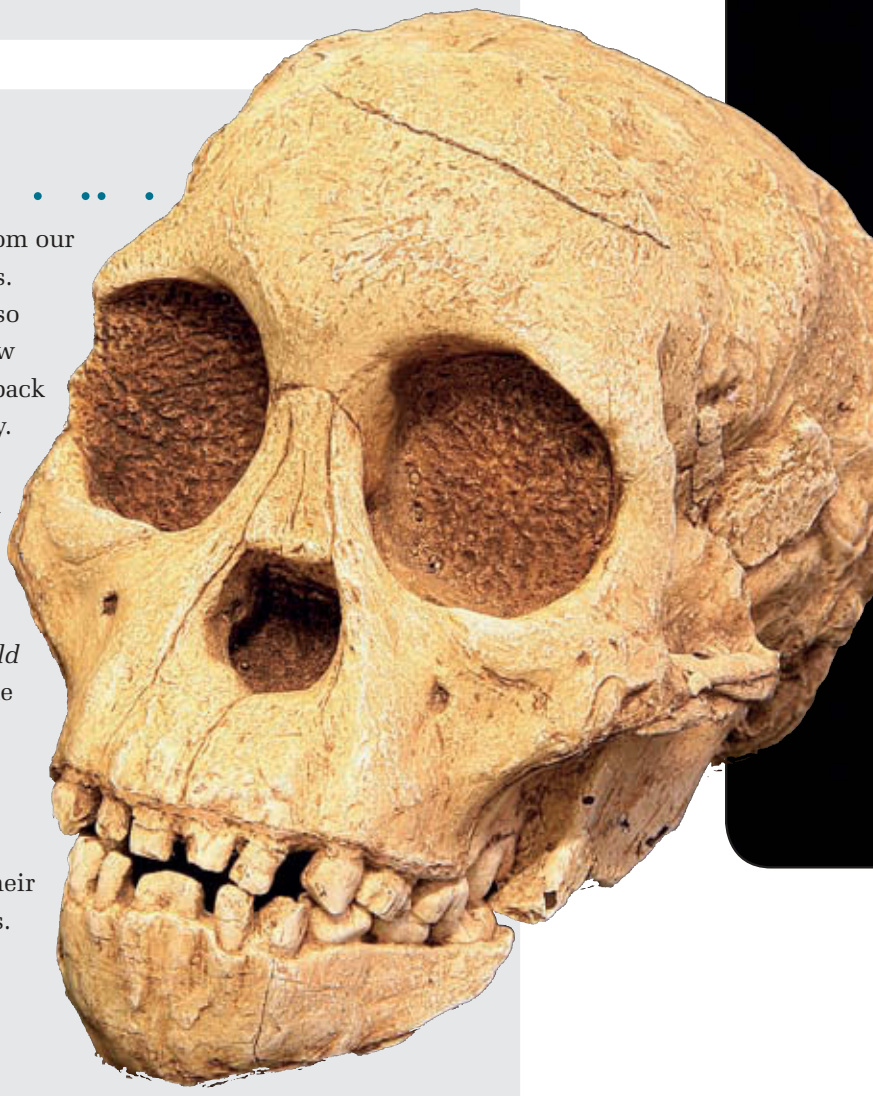
Since the time of Carolus Linnaeus, scientists had considered the great apes to be the closest relatives of humans because of their physical similarities. In the 19th century, scientists speculated that the closest living relatives of humans were chimpanzees owing to their physical similarities and their natural range. Over time further palaeontological evidence emerged that provided more evidence of this close link. More recently, biochemical comparisons have allowed evolutionary biologists to surmise that humans share a common ancestor with the African great apes and that fossils of these shared ancestors would be found in Africa.

Our evolutionary history

The incredible story of the evolution of humans from our ape ancestors covers approximately 7 million years. Life has existed for approximately 4 billion years, so 6 million years is really a snapshot in time, but how many years of your own family tree can you trace back in time? Maybe a couple of hundred if you're lucky.

Darwin's *On the Origin of Species*, published in 1859, suggested that humans were descended from African apes. With no fossils of our ancestors discovered until 1924, Darwin's suggestion was considered ridiculous and insulting to the human race. In 1924, Raymond Dart dug up the *Taung child* in Africa—a 3–4 million-year-old Australopithecine and our distant ancestor.

Since Dart's discovery nearly a century ago, approximately twelve to nineteen different species of human ancestor have been identified—although scientists are continually arguing and modifying their stance on the relationships between the fossil finds. As more fossils are uncovered, and more analyses performed, it is expected that the story of human evolution itself will continue to evolve.



→ Fig 5.85 The skull of the *Taung child*—a 3–4 million-year-old distant ancestor.



→ Fig 5.86 One of the most famous fossils is the remarkably complete 'Lucy', dug up in Ethiopia in 1974. Although her scientific name is *Australopithecus afarensis*, her discoverers named her 'Lucy' in honour of the Beatles song they were listening to at the time—*Lucy in the Sky With Diamonds*.



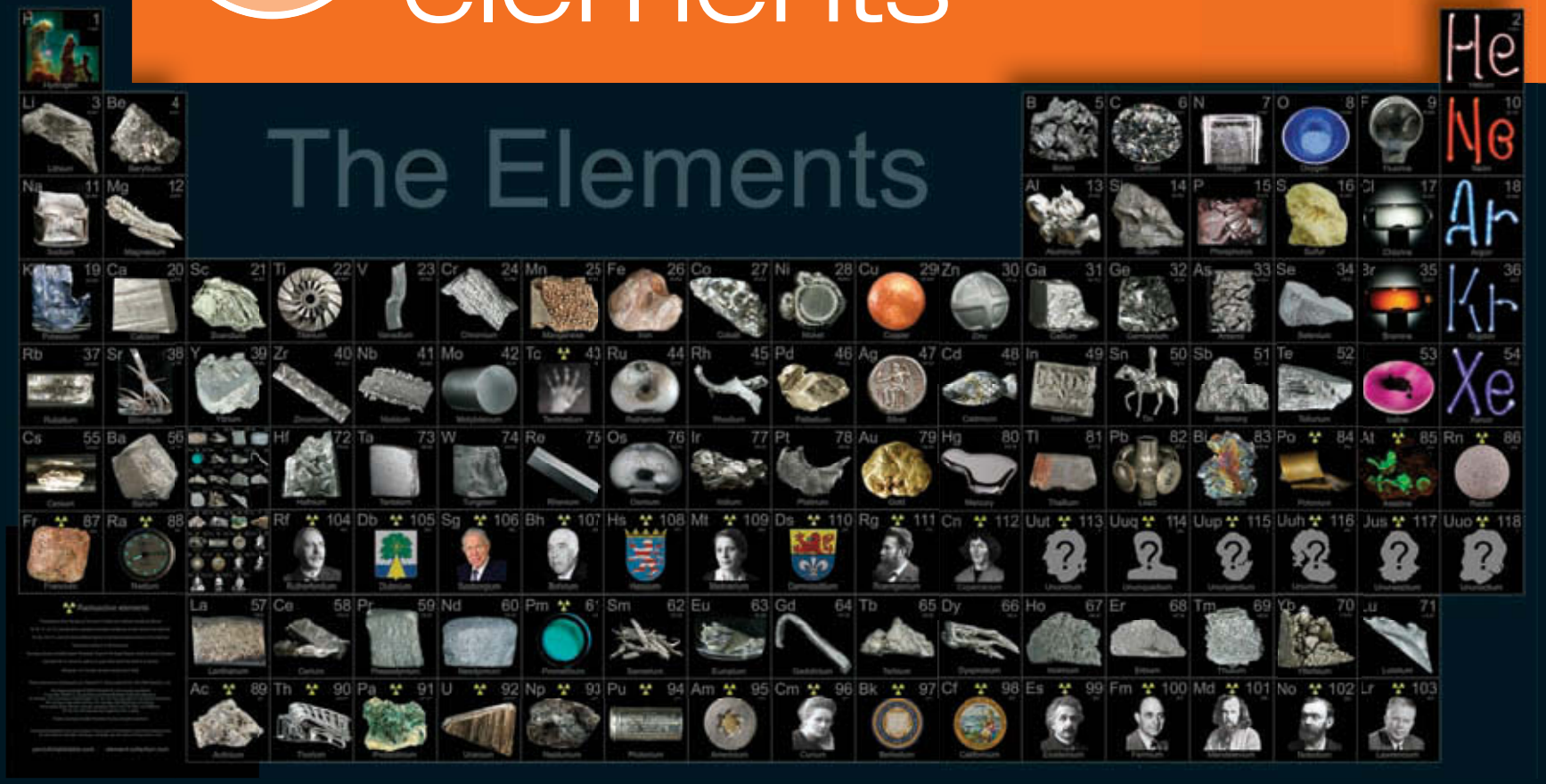
→ Fig 5.87 The astonishing 'hobbit' species, *Homo floresiensis*, found on an Indonesian island in 2004. Some scientists believe it is simply a dwarf form of modern *Homo sapiens*, but further analysis will be required to determine whether this is true.

Your task

Many pieces of evidence have formed the jigsaw pieces that tell the story of human evolution. Fossils are the most obvious, but the level of detail they can provide requires specialists to analyse the information. Consequently, many palaeontologists will specialise in the analysis of skulls or leg bones. Other forms of evidence, such as comparative biochemistry, require their own specialists.

1. Begin by defining the term 'hominid'.
2. Find a selection of images of hominid skulls to analyse. (You may be lucky enough to have access to replicas.)
3. Without looking at any of the data that may accompany these images, make careful observations of the various facial, cranial and even brain case features. Measurements could be made of lengths, diameters or even volumes. Use these observations to suggest a timeline from most recent (most like modern humans) to most distant relative. Record your reasoning, then present it to the class.
4. As a group:
   - **a** Discuss the similarities and differences between each person's observations.
   - **b** Discuss the similarities and differences between the skulls.
5. Conduct further research to find out whether you put the skulls in the correct order.
6. What additional information would palaeontologists have access to? What additional information would they find useful?

6 Organising elements



6.1 Why do we organise elements?

→ Fig 6.1 The periodic table of the elements
© 2011 Theodore Gray, periodictable.com.

Imagine trying to complete a jigsaw puzzle when you don't know what the image is and you're not sure you have all the pieces. Organising the elements was once like this. In the 18th century, new elements were being discovered: sometimes every few months, sometimes every few years. Usually this helped with the classification of the elements, but no one really knew how many more elements there were still to be discovered. Would any new discoveries prove earlier classification methods to be wrong?

The first periodic tables, published in the mid-19th century, were based on measured chemical properties. Later, the same arrangement was confirmed by the atomic number and electron configurations. It is nice to know that these early chemists got it pretty much right.

1 There is a bit of the 'unknown' to just about everything. What 'unknowns' were early chemists dealing with?

2 Have you ever refused to start or even try a task because of unknowns? What personality traits would be useful to complete such tasks? How would this have applied to the scientists working towards a classification system like the periodic table?

3 Examine Figure 6.1 of the elements of the periodic table. Can you identify any patterns simply by looking at it?

All the things we buy or use are made of different materials, which are made up of different elements, which, in turn, are made up of atoms. The choice of material to make something is based first on the properties needed—which material is best suited for its intended purpose. Additional factors may include availability, cost or the impact on health or the environment. Scientists use their knowledge of the elements to understand and explain why different materials behave in different ways. To ensure they're all speaking the same language and to assist in their investigations, scientists use universal methods to name and organise elements. The periodic table is the most fundamental way in which to organise elements because it is based on both the known properties of the elements and the very structure of the atoms themselves.

6.2 How do we organise elements?



→ Fig 6.2 New devices require materials with specific properties.

Our modern lives depend on a number of unfamiliar materials, the properties of some of which may have been discovered only recently. When was the last time you stopped to think how your MP3 player or mobile phone worked? Have you ever given any thought to where the materials that make these gadgets come from?

The touch screen technologies you have encountered rely on indium, which is element 49 of the periodic table. In its alloy form, combined with tin and oxygen, indium has the amazing ability to be both transparent and capable of conducting electricity. Hafnium, element 72, is so resistant to heat that it is used to coat rocket thrusters for trips to the Moon.

These types of properties have been used to classify elements for centuries. As more properties became known, with new technologies and a deeper understanding of matter, some rearrangement of the elements in the periodic table was necessary. The periodic table you know today may well change again in the future.

1. Think of three gadgets you use every day. For each gadget, identify the properties of the materials used that make them particularly suited to the purpose of the gadget.
2. Does it matter to you why certain materials have certain properties? Explain.
3. Consider an item of clothing. What is the purpose of the item? To keep you warm? To feel comfortable on your skin? Or to look good? Are there other properties of the materials used to make that item of clothing that make it particularly suited to your needs?

→ Fig 6.3 Emission spectra produce lines of different colours.

6.3 How are properties linked to atomic structure?

Many substances give off coloured light when small samples are placed in a flame. When this light is seen through a spectroscope—an instrument that breaks the light up into its colours—a pattern of coloured lines is observed. This pattern is known as an emission spectrum and is unique for each element.

Such a simple experiment could be conducted well before any understanding of atomic structure was proposed. Consequently, the emission spectra of different substances were one of several observations that contributed to early ideas about the connection between properties and the structure of atoms.

1. We now know that emission spectra are unique for each element. How do you think this would help scientists to analyse the composition of substances?
2. Would you consider observations of emission spectra to be classified as direct or indirect experimental evidence? Explain.
3. Without an explanation, observations can be misleading and/or misunderstood. In the absence of a clear explanation, how can scientists make sure that their observations are as reliable as possible?

6.1

Why do we organise elements?



Every day we use materials that have been selected because of their properties. Most materials are compounds made of different combinations of the eighty-eight naturally occurring elements chemically bonded together into definite arrangements. Although each of the elements is different to all the others, there are patterns and trends in their properties. The periodic table is a way of displaying the elements in a pattern with similar elements placed near each other. A chemist reads and interprets the periodic table like an architect reads a plan or a town planner reads a map.

DISCOVERING IDEAS

Memory tricks

Have you ever been presented with a large number of objects, facts or events to remember? How did you go about it? Teachers experience this challenge every year when new classes are assigned to them and they need to remember all your names!

- Work in small groups to test some of your methods. Groups may choose to work with pictures, words or objects that they have gathered. Numbers greater than 10 will work best. Methods to consider include the use of mnemonics, pairing or grouping the items into smaller, more manageable 'chunks' or finding a pattern that fits the entire set of items.
- Plan and conduct trials for several methods, analysing and evaluating each to decide on the most effective. Once complete, consider how this task may be related to the various systems for naming and/or grouping things in science.

1 What organising systems have you already encountered?

2 Think back to when you studied biological classification. How did Linnaeus affect the way scientists classify living things?

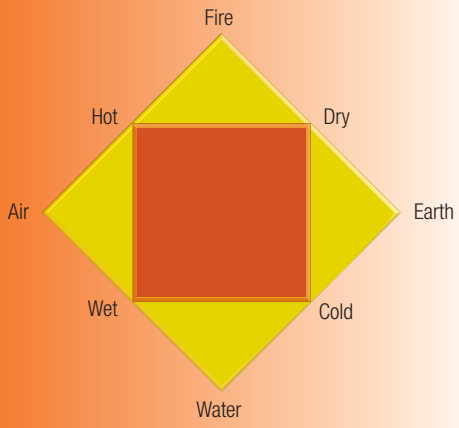
3 How may a similar system assist chemists?



Getting elements organised

The **periodic table** is a strange shape. It's not square or even rectangular, and there's a gap across the first couple of rows. Lower down there are 'missing' chunks and two lines of elements are written below the table, completely detached.

The story of how scientists organised elements goes back a long way, but the story of the periodic table itself is relatively short. Scientists have been trying to get their heads around matter for thousands of years. Sometimes, until a certain level of understanding is reached, the pieces of a puzzle remain in a bit of chaos. As soon as some evidence is uncovered, more detail can be worked out and this can speed up the process of discovery.



2000 years ago

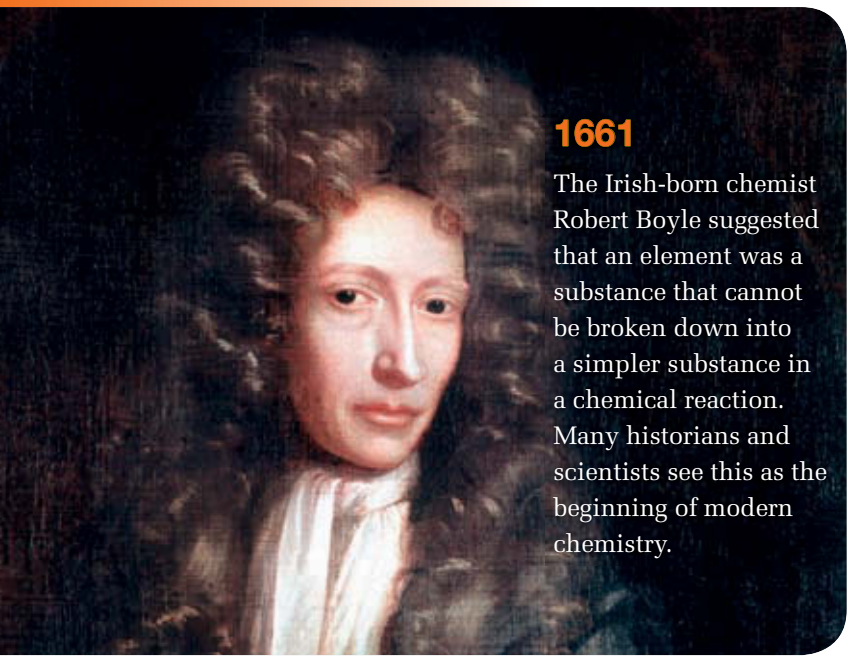
The ancient Greeks thought that everything was made of four 'elements' mixed together in different ratios.



1820s

Jakob Berzelius was a Swedish chemist who replaced the geometric patterns used as chemical symbols with letters that were an abbreviation of the element's name. Berzelius chose to use English names for most elements, with just a few retaining their Latin names. In addition, Berzelius used the weight of hydrogen to develop a coherent system of atomic weights. Because hydrogen was the lightest element, it was given a value of 1, with all remaining elements believed to have a whole number above 1.

Importantly, Berzelius is known for combining all current knowledge of his time into a single system. This enabled chemists across the world to share their thoughts and systems in a unified approach.



1661

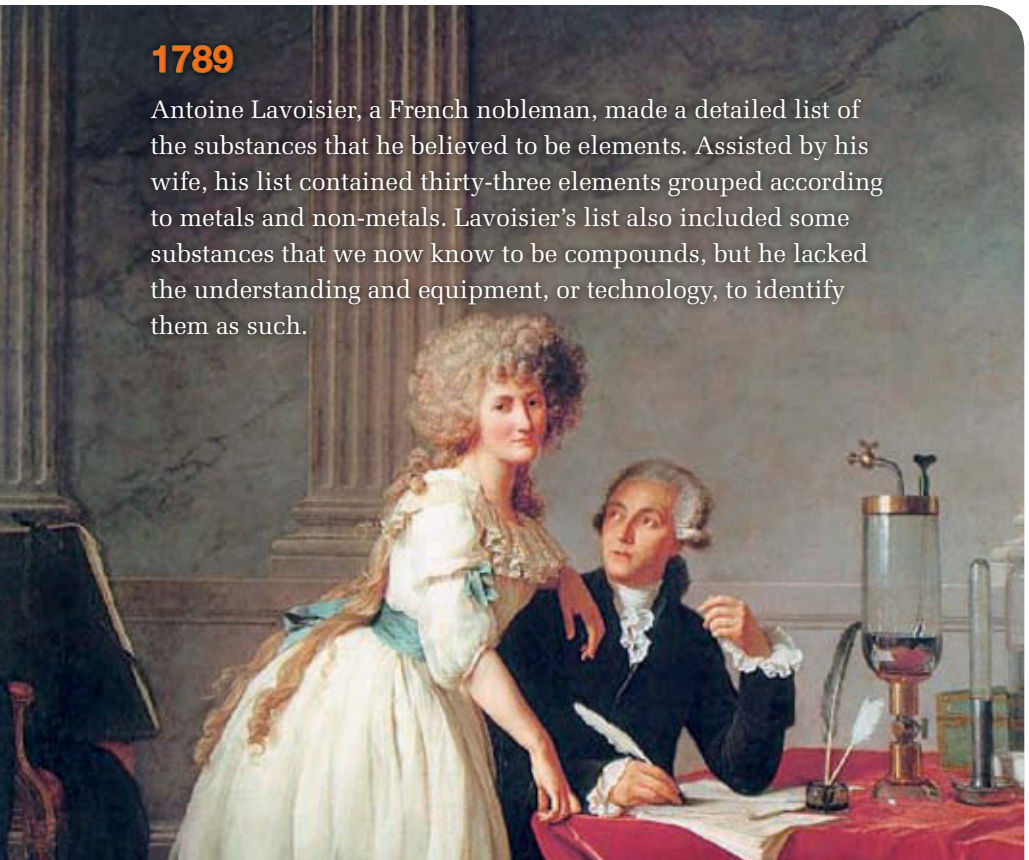
The Irish-born chemist Robert Boyle suggested that an element was a substance that cannot be broken down into a simpler substance in a chemical reaction. Many historians and scientists see this as the beginning of modern chemistry.

1829

As more elements were identified, more and more chemists studied them and their properties. In Germany, Johann Dobereiner was aware of forty elements. He noted that some groups of three elements had similar properties and named these groups triads. These groupings were instrumental in identifying patterns of behaviour, which assisted with more accurate speculation regarding atomic structures.

1789

Antoine Lavoisier, a French nobleman, made a detailed list of the substances that he believed to be elements. Assisted by his wife, his list contained thirty-three elements grouped according to metals and non-metals. Lavoisier's list also included some substances that we now know to be compounds, but he lacked the understanding and equipment, or technology, to identify them as such.





Some properties of Dobereiner's triads are listed in Table 6.1.

→ Table 6.1 Properties of the elements in Dobereiner's triads

Element	Atomic mass	Melting point (°C)	Density (g/mL)	Melting point of chloride (°C)
Lithium	7	180	0.53	LiCl = 610
Sodium	23	98	0.97	NaCl = 801
Potassium	39	64	0.86	KCl = 770
Element	**Atomic mass**	**Melting point (°C)**	**Density (g/mL)**	**Melting point of sodium salt (°C)**
Chlorine	35.5	–101	1.56	NaCl = 801
Bromine	80	–7	3.12	NaBr = 747
Iodine	127	114	4.94	NaI = 660
Element	**Atomic mass**	**Melting point (°C)**	**Density (g/mL)**	**Melting point of chloride (°C)**
Calcium	40	838	1.55	$CaCl_2$ = 772
Strontium	88	770	2.60	$SrCl_2$ = 872
Barium	137	714	3.50	$BaCl_2$ = 963
Element	**Atomic mass**	**Melting point (°C)**	**Density (g/mL)**	**Melting point of sodium salt (°C)**
Sulfur	32	113/119	2.07/1.96	Na_2S = 1180
Selenium	79	217	4.80	Na_2Se = >875
Tellurium	128	450	6.24	Na_2Te = 953

1864

English chemist John Newlands took a slightly different approach. Building on the atomic weights of the elements, he noticed that every eighth element had similar properties. Many of these 'eighth' elements were part of Dobereiner's triads. This pattern identification by Newlands was considered a recurring or 'periodic' feature among the elements. Newlands made the mistake of comparing the properties of the elements to music, with musical notes being grouped eight per octave. This comparison, called the Law of Octaves, was not taken seriously by Newlands' peers.



The birth of the periodic table

1869

Dmitri Mendeleev is hailed as the creator of the modern periodic table. Building on the ideas of his contemporaries, Mendeleev, who lived in Russia, knew of sixty-three elements.



→ Fig 6.4 A sculpture in honour of Dmitri Mendeleev and the periodic table in Saint Petersburg.

What do you know about getting elements organised?

1. Who proposed the modern idea of an element and when?
2. The chemist Jakob Berzelius did not discover anything. Why is he remembered?
3. What was a triad? Why were triads important?
4. Why were the ideas of Newlands not taken seriously? Is this a fair assessment of his ideas?
5. Originally, geometric symbols were used to represent each element. What would be some of the problems associated with using geometric symbols for the elements today?



It is said that Mendeleev wrote the names and properties of each element on a small card that he then arranged in order of atomic weight. The cards were then rearranged, maintaining their order, into groups with similar properties.

With this organisation complete, Mendeleev proposed the periodic law:

> 'Elements have properties that recur or repeat according to their atomic weight.'

More importantly, Mendeleev's organisation of cards identified 'holes' that he attributed to elements that had yet to be discovered. The properties of these undiscovered elements could be predicted from this first periodic table.

One of Mendeleev's predictions was for the element below silicon, which he called 'ekasilicon' ('eka' is a Greek word meaning 'first', 'beyond' or 'after'; see Table 6.2).

In all, Mendeleev predicted the properties of 21 unknown or undiscovered elements. His predictions started searches for the missing elements. When these elements were discovered, their properties were found to be very close to the properties that had been predicted by Mendeleev. This convinced many chemists of the accuracy and value of Mendeleev's periodic table.

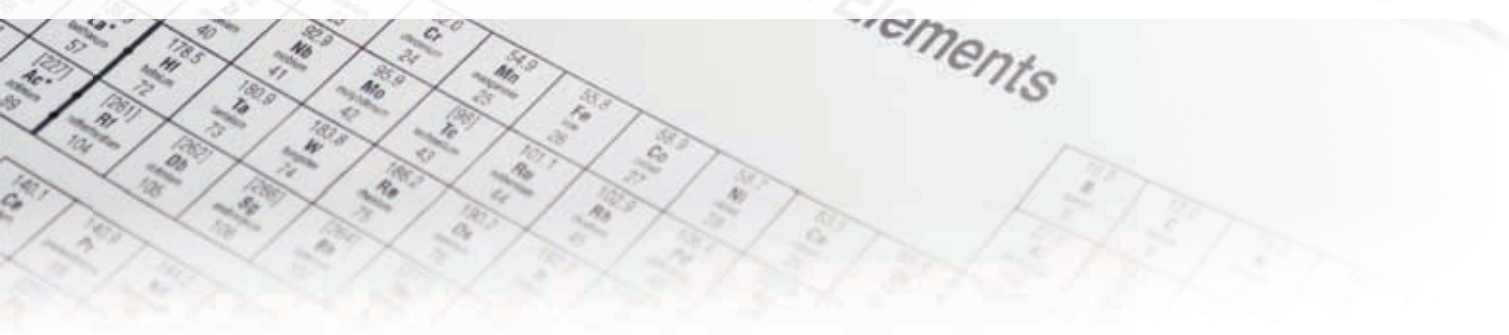
Mendeleev is given sole credit for the development of the periodic table. This is because of the evidence he provided to support his table and because he assumed that there were missing elements and he accurately predicted the properties of these elements.

→ Table 6.2 Predicted properties of ekasilicon compared with the actual properties of germanium

Ekasilicon (symbol Es)	Germanium (symbol Ge)
As predicted in 1871:	As discovered in 1886:
Atomic mass 72	Atomic mass 72.6
Density 5.50 g/mL	Density 5.36 g/mL
Colour: grey metal	Colour: grey metal
Forms oxide EsO_2: density 4.70 g/mL, slightly basic	Forms oxide GeO_2: density 4.70 g/mL, slightly basic
Forms chloride $EsCl_4$: boiling point 100°C, density 1.90 g/mL	Forms chloride $GeCl_4$ boiling point 86°C, density 1.88 g/mL



→ Fig 6.5 The German chemist Lothar Meyer compiled a periodic table of 56 elements a few months after Mendeleev. Meyer graphed properties of the elements against atomic weight, and noted the repeating properties.



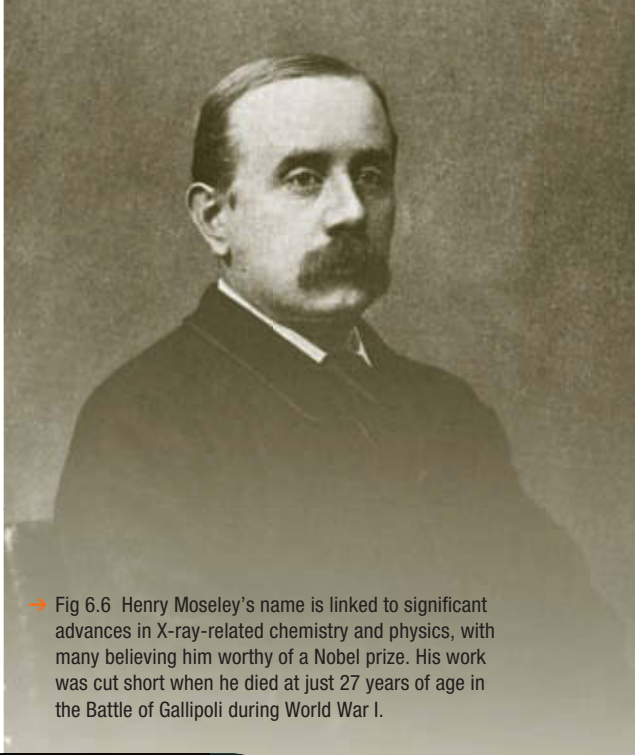
1894

William Ramsay, a Scottish chemist, used the then new technology of refrigeration to liquefy and separate the components of air. He successfully removed water, carbon dioxide, oxygen and nitrogen, but found he had some unknown gas left behind. This was argon, the first in its group to be discovered. Further experimentation identified helium, neon, krypton and xenon. All these gases form the group of noble gases at the far right of the periodic table.

1913

By the early 1900s, X-rays could be used to determine the atomic number of each element. Using this technology, a young English physicist by the name of Henry Moseley refined the order of some of the elements in Mendeleev's periodic table and proposed a minor change to the periodic law:

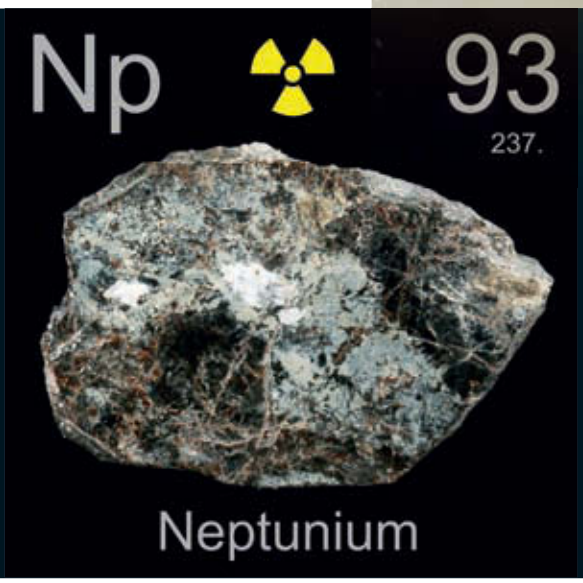
> 'Elements have properties that recur or repeat according to their atomic number.'



→ Fig 6.6 Henry Moseley's name is linked to significant advances in X-ray-related chemistry and physics, with many believing him worthy of a Nobel prize. His work was cut short when he died at just 27 years of age in the Battle of Gallipoli during World War I.

1940

With the development of nuclear processes, elements heavier than uranium could be created. The US scientist Glen Seaborg, winner of the 1951 Nobel Prize in Chemistry, used a cyclotron to slam neutrons into uranium atoms. This created the very first atoms of neptunium and plutonium.



→ Fig 6.7 Atoms heavier than uranium are called the 'transuranium' or 'transuranic' elements. None of them occurs naturally. The image shows a sample of neptunium.

Today

Since the 1940s, similar nuclear processes have been used to synthesise the elements up to and including element 118. These elements are given names based on their atomic number: 118 is called 'ununoctium' (1-1-8-ium).

In 2010, six atoms of element 117 were created by bombarding berkelium (97) with calcium (20). These six atoms existed for only a fraction of a second, but their creation filled a gap in the periodic table.

What do you know about the birth of the periodic table?

1. Who was the first chemist to lead a team that made elements that did not occur naturally?
2. When Mendeleev proposed the periodic table, he went one step further. What else did he do and why is this significant?
3. Why were the gases that Ramsay discovered not able to be discovered any earlier?
4. Moseley changed the periodic law proposed by Mendeleev by changing one word. What word was changed, and how did this improve the periodic table?

Navigating the periodic table

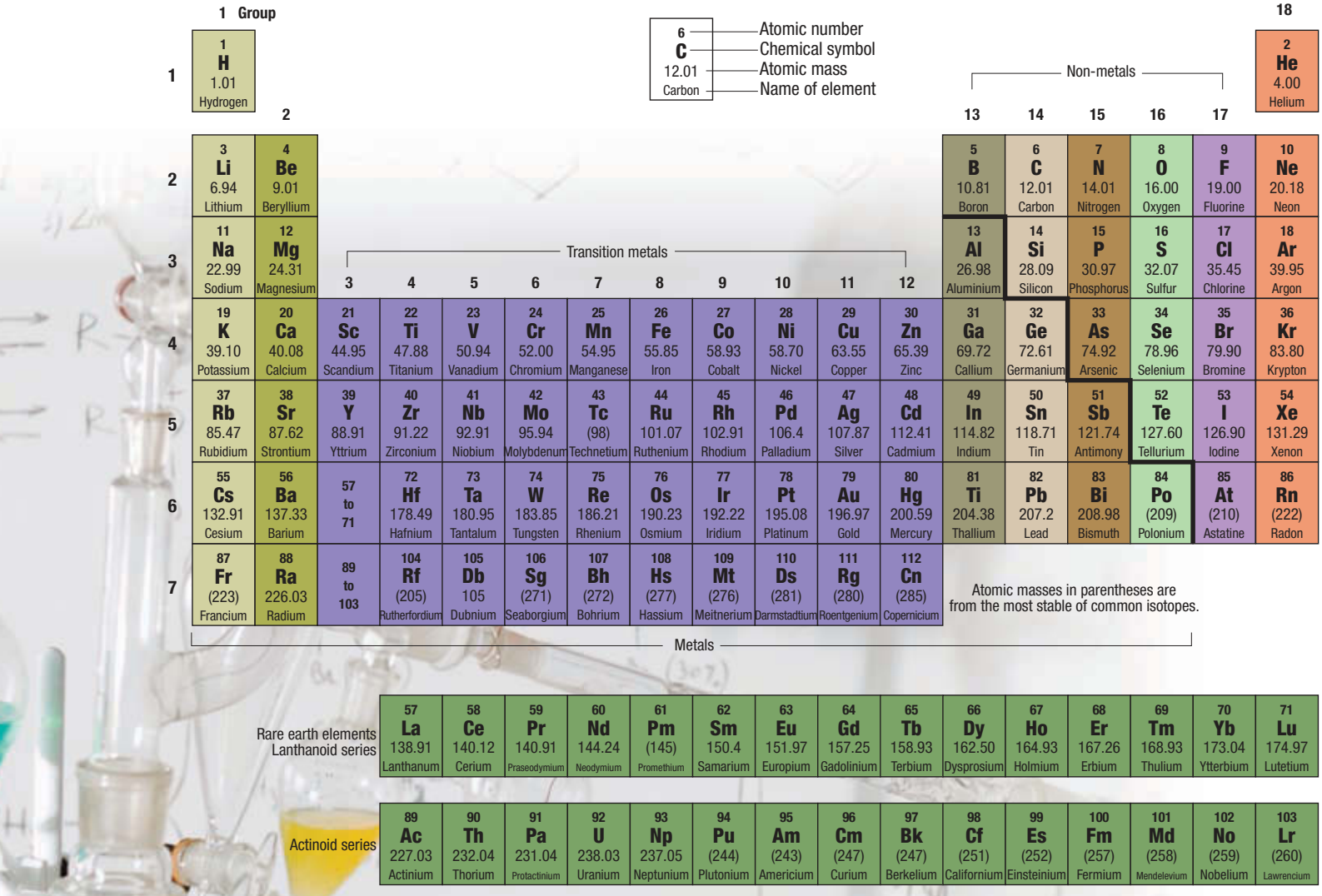
The periodic table shows the elements in rows and columns. The rows are called **periods**. The atomic number increases by one for each element as you go across the period. The vertical lists of elements are called **groups**, with the elements in each group having similar properties. These groups are similar to the triads described by Dobereiner.

The columns and rows in the periodic table have been given names and numbers. This makes communication easier, because these elements have similar properties and trends.

What do you know about navigating the periodic table?

1. What is the difference between a period and a group in the periodic table?
2. Examine Figure 6.8, of the periodic table.
   - **a** Identify the period and group for each of the following elements: fluorine, bromine, tin, radium, potassium, platinum, and arsenic.
   - **b** Are any of the elements listed above in the same group? What would this tell you about them?
   - **c** Are any of the elements listed above in the same period?

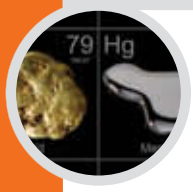
→ Fig 6.8 The periodic table of elements.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.01 Hydrogen																	2 He 4.00 Helium
2	3 Li 6.94 Lithium	4 Be 9.01 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
3	11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
4	19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.95 Scandium	22 Ti 47.88 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.95 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.70 Nickel	29 Cu 63.55 Copper	30 Zn 65.39 Zinc	31 Ga 69.72 Callium	32 Ge 72.61 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
5	37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc (98) Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.74 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.29 Xenon
6	55 Cs 132.91 Cesium	56 Ba 137.33 Barium	57 to 71	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.85 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Ti 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po (209) Polonium	85 At (210) Astatine	86 Rn (222) Radon
7	87 Fr (223) Francium	88 Ra 226.03 Radium	89 to 103	104 Rf (205) Rutherfordium	105 Db 105 Dubnium	106 Sg (271) Seaborgium	107 Bh (272) Bohrium	108 Hs (277) Hassium	109 Mt (276) Meitnerium	110 Ds (281) Darmstadtium	111 Rg (280) Roentgenium	112 Cn (285) Copernicium						

Rare earth elements Lanthanoid series	57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (145) Promethium	62 Sm 150.4 Samarium	63 Eu 151.97 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.93 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thulium	70 Yb 173.04 Ytterbium	71 Lu 174.97 Lutetium
Actinoid series	89 Ac 227.03 Actinium	90 Th 232.04 Thorium	91 Pa 231.04 Protactinium	92 U 238.03 Uranium	93 Np 237.05 Neptunium	94 Pu (244) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (247) Berkelium	98 Cf (251) Californium	99 Es (252) Einsteinium	100 Fm (257) Fermium	101 Md (258) Mendelevium	102 No (259) Nobelium	103 Lr (260) Lawrencium

6.1 Why do we organise elements?



Remember and understand

1 What is the atomic number of the element known as ununpentium?

2 What is the overall order of elements in the periodic table based on?

3 Arrange the following people in chronological (time) order and match them with the concepts listed.
- People: Bohr, Lavoisier, Seaborg, Mendeleev, Newlands, Berzelius, Dobereiner
- Concepts: periodic table developed, modern concept of an element, atomic symbols and weights standardised

4 What is the difference between an atom and an element?

Apply

5 The element mendelevium (101) is named after the scientist who developed the first version of the periodic table. Mendeleev combined the ideas of two earlier scientists: who were these scientists and what did they do?

Analyse and evaluate

6 Scientists like Berzelius and Mendeleev worked on their own to produce new ideas. Others, like Seaborg, worked in a team. Now most scientists work in teams. What are the advantages of working in a team?

7 Scientists have had to deduce what it is like inside an atom from indirect evidence, similar to the work of astronomers in determining the temperature and composition of stars. List three advantages and three disadvantages of using indirect evidence to develop scientific theories.

Ethical behaviour

8 Meyer and Mendeleev both published a periodic table within months of each other. However, Mendeleev is given sole credit for developing the periodic table.

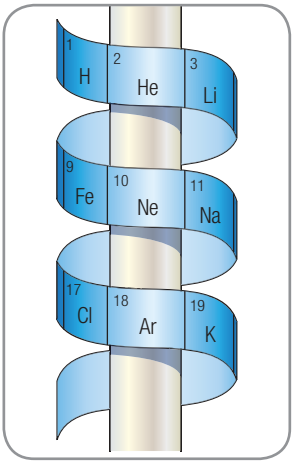
a Is it fair that the person who first discovers/develops/publishes something gets the credit for this discovery?

b What did Mendeleev do to get sole credit for developing the periodic table?

Critical and creative thinking

9 Make a spiral periodic table of the first twenty elements. Use Figure 6.9 as a guide. Glue a paper strip onto a piece of wood, such as an ice block stick.

→ Fig 6.9



10 Some elements are newly discovered, whereas others have been known for hundreds of years. What is the relationship between the date of discovery and the features of the element? Use the table as a guide to answer this question.

Element	Date of discovery	Notes
Gold, tin	Ancient times	Found on the surface of the Earth
Iron, copper	1500 BCE	Separated in the heat of an open fire
Aluminium, sodium	1800s	Separated using electricity
Argon, neon	Early 1900s	Separated from liquid air
Neptunium, plutonium	1940s	Synthesised in nuclear reactors or cyclotrons

6.2

How do we organise elements?



In a manner similar to that of biological classification, whereby organisms are grouped according to their similarities and differences, many other objects can be groups based on their similarities and differences. When you walk into a supermarket, the items on sale are not randomly distributed among the shelves, but are grouped according to foods versus cleaning products, as well as fresh versus packaged or frozen. Within these groupings there are further groupings, all identified by signs to assist you. The periodic table is another example of grouping that helps you find your way efficiently around the elements.

DISCOVERING IDEAS

Getting elements organised

Table 6.3 lists some observable properties of a selection of common elements. This is the level of information early chemists would have had to work with in their attempts to find a unified approach to organising the elements.

1 Use the information provided in Table 6.3 to organise the elements into your own version of the periodic table. Present your periodic table to the class, complete with explanations for the arrangements and groupings you chose.

2 As a class, discuss the similarities and differences between the various periodic tables created. Critically analyse the impact of the level of information available on the table you were able to create and evaluate the restrictions this would have placed on early chemists.

→Table 6.3 Properties of some common elements

Element	Symbol	State	Colour	Features and use
Aluminium	Al	Solid	Shiny, silver	Used to make foil wrap and silver paper
Carbon	C	Solid	Black, dull	Found impure in charcoal and soot
Magnesium	Mg	Solid	Shiny, silver	Burns with a bright white flame
Sulfur	S	Solid	Yellow, dull	Found near volcanoes, part of sulfuric acid
Iron	Fe	Solid	Silvery grey	Magnetic, commonly used metal
Phosphorus	P	Solid	Dark red, dull	Used on match heads, flammable
Lead	Pb	Solid	Silvery grey	Used to make fishing sinkers
Nickel	Ni	Solid	Shiny, silver	Main metal in 'silver' coins
Copper	Cu	Solid	Shiny, brown	Used in electrical wires and water pipes
Gold	Au	Solid	Shiny, yellow	Used in electronics, used as money
Tin	Sn	Solid	Shiny, silver	Used in tin cans because it will not taint food
Zinc	Zn	Solid	Shiny, silver	Metal used to galvanise iron
Silver	Ag	Solid	Shiny, silver	Used in jewellery
Oxygen	O	Gas	Colourless	Needed for breathing, tested with glowing splint
Hydrogen	H	Gas	Colourless	Explosive, lighter than air, tested by pop test
Chlorine	Cl	Gas	Yellow–green	Used in bleaches and disinfectants
Mercury	Hg	Liquid	Shiny, silver	Used in thermometers and some switches
Calcium	Ca	Solid	Shiny, grey	Reacts quickly with water and air
Iodine	I	Solid	Shiny crystals	Stains your fingers brown, sublimes easily
Sodium	Na	Solid	Shiny, grey	Soft, very reactive in air and water, burns skin
Potassium	K	Solid	Shiny, white	Similar to sodium
Bromine	Br	Liquid	Dark red	Fuming liquid, burns skin very badly

Grouping elements

The two main types of elements are metals and non-metals, with metals constituting nearly three-quarters of all elements. In addition, there are some elements with properties that are between those of metals and non-metals. These elements are termed metalloids.

Metals

Metals have many properties in common. Pure metals are:

- lustrous (shiny)
- able to conduct heat and electricity
- malleable (able to be beaten into a new shape)
- ductile (able to be drawn into a wire)

Metals are divided into different groups according to their position in the periodic table.



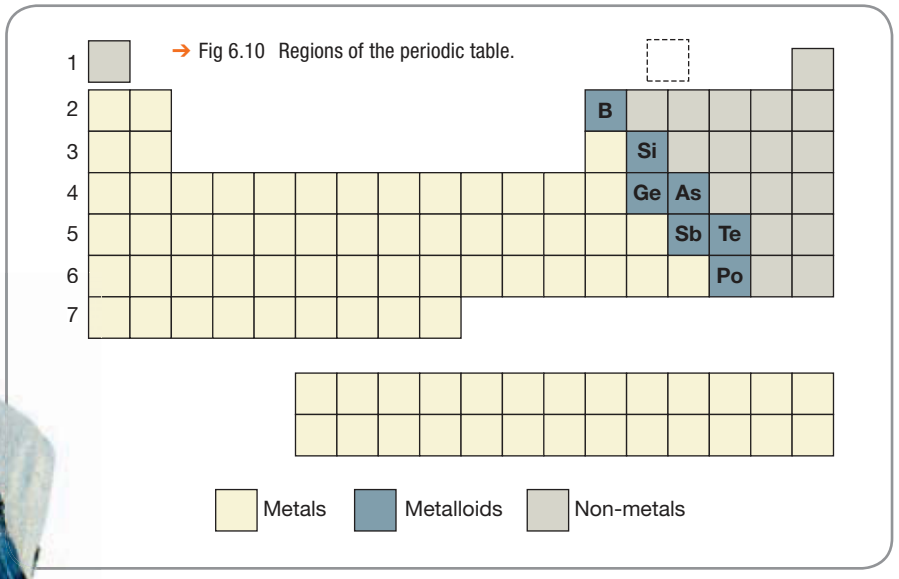
→ Fig 6.11 Freshly cut sodium, a group 1 metal.

Group 1 metals

The **alkali metals**, such as sodium and potassium, are found in group 1—the far left column. Their position tells us that the uncharged atoms of all the alkali metals have just one electron in the valence shell. The alkali metals have quite a low melting point and are soft and highly reactive. If you were to see them in their pure state, they often resemble plasticine that, when cut, is very briefly shiny silver before reacting with the air to become white again. Alkali metals react very strongly—some violently—with water, producing hydrogen gas and an alkaline solution. (An alkali is a soluble base.) The further down the group you go, the more violent this reaction.

Group 2 metals

The **alkaline earth metals**, such as magnesium and calcium, are found in group 2. Their position tells us that the atoms of all the alkaline earth metals have two electrons in the valence shell. The alkaline earth metals have quite a low melting point and are relatively soft and very reactive, although in general they are not quite as reactive as group 1 alkali metals. Like the alkali metals, alkaline earth metals also react with water, some strongly, producing hydrogen gas and an alkaline solution. Again, the further down the group you go, the more reactive the metal.



→ Fig 6.10 Regions of the periodic table.



→ Fig 6.12 Potassium reacting with water produces a spectacular reaction.



→ Fig 6.13 Magnesium, an alkaline earth metal, (a) before burning and (b) during burning.

Transition metals

The **transition metals** are found in a large block of the periodic table that consists of the ten groups across the centre (groups 3–12). Many have special properties that are not shown by group 1 or 2 metals:

- A small number are magnetic.
- The transition metals gold and copper are the only metals that are not silvery in colour.
- Many of the transition metals form coloured compounds.
- Many of the transition metals form more than one compound with a non-metal like chlorine. For example, iron forms $FeCl_2$ and $FeCl_3$.





→ Fig 6.14 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.



EXPERIMENT 6.1

Reactivity of metals

Aim

To compare the reactivity of various metals by observing their reaction with hydrochloric acid.

Remember to wear safety glasses and protective gloves when you do this experiment.

Materials

2 M hydrochloric acid
Detergent
Test tubes and test tube rack
0.5 cm pieces of magnesium, aluminium, iron, zinc and copper
Steel wool
Ruler
Timer
Bench mat

Method

1. Clean the surface of the magnesium with a piece of steel wool.
2. Place the magnesium into a test tube.
3. Add three drops of detergent to the test tube.
4. Add 2 cm of hydrochloric acid to the test tube. Set the timer for 5 minutes and record your observations, including the height of the foam produced in a results table like the one below.
5. Repeat the process for the remaining metals.
6. This equipment can be left set up overnight to observe any further changes.

Results

Metal	Observations	Height of foam (cm)
Magnesium		
Aluminium		
Iron		
Zinc		
Copper		

Discussion

1. Which metal was the most reactive?
2. Which metal was the least reactive?
3. Why were the metals cleaned with steel wool first?
4. Why was detergent added to the test tubes with the hydrochloric acid?
5. What properties would you think the most reactive metal would also exhibit?
6. Is there any link between the reactivity of the metals and where they are located in the periodic table?



→ Fig 6.15 Gemstones contain atoms of different metals, which results in different colours.

→ Fig 6.16 (a) Pale green $FeCl_2$ and (b) brown $FeCl_3$.





Metalloids

Metalloids are the small set of elements along the 'staircase' diagonal boundary between the metals and non-metals. As might be expected from this location, metalloids exhibit properties between those of metals and non-metals. Most of their properties would be considered un-metallic; however, metalloids conduct electricity like the metals. Three of the metalloids are semiconductors, which means that they only conduct electricity in a certain way under certain conditions.

→ Fig 6.17 Boron and silicon are combined to form borosilicate glassware, such as the common Pyrex brand. This glassware is tough and has excellent heat conduction properties that make it suitable for cooking.





→ Fig 6.18 Silicon and germanium are widely used in electronic devices because of their semiconductor properties—they conduct electricity in a very controlled way.

What do you know about grouping elements?

1 What proportion of the periodic table is composed of metals?
2 What properties are shared by all metallic elements?
3 Only one of the metals is not a solid. Which element is this and in what state does it occur naturally?
4 Design a way to represent the different groups of metals in a clear and informative way, identifying the distinguishing properties of each group.
5 Name two properties shown by some transition metals that are not shown by group 1 or 2 metals.
6 Why could the term 'metal-like elements' be used to describe 'metalloid' elements? Suggest a better name for this group of elements. Explain your answer.

Non-metals

Non-metals, as the name suggests, are elements that do not exhibit the set of properties common to all metals. None is lustrous (shiny), none is ductile (easily manipulated); a small number of non-metals are coloured; some are brittle. In addition, non-metals have a much larger range of melting points and boiling points than do the metals. At room temperature, quite a number of the non-metals are gases and one (bromine) is a liquid, whereas all the metals except for one (mercury) are solids at room temperature. Only eighteen elements in the periodic table are considered non-metals, compared with more than eighty metals. Despite this, non-metals make up most of the crust and atmosphere of our planet, as well as the bulk of living organisms' tissues.

As far as the properties of non-metals are concerned, there are only two groups (vertical columns) in the periodic table that are made up entirely of non-metals: groups 17 and 18.



→ Fig 6.20 Fluorine, the most reactive non-metal, is used to etch glass. It is extremely dangerous to handle.



→ Fig 6.19 Bleaches often contain halogens.

Group 17: the halogens

The **halogens**, such as fluorine and chlorine, are found in group 17. The atoms of all the halogens have seven electrons in their valence shell. The halogens are mostly known for their capacity to react with metals to form salts. Indeed, the word 'halogen' means 'salt-forming' and the term was coined for this group by Jakob Berzelius. Some halogens have bleaching properties as well.



→ Fig 6.21 Halogen lamps have been commonly used in car headlights and outdoor lighting for decades. The halogen reversibly reacts with a tungsten filament to provide a bright light that also keeps the bulb clean.

As you go down the group, the melting points and boiling points of the halogens increase. At room temperature, fluorine and chlorine are gases, bromine is a liquid and iodine and astatine are solids. This is the only group in which the elements range from gas to liquid to solid at room temperature. Astatine, however, is radioactive and very unstable.

Unlike the metals in groups 1 and 2, the further down you go in this group of non-metals, the less reactive the element. Fluorine is the most reactive non-metal of all and is extremely dangerous to handle. Halogens are very effective cleaning and sterilising substances because of the lethal effects they can have on bacteria and fungi.

Group 18: the noble gases

The **noble gases**, such as neon and argon, are found in group 18. The uncharged atoms of the noble gases have eight electrons in their outer shell, except for helium, which has two. The noble gases are so called because they are all gases at room temperature and are unchanged if mixed with other elements; that is, they are very unreactive, or inert. The first three in the group (helium, neon and argon) do not react with any other element and form no compounds. It was first thought that the same was true of xenon and krypton, but, in recent years, chemists have discovered these two elements will react with fluorine under certain conditions and form a very small number of compounds. The last member of the group, radon, is very dangerous—not because of any chemical reactivity, but because it is a radioactive gas.



→ Fig 6.22 Radon is responsible for the majority of background radiation experienced in public spaces. It occurs naturally as the decay product of uranium and can be found in natural springs.

What do you know about non-metals?

1 Why are non-metals named according to what they are 'not' rather than what they have in common?

2 The two main groupings of non-metals are in groups 17 and 18.
   a What does the group number tell you about the elements it contains?
   b What properties do members of each of these groups share?

3 What is the dominant state of matter within the groups of non-metals?

OVERARCHING IDEAS Matter and energy

Extreme halophiles

Halogens are salt-forming elements. Halophiles are salt-loving organisms. We generally associate salts with environments that suppress life: the Dead Sea is so called because of the amount of salt it contains and the lack of life it sustains. Halogen-based products are used to kill bacteria around our homes because of these very properties.

However, one group of organisms has managed to survive, and even thrive, in salt-rich environments. Salt limits the availability of oxygen, but these organisms can instead extract halogens from the salts by using mechanisms called ion pumps that are driven by energy from light. These pumps, in the presence of light, can literally pump the necessary elements in and out of the cells to keep the organisms alive.

1 Find out more about extreme organisms, such as the halophiles.
   a How are these organisms able to use matter in unconventional ways to suit their needs?
   b Do they rely on cellular respiration, like most organisms, to meet their energy requirements, or do they have their own version of this metabolic process?
   c Where on Earth are you likely to encounter such organisms?



→ Fig 6.23 Coloured algae living in a salt-rich environment.

6.2

How do we organise elements?



Remember and understand

1 What is the name given to the following features of the periodic table?
   - **a** a horizontal row
   - **b** a vertical column
   - **c** the set of ten groups from group 3 to group 12

2 State the group number of the following sets of elements:
   - **a** alkaline earth elements
   - **b** halogens
   - **c** noble gases
   - **d** alkali metals

3 What is a valence shell?

4 State the features that elements in the same group have in common.

5 Suggest why transition metals are much more widely used than the alkali metals.

6 Give explanations for the following.
   - **a** Hydrogen was placed in the same group as a set of metals, even though it is a non-metal.
   - **b** Helium was placed in the same group as the noble gases, even though its atoms have a different number of electrons in the valence shell to those of the other group members.

7 An inert substance is one that will not react with any other substance. Originally, group 18 elements were known as the 'inert gases'. Suggest why the name was changed to 'noble gases'.

Apply

8 Only two elements are liquids at room temperature—bromine and mercury. Bromine is a non-metal and mercury is a metal. Describe how these two liquids are likely to appear and behave differently from each other.

Analyse and evaluate

9 **a** Some sodium metal was introduced into a sealed jar containing chlorine gas. The metal and gas reacted to produce sodium chloride, which is table salt. Would you expect this reaction to need heat to get it going or would you expect it to produce heat? Would you expect it to be a mild reaction or a more violent one? Justify your answers.
   - **b** What two elements would you expect to react together in the most violent way? Justify your answer.

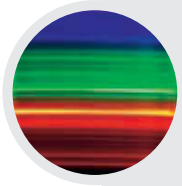
10 Before the 1980s, the groups of the periodic table were numbered with Roman numerals. Some scientists prefer this version because the atoms of the elements in group III (now 13) have three electrons in their valence shell, those in group IV (now 14) have four electrons in their valence shell and so on. Examine how the groups of transition metals were numbered in the old way. Which numbering system do you think is the most helpful? How can you deduce the number of electrons in the valence shell from the new group number?

CONNECTING IDEAS Properties and structure

11 The elements are ordered according to their atomic number. Groupings reflect the properties of the elements. Properties can change when elements combine. How might the location of an element on the periodic table give you an indication of how the elements are likely to combine with other elements?

6.3

How are properties linked to atomic structure?



The emission spectrum of an element is known to be unique to that element. Therefore, the logical conclusion would be that something in the structure of an element is responsible for its emission spectrum. In fact, the same could be said for all the chemical and physical properties observed for a particular element. To really get to the bottom of why elements behave in the way they do, we need to go back to the atomic structure of the atoms that make up the elements. Why do metals conduct electricity? Why are some elements solids? Why are some metals more reactive than others? Now that scientists know about the structure of atoms, these and other questions can be answered.

<<DISCOVERING IDEAS>>

Explaining differences in reactivity

In unit 6.2 you saw that different elements exhibit different reactivity. You would have found that some metals, like sodium and potassium, are very reactive. In fact, for metals, the lower down the group in the periodic table, the more reactive the metal. But what about the non-metals? For these, reactivity increases as you go up the group, with fluorine being the most reactive of the halogens in group 17. So, what does this tell you about what happens to the atoms of metals and non-metals when these elements react? Do you think that the same things are happening to the different types of atoms as they react?

You should know that it is the electrons on the outside of the atoms that are affected when atoms are involved in chemical change. For metals in group 1, how many electrons are on the outer (valence) shell of electrons? What do you think happens to these electrons when they react? What do you think happens to the valence shell of non-metals, like chlorine, when these atoms interact with other atoms?

Think about these questions and, if possible, discuss them in groups to suggest why potassium is a more reactive metal than sodium. Remember, the answer is found inside the atom!

Atoms and their electrons

The protons and neutrons of an atom exist within a nucleus. These subatomic particles are responsible for the majority of the mass of the atom and therefore have a strong influence on the properties of the atom. In fact, it is the number of protons that has been used to order the elements in the periodic table—this is the **atomic number**.

In contrast, electrons may have almost negligible mass. However, because they orbit around the nucleus, these subatomic particles interact with other atoms.

The nucleus of an atom is generally stable: it doesn't change in chemical reactions. Rather, interactions between the electrons of one atom and those of other atoms explain the differences in the properties of different compounds and, therefore, have been the focus of much research.

Electron configurations

When considering the way electrons are arranged in an atom, the Bohr model of the atom can be used. In this model, the electron shells are numbered from the nucleus outward. These are shown in Table 6.4, along with the maximum number of electrons in each shell.

→ Table 6.4 The Bohr model of the atom

Shell number (from the nucleus outwards)	1	2	3	4
Maximum number of electrons in the shell	2	8	18*	32

*The maximum number of electrons in any given shell can be determined by the formula $2n^2$, where n is the shell number. This formula works for most atoms, but note that until we get to atomic number 20 (calcium) there is actually only room for eight electrons in the third shell of electrons.

Table 6.4 shows that the further the electron shell is from the nucleus, the larger the number of electrons it can contain. Looking at the size of the electron shell, the distance within which electrons could 'fit' is much greater, supporting this theory. The maximum number of electrons a shell can hold is related to its shell number by the simple formula $2n^2$, where n is the number of the shell from the nucleus.

Bohr also stated that the electrons of an atom are normally located as close to the nucleus as possible—negatively charged electrons are attracted to the positive charges of the protons—because this is a lower energy state and is more stable. Therefore, the shells are filled up from the inside out. In Year 10 we only need to consider atoms up to calcium, but you can use the information provided to work out the arrangement of electrons of just about any atom.

The arrangement of electrons in an atom is termed its **electron configuration**.

Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are shown in pairs. This makes it easier to draw the diagrams and is actually scientifically correct because, in atoms, electrons do actually exist in pairs within the shells. The outermost occupied shell of atoms is known as the **valence shell**.

Electron configuration of oxygen

The atomic number of oxygen is 8, so an uncharged atom contains eight electrons.

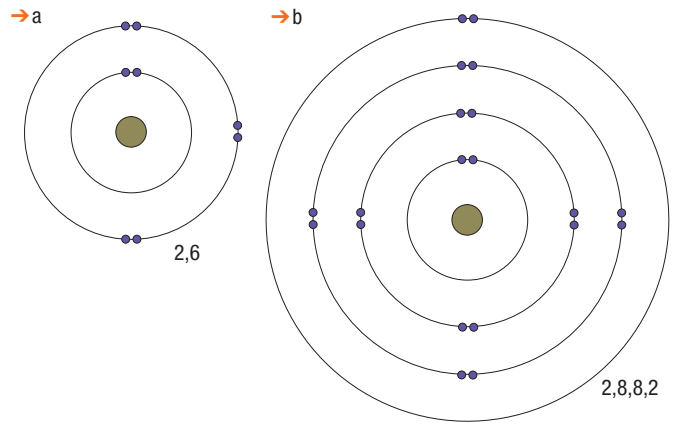
- The first shell can only hold two electrons.
- The second shell holds the other six electrons.
- The electron configuration of oxygen is written as: 2,6.

Electron configuration of calcium

The atomic number of calcium is 20, so an uncharged atom contains twenty electrons.

- The first shell can only hold two electrons.
- There are eighteen electrons left to place in shells. The second shell can only hold eight electrons.
- There are ten electrons left to place in shells. The third shell can only hold eight electrons.
- The fourth shell holds the last two electrons.
- The electron configuration of calcium is written as: 2,8,8,2.

→ Fig 6.24 The electron configurations for (a) oxygen and (b) calcium are shown as simple shell diagrams.





Emission spectrum and electron shells

When atoms are heated in a flame, the electrons gain heat energy from the flame and become 'excited', jumping from their normal shell to one further out from the nucleus. When this 'excited' state fades and the electrons have moved back to their usual shell, this 'extra' energy is given back out in the form of light energy. Because the energy gaps between electron shells vary from one atom to the next, the energy released by the different atoms also varies. This variation is seen as different levels of light energy, which have different frequencies; different frequencies of light have different colours. Hence, the emission spectrum of each atom will be a 'fingerprint' of different colour patterns. These spectra cause flames from burning the different elements to have different colours, as you have seen in an experiment in Year 9.

What do you know about atoms and their electrons?

1 For the Bohr model of the atom, what is the maximum number of electrons that the fourth electron shell can contain?

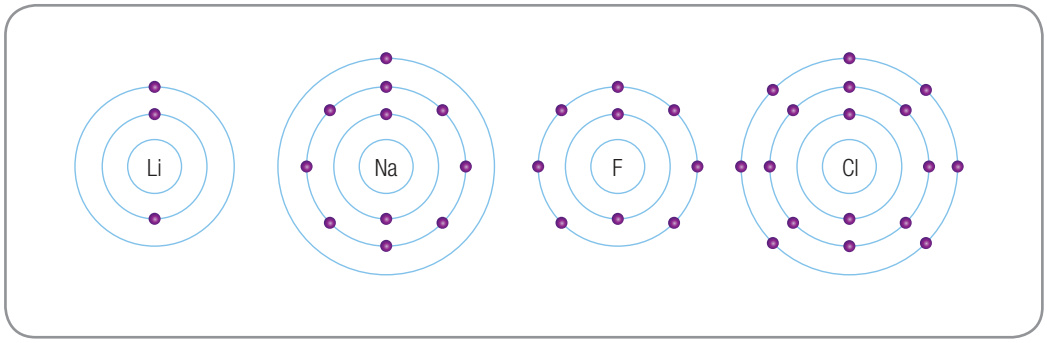
2 A potassium atom contains nineteen protons.
   - **a** How many electrons will be present in a potassium atom? Justify your answer.
   - **b** What is the electron configuration of a potassium atom according to the Bohr model?
   - **c** From the electron configuration of potassium, it is clear that electrons do not normally occupy the fifth shell. What could be done to potassium atoms for electrons to jump into this shell?

3 Copy out and complete the table.

Element	Atomic number	Electron configuration
Beryllium		
	9	
Magnesium		
Neon		
		2,8,3
	11	
		2,8,7
Sulfur		

Electrons and properties of elements

The electron configurations of the elements can explain the properties of the elements. Being able to confidently navigate the periodic table enables you to identify trends in electrons, the properties of elements and the uses of compounds formed from them.

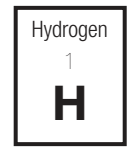


→ Fig 6.25 In group 1, the electron configuration of lithium is 2,1, whereas that of sodium is 2,8,1 and that of potassium is 2,8,8,1. The atoms of all other group 1 elements have one electron in their valence shell of electrons. In group 17, the electron configuration of fluorine is 2,7 and that of chlorine is 2,8,7. The atoms of all other group 17 elements also have seven electrons in their valence shell.

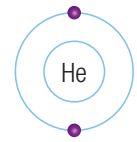
Groups and valence electrons

The groups of the periodic table are numbered 1–18. Elements in the same group have similar chemical properties that we now know to be attributable to the arrangement of their electrons.

Elements in the same group have the same number of electrons in their outermost or valence shell. The valence electrons are those that interact with other atoms.



→ Fig 6.26 Hydrogen has unique properties—no other element is like it! Hydrogen was originally placed in group 1, even though all the other elements in group 1 are metals, simply because its uncharged atoms have one electron in their valence shell, like all the other elements in this group. However, because of its unique properties, it is placed alone and is not part of any group.



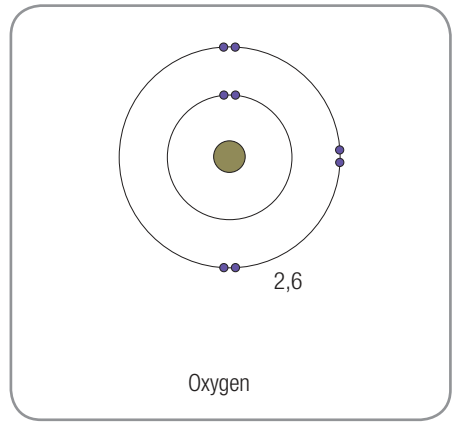
→ Fig 6.27 Helium is placed in group 18. All members of group 18, except helium, have eight electrons in the valence shell of their uncharged atoms; helium atoms only have two. However, this means that, in all group 18 elements including helium, the valence shell of their uncharged atoms contains as many electrons as possible. Because helium also has very similar properties to the other elements in group 18, it remains placed within this group.

Forming ions

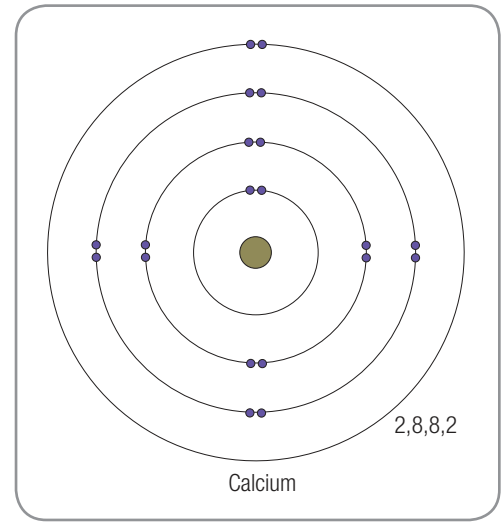
Electron shells are most stable when they are full—containing eight valence electrons. The behaviour of valence electrons can be explained by the atom seeking a stable state: electrons can be gained and lost from neighbouring atoms a full outer (valence) shell of electrons. In certain cases, electrons are shared between atoms to achieve this balance.

The easiest way to achieve stability for atoms with only a few valence electrons is to lose these electrons. In contrast, if the valence shell is almost full, there is a greater likelihood of that atom gaining electrons to fill the gaps in the shell. Because electrons carry a negative charge, the movement of the electrons results in an overall charge for the atom. The atom is then referred to as an **ion**—a charged atom.

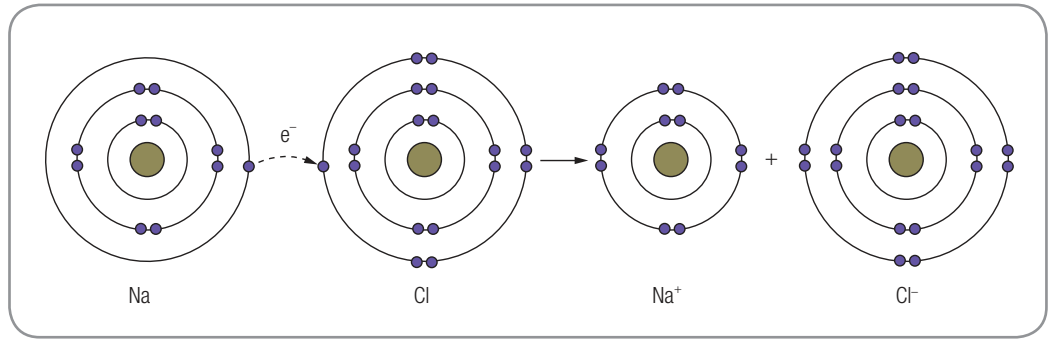
The ions formed by the various elements impact on the elements they are likely to interact with. An ion with a 2+ charge is likely to combine (bond) with an ion of 2– charge or with two ions each with a charge of 1– (oppositely charged ions attract each other). The positive charge is balanced out by an equal negative charge. The bonds that are formed after ions interact are referred to as ionic bonds.



→ Fig 6.28 Oxygen tends to gain two electrons to fill its valence shell. Overall, there will be two extra negative charges compared with positive charges (from the protons in the nucleus), so the ion is written as O^{2-}.



→ Fig 6.29 Calcium has two electrons in its valence shell, so it tends to lose them to achieve stability. The calcium ion formed is then written as Ca^{2+} to show that there are two more protons compared with the number of electrons.



→ Fig 6.30 Sodium chloride is formed when sodium donates an electron to chlorine.

EXPERIMENT 6.2

Conductivity of ionic compounds

Aim

To investigate the electrical conductivity of two ionic compounds as a solid and in aqueous solution.

Equipment

Large sodium chloride crystals
Coarse sea salt crystals
One small Petri dish
4 V battery or other 4 V DC power source
Ammeter
Wires with alligator clips
Two graphite electrodes
Three 100 mL beakers
Large spatula
Glass stirring rod
Paper towel

Method

1 Set up the electrical circuit as shown in Figure 6.31. Have your teacher check that it is correct before proceeding. Ensure that you know how to use the ammeter and its scales correctly.
2 Using the spatula, place the largest sodium chloride crystal onto a Petri dish, then touch each end with an electrode, making sure that the two electrodes do not touch each other. Does the crystal conduct electricity? If it doesn't appear to, connect the wire to the more sensitive scale on the ammeter. Does a reading register now? Record your result.
3 In a 100 mL beaker place half a large spatula of sodium chloride crystals and add 50 mL of water. Stir to dissolve to the crystals.
4 Place the electrodes into this solution, again ensuring they do not touch each other. Does the solution conduct electricity? If it doesn't appear to, connect the wire to the more sensitive scale on the ammeter. Does a reading register now? Record your result.
5 Rinse the electrodes with fresh tap water, then dry them with a paper towel.
6 Repeat steps 1–2 for the coarse sea salt crystals.

Results

Devise a simple table or spreadsheet in which to record your results.

Discussion

1 Sea salt is a mixture of different ionic compounds, including sodium chloride. What can you conclude about the ability of solid ionic compounds to conduct electricity, whether they are pure or mixed up together?
2 What effect does dissolving an ionic compound in water have on its ability to conduct electricity?
3 To conduct electricity, a substance must have charged particles that can move about. Suggest an explanation for your findings.
4 The melting point of sodium chloride is 801°C, so it is not practical to melt it in the school laboratory. Predict whether molten sodium chloride would conduct electricity and justify your answer.

→ Fig 6.31 Experiment set-up.



Identifying patterns in the periodic table

What you need: A3 sheet of paper, pens, highlighter pens

1. On an A3 sheet of paper, make a copy of the periodic table only up to element 20. Leave a gap for the block of transition metals. Ensure that the size of the box for each element will fit the information you will need to insert, as detailed below. (Chlorine has been completed for you as an example.)
2. Use different colours to shade in the metals, the noble gases, hydrogen, the non-metals other than the noble gases and hydrogen, and the metalloids. Place a suitable key under your periodic table.
3. Identify the elements that will not gain or lose electrons in a reaction because their uncharged atoms are already very stable. Beneath them, write:
   - 'already a stable structure'
   - 'does not form an ion'
4. Identify the elements that will not gain or lose electrons in a reaction, because this would require them to gain or lose more than three electrons. Beneath them, write:
   - 'needs to gain or lose more than three electrons for a more stable structure'
   - 'does not form an ion'.
5. Complete the box for each of the other elements listed, except for the metalloids and hydrogen, by stating how many electrons the element needs to gain or lose to achieve a more stable structure, and hence what charge its ion should have, like the example of chlorine.

   Information for chlorine:
   - Chlorine (Cl)
   - needs to gain one electron
   - charge on ion = –1

- What patterns do you notice in your entries for the alkali metals?
- What patterns do you notice in your entries for the alkaline earth metals?
- What patterns apply to all the metals listed?
- What patterns do you notice in your entries for the halogens?
- What patterns do you notice in your entries for the group 16 elements?
- What patterns apply to the non-metals, except for hydrogen and the noble gases?
- In general, what do you expect to happen when a metal atom and a non-metal atom meet? Which groups of non-metals will not react in this way? Discuss.
- Predict what might happen if:
  - **a** a potassium atom and a fluorine atom meet
  - **b** a calcium atom and an oxygen atom meet.
- You can illustrate your predictions by drawing shell diagrams of the atoms and showing what happens in the reaction.
- Suggest why hydrogen and the metalloids were not considered in this activity.



What do you know about electrons and properties of elements?

1. Carefully examine the periodic table.
   - **a** Which elements are likely to form positively charged ions?
   - **b** Which elements are likely to form negatively charged ions?
   - **c** What does this tell you about which elements will combine to form ionic compounds?
2. How does the group in which an element is found in the periodic table quickly identify one or more of its properties?
3. Helium is placed in group 18 of the periodic table, even though it has only two electrons in the outer shell compared with the eight electrons that the other elements in this group have in their outer shell. Why is helium placed in this group?
4. Hydrogen is not placed in a group or period in the periodic table. Why is this?
5. What is the maximum number of electrons that can be gained or lost by an atom? Why?

SKILLS LAB

Ionic compounds

Ionic compounds are those formed from the bonding of ions. Let's consider sodium chloride, which is produced when sodium and chlorine meet and react. In this compound, the metal sodium is present in the form of positively charged ions (Na^+) and the non-metal chlorine is present as negatively charged ions (Cl^-). Notice that the:

- metal is named first and its name is not changed
- non-metal is named second and the end of its name is changed from -ine to -ide

This follows a standard naming convention, as follows.

- The positively charged ion (cation) in the compound is written first and keeps the name of the metal from which it was formed.
- The negatively charged ion (anion) in the compound is written second. Replace the end of the name of the non-metal from which it formed with -ide.
- Some transition metals can form more than one ion. In these cases, a Roman numeral is used to show the charge on the ion. For example, copper forms two ions: one with a 1+ charge and one with a 2+ charge. These ions are called copper(I) and copper(II) ions, respectively.

The names and formulas of some common ions are listed in Table 6.5.

→Table 6.5 Formulas of some common ions

Cations		Anions	
Name	Formula	Name	Formula
Lithium	Li^+	Fluoride	F^-
Sodium	Na^+	Chloride	Cl^-
Potassium	K^+	Bromide	Br^-
Magnesium	Mg^{2+}	Iodide	I^-
Calcium	Ca^{2+}	Oxide	O^{2-}
Aluminium	Al^{3+}	Sulfide	S^{2-}
Silver	Ag^+	Nitride	N^{3-}
Zinc	Zn^{2+}		
Copper(II)	Cu^{2+}		
Iron(II)	Fe^{2+}		
Iron(III)	Fe^{3+}		

The properties of ionic compounds

Compounds that are held together by ionic bonds are called **ionic compounds**. As an ionic compound forms, the like charged ions repel each other and the oppositely charged ions attract each other. After all the pushing and pulling, the ions settle into alternating positions, as shown in Figure 6.32, because this is the most stable arrangement. The particles are held together by strong electrostatic forces of attraction between the positively charged ions. Because these forces bind the ions together, this is known as **ionic bonding**.

A lot of energy is required to move the ions out of their positions because the electrostatic forces are so strong. This means that ionic compounds are hard to melt. At room temperature, they are in the form of hard, brittle crystals. The most commonly known example of an ionic compound is sodium chloride (table salt). Its melting point is 801°C. If you use a salt grinder at home, you will be aware of how hard and brittle salt crystals are.

Polyatomic ions

A number of ions are made up of more than one atom. These are termed **polyatomic ions**. Figure 6.33 shows some examples of polyatomic ions.

These clusters of atoms have a charge because the total number of protons does not equal the total number of electrons present. For example, in the hydroxide ion, which is made up of two atoms (one each of oxygen and hydrogen), there are nine protons and ten electrons. This means the ion has an overall charge of 1–.

Calcium carbonate, the main constituent of marble, is an example of an ionic compound that contains a polyatomic ion. Calcium carbonate contains calcium ions, Ca^{2+}, and carbonate ions, CO_3^{2-}. These ions must be present in the ratio 1:1 so that the total positive charge equals the total negative charge. The formula of calcium carbonate is $CaCO_3$. Ammonium carbonate is used in smelling salts. It contains ammonium ions, NH_4^+, and carbonate ions, CO_3^{2-}. In this case, the ions need to be present in the ratio 2:1. The formula of ammonium carbonate is $(NH_4)_2CO_3$.

The formula for sodium chloride is NaCl, whereas the formula of magnesium chloride is $MgCl_2$. The formula NaCl means that the cations and anions are present in a ratio of 1 : 1. That is, for every Na^+ ion present in a sodium chloride crystal, there is one Cl^- ion present. The formula $MgCl_2$ means that the cations and anions are present in a ratio of 1 : 2. That is, for every Mg^{2+} ion present in a magnesium chloride crystal, there are two Cl^- ions present. This is necessary to achieve an overall neutral charge.

We can use this principle to deduce the formula of an ionic compound. First, use Table 6.5 to list the formulas of the cations and anions present. Then, work out the simplest ratio they need to be in so that the total positive charge and total negative charge are equal.

Example

1 What is the formula for iron(II) oxide?

- The ions are Fe^{2+} and O^{2-}.
- Because the charges 2+ and 2– are equal, the ions only need to be in a ratio of 1 : 1.
- Therefore, the formula is FeO.

2 What is the formula for silver sulfide?

- The ions are Ag^+ and S^{2-}.
- Because the charges are 1+ and 2–, the ions need to be in a ratio of 2 : 1 (making it a total of 2+ and 2–).
- Therefore, the formula is Ag_2S.

Your turn

Write the formulas for the following compounds:

a lithium bromide

b iron(III) chloride

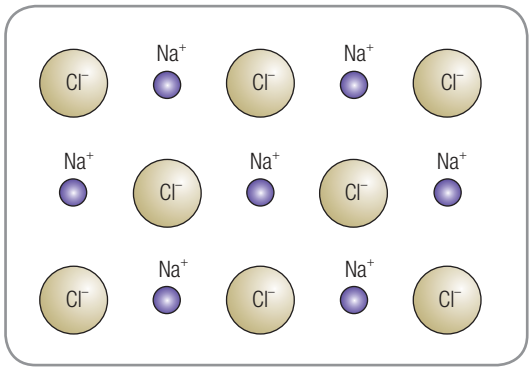
c sodium nitride

d aluminium oxide

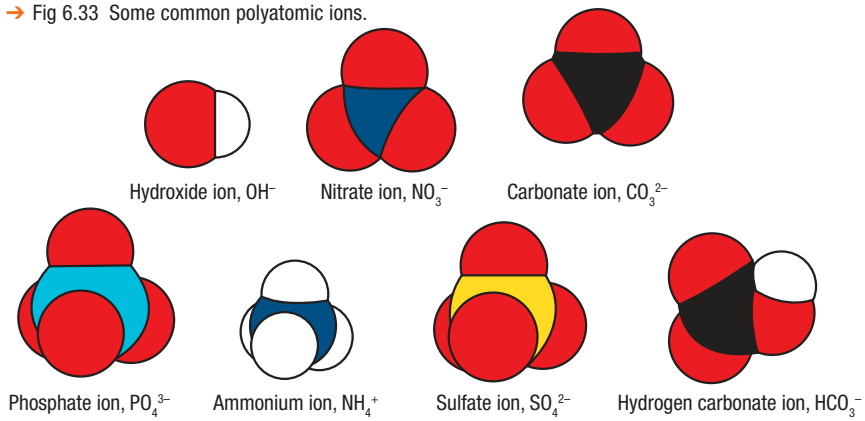
Answers

a LiBr **b** $FeCl_3$ **c** Na_3N **d** Al_2O_3

→ Fig 6.32 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.



→ Fig 6.33 Some common polyatomic ions.



What do you know about the properties of ionic compounds?

1 What kinds of particles are present in ionic compounds?

2 Draw a sketch of part of a solid crystal of an ionic compound and explain why the particles are arranged like this.

3 Explain why ionic compounds are all solids at room temperature.

4 Use your knowledge of atomic structure and valence electrons to explain why many ionic compounds are made up from a metal and a non-metal.

Electrons and electricity

Where would we be today without electricity? It lights up our homes, heats our water, cools our food and runs our computers. But the last thing we need is to be electrocuted or to have our house burn down due to a flammable substance coming into contact with hot electrical wires. It is fortunate that although all metals conduct electricity (some better than others), other materials will not conduct electricity and so can be used to protect us from harm. To understand why it is that metals conduct electricity we need to look at the atomic structure of metallic atoms.

Remember that metals are found on the left-hand side of the periodic table. Metals do not have many electrons in their outer shells, and it does not take much energy for these outer electrons to move from one atom to another. This is the clue as to why metals are so good at conducting electricity.

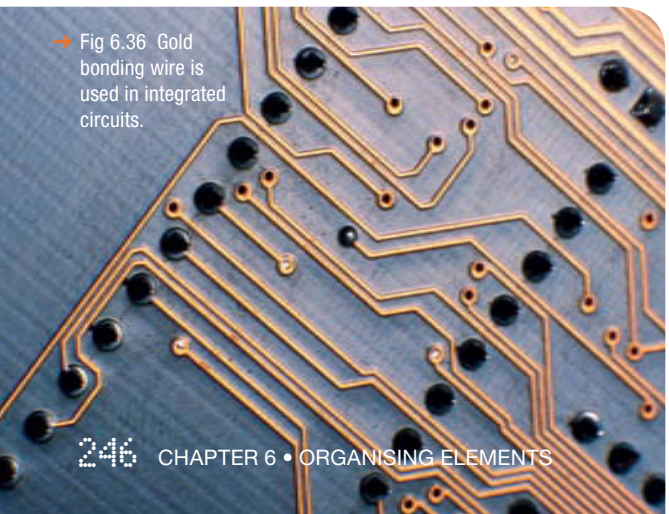
Table 6.6 gives the electrical conductivity of a number of elements at 25°C.

→ Table 6.6 The electrical conductivities of some common elements

Element	Electrical conductivity ($\times 10^6$ ohm^{-1} cm^{-1})
Aluminium	0.37
Silver	0.63
Carbon (graphite)	0.100
Copper	0.596
Gold	0.452
Iron	0.093
Lead	0.048
Magnesium	0.226
Sodium	0.210

Scientists have determined rules for electrical conductivity. These are outlined below.

- All metals conduct electricity in the solid state, some better than others. They continue to conduct electricity when molten, but more weakly. The higher the temperature, the lower their electrical conductivity.
- The non-metal carbon, in the form of graphite, only conducts electricity to a small extent, enough to be used in a number of applications.
- Ionic compounds only conduct electricity when molten.
- Most compounds that are not ionic do not conduct electricity at all. However, a small number of designer plastics also conduct electricity.



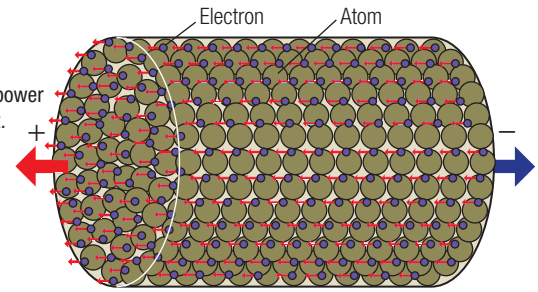
→ Fig 6.36 Gold bonding wire is used in integrated circuits.

Metals and conductivity

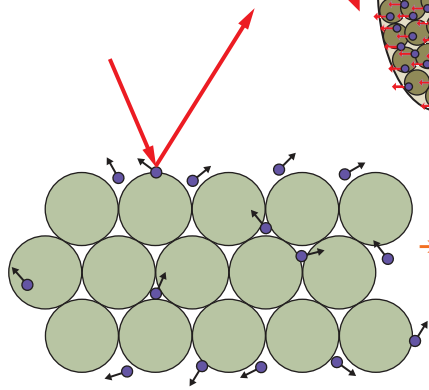
A substance will conduct electricity if it contains charged particles that are free to move around the structure. In the case of metals, these charged particles are electrons. Scientists refer to them as **delocalised electrons** because they are not 'stuck' in one locality. (Most electrons in metal atoms are not delocalised because they move about the nucleus of each metal atom in electron shells.)

Delocalised electrons are responsible for a pure metal being so lustrous (shiny). The delocalised electrons in its surface reflect light exceptionally well.

Only some metals are used for their electrical conductivity. For example, power lines have a core of steel and an outside layer of aluminium. Household wiring is usually copper, which is coated with a special kind of plastic. Metals like silver and gold are used in more specialised applications, such as in electronic devices.



→ Fig 6.34 Delocalised electrons move about randomly in a metal, but move towards the positive terminal of the power source when connected into a circuit.



→ Fig 6.35 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

Electrons and molecules

You have seen that when electrons are transferred from one atom to another, positive and negative ions are produced and ionic compounds are formed. However, what about two non-metals that complete their outer shells of electrons by gaining electrons? Can they bond together?

The answer is yes, they can, and we can see this with the smallest, lightest atom there is: hydrogen.

Hydrogen molecules

Let's look at hydrogen as an example. An uncharged atom of hydrogen has just one electron in the first shell. If it could gain one more electron, this shell would contain its maximum number of electrons; in this case, two electrons. If hydrogen was in contact with a reactive metal like lithium, the hydrogen atom could gain that extra electron from a lithium atom. An ionic compound would form as a result. But what if only other uncharged

hydrogen atoms were present? The only way each hydrogen atom can gain an extra electron is by sharing its electron with another hydrogen atom.

As two uncharged hydrogen atoms come close together, the electrons are drawn into the region between the two nuclei. The atoms partially merge into one another, with both atoms now sharing the two electrons. In effect, each atom now has a stable electron configuration because its outer shell is full.

The particle produced has two hydrogen atoms bonded strongly together and is termed a molecule. A molecule is a particle produced when two or more atoms combine so that the atoms share electrons. A molecule has no overall charge because the total number of electrons present and the total number of protons present is the same.

The hydrogen molecule is given the formula H_2 because there are two hydrogen atoms present in the cluster.

The hydrogen molecule is an example of a molecule of an element. It is called a **diatomic molecule** because it is made up of two atoms. Other examples of diatomic molecules of non-metals are fluorine (F_2), chlorine (Cl_2), oxygen (O_2) and nitrogen (N_2).

In a molecule such as the hydrogen molecule, there is strong electrostatic attraction between each positively charged nucleus and the negatively charged electrons that they share, which spend a considerable part of their time between the two nuclei. This electrostatic attraction is termed **covalent bonding**. The two shared electrons create a bond between the two atoms.

Molecular compounds

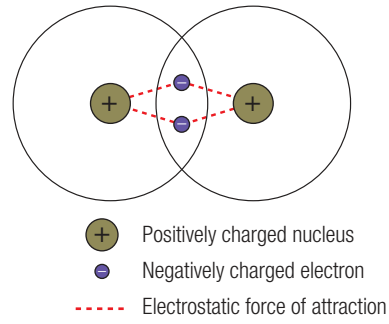
Like elements, compounds also form molecules. Water is an example of a **molecular compound**. Its formula is H_2O. You are now in a position to understand why it has this formula. To gain a more stable electron configuration:

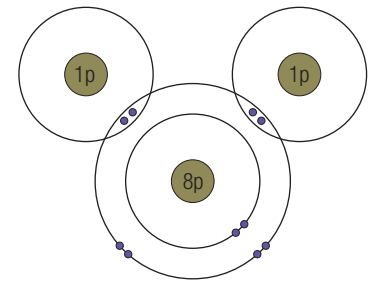
- an uncharged hydrogen atom has one valence electron and requires one more electron
- an uncharged oxygen atom has six valence electrons and requires two more electrons.

A single hydrogen atom cannot supply the two electrons the oxygen atom needs, but two atoms can! This is why there are two hydrogen atoms and just one oxygen atom in a water molecule. An oxygen atom now effectively has eight electrons in its valence shell and each hydrogen atom has two electrons. This is shown in Figure 6.38. Notice how each atom now has a full outer shell of electrons.

There are other ways of representing the structure of molecules, including with three-dimensional models. However, remember that in any representation, a single chemical bond holding the molecule together is actually a pair of negative electrons, shared between two atoms, attracted to the positive nuclei of both of these atoms.

→ Fig 6.37 Covalent bonding within a hydrogen molecule.





→ Fig 6.38 A shell diagram of a water molecule.

Properties of molecular substances

Almost all molecular substances do not conduct electricity, even in the liquid state, because molecules are uncharged and so they cannot carry a current. There are no strong forces of attraction between molecules, so most molecular substances are liquids or gases at room temperature. It does not take much energy to separate the molecules and get them to move around.

What do you know about electrons and electricity?

1. Explain why molecular substances cannot conduct electricity.
2. In terms of the structure of the substance, why is it easy to turn liquid water into a gas?
3. When chlorine atoms combine to form molecules, how many electrons need to be shared between the two chlorine atoms?
4. Would this be the same for two oxygen atoms combining to form a molecule? Explain your reasoning.
5. Why do ionic substances have much higher melting points than molecular substances?

6.3

How are properties linked to atomic structure?



Remember and understand

1 What is the term that scientists use for each of the following?
   - **a** a positively charged ion
   - **b** the forces that hold an ionic compound together

2 What special feature of metals allows them to conduct electricity in the solid state?

3 What number of electrons in the valence shell makes an atom particularly stable?

4 When naming an ionic compound, which ion is given first?

5 Give explanations for the following:
   - **a** Argon will not react with any other element.
   - **b** The reaction between sodium and chlorine gives out a lot of heat and light.
   - **c** When you accidentally spill sodium chloride onto a stove while cooking, it does not melt.

Apply

6 Consider the following pairs of elements:
   - **i** chlorine and oxygen
   - **ii** nitrogen and lithium
   - **iii** fluorine and argon
   - **iv** aluminium and potassium

   - **a** Which pair(s) will react to form an ionic compound?
   - **b** Which pair(s) will react to form a molecular compound?
   - **c** Which pair(s) will not react to form a compound?

   In each case, justify your answer.

Analyse and evaluate

7 A certain particle was found to contain sixteen protons and eighteen electrons.
   - **a** What element must it be? State your reasoning.
   - **b** Is the particle neutral, positively charged or negatively charged?
   - **c** What is the formula of the particle? Justify your answer.

8 When the uncharged atoms of potassium lose an electron, they then have an electron configuration of 2,8,8. This is the same as the electron configuration of argon. Does this mean that the potassium atoms have become argon atoms? Discuss.

Critical and creative thinking

9 A substance will conduct electricity if it contains charged particles that are free to move across the sample. The charged particles can be electrons or ions. Suggest why ionic compounds cannot conduct electricity when in the solid state, but can conduct electricity when melted.

10 A student claimed that sodium chloride is made of molecules. Is the student correct? Discuss.

CONNECTING IDEAS Properties and structure

11 Consider the following three substances: sodium metal (Na), chlorine gas (Cl_2) and sodium chloride (NaCl). These three substances have very different properties and very different structures. However, all the properties of the substances can be explained by referencing the atomic structures of sodium and chlorine atoms. Design a table to show the key properties of the three substances. For each property, use your knowledge of atomic structure to explain the reasons why the substance exhibits this property. Hint: Use diagrams where possible and remember to concentrate on the behaviour of the electrons.

Research

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

The noble gases

The story behind the discovery of the noble gases is a fascinating one. The challenge was this: how do you detect the existence of something that only exists as a gas that does not react with anything and, except for argon, is only present in the air in extremely small concentrations? How was the first noble gas found? What role did the periodic table of that time play in helping chemists hunt for other noble gases?

Hydrogen

Hydrogen is a most unusual non-metal because it can form H^+ ions and H^- ions depending on what it reacts with. Although alkali metals do not react with one another, hydrogen will react with alkali metals and form compounds, such as lithium hydride (LiH). Show why the hydride ion, H^-, is stable. What are the properties of metal hydrides such as lithium hydride? What uses are made of these compounds?

Reflect

Me

1 What was the most surprising thing you found out about the elements?
2 What were the most difficult aspects of this topic?
3 How has your understanding of the organisation of elements improved?
4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know how different elements and compounds behave?
6 How has our increasing understanding of the atom and knowledge of the elements affected the technology and resources now available?

My future

7 Will there be any opportunities for new discoveries about the atom and the elements?
8 Do you think that increasing knowledge and technology will lead to future changes in the periodic table?

Review

Key words

alkali metals
alkaline earth metals
atomic number
covalent bonding
delocalised electrons
diatomic molecule
electron configuration
group
halogens
ion
ionic bonding
ionic compound
metalloids
metals
molecular compound
noble gases
non-metals
period
periodic table
polyatomic ion
shell diagram
transition metals
valence shell

Elements in our oceans



Fig 6.39 There are more elements in our oceans than you may think.

We all know that water has the formula H_2O and therefore contains oxygen and hydrogen. Sea water contains salt, so it also has the elements sodium and chlorine. But did you know that our oceans contain a whole range of other elements, such as magnesium, sulfur, calcium, potassium, bromine and even gold? So how did the elements get into the water that covers two-thirds of the surface of our planet? And in what form are these elements present within the sea water?

Many of the metals present in sea water have been leached from minerals on the floor of the ocean. Sodium is an example of this; it dissolves into the water in the form of sodium ions (Na^+). Over time, gases from volcanic activity on Earth have passed through the oceans. Some of these gases, such as hydrogen chloride, contain chlorine and this element also becomes dissolved in sea water in the form of ions. Sulfur is also a product of volcanic activity and most sulfur in today's oceans exists in the form of sulfate ions.



→ Fig 6.40 The water in the Dead Sea has extremely high levels of salt.

Sea water is denser than pure water. The average density of salt water is 1.025 kg/L, compared with a density of 1.000 kg/L for pure water. The concentrations of dissolved ions vary depending on location. The Dead Sea, which is between Jordan and Israel in the Middle East, is almost ten times saltier than normal sea water and has a density of 1.24 kg/L. It is also unusual because it has higher concentrations of magnesium chloride than the more usual sodium chloride.

1 **a** List the group 1 metals present in sea water.

b Explain why these metals are not found in their elemental (uncombined) state in nature.

2 Explain in detail, with reference to the periodic table, why the formula of magnesium chloride is $MgCl_2$, whereas the formula of sodium chloride (NaCl) only contains one chloride ion.

3 Give the formula of sulfate ions and suggest how these ions have been formed from the sulfur over time.

4 If sea water contains 2.8% sodium chloride by mass and the density of water is 1.025 kg/L, what mass of salt could be produced from 5000 L of water?

5 If the density of sea water is greater than the density of pure water, what does this tell you about the packing of particles within seawater? Use diagrams to illustrate your answer.

Desalination

Given the fact that so many countries do not have enough fresh water suitable for drinking, many governments, including some in Australia, have decided to establish desalination plants to extract water from our oceans.

There are two main methods used in desalination plants. One is based on distillation. In this case, sea water is drawn into the plant and boiled. The water evaporates, leaving all the salts behind. The evaporated water is then cooled so it condenses; it is now pure water. This is the method used in a number of Middle Eastern countries, including Saudi Arabia and the United Arab Emirates. All the pumping and heating consumes a huge amount of electricity, although some of the cost is offset by some of the valuable minerals extracted as by-products from the water.

An alternative method is called reverse osmosis. This is the method used in Australian desalination plants such as the Kwinana desalination plant in Western Australia, which provides 17% of Perth's drinking water. In this process, sea water is passed through membranes at high pressure, which removes a large proportion of the dissolved salts. The waste water from the plant, which will have a very high salt content, is pumped back into the ocean, further out to sea.

6 Given the properties of ionic compounds, such as sodium chloride, and molecular compounds, such as water, suggest why the water evaporates away leaving the salt behind when the sea water is heated during distillation.

7 Given the properties of metals, what might be a problem with all the metal parts within a desalination plant?

8 Suggest reasons why distillation methods are commonly used for desalination plants in oil-rich countries such as Saudi Arabia, whereas reverse osmosis is the method used in Australian desalination plants.

9 Conduct research into existing or planned desalination plants in your state or territory and find out:

- **a** the reasons the plants have been sited where they are
- **b** the potential environmental impact of the desalination plant.

→ Fig 6.41 Desalination plants in Australia are providing more and more of our drinking water.





→ Fig 6.42 Bromine compounds are used to protect Australia's borders from dangerous pests.

Halogens in the ocean

Element 35 is bromine. It is one of the halogens in group 17 of the periodic table. Bromine can control bacterial growth and is used in the maintenance of swimming pools. Bromine compounds are also used as pesticides and as pharmaceuticals. Although the concentration of bromide ions in sea water is very low, bromine can be extracted from sea water on an industrial scale. Chlorine gas is bubbled through water. Because chlorine is more reactive than bromine, the chlorine atoms are able to 'take' an electron from the bromide ions (Br^-), becoming chloride ions (Cl^-), whereas the bromide ions become neutral once they have lost that 'extra' electron. Bromine atoms, like chlorine atoms, form molecules (Br_2). This process can be represented by an equation, as shown below.

$$Cl_2 + 2\ Br^- \rightarrow 2\ Cl^- + Br_2$$

10 Use your knowledge of electrons and chemical bonding to explain why group 17 elements, such as bromine and chlorine, form ions with a charge of 1–.

11 Draw a labelled representation of a bromine molecule.

12 Look at the positions of chlorine and bromine in the periodic table and suggest why chlorine is more reactive than bromine.

13 Which member of the halogens (group 17) is the most reactive? Explain your answer.

14 The pesticide methyl bromide has the formula CH_3Br. It is used by the Australian Quarantine and Inspection Service (AQIS) to treat imported organic goods.

a Do you think that methyl bromide actually contains bromide ions? Explain the reasons for your answer.

b Find out why the use of methyl bromide (or bromomethane as it is also called) has been restricted in a number of countries.

7 Using chemistry

7.1 How do we use the products of chemical reactions?

Each year, 80 million tonnes of polythene is manufactured worldwide. Polythene is a synthetic compound; it is not found in nature. Before humans discovered a way of making it, polythene did not exist. Today we use polythene for shopping bags and the packaging of a whole range of goods. In addition, polythene can be made as foam to make cushions or buoyancy equipment. Polythene is not a biodegradable product and the use of disposable polythene bags is being discouraged in an attempt to reduce the amount of polythene that needs to be disposed of each year.

The way to make polythene (or polyethene, to give it its more scientifically accurate name) was discovered by accident back in 1898. As with most chemical processes, over time more effective, efficient and economic ways were discovered to make the product. Nowadays polyethene is produced from the gas ethene, heated to very high temperature and reacted at high pressure in the presence of a catalyst that helps speed up the chemical reaction.

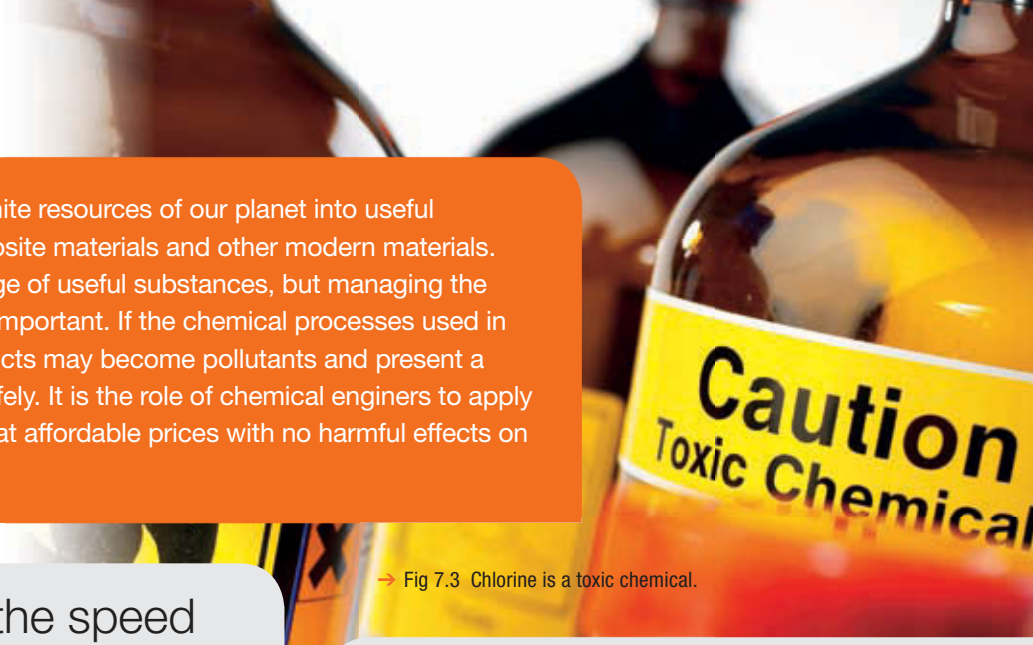
1 The reaction used to produce ethene is called a 'polymerisation reaction'. Conduct research to find out what is meant by 'polymer'.
2 All manufactured substances start as raw materials. Find out what main raw material is used to produce ethene, which then is used to produce polyethene.
3 As the use of polyethene has increased, what natural materials do you think have been replaced by the synthetic polyethene?
4 What measures are being put in place to try to reduce the use of polyethene bags?
5 Of the 80 million tonnes of polyethene produced in the world each year, how much do you think is disposed annually? Discuss your estimate with others in a group.





→ Fig 7.1 Polythene is used to keep food fresh.

Our society relies on the ability to convert the finite resources of our planet into useful materials including polymers, medicines, composite materials and other modern materials. Chemists know how to manufacture a wide range of useful substances, but managing the by-products of these processes is increasingly important. If the chemical processes used in industry are not managed correctly, these products may become pollutants and present a threat to the environment and our health and safely. It is the role of chemical enginers to apply chemical reactions to make quality substances at affordable prices with no harmful effects on the environment.



→ Fig 7.3 Chlorine is a toxic chemical.

7.2 How can we control the speed of chemical reactions?

If you buried a polyethene bag in the soil today that bag would probably still be there in 200 years time. The reaction that causes the decomposition (breaking down) of the polyethene is very, very slow. In contrast, the reactions used to produce the polyethene used to make the bag are very fast. The faster the reaction, the more polyethene can be made in a certain amount of time. To speed up these reactions, high temperatures are used, the gases involved are pressurised and a chemical catalyst is used to get things moving even more quickly. Can you think of reactions that you would want to go faster? What about reactions that need to be slowed down? Do you think there might be a way of speeding up how quickly the polyethene in the bag decomposes? What would be a problem if polyethene decomposes too quickly?


→ Fig 7.2 Chemical catalysts are used to create explosions in querries.

1 Why do industrial chemists and chemical engineers generally look at ways of increasing the rate of chemical reactions?
2 What problems might be caused in a chemical plant if some reactions occurred too quickly?
3 List two things that are used to slow down chemical reactions and give a real life example of each.
4 Suggest why heating up chemicals generally causes them to react more quickly. Discuss your answers with others in the class. What scientific ideas or theories did you use to come up with your suggestions?

7.3 What are the risks of using chemicals?

All substances that we see, smell and touch are chemicals: the water we drink, the oxygen we breathe and the plastic materials we use every day. All substances have risks associated with their use. Oxygen in high concentrations would have harmful effects, drinking too much water can be dangerous and, of course, plastic products can contribute to basic problems of litter and can injure or even kill wildlife. When we consider the potential risks of chemicals, it is often about having to consider the reactions that the materials will undergo, reactions that may cause harm to us or our environment. Will the plastics decompose to release other chemicals, such as chlorine, into the environment? Will the oxygen enable other chemicals to react in uncontrolled ways? What chemicals will be produced when materials are added into water supplies? These are the types of questions that need to be considered to ensure that chemicals are used safely.

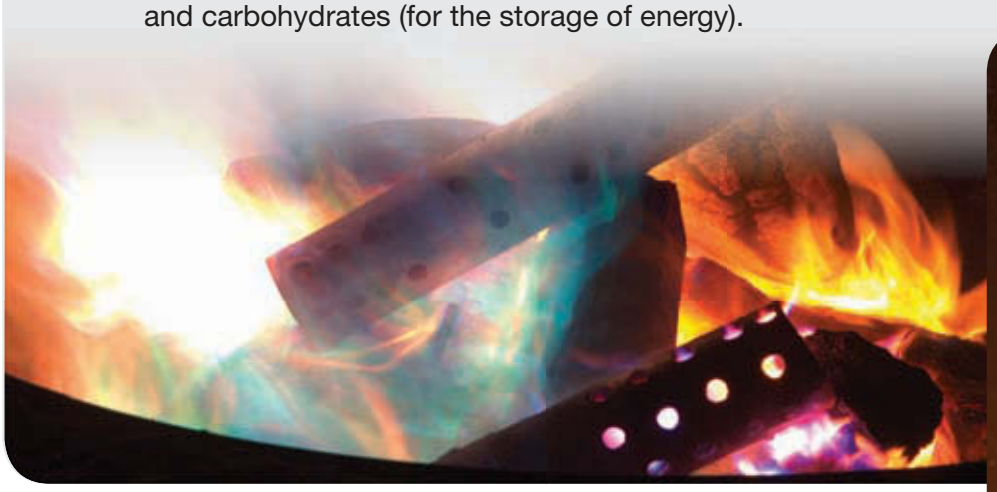
1 Why do you think that some products are advertised as 'chemical free'?
2 Apart from the example of oxygen above, can you think of another chemical that is safe in low concentrations but can be very dangerous in high concentrations? Explain the risks associated with that chemical.
3 Some chemicals are regarded as toxic themselves, whereas others only become dangerous if they react in certain ways. Can you describe an example of each?

7.1

How do we use the products of chemical reactions?



We use chemical reactions all the time and all chemical reactions result in the formation of products. Sometimes the chemical reactions are used because they give off energy, such as the combustion of fuels, including oil and gas, but it is often the products of the reactions that are the most important. Examples of how humans have learned to use the power of chemistry include the production of metals from metal ores and the manufacture of fertilisers from acids and bases. In nature, organisms have evolved to use chemical reactions to combine the elements carbon, oxygen, hydrogen and nitrogen into products such as proteins (for growth) and carbohydrates (for the storage of energy).





→ Fig 7.4 Iron ore exports are vital to the Australian economy.

DISCOVERING IDEAS

Producing iron

Iron is one of the resources that Australia is extremely rich in. Exports of iron ore bring millions of dollars into the Australian economy, with China and other Asian countries relying on iron from Australia to support the development of their industries and infrastructure. One of the major forms of iron ore is haematite, or iron(III) oxide to give it its chemical name.

1 Research four uses of iron: one household, one related to infrastructure, one related to transport and one related to sport or recreation. For each use, explain why the properties of iron make it suitable for use in that particular way.

2 Iron can be produced from haematite by reduction reactions. One such reaction is called the 'thermite process'. Your teacher may demonstrate this for you.

The reaction can be described using the following equation:

$$Fe_2O_3 + 2\ Al \rightarrow Al_2O_3 + 2\ Fe$$

Describe the role of the aluminium in the process.

Types of chemical reactions

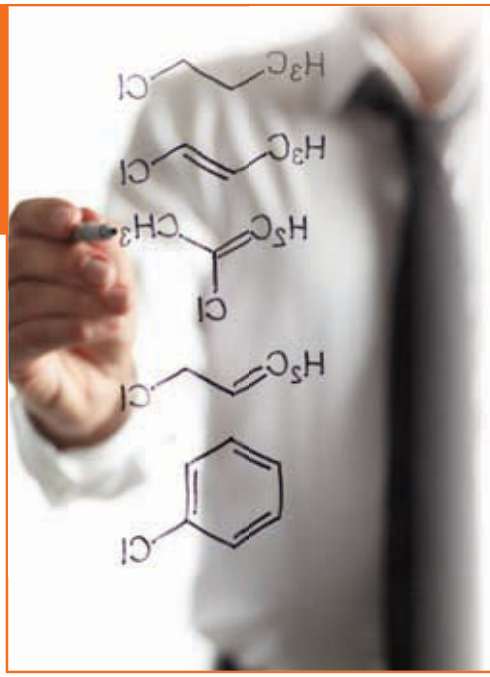
Almost every substance that you will use today was made in a chemical reaction. The role of chemists is to understand chemical reactions and the products they form. Classifying reactions into different types helps predict the products produced by reactions and helps us understand what reactants are required to produce particular products. To assist in classifying reactions, we can sort compounds into types, such as acids, bases, salts, hydrocarbons and polymers.

Classifying compounds into groups makes them easier to name and identify. Because all the compounds in the same group have similar properties, we can predict most of the properties of an unknown substance if we know to which group it belongs.

Similarly, the chemical reactions that are used to make compounds can also be classified. Reactions can be classified as combustion, decomposition or hydrolysis (reaction with water) reactions, among others.

Some of the main reaction types are summarised below.

ZOOMING IN



Synthesis

Synthesis is the building up of compounds by combining simpler substances, normally elements.

Metal + non-metal

metal + non-metal → salt (an ionic compound)



Example:

sodium + chlorine → sodium chloride

$2\ Na + Cl_2 \rightarrow 2\ NaCl$

Non-metal + non-metal

non-metal + non-metal → compound (a covalent compound)

Example:

carbon + oxygen → carbon dioxide

$C + O_2 \rightarrow CO_2$

3 Why do you think the iron(III) oxide is described as being reduced in the thermite reaction?

4 The thermite process is not used to produce iron on an industrial scale. Rather, carbon monoxide is used to reduce the iron in blast furnaces within iron and steelworks. Carbon dioxide is produced as a by-product in the process. Copy and complete the following equation for the reaction.

$Fe_2O_3 + 2\ CO \rightarrow$ _____

(Hint: Make sure that you have applied the law of conservation of mass when writing the final equation.)



→ Fig 7.5 Molten iron produced from a blast furnace.

EXPERIMENT 7.1

Direct synthesis with a 'pop'

Aim

To produce water by direct synthesis.

Materials

Two test tubes
Test tube rack
Rubber stopper
Wooden splint
Matches
Magnesium ribbon
Dilute hydrochloric acid (1 M)

Safety

Wear safety glasses and protective clothing.
Avoid contact with the hydrochloric acid.

Method

For this reaction you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1-cm length pieces of magnesium ribbon into 10 mL dilute hydrochloric acid in a test tube. Place the other test tube (make sure it is dry) over the top of the first test tube so that any hydrogen gas produced enters the second test tube.

After 15 seconds, place a rubber stopper over the end of the second test tube to trap the hydrogen gas: you now have a test tube of hydrogen gas.

1. Place the sealed test tube containing your gas into a test tube rack.
2. Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.
3. Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1. What evidence was there that water was formed in the reaction?
2. Write a chemical equation for the reaction that occurred, ensuring that no atoms are created or destroyed in the process.
3. Why do you think that heat was required to start the reaction?
4. Apart from synthesis, what other ways could this reaction be classified? (Hint: Think about the energy involved in this reaction.)





ZOOMING IN

Decomposition reactions

Decomposition reactions are the breakdown of compounds into simpler substances, either elements or more simple compounds.

- Thermal decomposition—this uses heat to provide energy for the reaction. For example:

copper (II) carbonate → copper (II) oxide + carbon dioxide

$CuCO_3$ → CuO + CO_2

- Electrolytic decomposition or electrolysis—this uses electricity to provide energy for the reaction. For example:

aluminium oxide → aluminium + oxygen

$2\ Al_2O_3$ → $4\ Al$ + $3\ O_2$

EXPERIMENT 7.2

Decomposing a carbonate

Aim

To use heat to decompose copper(II) carbonate to produce copper oxide and carbon dioxide.

Materials

One Pyrex (high-strength) test tube
Test tube holder
Bunsen burner
Matches
Spatula
Copper(II) carbonate
Copper(II) oxide
Calcium carbonate powder

Safety

Wear safety glasses throughout this experiment.

Make sure that the open end of the test tube is facing in a safe direction while heating.

Method

1. Describe the appearance of copper(II) carbonate and copper(II) oxide.
2. Place one spatula of copper(II) carbonate into the test tube.
3. Hold the test tube at an angle of approximately 45° and gently heat the bottom of the test tube by moving it carefully in and out of a Bunsen burner flame.
4. Carefully observe the changes that occur.

Results

Record your observations in an appropriate format.



Discussion

1. What evidence is there that copper(II) oxide was formed in the reaction?
2. What evidence is there that a gas was given off in the reaction?
3. Write a chemical equation for the reaction that occurred, including state symbols.
4. Apart from decomposition, what other ways could this reaction be classified?

Further investigation

How could you redesign this experiment to provide evidence that it is carbon dioxide gas that is produced in the reaction? Write an experimental method, including labelled diagrams, and list any additional equipment you will need. Show your design to your teacher and, if it is safe, try your method using copper (II) carbonate and then repeat using calcium carbonate.

EXPERIMENT 7.3

Electrolysis



Background

Copper sulfate ($CuSO_4$) is an ionic substance containing copper(II) ions (Cu^{2+}) and sulfate (SO_4^{2-}) ions combined in an ionic network.

Aim

To use electricity to produce copper metal from copper(II) sulfate.

Materials

100 mL beaker
Stirring rod
Spatula
Copper(II) sulfate
DC power supply
Three leads
One 6 V globe and globe holder
Wires with alligator clips

Safety

Wear safety glasses throughout this experiment.

Do not let the carbon rods touch when they are in the beaker.



→ Fig 7.6

Method

1. Add one spatula of the copper(II) sulfate to the beaker and half fill it with water.
2. Stir until the crystals are all dissolved.
3. Set the power supply to a maximum of 6 volts and connect the circuit as shown in Figure 7.6.
4. Touch the carbon rods together to check the circuit works and then place the carbon rods in the beaker with a 1 cm gap between them.
5. Hold the rods in place for 30 seconds and observe any changes that occur.
6. Turn the power supply off.

Results

Record your observations in an appropriate format.

Discussion

1. What evidence was there that copper was formed in the reaction?
2. Considering the structure of the copper sulfate, describe:
   - the role of the water in the process
   - the role of the electric circuit
   - the reason that the copper was only found on one of the carbon electrodes.
3. Do you think that a usable amount of copper could be produced this way? If not, what changes would need to be made to the set-up to produce more copper?





→ Fig 7.7 (a) A lime kiln being used to produce quicklime. (b) A modern furnace used to decompose limestone.

Products from chemical reactions

QUICKLIME

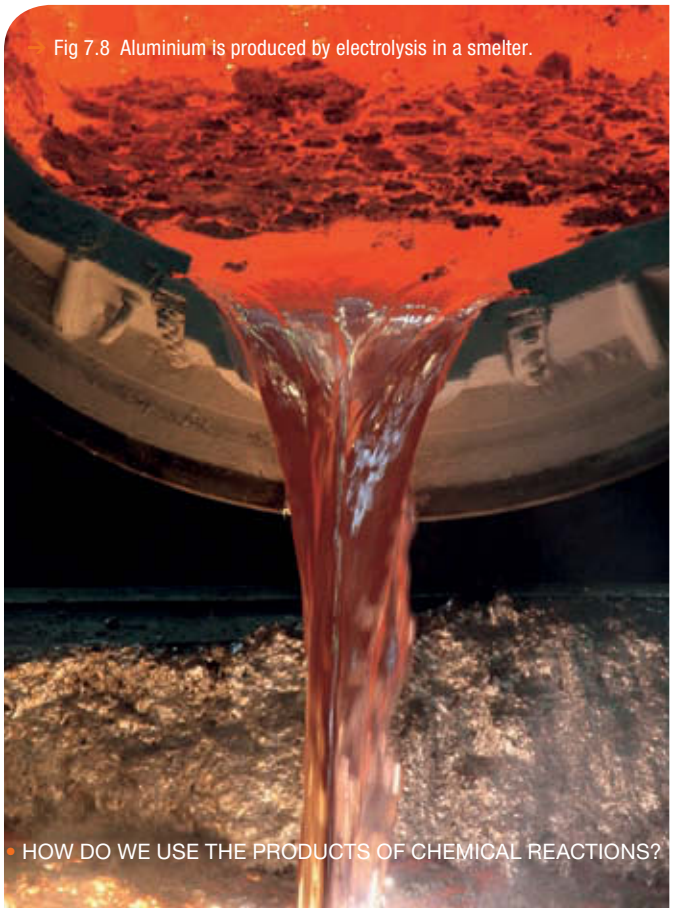
Quicklime, or calcium oxide (CaO), is an important industrial product. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also key component in building materials, such as mortar. The ability of quicklime to absorb other chemicals enables it to be used in the preparation and purification of a range of chemicals. When added to water, quicklime produces calcium hydroxide ($Ca(OH)_2$), which is known as slaked lime. This compound is a base and is a key component in whitewash, as well as being used in the treatment of drinking water.

Calcium oxide is produced by the thermal decomposition of calcium carbonate ($CaCO_3$). The most common and cheapest naturally occurring form of calcium carbonate is limestone. Calcium oxide has been produced from limestone for many centuries using lime kilns. These stone structures were fuelled by coal, with blocks of limestone having to be broken up, often by hand, and added to the kiln, where the temperatures could reach close to 1000°C.

Nowadays limestone is roasted in more modern furnaces, often fuelled by gas, where the temperature can be regulated by controlling the flow of gas and air into the furnace.

ALUMINIUM

Aluminium is used extensively in modern life in food packaging, buildings, casings for computers and in electric cabling. Aluminium is produced by electrolytic decomposition. The raw material for this process is bauxite, an ore of aluminium mined extensively in Australia. The bauxite provides aluminium oxide (Al_2O_3), an ionic solid. This solid is heated to high temperature and then separated into aluminium and oxygen using electrolysis. Very high temperatures are required for this process because the pure aluminium oxide needs to be in a liquid form for electrolysis to work. For this reason, aluminium remains a relatively expensive metal, despite the fact that bauxite, and other aluminium-containing compounds, are very common in the Earth's crust.



→ Fig 7.8 Aluminium is produced by electrolysis in a smelter.

AMMONIA

Ammonia (NH_3) is a very important chemical produced by direct combination of its elements, nitrogen and hydrogen. It is used in a large number of fertilisers, as well as in a range of household cleaning products. You will learn more about how the method used to produce ammonia was developed at the end of this chapter. The modern method used to produce ammonia is called the Haber process, which relies on the reaction shown below:

$$3\ H_2(g) + N_2(g) \rightarrow 2\ NH_3(g)$$

Nitrogen is not a very reactive element, so specific conditions are required for this reaction to occur. It involves heating the two gases so that the reaction will happen quickly enough.

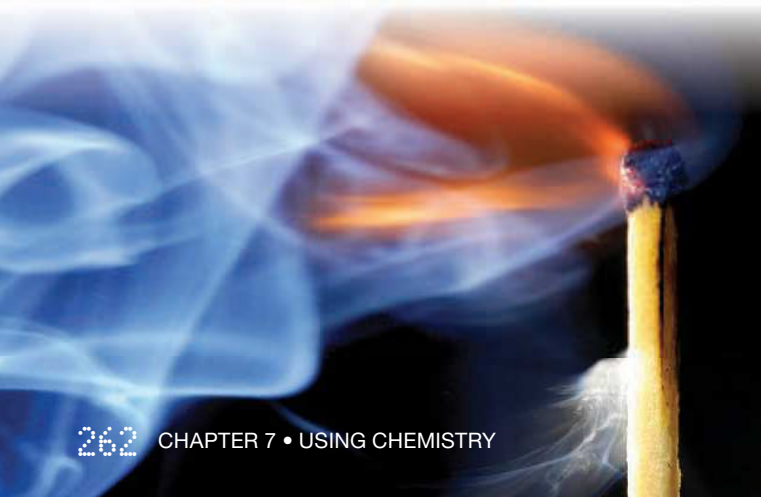


What do you know about types of chemical reactions?

1. Why do decomposition reactions always produce more than one product?
2. What is meant by a by-product?
3. Describe, in terms of the types of chemical reactions, major differences between the reaction used to produce ammonia and the reaction used to produce calcium oxide.
4. Why is energy required in:
   - **a** decomposition reactions
   - **b** direct synthesis reactions?

Other chemical reactions

A wide variety of products can be produced by a range of other chemical reactions. Below are some reactions that you will have come across before. Look at the types of products produced by these reactions. Are there any patterns you can identify? Can you give examples of where these reactions are used to produce specific products for a specific use? Do these reactions occur naturally or are they used by humans to produce things specifically for our use?



ZOOMING IN

Combustion and respiration

Combustion is the fast reaction with oxygen. The reaction releases light and heat energy, which we may see as a flame. Combustion is a type of reaction called oxidation. Other oxidation reactions are corrosion and respiration.

Combustion

$$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide}$$

Example:

$$\text{magnesium} + \text{oxygen} \rightarrow \text{magnesium oxide}$$
$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

Respiration

$$\text{sugar} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

Example:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$
$$C_6H_{12}O_6(aq) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$$

Reactions of acids

Acids are substances that dissolve in water to form hydrogen ions. The hydrogen ions are reactive and give the acids their special properties. Acids react with many groups of compounds.

ZOOMING IN

Acid and metal reactions



Acids and metals

acid + metal → salt + hydrogen

Example:

sulfuric acid + zinc → zinc sulfate + hydrogen

$H_2SO_4(aq)$ + $Zn(s)$ → $ZnSO_4(aq)$ + $H_2(g)$

Note: Only the more reactive metals will form a salt and hydrogen when reacting with acids. Copper, silver and gold are unreactive metals.

Acids and metal oxides

acid + metal oxide → salt + water

Example:

nitric acid + magnesium oxide → magnesium nitrate + water

$2\ HNO_3(aq)$ + $MgO(s)$ → $Mg(NO_3)_2(aq)$ + $H_2O(l)$

Acids and metal hydroxides

acid + metal hydroxide → salt + water

Example:

sulfuric acid + sodium hydroxide → sodium sulfate + water

$H_2SO_4(aq)$ + $2\ NaOH(aq)$ → $Na_2SO_4(aq)$ + $2\ H_2O(l)$

Acids and metal carbonates

acid + metal carbonate → salt + water + carbon dioxide

Example:

nitric acid + calcium carbonate → calcium nitrate + water + carbon dioxide

$2\ HNO_3(aq)$ + $CaCO_3(s)$ → $Ca(NO_3)_2(aq)$ + $H_2O(l)$ + $CO_2(g)$

→ Fig 7.9 Zinc metal reacting in acid.

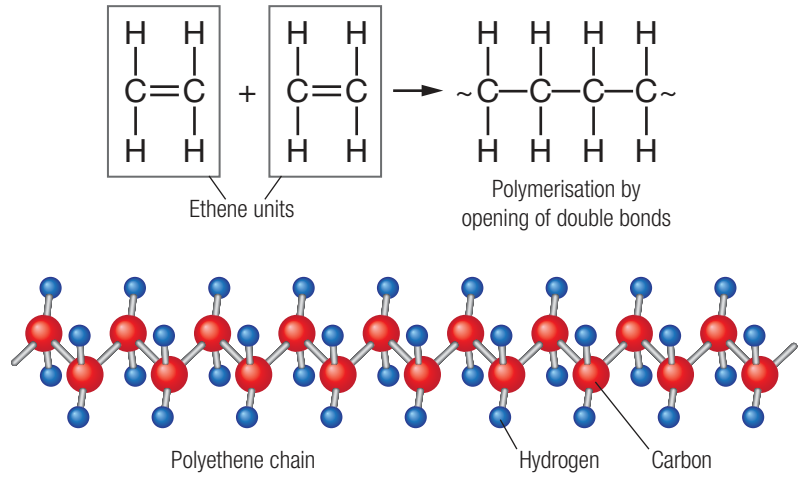
Polymers and plastics

Plastics are a major part of our lives. They form the wrap we put around our sandwiches and the containers we store our food and other products in. Recycled plastics are used to make wheelie bins. Plastics are made up of giant molecules called **polymers**. These polymers have been synthesised by chemists. There are also many naturally occurring polymers, including proteins, DNA and cellulose.

FORMATION OF POLYMERS

Polymers are formed in reactions where smaller molecules are combined to form long chain molecules. There are many different types of polymerisation reactions, but they all follow the same process, with the small molecules being placed under reaction conditions (i.e. specific temperature and/or pressure) that encourage them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polythene is produced in this way, with molecules of ethene (C_2H_4) reacting together to form long chain molecules of polyethene. This process can be represented using a diagram, as shown in Figure 7.10.

This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.



→ Fig 7.10 The formation of polyethene from ethene molecules.

EXPERIMENT 7.4 (TEACHER DEMONSTRATION)

Making nylon fibre

Aim

To observe the polymerisation reaction used to make nylon.

Materials

5% 1,6-diaminohexane solution

5% adipoyl chloride solution in cyclohexane

Distilled water

Forceps or stirring rod

Two x 50 mL beakers

Glass Petri dish containing 50% alcohol (ethanol) water mix

Paper towel or filter paper

Method

The preparation of the chemicals, the making of the nylon, and clean-up, must be done in a fume cupboard. Do not breathe vapours. Lab coat, safety glasses, gloves and closed-in shoes must be worn. This experiment should only be done as a teacher demonstration.

1. In a 50 mL beaker, mix 0.5 mLof adipoyl chloride and make up to 10 mL with cyclohexane. Stir.
2. In the other 50 mL beaker place 0.5 g of 1,6-diaminohexane solution and make up to 10 mL with distilled water. Stir until dissolved.
3. Gently pour the 10 mL of 5% 1,6-diaminohexane solution down the side of the second beaker containing the 10 mL of the 5% Adipoyl chloride solution. Do not mix.
4. A skin will form between the interface of the two liquids. Lift the skin out using forceps and gently wrap it around the length of the glass rod. This skin will continue to re-form for quite some time.
5. Unroll the thread into a Petri dish or a beaker containing 50% alcohol and leave to soak for 10 minutes.
6. Remove thread from the alcohol solution and dry between paper towel or filter paper.
7. Examine under a microscope and sketch its appearance.

Results

Record your observations in an appropriate format.

Discussion

1. Describe the reactants used.
2. Describe the product formed.
3. What changes have taken place?
4. State a use for nylon and explain what properties of nylon make it suitable for that use.

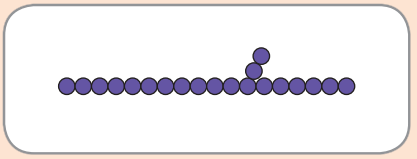
Different types of polymers

A polymer is a giant molecule that has been produced by joining many, many smaller molecules together—often thousands! Polymer means 'many parts'. The small molecules from which the polymers are made are termed **monomers**.

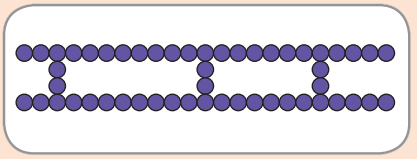
If the polymer has been produced by chemists or chemical engineers, it is termed a synthetic polymer. An example of a synthetic polymer is nylon. Before nylon was created, stockings were made from silk, which is a natural fibre produced by the silkworm. Apart from being expensive, stockings made from silk easily developed holes and 'ladders'. Toothbrush bristles were made from another natural fibre—the fine hairs from boars! Nylon was able to replace both of these because nylon fibre was shown to be much tougher and more suitable for these applications.

There are three types of polymer structures: linear polymers, occasionally cross-linked polymers (also known as elastomers) and cross-linked polymers.

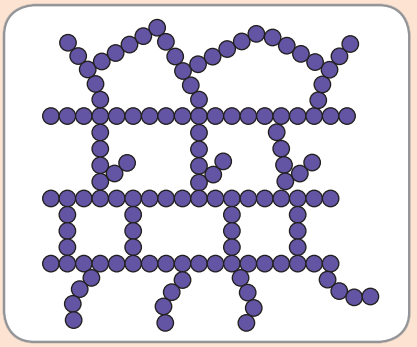
Linear polymers are in the form of long chains. Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups attached to the carbon atoms. In some linear polymers, the atoms of another non-metal are found at regular intervals along the chain of carbon atoms. In nylon, for example, a nitrogen atom is found about every tenth atom along the chain. There may also be 'branches'—segments like the main chain—hanging off the main chain.



→ Fig 7.11 The basic structure of a linear polymer. The small circles represent small groups of atoms.



→ Fig 7.12 The basic structure of an elastomer.



→ Fig 7.13 A cross-linked polymer.

The elastomers are like a ladder. They are in the form of long chains that are connected every now and then with a small chain of atoms. They are termed elastomers because they are elastic. That is, they can be stretched and, when you let them go, they spring back into shape.

Cross-linked polymers are giant covalent lattices. Generally, they are largely made up of carbon atoms, although the atoms are much more haphazardly arranged than the carbon atoms in other covalent lattices, such as diamonds.

Apart from being classified according to their structure, another way in which polymers are classified is according to how they respond to heat. This is a very important property.

Thermoplastic polymers soften when heated gently and solidify again when cooled. They can be readily worked into different shapes by warming and pressing them, squeezing them through holes or even blowing them into the required shape. 'Plastic' means being able to have its shape changed. So, these are the only polymers that really should be described as 'plastic'.

Thermosetting polymers do not melt or change shape when heated. If heated very strongly, they may char (turn black). These polymers must be produced in a mould because once they are formed they will not change shape again. Once formed, they are hard and rigid.



→ Fig 7.14 Plastic film is a thermoplastic material.



→ Fig 7.15 The plastics that make up the cover of a Playstation are made of thermosetting polymers.

EXPERIMENT 7.5

Testing polymers

Aim

To classify polymers based on their properties.

Materials

Samples of different polymers
Forceps
Beaker of very hot water
Large white ceramic tile

Be very careful not to be burnt by the water or steam.

Method

1. Drop each of the polymer samples individually into the beaker of hot water using the forceps.
2. After 1 minute, remove the sample and place it on the tile.
3. Examine it carefully as you handle it.

Results

Record your observations for each polymer you tested. Did it become softer and more pliable after being dropped in the beaker of hot water?

Discussion

1. When a polymer softens on heating and can be made to change shape, it is said to be in a plastic state. The softening temperature is the temperature at which this occurs. Did any of the polymers you tested become plastic?
2. From your results, identify which of the polymers is thermoplastic.
3. Suggest why this property was not tested by placing the samples in a flame.
4. For a fair comparison, what should have been true of all the samples tested? On the basis of this, did you conduct a fair test? Discuss.

What do you know about other chemical reactions?

1. What are the differences between a linear polymer and a cross-linked polymer?
2. For each of the following applications, state whether it would be better to make the object from a thermosetting polymer or a thermoplastic polymer:
   - **a** food wrap
   - **b** a light switch
   - **c** a disposable cup for soft drinks
   - **d** a wash bottle for a science laboratory
   - **e** the handles of barbecue tongs
3. Which would you expect to be a thermosetting plastic: a linear polymer or a cross-linked one? State your reasoning.

How do we use polymers today?

Many different polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Before the Second World War and the invention of nylon, tents were made of canvas. Canvas is a strong, durable, natural fabric. However, it can tear and leak, which is the last thing you need in stormy weather. Moreover, canvas is heavy to carry. Today, many tents are made from nylon, which is used to produce a lightweight, tear-resistant fabric. Bigger tents are made of cotton polyester. The bases of the tents are made of polyurethane, another useful, waterproof polymer.

The downside of using synthetic polymers for tents and other outdoor applications is that, over time, many deteriorate as a result of the action of ultraviolet (UV) radiation from the Sun. Substances known as UV stabilisers can be added to the polymer material to help slow this process down.





→ Fig 7.16 Tents are made of nylon, which makes them lightweight.

These days, most people have at least one piece of clothing made of Polarfleece, but do you really know why it is so warm and yet lightweight? Polarfleece is a synthetic wool made from PET, or PETE (polyethylene terephthalate). PET is a thermoplastic polymer and, for Polarfleece, is sourced from recycled plastic bottles that have been processed into a clothing fabric. PET gives Polarfleece its soft, warm, durable and fast-drying properties, which make it perfect for camping and other outdoor activities.



→ Fig 7.17 Polarfleece has many uses when camping in the great outdoors.

ZOOMING IN

Bubble wrap buildings

The 2008 Olympics famously used a number of different polymers, mainly at the swimming pool. The new Speedo LZR racing suit is one example of a high-technology synthetic polymer, as is the building in which the swimming pool was housed! The outer structure of the Water Cube was composed of a super strong plastic material known as EFTE (or ethylene tetrafluoroethylene). This polymer is made from carbon, hydrogen and fluorine atoms.



→ Fig 7.18 Beijing's Water Cube.

The designers of the Water Cube received a huge rap (pardon the pun!) for using a material that is not only cheap, but also lightweight, flexible and strong. The building was made up of 3000 bubbles that let the light in and retained heat like a greenhouse. Therefore, the building heats up naturally, minimising energy use. If designers continue to build 'bubble wrap' buildings, imagine what cities would look like in 100 years time!

Precipitation reactions

Precipitation reactions are used to produce solid products from solutions of ionic substances. Precipitation reactions are used in the removal of impurities during water treatment and to produce pigments, which are often mixed with oil or water to produce paints.

A solution of an ionic substance consists of ions separated in a solvent. For example, a solution of lead(II) nitrate ($Pb(NO_3)_2$) consists of lead (Pb^{2+}) ions and nitrate ions (NO^{3-}) together with many water molecules. When two solutions are mixed, a solid substance may form. This is because a positive ion from one solution combines with a negative ion from the other solution to form an insoluble compound. This insoluble compound is known as a **precipitate.**

When a solution of lead(II) nitrate is added to potassium iodide—both colourless solutions—a bright yellow precipitate of lead iodide (PbI_2) is formed. The reaction can be written as shown here.

lead(II) nitrate	+	potassium iodide	→	lead(II) iodide	+	potassium nitrate
$Pb(NO_3)_2(aq)$	+	2 KI(aq)	→	$PbI_2(s)$	+	2 $KNO_3(aq)$

The lead ions and the iodide ions have combined together to form a precipitate of the insoluble lead(II) iodide, which forms as a solid in the solution. But what has happened to the potassium and nitrate ions? These are still dissolved in solution. They are not taking part in the reaction. This is why they are called spectator ions. Because of this, it is actually possible to write this equation in a different way that shows only those ions that are changing in the reaction.

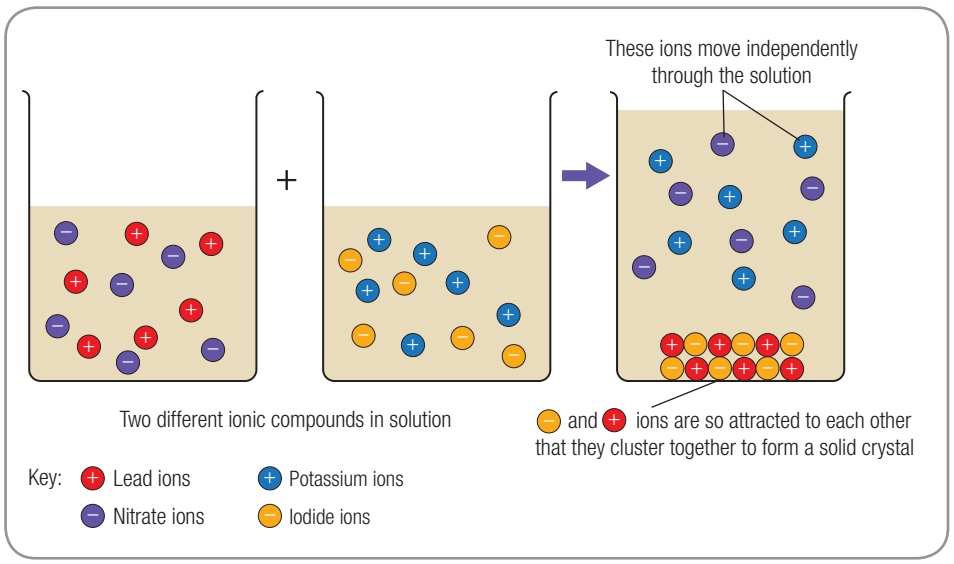


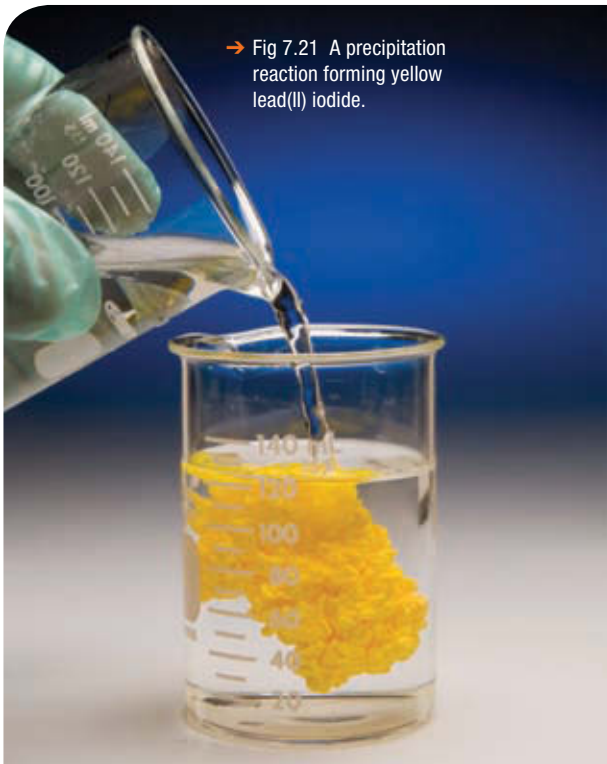
→ Fig 7.19 Pigments are insoluble compounds.

$$Pb_2^{+} + 2\ I^{-} \rightarrow PbI_2(s)$$

Lead compounds were used in a number of pigments until the 1970s, when it was discovered that the lead in these pigments could damage the nervous system.

→ Fig 7.20 At the particle level, when a solution of lead(II) nitrate ($Pb(NO_3)_2$) is added to potassium iodide (KI), the ion partners are swapped.





→ Fig 7.21 A precipitation reaction forming yellow lead(II) iodide.

Using precipitation reactions

Precipitation reactions are important for chemical analysis. The data shown in Table 7.1 can be used to decide whether a precipitate will form. For example, PbI_2 is insoluble, as you have just learnt. So, if any soluble lead(II) compound is mixed with any soluble iodide, this precipitate will form. Similarly, Table 7.1 tells us that $Cu(OH)_2$ is insoluble. This means that if any soluble hydroxide, such as NaOH, is mixed with any soluble copper(II) compound, such as $CuSO_4$, a precipitate of $Cu(OH)_2$ will form.

Chemists sometimes use precipitation reactions to find out which chemicals are present in a substance or how much is present. Common table salt (NaCl) is essential in our diet because the sodium is needed to maintain the correct concentration of body fluids, assist in the transmission of nerve impulses and to help cells absorb nutrients.

Chemical analysis can determine the amount of salt in foods by using a precipitation reaction with silver nitrate. The salt reacts with the silver nitrate to form a precipitate of silver chloride. The mass of sodium chloride can be calculated using the mass of silver chloride that has been precipitated:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$

→ Table 7.1 Solubility of some common ionic compounds in water

Soluble	Insoluble	Slightly soluble
Group 1 elements		
All ammonium salts		
All nitrate salts		
Most chlorides, bromides and iodides	AgCl, AgI, AgBr, $PbCl_2$, PbI_2, $PbBr_2$	
	Most carbonate and phosphate compounds	
Group 1 hydroxides, $Ba(OH)_2$, and Sr $(OH)_2$	Most hydroxides and sulfates	$Ca(OH)_2$, Ag_2SO_4, $CaSO_4$

What do you know about how we use polymers today?

1. Draw a diagram to show which particles are present in a beaker containing a sodium chloride solution.
2. What symbol is used to show the state of an insoluble compound?
3. What precipitate would form if solutions of lead(II) nitrate and sodium sulfate were mixed?
4. Complete the following word equations below and then write balanced chemical equations for each reaction.
   - **a** zinc nitrate + potassium hydroxide →
   - **b** calcium nitrate + sodium carbonate →

Writing chemical equations

Explosions occur when a large amount of gas and a vast amount of energy is produced very suddenly in a chemical reaction that takes place within a sealed container or closed environment. The gas particles gain an enormous amount of kinetic energy from the reaction and so are propelled violently outwards, resulting in a huge blast of gases that causes all the damage.

An example of an explosive substance is nitroglycerine, which is the active constituent of dynamite. In chemical equations, such as for the explosion of nitroglycerine, the substances before the arrow are those substances we start with and they are termed the reactants. The substances after the arrow are the substances formed in the reaction, known as the products. The symbols (s), (l), (g) and (aq) indicate the state of the substance. The numbers in front of the chemical formulas show us the relative numbers of molecules involved.

EXPERIMENT 7.6

Precipitation reactions

Aim

To determine which compounds form precipitates and write equations for the reactions occurring.

Materials

Plastic document sleeve

0.1 M solutions of the following compounds in dropper bottles:

Group A

Calcium nitrate, $Ca(NO_3)_2$

Copper(II) nitrate, $Cu(NO_3)_2$

Magnesium nitrate, $Mg(NO_3)_2$

Potassium nitrate, KNO_3

Silver nitrate, $AgNO_3$

Iron(III) chloride, $FeCl_3$

Copper(II) sulfate, $CuSO_4$

Group B

Sodium chloride, NaCl

Sodium hydroxide, NaOH

Sodium bromide, NaBr

Sodium sulfate, Na_2SO_4

Sodium carbonate, Na_2CO_3

Sodium nitrate, $NaNO_3$

Method

1 Draw up a large table with group B solutions listed across the first row and group A solutions in the first column as shown here:

	NaCl	NaOH	NaBr	Na_2SO_4	Na_2CO_3	$NaNO_3$
$Ca(NO_3)_2$						
$Cu(NO_3)_2$						
$Mg(NO_3)_2$						
KNO_3						
$AgNO_3$						
$FeCl_3$						
$CuSO_4$						

2 Make a second copy of your results table on a piece of A4 paper and place this table into the plastic document sleeve. Place this on the laboratory bench. This now becomes your working area for the experiment and you will add drops of the solutions to corresponding cells on the results table, which is now protected by the plastic sleeve.

3 Place one drop of each of the group A solutions in each cell of the results table in the correct row.

4 Add one drop of each of the group B solutions to the drops of the group A solutions in the correct columns.

Results

Record whether a precipitate forms, as well as its appearance, on your other copy of the results table.

Use Table 7.1 to help you answer the following questions. For each precipitate formed:

- identify the ions that have combined to form the precipitate and write the formula of the ions
- write the formula of the precipitate
- write a word equation for the reaction.



Discussion

1. The sets of compounds tested had a range of anions: NO_3^-, OH^-, CO_3^{2-}, Cl^-, SO_4^{2-} and Br^-.
   Of these:
   - **a** which did not form any precipitates?
   - **b** which only formed precipitates with one or two cations?
2. The sets of compounds tested had a range of cations: Na^+, K^+, Ag^+, NH_4^+, Cu^{2+}, Ca^{2+} and Mg^{2+}.
   Of these:
   - **a** which did not form any precipitates?
   - **b** which formed precipitates with only one or two anions?
3. Did the precipitation reactions you observed match those predicted from Table 7.1? Discuss.
4. Write balanced chemical equations for the reactions between:
   - **a** silver nitrate and sodium chloride
   - **b** iron(III) chloride and sodium hydroxide
5. Why is it important not to touch the tip of the dropper bottles on the top of the solution already on the plastic sleeve?
6. What other factors may affect the outcome of these precipitation reactions?



Chemists use equations as a shorthand way of representing a reaction. The equation for the explosion of nitroglycerine can be written as:

$$4\ C_3H_5N_3O_9(l) \rightarrow 6\ N_2(g) + 12\ CO_2(g) + 10\ H_2O(g) + O_2(g)$$

nitroglycerine → nitrogen + carbon dioxide + water + oxygen

This equation shows that for every four molecules of nitroglycerine that react, six molecules of nitrogen, twelve molecules of carbon dioxide, ten molecules of water and one molecule of oxygen are produced, as well as energy. That is, from four molecules of nitroglycerine, a total of twenty-nine molecules of gas are produced, as well as energy. This is typical of the chemical equation for an explosion, with a large number of gas molecules being produced, as well as the reaction being highly exothermic.

The **law of conservation of mass** states that, in a chemical reaction, the total mass of all the reactants is equal to the total mass of the products. All the atoms that are present at the beginning of a chemical reaction are there at the end; they are just arranged in a different way. This is why the equation for this reaction, and all chemical equations, needs to be balanced, with the same number of atoms on each side of the equation.

Oxidation and reduction reactions

As you are reading this book, an **oxidation** reaction is keeping you alive. It is respiration. Respiration is a reaction in which sugar combines with oxygen to give our cells the energy they need to stay alive. Many chemical reactions involve oxygen. Common examples are combustion and corrosion. These reactions involve the combination of oxygen with a fuel or a metal.

The opposite process is called **reduction**. Compared with oxidation, reduction is the removal of oxygen. One such example is the reduction of iron ore into iron metal. An example of an iron ore is iron(III) oxide, with the formula Fe_2O_3. In real processes, carbon is added to remove the oxygen. Carbon has a greater attraction for oxygen than does iron. As an equation, this process is written as:

$$2\ Fe_2O_3(s) + 3\ C(s) \rightarrow 4\ Fe(s) + 3\ CO_2(g)$$



This reduction reaction occurs in the making of iron and steel from iron ore. Carbon, in the form of coke, is added to a blast furnace. Molten iron forms and is drained off to form ingots of iron, or further purified and alloyed to become steel.

Some chemical jars have a diamond-shaped warning label on the side, with the words 'OXIDISING AGENT' or 'OXIDANT'. These substances can supply oxygen, or take the place of oxygen, in an oxidation reaction. In gunpowder, the oxidant is potassium nitrate, $KNO_3(s)$, which provides the oxygen for the combustion process to occur. This is why gunpowder burns without air. Similar oxidants are potassium chlorate ($KClO_3$), potassium perchlorate ($KClO_4$) and potassium permanganate ($KMnO_4$). Other oxidants are chlorine (Cl_2) and hydrogen peroxide (H_2O_2).

The opposite of an oxidant is a reductant (reducing agent). Reductants remove oxygen, or take it, from other substances; they combine with the oxygen atoms they have taken. Common reductants are carbon and carbon monoxide. Both of these reductants take oxygen to form carbon dioxide.

$$C(s) + \text{oxygen} \rightarrow CO(g)$$

$$CO(g) + \text{oxygen} \rightarrow CO_2(g)$$

Carbon is the most common reductant in the processing of metals. Carbon is readily available, and cheap, in coal. When coal is heated in the absence of air, the volatile components are released. The solid left behind is called 'coke', which is nearly pure carbon. Coke is porous and ideal for use as a reductant in many chemical processes.

What do you know about writing chemical equations?

1. What are oxidation and reduction? Give an example of each process.
2. What are oxidants and reductants? Give an example of each.
3. What is the oxidant and reductant in the smelting of iron ore to form iron?
4. Torpedoes (underwater missiles) contain a solid fuel and a solid oxidant. What is the advantage of this?

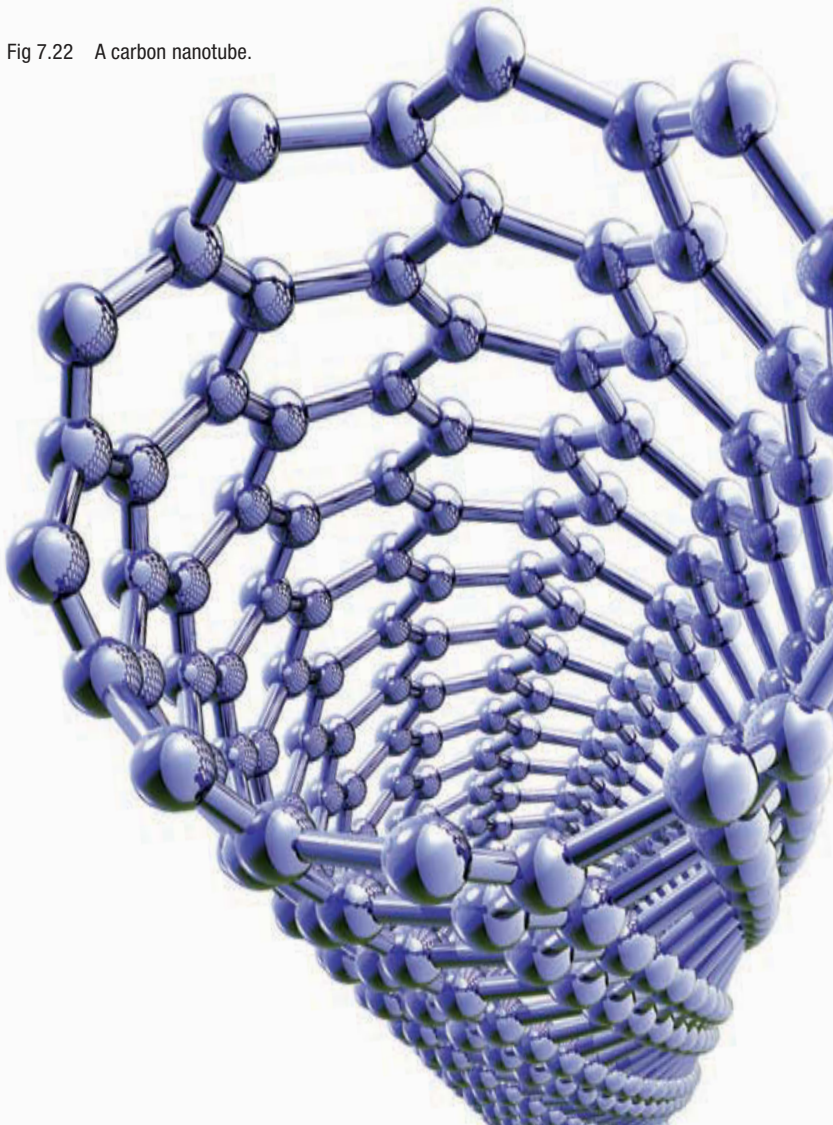
Nanotechnology

Nanotechnology operates at the scale of the nanometre, which is approximately one-ten thousandth of the width of a human hair. This is the level of atoms or molecules. Nanotechnology allows artificial manipulation of atomic or molecular processes or objects. For example, computers the size of blood cells with tiny wireless transmitters could report on the health of a person without that person requiring surgery. Nanomachines (or nanobots) are tiny machines that are being developed at the molecular level. Scientists hope to develop nanobots as small as viruses or bacteria to perform tasks on a nanometre scale.

A **carbon nanotube** is an allotrope of carbon with very different properties to its other allotropes, such as graphite and diamond. Carbon nanotubes are the focus of intensive research for many applications in the future.

Carbon nanotubes are extremely hard, have very high tensile strength and are very efficient conductors of heat and electricity. That is, carbon nanotubes exhibit many properties usually found in metals. However, in contrast with most metals, carbon nanotubes are extremely light and flexible.

→ Fig 7.22 A carbon nanotube.





Carbon nanotubes might be used:

- in medicine, where their high electrical conductivity may make them suitable to bypass faulty nerve cell wiring in damaged brains
- to create clothing with unique properties, such as protection against bullets and other missiles
- in computing and television, where they are being used to develop flat, folding, futuristic television screens with greater image resolution than the human eye can detect
- for renewable energy devices, such as solar panels, due to their efficient absorption of heat, and in wind turbines for making blades lighter and stronger.



How are carbon nanotubes made?

The emergence of nanotechnology as a key scientific force has resulted from relatively recent and rapid developments in the capacity of scientists to:

- put (nano-sized) quantities of matter where it is wanted
- use controlled amounts of nano-sized materials for a practical purpose
- detect and monitor the location and configuration of nanoscale materials.

There are two manufacturing approaches to making nano-sized materials:

1 The top-down method involves using mass materials and breaking them down by physical or other means into nanoscale components.

2 The bottom-up method, also referred to as molecular manufacturing, is a more complicated process because it relies on the construction of templates on which nanomolecules will form under the appropriate chemical and physical conditions.

A good example of the top-down method can be found in the sunscreen industry, where materials to block UV light, such as titanium oxide and zinc oxide, can be transformed by a grinding process from their white, opaque mass forms into invisible, nano-sized particles. These are known as nanopowders.

A good example of the bottom-up method is the production of carbon nanotubes. A layer of metal catalyst particles is exposed to high heat and a carbon-containing gas. The nanotubes form at the interface between the gas and the metal catalyst.

What do you know about nanotechnology?

1 What two main manufacturing processes are used to make nanomaterials?

2 Which one of these two would be described as a chemical process? Explain your reasoning.

3 All powders are made up from small particles. How is a nanopowder different from a normal powder?

4 What is a carbon nanotube? Describe its structure.

5 The production of carbon nanotubes involves the use of a catalyst. What do you understand by the term 'catalyst'?

7.1

How do we use the products of chemical reactions?



Remember and understand

1 Describe the differences between decomposition reactions and direct synthesis reactions.

2 What types of products are formed when acids react with metals, carbonates or bases?

3 Describe two different types of reactions that both produce carbon dioxide.

4 Using an example, describe what is meant by the term ‘oxidant’.

Apply

5 Polypropylene is a plastic that can be easily melted and formed into a range of products. Describe the likely structure of polypropylene and explain how its structure allows the plastic to be moulded into a range of shapes.

6 A student mixed the following solutions together in a beaker: ammonium nitrate, sodium chloride, lead(II) nitrate, sodium sulfate. Describe what would be seen in the beaker. Explain your answer using a chemical equation.

7 Sodium metal was used to produce aluminium from purified bauxite (Al_2O_3).

- **a** What type of reaction would be occurring?
- **b** Write a chemical equation for the process, ensuring that the law of conservation of mass is applied to the equation.

8 Describe two examples of the use of catalysts in the production of chemical products.

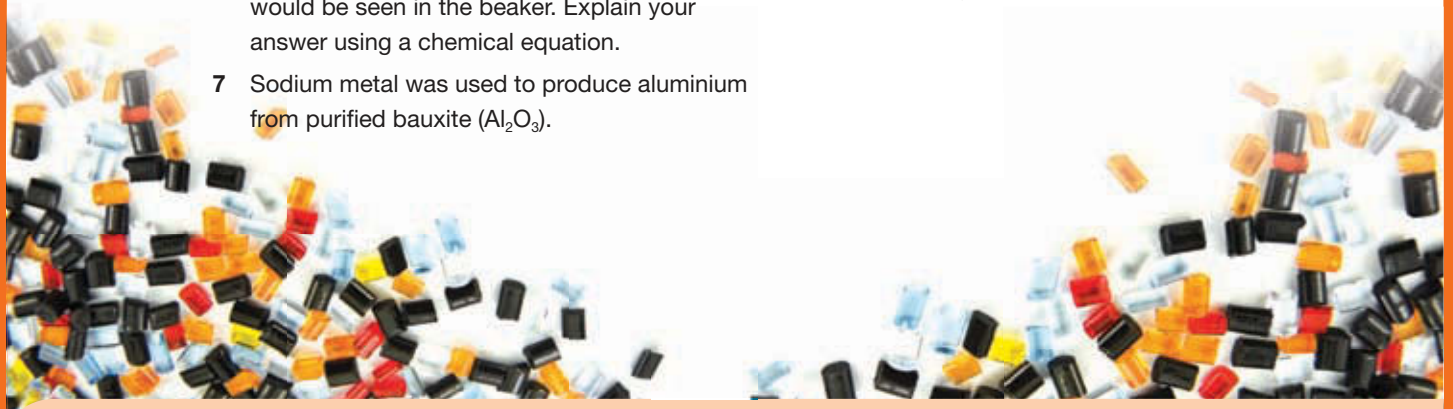
Analyse and evaluate

9 Describe, in terms of molecules, the key differences between the formation and melting of a polymer.

10 A student read in a science textbook that when an oxidation reaction happens, a reduction reaction always occurs. Use an example to demonstrate this fact.

Critical and creative thinking

11 How do you think advances in technology will have helped scientists improve their methods for producing chemical products?



CONNECTING IDEAS Interaction and change

12 When the plastic polyethene is produced, molecules of ethene, which is a gas at room temperature, interact and produce the long chain molecule polyethene. A chain reaction occurs, which enables the chain to build up.

- **a** What conditions are used in this reaction to ensure that the interactions result in a new product?
- **b** Explain how a gas is able to be changed into a solid product in this reaction.
- **c** Suggest why the ethene gas must be very pure for this reaction to succeed.
- **d** Do you think this type of chemical change can be described as direct synthesis? Explain your reasoning.

7.2

How can we control the speed of chemical reactions?



How fast a chemical reaction happens can be a life and death issue. The rapid combustion reactions occurring in a bushfire can easily get out of control as the fire spreads, turning wood to ash and producing vast amounts of heat energy as the fire proceeds. Our bodies rely on chemical reactions that convert the glucose in our blood to glycogen. If this process is too slow, as is the case in some types of diabetes, high levels of blood sugar ensue, a condition called hyperglycaemia. This has the potential to result in heart or other diseases. Controlling chemical reactions is vital in our environment, in our lives and in our bodies.

DISCOVERING IDEAS

Fast or slow?

We are surrounded by chemical reactions. Some are fast, like the gas burning in a barbecue, and some are slow, like the corrosion on the outside of the barbecue. Sometimes we want reactions to occur quickly, but sometimes a fast reaction may not be required or may, in fact, be dangerous.

For each of the following situations, describe whether you think a fast or slow chemical reaction is preferred. Discuss your thoughts with others. For each situation, write down ways that we are able to control the rate of the reaction, either to slow down or speed up the production of products.

- the rusting of an iron bridge
- the reaction in the baking of bread that produces carbon dioxide (which makes the bread rise)
- the oxidation of alcohol in wine to form vinegar
- the combustion of a fuel in a rocket engine
- the chemical processes involved in the action of a pain-killing drug

For one of the situations for which you chose to speed up the reaction, think about what is happening to the particles (atoms or molecules) during the reaction. Explain how your chosen method to speed up the reaction would enable the particles to interact and change more quickly.



Why are reaction rates important?

A **reaction rate** is how fast a reaction proceeds. A fast reaction has a high reaction rate; a slow reaction has a low reaction rate.

The reaction rate is very important. Explosions must have a high reaction rate if they are to be useful. The rusting of iron has a slow reaction rate. Imagine what would happen to iron if it rusted at the same rate as an explosion. Chemists have a role to ensure that reactions occur quickly enough to be useful, but not too quick so as to be explosively dangerous.

In the chemical industry, controlling the rate of a reaction is vital. Reactions that are too slow are not economic, because equipment is tied up for a long time. Reactions that are too fast need to be controlled, or contained in strong reaction vessels. The containment vessels cost a lot of money to build and maintain. Chemists and chemical engineers have the role of making chemical reactions as cheap as possible. A large part of this is achieved by controlling the rate of the reaction.



What controls the rate of a reaction?

The factors that control the rate of a reaction in a factory are the same as the factors that control reactions in your school laboratory. You can therefore investigate each factor and then relate it to a chemical process in a factory.

DESIGN YOUR OWN ...

Effect of the size of pieces on reaction rate

Aim

To discover how the size of pieces (chunky, fine, powder) affects the rate of a chemical reaction.

Materials

Pieces of calcium carbonate (limestone, chalk or marble)
Dilute hydrochloric acid (1.0 M)
Test tubes
Test tube rack
Stopwatches
Weighing scales
Measuring cylinders
Safety glasses
(Note: you may be able to access other equipment depending on your experimental plan.)

Method

1. Separate the samples of calcium carbonate according to size and/or use a hammer to crush some pieces to make smaller pieces or powder.
2. Gather up approximately half a teaspoon of each size.
3. Plan an experiment—on your own or in a group, as your teacher directs—that will determine the relationship between the size of the pieces and the rate of the reaction.

Notes

- The reaction that you are investigating is between calcium carbonate and hydrochloric acid. The equation for this reaction is:
  $CaCO_3(s) + 2\ HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
- You will need to decide on the best way to measure the rate of this reaction. This may involve some preliminary trials to test whether your method will work.

Discussion

Using the guide on the opposite page to help you, write a conclusion for your experiment.

SKILLS LAB

How to conduct an investigation

Below is a guide to finding answers to questions using an experiment and scientific method.

Generic guide	Specific notes for this experiment
Questioning and predicting	
What question do you want to answer?	How does the size of the pieces (with a different surface area) affect the rate of reaction?
Rewrite the question as a hypothesis that can be easily tested.	If there are small pieces, with a large surface area, then the reaction rate will be faster.
Planning and conducting	
Plan an experiment to test the hypothesis. • What will you do? • How will you set up the experiment? • What will you observe or measure? • Will this actually test the hypothesis? • What are the dependent and independent variables?	• Use limestone chips, $CaCO_3$, and select a range of sizes or crush some with a hammer. React with dilute hydrochloric acid, HCl. • Use a series of test tubes, each containing limestone chips of a different surface area. Add acid to each test tube. • Look for bubbles, or fizzing, of CO_2 gas. The more bubbles, the faster the reaction rate. • Use the same volume of acid, the same sized test tubes and the same mass of chips.
Safety assessment: • Is this experiment safe? • What personal protective equipment will you need? • What actions should you take to ensure your safety, as well as that of others?	• Safety glasses are essential every time you use acid. Make sure that they fit properly. • Enclosed shoes protect your feet from broken glass, drop injuries and spilt acid. • A plastic apron to protect your school uniform is a good idea.
What will be your control, or comparison, in this experiment? What variables should you control?	Consider: • the amount of $CaCO_3$ used • the volume of acid used • the concentration of acid used • the temperature of the acid and $CaCO_3$ chips • the size of the test tubes used
Processing and analysing data and information	
How will you record your results? Will the results be quantitative or qualitative?	Construct a table to show the results.
Is the hypothesis supported by these results? Will this be the same with other chemicals and other reactions?	You will have to answer this question when you have completed this experimental investigation.
What generalisations can you make from your hypothesis and the results of the experiment?	Can the conclusions from the reaction of acid and calcium carbonate be applied to other chemical reactions?
Evaluating	
What were the sources of error and how could you improve the quality of the evidence that was obtained from the experiment?	Was the way of measuring the rate of the reaction accurate? How could that be improved? Were the quantities of chemicals used measured accurately enough?

Investigating other factors that may affect reaction rates

There are other factors that affect the rate of a reaction. Table 7.2 lists some of the other factors that can affect reaction rate, along with a hypothesis that could be written for each of the variables. In the table there are suggestions for chemical reactions that are suitable for testing the hypothesis.



Table 7.2 suggests some aspects of the rates of chemical reactions that can be investigated. Your teacher may guide you with these or other investigations. In all cases, the guide to performing a scientific investigation on page 277 will help you design your experiments and to use your results effectively.

The next section includes some more specific experiments that can be performed to investigate the rates of chemical reactions.

→Table 7.2 Factors that can affect reaction rates

Variable	Hypothesis
Surface area	If there are small grains, with a large surface area, then the reaction rate will be faster
Concentration	The more dilute a solution, the slower the reaction rate
Heat or temperature	Reactants with more heat (at a higher temperature) react faster than reactants with less heat (at a lower temperature) or if reactants have a higher temperature, they will react quicker
Mixing or stirring	Reactants that are mixed by stirring will react faster than reactants that are not mixed
Adding a catalyst	**1** Adding a catalyst increases the reaction rate compared with not using a catalyst **2** A catalyst can be recovered and used again

EXPERIMENT 7.7

Effect of temperature on reaction rate

Aim

To investigate the effect of temperature on reaction rate.

Materials

0.001 M potassium permanganate solution
0.005 M oxalic acid solution
Test tubes
Stopwatch
250 mL beaker
10 mL measuring cylinders
Safety glasses
Kettle or access to hot water
Thermometer

Avoid contact with the potassium permanganate solution and oxalic acid solution. Wear protective gloves, lab coats and safety glasses.

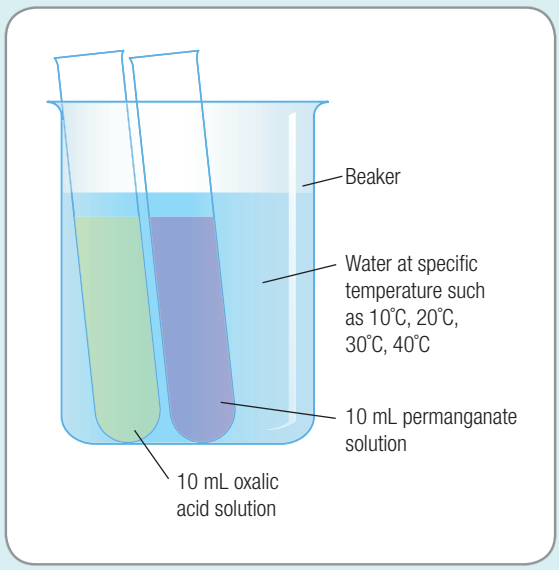
Method

1. Construct a hypothesis for your experiment.
2. This experiment can be performed using a water bath to warm or cool specific amounts of the two solutions to the required temperature before they are mixed. Leave the test tube containing the reaction mixture in the water bath while the reaction time is measured. (The reaction is finished when the purple colour of the potassium permanganate disappears.)
3. Consider what different temperatures will be used, how the temperature will be measured, what volumes of solutions should be used and how the results will be best presented.

Conclusion

Write a conclusion for your experiment that includes a discussion of your hypothesis based on the data from the experiment and an evaluation of the methods used to produce these data.

Suggestions for chemicals and reactions suitable to test the hypothesis
Calcium carbonate and dilute hydrochloric acid
Use powdered $CaCO_3$ and different concentrations of hydrochloric acid or use magnesium ribbon and different concentrations of hydrochloric acid (in both cases, the volume of gas produced can be measured)
Use a solution of potassium permanganate mixed with a solution of oxalic acid (the purple permanganate solution becomes colourless when the reaction is complete); the solutions can be warmed before mixing to investigate the effects of changes in temperature
Use a solution of potassium permanganate mixed with a solution of oxalic acid—the amount of stirring of the reaction mixture can be varied
Dilute hydrogen peroxide (H_2O_2) solution decomposes slowly and can be used to investigate the effect of the catalyst manganese dioxide



→ Fig 7.23 A water bath can be used to control the temperature of solutions.

EXPERIMENT 7.8

Using a catalyst

Aim

To investigate the effect of adding a catalyst to a reaction. The reaction used in this experiment is the decomposition of hydrogen peroxide:

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$$

Materials

Hydrogen peroxide solution (H_2O_2) (10 volume)

Manganese dioxide powder (MnO_2)

Test tubes

Safety glasses and protective clothing must be worn at all times. Avoid contact with the hydrogen peroxide.

Method

1. Place 5 mL hydrogen peroxide solution into two separate test tubes.
2. Allow one of the tubes to stand; add a small amount of the manganese dioxide to the other test tube using a spatula.
3. Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1. Was there any evidence of any reaction in the test tube in which manganese dioxide was not added?
2. Would you say that the manganese dioxide acted as a catalyst in this reaction? Justify your answer.

Further investigation

For each of the two scenarios below, write a hypothesis and design an experiment to test your hypothesis. You may need to use some additional equipment. Once you have checked with your teacher, you may be able to complete your investigation. Don't forget to write a report of your findings.

1. Is the manganese dioxide used up in the reaction?
2. Does the amount of the catalyst used affect the rate of the reaction?

EXPERIMENT 7.9

Effect of concentration on reaction rate

Aim

To investigate the effect of concentrations of solutions on reaction rate.

Materials

20 mL x 0.5 M HCl (hydrochloric acid)
20 mL x1.0 M HCl
20 mL x 2.0 M HCl
30 g small marble chips of similar size
3 x 100 mL conical flasks
Electronic balance
Stopwatch
25 mL measuring cylinder

Avoid contact with the acid solutions because they are corrosive. Wear lab coats, gloves and safety glasses. Wash off with water immediately if contact is made.

Method

1. Construct a hypothesis for your experiment.
2. Prepare a table for your results as shown in Table 7.3.
3. Place a conical flask on the digital balance and tare the balance so it reads zero. Weigh approximately 10 g of marble chips to the flask.
4. Using a measuring cylinder add 20 mL of 0.5 M hydrochloric acid to the conical flask still sitting on the digital balance. Immediately tare the balance once so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero, as gas is given off.
5. Record in your results table the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.
6. Repeat the experiment as described above using 1.0 M HCl and then 2.0 M HCl.
7. Plot a graph of the mass loss by minutes as shown in your table. All three acid concentrations can be plotted on the same graph for comparison.

Conclusion

Write a conclusion for your experiment that includes a discussion of your hypothesis based on the data from the experiment and an evaluation of the method used to produce these data.

→Table 7.3 Effect of concentration on reaction rate

HCl concentration (M)	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
0.5									
1.0									
2.0									



What do you know about why reaction rates are important?

1. What are the steps of the scientific method?
2. Why is it important to follow the steps of the scientific method?
3. What is a 'hypothesis'? Why is one important in an investigation?
4. What is a 'variable'?
5. What are the controlled variables in the experiment investigating the effects of particle size on reaction rate?
6. What are the independent and dependent variables in the experiment investigating the effects of temperature on reaction rate?

Reaction rates and particles

Party time!

Imagine this scenario. It's Sunday morning. You have a science assignment due on Monday morning but your friends have asked you to an important party on Sunday afternoon.

You decide to do your assignment, but it takes longer than you thought. So you rush to the shower and get dressed. But your hair is wet. There is not enough time to allow it to dry. How can you dry your hair quickly?



- blow air over it—moving air carries away water vapour, bringing in dry air to carry away more vapour
- heat the air—heat energy is needed to evaporate water, so the water will evaporate faster if the air is heated
- spread out or fluff up your hair—this gives a larger surface area for the water to evaporate from so that more water can evaporate at the same time.

Each of these methods will help you dry your hair quickly, so you will not be late for the party. Drying hair is a physical change. But the methods used to dry hair are similar to the methods chemists use to speed up the rate of chemical reactions.

How can you speed up the rate of a chemical reaction?

A chemical reaction proceeds when the reactants interact. The reactants combine to form the products. The more reactants that can interact in a certain amount of time, the faster the products will form and the reaction will be faster. A faster reaction has a higher reaction rate.

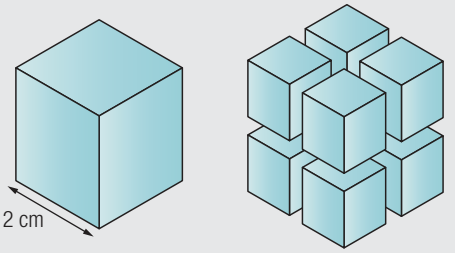
The theory that explains how reactions occur is called **collision theory**. It states that the particles of the reactants, such as atoms, ions or molecules, must collide so they can react. In explaining how to make a reaction occur faster, it is best to think of how to make more collisions.

There are a range of ways in which a reaction can be made to go faster, or have a higher reaction rate.

INCREASE THE SURFACE AREA

A metal like magnesium reacts with dilute hydrochloric acid. The hydrogen ions in the acid have to collide with a magnesium atom in order for the two of them to react. There are more metal atoms exposed to the hydrogen ions if the metal is in small pieces. Because the reaction occurs on the surface of the magnesium, breaking it up into smaller pieces provides a larger surface area on which the reaction can occur.

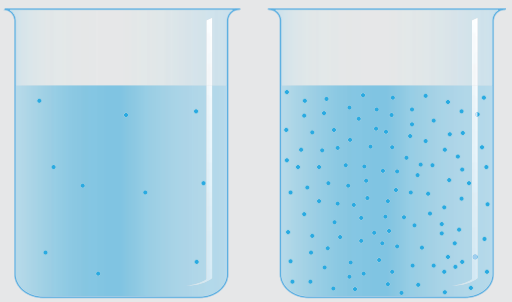
Powders have a much larger surface area than large-sized bits of material. Remember, the surface area is not the size of the pieces, but rather the total area exposed to the surroundings.



Total surface area
= 2 cm x 2 cm x 6 sides
= 24 cm^2

Total surface area
= 1 cm x 1 cm x 6 sides x 8 cubes
= 48 cm^2

→ Fig 7.24 Many small particles have a larger surface area than a single large particle of the same volume.



→ Fig 7.25 A more highly concentrated solution will contain more dissolved particles than a dilute solution.

INCREASE THE CONCENTRATION

In a dilute solution, the particles (molecules or ions) of the reactant are spread out in a solvent, such as water. There is a lot of space between the reactant particles. In a concentrated solution, there are many more reactant particles in the same volume, so they are much closer together.

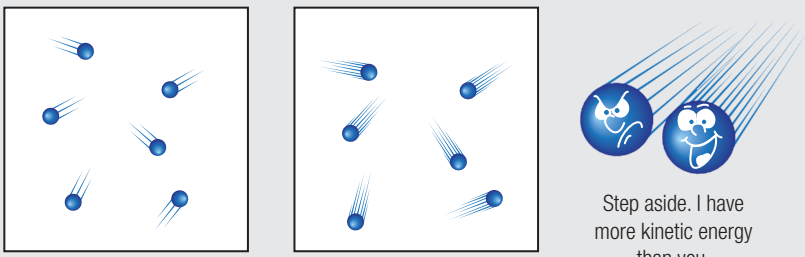
In the reaction between magnesium and hydrogen ions, the reaction will go faster if there are more hydrogen ions. So, using a hydrochloric acid solution with a higher concentration (i.e. when there are more hydrogen ions in a given volume) will speed up the reaction.

To speed up a reaction, it is best to use more concentrated solutions of reactants. This is because, in concentrated solutions, there are more particles available for a given volume that can react. When there are more particles, there are more collisions and therefore a higher reaction rate.

INCREASE THE TEMPERATURE

Particles in a hot substance have more kinetic energy than particles in a cold substance. This means that the particles in a hot substance are travelling faster than the same particles in a cold substance.

In a reaction, hotter particles will collide faster and more often than cold particles. More collisions, and more energetic collisions, mean a greater proportion of collisions that result in a reaction.



Cold substance (particles have low kinetic energy)

Hot substance (particles have high kinetic energy)

Step aside. I have more kinetic energy than you.

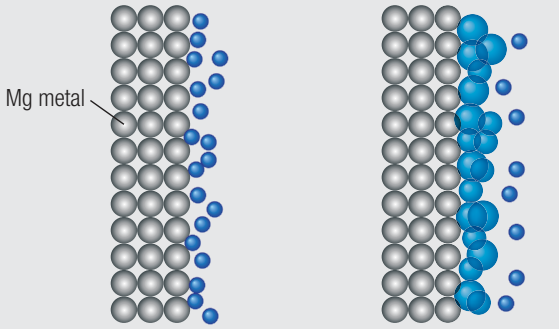
→ Fig 7.26 At higher temperatures, the average energy of the particles is increased.

INCREASE GAS PRESSURE

For chemical reactions that involve gases, high pressures may be caused by a high concentration of gas particles and/or by fast (hot) gas particles. Fast gas particles have more energy and collide more often than slower particles because they are travelling faster.

Increasing gas pressure increases the rate of reactions because there are more collisions as a result of the higher concentration of gas particles.





Initially, hydrogen ions react with magnesium

Later, hydrogen bubbles that cover the magnesium stop the ions from reacting

→ Fig 7.27 Sometimes the presence of the product can slow down a chemical reaction.

STIR AND MIX

As a chemical reaction proceeds, the particles of the reactants get used up: when there are fewer reactants, there are fewer collisions and so the reaction rate slows down. To maintain the reaction rate, the products of the reaction should be removed and replaced with more reactants. A basic way of doing this is by stirring or mixing the reactants.

In the reaction between magnesium and acid, one of the products is hydrogen gas. The gas forms bubbles that gather on the surface of the magnesium, covering the unreacted magnesium. This prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

USE A CATALYST

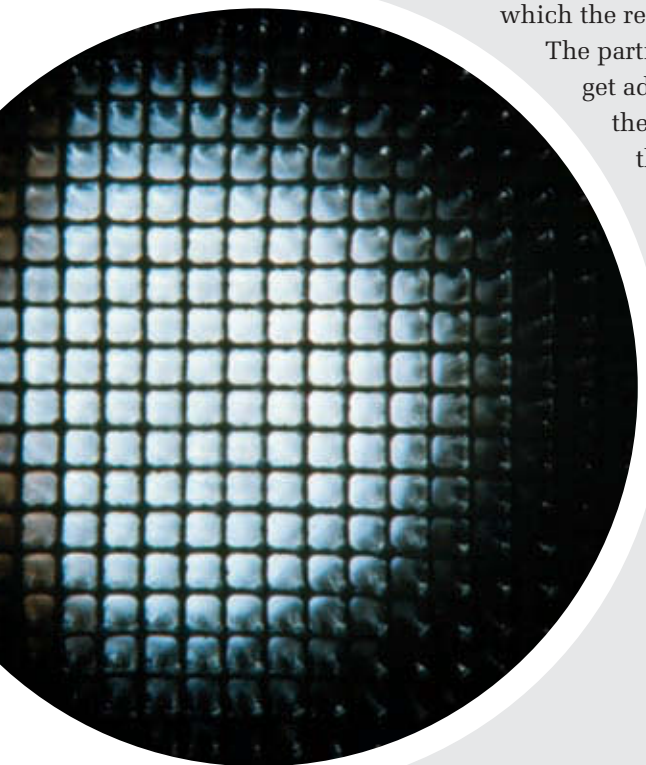
A **catalyst** is a substance that speeds up a chemical reaction but is not used up in the reaction. Catalysts work in many different ways.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants get adsorbed (stuck onto) the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

This sort of catalyst is used in the catalytic converters of cars. A honeycomb-like grid of metals provides a large surface area. The metals adsorb pollutant gases, but not clean gases such as nitrogen and carbon dioxide. The pollutant gases are adsorbed onto the catalyst, where they react to form the gases nitrogen and carbon dioxide. These clean gases are passed through the car exhaust.

Sometimes these catalysts are poisoned. This is when an impurity prevents the catalyst from functioning fully. Impurities in petrol can poison a car catalyst.

Another way in which catalysts work is to take part in the reaction and be regenerated later. One example of this is the destruction of ozone. Chlorofluorocarbons (CFCs), such as CCl_3F (trichlorofluoromethane or freon-11), are broken apart by the UV rays from the Sun, releasing a free chlorine atom. This chlorine atom catalyses the destruction of ozone and is regenerated.



→ Fig 7.28 Catalysts are often used in the form of a grid to maximise the surface area.



In this way, one chlorine atom from the original CFC can destroy up to ten thousand ozone molecules. The reactions occurring can be shown as follows:

$$CCl_3F + UV \rightarrow CCl_2F + Cl$$

Then ozone is destroyed:

$$Cl + O_3 \rightarrow ClO + O_2$$

The ClO is destroyed by O atoms, making more Cl:

$$ClO + O \rightarrow Cl + O_2$$

The Cl atoms are then free to destroy more ozone.

→ Fig 7.29 Chlorofluorocarbons (CFCs) were used to pressurise the gas used in aerosol cans before it was proven that the CFCs damaged the ozone layer.

Enzymes as catalysts

An enzyme is a catalyst made and used in living cells. Enzymes play an important part in all cellular processes. All the reactions that occur inside a cell are helped along by these catalysts. There are numerous enzymes in our bodies to help speed up reaction rates. For example, enzymes in the digestive system help break down food. Enzymes only work with specific reactants and so will only catalyse certain reactions.

Enzymes are also responsible for the ripening of fruit. When an apple is cut and left exposed to the air, it turns brown. But when vitamin C is sprinkled on the cut surface of the apple, it does not turn brown. The browning process is a result of enzymes in the fruit. As the fruit is exposed to air, enzymes in the fruit cells react with oxygen and digest the fruit cells. This process is known as oxidation. It is shown by changes in the colour (brown) and taste (bitter) of the fruit. Vitamin C is an antioxidant. It stops this reaction from taking place because it reacts with the enzymes, preventing them from digesting the fruit cells. So, the fruit does not brown.

What do you know about reaction rates and particles?

1. What are the six ways of speeding chemical reactions in a solution in a beaker?
2. Why does a greater surface area increase the rate of reactions?
3. Why does a more dilute solution decrease the rate of reactions?
4. Why does a reaction occur faster when the reactants are stirred together?
5. What is a catalyst?
6. Explain the two ways in which catalysts can work.
7. Why is an enzyme often called a 'biological catalyst'?

The collision theory

For a chemical reaction to occur, the atoms or ions or molecules must collide together with enough energy for that reaction to occur. This idea is known as collision theory.

One reaction that has been studied is the decomposition reaction of hydrogen iodide. The reaction, in symbols, is:

$$2\,HI(g) \rightarrow H_2(g) + I_2(g)$$

Hydrogen iodide is a gas and its molecules travel quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in order to react.

Some collisions do not result in a reaction. In these collisions, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 7.30.

In the collision shown in Figure 7.31, there is a reaction. A weak chemical bond forms between the iodide ions and the hydrogen ions. This intermediate substance is unstable and only exists for a short period of time, before it breaks apart.

Only some collisions result in a reaction. The molecules must collide in the correct orientation for a reaction to occur.

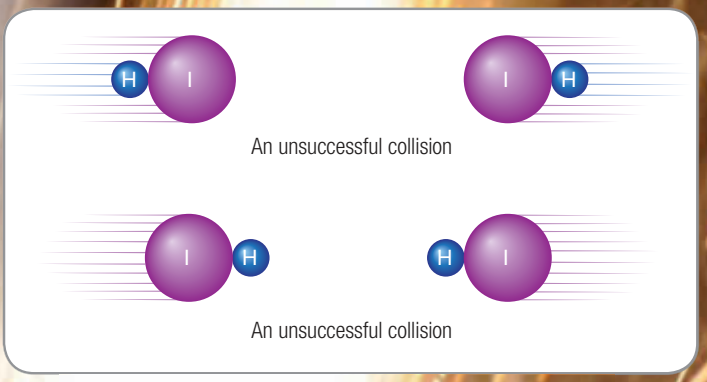
Reversible reactions

Many reactions can occur in reverse and these sorts of reactions are called **reversible reactions**. For example, the decomposition of hydrogen iodide can occur in reverse. This would then be called the synthesis of hydrogen iodide.

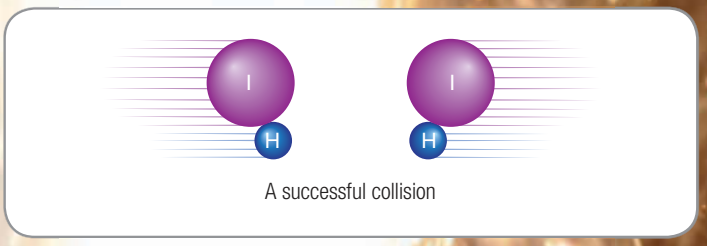
Effect of temperature

Reactions occur faster, with a higher reaction rate, when the temperature is higher. This is because the particles in a hot gas have more kinetic energy, and move faster, than the particles in a cold gas. Faster moving particles will collide more often because they travel further in the same time as a cold particle. In addition, hot gas particles that collide have more energy. Think of a collision between two cars—if both cars are moving at 30 km/h, there are not many injuries to the occupants; however, if both cars are moving at 100 km/h, severe injuries may occur.

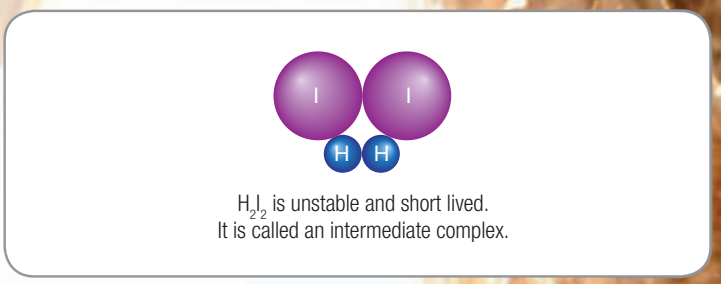
Slow moving gas molecules will be pushed apart by the repulsion of the electrons that orbit the atoms: they never come close enough to form new chemical bonds. Fast moving molecules can 'push through' the repulsion and their electrons can orbit around a different atom. The faster the molecules, the higher the proportion of molecules with sufficient energy to change into products.



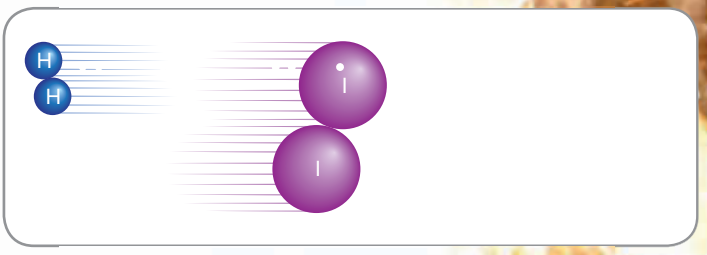
→ Fig 7.30 Not all collisions result in a chemical reaction.



→ Fig 7.31 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.



→ Fig 7.32 An intermediate stage during the reaction. The products of this reaction move apart. (This is due, in part, to electrical repulsion.)



→ Fig 7.33 The final products are formed.

What do you know about the collision theory?

1. Is it true that every time the molecules of reactants collide they form molecules of the products? Explain.
2. How does temperature affect the rate of a chemical reaction?
3. What is a reversible reaction?
4. What is the collision theory?
5. How does the collision theory explain the dramatic increases in the rate of a reaction as the reactants are heated?

7.2

How can we control the speed of chemical reactions?



Remember and understand

1 In terms of particles, what is required for a chemical reaction to take place?

2 List four factors that will affect the rate of a chemical reaction.

3 Describe two ways that the rate of chemical reactions can be measured.

4 Describe one situation where it could be dangerous if a reaction occurs too quickly.

Apply

5 Why is food stored in a refrigerator?

6 In many industrial environments, the presence of a fine dust is regarded as an explosion hazard. Why is coal dust more likely to explode than chunks of coal?

7 A student wanted to investigate the effect of temperature on the reaction between hydrochloric acid and magnesium metal.

a List four variables that should be kept constant in this investigation.

b For two of these variables, explain how the experimental error would be increased if they were not controlled properly.

Analyse and evaluate

8 How does the particle model of matter help us understand the rate of reactions?

9 The reaction $2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$ is very slow at room temperature. The reaction occurs in two steps, which are shown below. The reaction occurs more quickly in the presence of nitrogen dioxide gas.

- Step 1 $2\ SO_2(g) + 2\ NO_2(g) \rightarrow 2\ SO_3(g) + 2\ NO(g)$
- Step 2 $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

Explain two reasons why the nitrogen dioxide is regarded as a catalyst.

Critical and creative thinking

10 A student was investigating the reaction that occurs when starch is broken down into glucose in the presence of the enzyme amylase. The student found that initially, as the temperature increased the rate of the reaction also increased but, once the reaction mixture was above 60°C, the reaction became very slow. Suggest an explanation for these observations.

11 Indigestion tablets often contain carbonates, which take part in neutralisation reactions in our stomach to reduce excess acidity. The general reaction can be described as:

- acid + carbonate → salt + water + carbon dioxide
- Describe problems that might result if the reaction occurred:
  - **a** too quickly
  - **b** too slowly.

CONNECTING IDEAS Interaction and change

12 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact together on the surface of the catalyst.

a Why would attracting particles onto a surface of another chemical encourage a chemical change to occur?

b Why would a substance that actually bonded chemically to the reacting particles not make a good catalyst?

c Give an example of the use of a surface catalyst, describing in detail the chemical reaction.

d Use your knowledge of collision theory to explain why most catalysts are used in the form of a powder or fine mesh.

7.3

What are the risks of using chemicals?



Chemicals may have a public relations problem. We often see products advertised as 'chemical free' or 'organic'. It is easy to tap into people's fear of chemicals because the word 'chemical' is often associated with substances that are seen to do harm to the environment. Acids, pesticides, chlorofluorocarbons (CFCs), industrial waste and food additives are all chemicals, but chemistry is not just about these types of materials, and even these are safe to use if their quantities are controlled and their use is monitored. A better understanding of chemistry allows us to predict, manage and reduce the risks of using chemicals in our environment.

DISCOVERING IDEAS

Oxygen—a toxic chemical?

We all know that the presence of oxygen on Earth is essential for our survival. But can oxygen be toxic? Can it be considered a harmful substance? In what situations is the presence of oxygen dangerous?

Hyperbaric chambers are often used by sports stars to speed up recovery from injury. It is believed that breathing in an atmosphere of pure oxygen improves wound healing and stimulates the growth of new blood vessels. However, the discovery that oxygen was toxic came through the experiences of early scuba divers, who were breathing pure oxygen for long periods of time at higher than normal pressure. Considering more long-term effects, it is thought that oxygen in our bodies causes the formation of reactive particles called 'free radicals'. These free radicals cause the tissues and organs in our bodies to age.



→ Fig 7.35 Football players have often used oxygen treatments to speed up their recovery from injury.



→ Fig 7.34 Some harmful effects have resulted from scuba divers breathing pure oxygen.

1 Do you think that oxygen should be described as a 'toxic' substance?

2 Why do you think that some people ensure that their diet contains a certain amount of antioxidants?

3 Do you know of any specific examples where oxygen treatment has been used by sports men or women to recover from injury before an important match?

4 Why do you think that breathing oxygen at high pressure might increase the chance of ill effects?

Chemicals and pollutants

The chemicals we use contribute to the lifestyle we enjoy. But there may be a trade-off. Sometimes unwanted substances enter the environment and cause pollution.

Pollutants are chemical substances that are in the wrong place or are present in the wrong amounts. Carbon dioxide is not normally a pollutant, but too much in the atmosphere is one factor contributing to climate change.

Chemists are constantly developing new products and processes. New products are often more environmentally friendly than the products they replace. New processes reverse many of the negative environmental effects. Consider the methods used to prevent pollution from cars and the plans to implement carbon capture at coal-burning power stations.

Our carbon economy

The chemical fuels that our society relies upon are based on carbon. Our ancestors burnt wood, which is mainly the carbon compound cellulose. Later generations burnt coal, which is close to pure carbon. Coal is made by the dehydration and compaction of buried plant remains. Our generation uses coal to produce electricity and petroleum as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Cellulose is a polymer of $C_5H_{10}O_5$ units arranged end-to-end, coal is 95% pure carbon (depending on the type) and petroleum is a mixture of hydrocarbons. Petrol is mostly octane (C_8H_{18}), diesel is a mixture with the average formula $C_{12}H_{23}$, natural gas is CH_4 and liquefied petroleum gas (LPG) is propane (C_3H_8).

Petrol, diesel, natural gas and LPG are fossil fuels. They are obtained from the Earth and were formed from the fossilised remains of plants and animals. The energy in them was captured by photosynthesis millions of years ago. This carbon has been locked away out of the atmosphere for millions of years. Even renewable fuels, such as biodiesel and ethanol, contain carbon atoms. The carbon atoms in renewable fuels were captured by photosynthesis in the last growing season.

It is fair to say that our society runs on carbon. It is in every important fuel. Carbon is the mainstream of our economy. This is why is it called a carbon economy.

Carbon pollution

Burning carbon fuels provides energy at a relatively low cost, but there is a price to the environment.

Burning carbon fuels in excess oxygen produces carbon dioxide and water. When there is less oxygen available, carbon monoxide and soot (carbon) form. With even less oxygen, unburnt hydrocarbon is released, with water. As an example, the following equations show three possible reactions for the combustion of propane (C_3H_8). Note that as less oxygen is available, the product of the reaction will change.

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$
$$C_3H_8 + 3½\ O_2 \rightarrow 3\ CO + 4\ H_2O$$
$$C_3H_8 + 2\ O_2 \rightarrow 3\ C + 4\ H_2O$$

Carbon monoxide (CO) is a poison that binds tightly onto the haemoglobin in red blood cells, much tighter than oxygen. Victims of carbon monoxide poisoning die because

→ Fig 7.36 Carbon is the chemical basis for oil that we extract from the Earth.



of a lack of oxygen to the brain and other body tissues. Small particles of soot cause breathing problems, especially in people with asthma. It is important that all users of fossil fuels burn them cleanly. In addition to releasing less pollution, burning fossil fuels cleanly provides more energy.

Other pollutants from burning fuels

Carbon fuels are not pure. Wood contains water and plant oils, whereas coal contains dust, nitrogen, sulfur and tar. Oil refineries now process petroleum to remove the sulfur from it, but this has not always been the case.

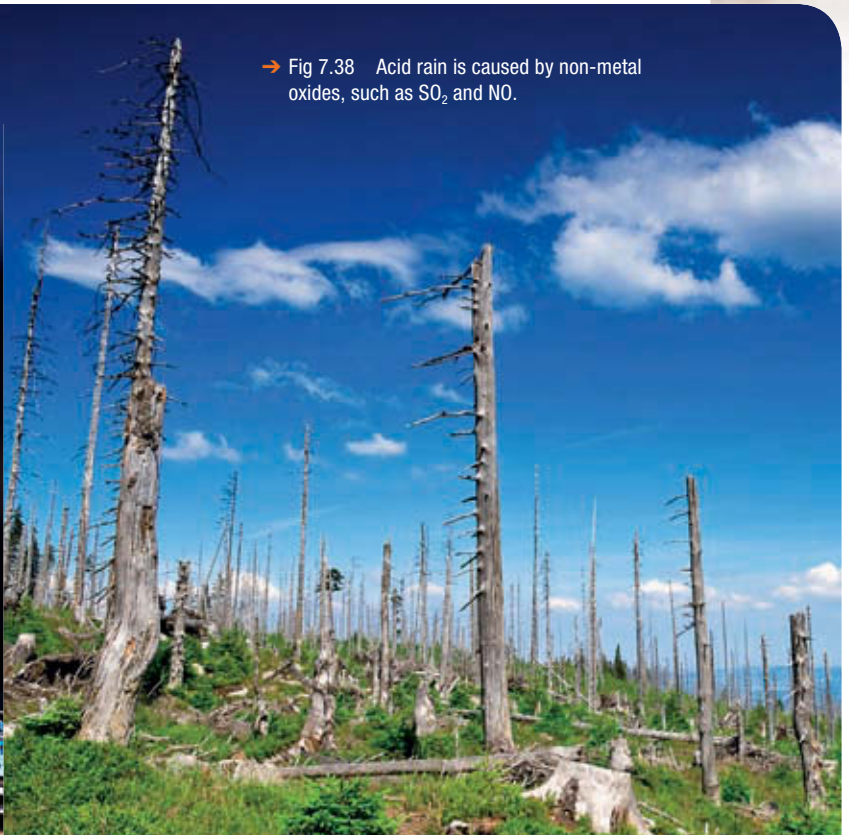
When a fuel is burnt, the impurities in it, such as sulfur, are also burnt.

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

At high temperatures in an engine or furnace, nitrogen in the air can react with oxygen.

$$N_2(g) + O_2(g) \rightarrow 2\,NO(g)$$

The gases sulfur dioxide (SO_2), sulfur trioxide (SO_3; made from SO_2 in the atmosphere) and nitric oxide (NO) dissolve in water and form acid. Even small amounts of acid can raise the acidity enough to destroy the ecosystems in forests, lakes and rivers. In cities, **acid rain** dissolves the limestone and marble on buildings and statues.



→ Fig 7.38 Acid rain is caused by non-metal oxides, such as SO_2 and NO.

Pollution control in cars

Modern cars produce much less pollution than older cars. The pollutants are reduced by computer-controlled combustion in the engine and are removed in the exhaust system by a catalytic converter. As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals that act as catalysts are platinum, palladium and rhodium. These metals are expensive.

The overall reaction that occurs in the catalytic converter is:

$$2\,CO(g) + 2\,NO(g) \rightarrow 2\,CO_2(g) + N_2(g)$$



→ Fig 7.37 In rockets, liquid hydrogen and liquid oxygen react to provide the thrust for the launch.



→ Fig 7.39 Catalytic converters are used to reduce pollution from exhaust gases.



→ Fig 7.40 Heavy traffic increases pollution levels.

What do you know about chemicals and pollutants?

1. Why are carbon fuels so important to our society?
2. Why is the sulfur removed from the petrol used in cars?
3. What is a catalytic converter? Why are they used?
4. What is the difference between renewable and non-renewable fuels?
5. Why does the amount of oxygen available affect the products formed in the combustion process?

Acid pollution

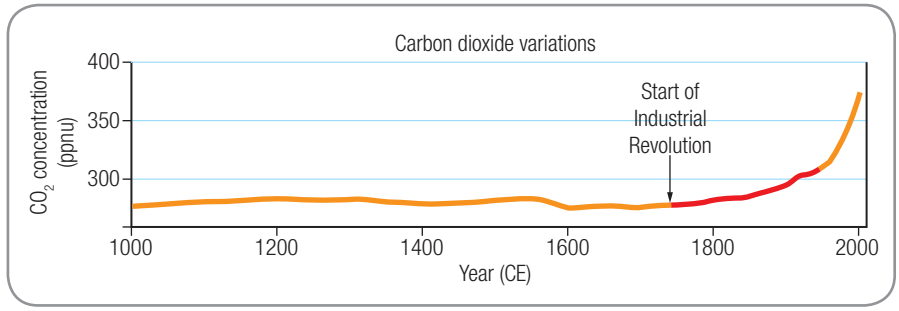
Many people think that acids are only found in bottles in the laboratory, but acids are also found in the environment. Some acids in the environment are made by people. Anything made by people is said to be anthropogenic.

Carbon dioxide

Carbon dioxide is a natural product, but is a pollutant when there is too much of it. The levels of carbon dioxide in the atmosphere are increasing all the time. Some of this carbon dioxide dissolves in the oceans, where it can change the acidity of the sea water.

Carbon dioxide is an essential part of the environment. Plants use it for photosynthesis and animals produce it in respiration. It also helps form bones and shells in many animals. Large quantities of carbon are present in the oceans and in the carbonate rocks called limestone and dolomite.

→ Fig 7.41 Carbon dioxide levels in our atmosphere have been increasing dramatically in recent years.



EXPERIMENT 7.10

Reactions of acids and a carbonate

Aim

To investigate and compare the reactions of calcium carbonate with a strong acid (hydrochloric acid) and a weak acid (ethanoic acid).

Materials

1 M hydrochloric acid, HCl

1 M ethanoic acid (acetic acid), CH_3COOH

Limewater (calcium hydroxide), $Ca(OH)_2$

Marble chips (calcium carbonate), $CaCO_3$

Test tubes

Test tube rack

Spatula

Two 100 mL conical flasks

One-holed rubber stopper with bent glass delivery tube

Wear safety glasses and lab coats, and avoid skin contact with the acids.

Method

1 Draw up a table to record each test and the results for each acid.

2 Using a clean spatula, transfer four to five marble chips to one of the conical flasks. Add approximately 2 cm of limewater to a test tube. Now add enough 1 M hydrochloric acid to cover the marble chips and place the stopper delivery tube in the mouth of the flask so that any gas produced will bubble into the limewater in the test tube.

3 Record your observations of any changes that occur in both the flask and the test tube.

4 Repeat step 2 with 1 M ethanoic acid, using a fresh conical flask and a fresh tube of limewater. Compare the rate of this reaction with that of the hydrochloric acid.

Discussion

1 What can be concluded about the strength of ethanoic acid compared with that of hydrochloric acid? Discuss.

2 The limewater test is the standard test for carbon dioxide gas. It goes milky because the carbon dioxide reacts with the limewater to produce a precipitate of calcium carbonate. The equation for the reaction is:

$$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

3 Did your tests confirm that carbon dioxide gas was produced? Was there a difference in the rate of its production? If so, suggest why.

4 Write balanced equations for the reactions of the two acids with calcium carbonate.

Oxides of nitrogen and sulfur

Natural rainwater is slightly acidic due to the carbonic acid dissolved in it. However, acid rain is more acidic because of oxides of non-metals that have dissolved in it.

Small amounts of sulfur in fuels and nitrogen in the air combine with oxygen to form oxides of sulfur and nitrogen. Because there is a variety of oxides formed, each with a different formula, these compounds have been given the formulas SO_x and NO_x, where 'x' stands for a small number, such as 1, 2 or 3.

These oxides can react with water in the atmosphere to form acids, which contribute to the formation of acid rain.

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq) \text{ (sulfurous acid)}$$

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq) \text{ (sulfuric acid)}$$

$$2\,NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq) \text{ (nitrous acid and nitric acid)}$$

These are a selection of some of the reactions that occur. Acid rain is really a mixture of many acids. The water could be rain, snow, cloud or dew, but it is all called acid rain. Even small amounts of acid can raise the acidity enough to disturb the ecological balance.

Natural rainfall has a pH of between 5.8 and 4.8, depending on the amount of carbon dioxide dissolved in it. The urban average is pH 4.5. The most acidic rain recorded worldwide had a pH of 2.3.

The effects of acid rain include:

- increased corrosion of masonry and metals
- changes to availability of ions in the soil
- damage to new growth on trees
- effects on marine life, such as shell formation.

What do you know about acid pollution?

1. What is the difference between natural and anthropogenic carbon dioxide?
2. What is the name of the acids formed from carbon, sulfur and nitrogen?
3. What is the pH of natural rain? What is the pH of acid rain? Why is there such a difference?
4. What are the effects of acid rain?
5. What can be done to reduce the incidence of acid rain in the environment?

OVERARCHING IDEAS

Stability and change

Reactions in the ozone layer

The ozone layer is part of the stratosphere. It is the region in the stratosphere from 10 to 50 km high, with the greatest concentration at an altitude of 30 km. Ozone in this region absorbs the UV light that would otherwise cause many more skin cancers and eye problems.

Chlorofluorocarbons (CFCs) are the main destroyers of ozone. The CFCs were developed as refrigerants for use in refrigerators. The CFCs are non-flammable, non-toxic, cheap to manufacture, easy to store and chemically stable and were used in aerosol cans, fire extinguishers and asthma puffers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers.

The depletion of ozone in the upper atmosphere was first noted in 1974. It was worst over Antarctica during the spring, but occurred over the rest of the world as well. Teams of scientists studied the depletion in the ozone layer.

The reactions that take place are shown below.

When exposed to ultraviolet ($h\nu$) radiation, as they are in the upper atmosphere, the CFC molecules lose a chlorine atom.

$$CCl_2F_2 + h\nu \rightarrow CClF_2 + Cl$$

If the chlorine atom collides with an ozone molecule, it may then react with it.

$$Cl + O_3 \rightarrow ClO + O_2$$





→ Fig 7.42 Ozone offers some protection from some harmful ultraviolet radiation.

The ClO groups of atoms will react with oxygen atoms that are present in this region of the atmosphere, formed by the breakdown of oxygen molecules.

$$ClO + O \rightarrow Cl + O_2$$

This reaction releases the same chlorine atom to destroy another ozone molecule. The chlorine atoms act as catalysts—they help the reaction but do not get used up themselves.

Ozone, essential for our protection, is destroyed. The chlorine atoms, which caused the destruction, still exist. Every chlorine atom can destroy ten thousand ozone molecules. The only way to break the cycle is to remove the CFCs from the atmosphere.

The Montreal Protocol (an agreement made in the Canadian city of Montreal) in 1987 phased out the use of CFCs. Replacement chemicals that were 'ozone friendly' were developed and used as replacements for the ozone-depleting substances.

1 Is the concentration of ozone in the atmosphere constant throughout each year?

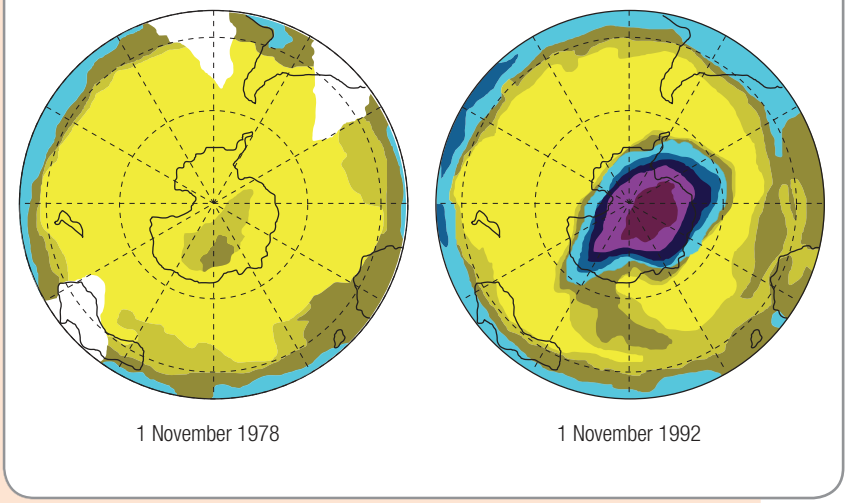
2 Why is it important that, over time, the amount of ozone in the atmosphere is stable?

3 What has caused a change in the amount of ozone in the atmosphere over time?

4 Which part of the CFC molecule destroys ozone? How does this atom become detached?

5 What is the name of the international agreement to ban the use of CFCs and find replacements?

→ Fig 7.43 Ozone levels reduce over the southern hemisphere every year. The darker colours show where the 'hole' in the ozone layer has grown.



Green chemistry and sustainability

Being 'green' means doing something positive for the environment. Scientists with special knowledge in ecology, biochemistry, zoology and botany study the environment and how it responds to changes. It is these scientists who detect changes caused by natural events, as well as by human-made actions. They monitor the environment for changes that may have been caused by the actions of society.

There are some chemicals that have a negative impact on the environment and living things. When these substances are identified, scientists take action to reduce their use and to prevent them from entering the environment. Sometimes some substances are banned from use altogether.

New chemical products and processes are described as being 'green' if they have less impact on the environment than the product or process they replace. The study and development of new substances that have a low impact on the environment is called 'green chemistry'.



Some examples of the development of 'green' alternatives are described below.



- Pesticides and herbicides have been used to kill the living things that eat our food crops and the plants that compete with these crops for sunlight and nutrients. Some of these products killed all living things, not just the target species. Most were non-degradable (did not break down) and remained in the environment long after they were no longer needed. These substances are now banned and have been replaced with biodegradable poisons. In many cases chemical poisons have been replaced with new farming practices, such as crop rotations and pest-resistant crop varieties.
- CFCs were developed as refrigerants and quickly found other uses in aerosol cans and fire extinguishers. It was later discovered that their use caused severe environmental damage—destruction of the ozone layer. The CFCs were banned and new substances were developed to replace them.
- Heavy metals include lead, mercury and cadmium. Heavy metals had many uses, especially in dyes, and were used in chemical processes, especially as catalysts. But these metals accumulated in the bodies of living things, including people. The most dramatic example is that of Minamata disease, caused when people in Minamata, Japan, in 1956, were poisoned by mercury after eating contaminated seafood. The use of these metals in situations where they could enter the environment has been largely stopped. They have been replaced by different catalysts and even different production processes.
- Acrylic paints have replaced solvent-based enamel paints and lacquers. The solvent used in the old paints was a hydrocarbon, such as turpentine, and it evaporated as the paint dried. These solvent-based paints have been replaced with acrylic paints, which are water based and set by polymerisation of the paint, not by evaporation of a solvent. The hydrocarbon solvents in enamel paint were toxic to aquatic life in waterways and the fumes from the paint caused 'painter's disease' in the workers who inhaled them.
- Green chemistry is sometimes called 'sustainable chemistry'. It is about reducing the impact of chemicals on the environment—chemists produce substances in processes that have less impact on the environment than the substances they replace.



→ Fig 7.44 Many chemical products considered safe for use in the past have been replaced by more environmentally friendly substances.

What do you know about green chemistry and sustainability?

1 How do scientists determine how safe a product is?

2 The 'old masters', the painters of 1600s–1800s, used pigments made of compounds of lead, mercury and cadmium. Why are these paints no longer available to today's painters?

3 If you discovered an important new chemical today, could you be responsible for any consequences that occurred 30 years in the future? Could the people who are affected in 30 years time blame you?

ZOOMING IN

What can you do to control chemicals in the environment?



What can you, as one person, do to protect the environment and the planet?

By adapting the slogan REDUCE REUSE RECYCLE you can reduce your footprint on the environment. You can do this by:

- taking your own shopping bag and not using plastic
- composting grass clippings and food scraps and using this compost instead of chemical fertilisers.

1 What other materials can be recycled to reduce the risk of chemical pollution?

2 What are the properties of substances that would make them suitable for recycling?

By adapting the slogan ACT LOCAL, THINK GLOBAL you can act to reduce your footprint on the planet. You can do this by:

- buying trigger-action spray cans, not aerosols
- avoiding non-degradable products, such as some biocides
- leaving the car at home for short journeys, catching public transport or riding a bike
- using natural cleaning products and avoiding chlorine-based cleaners.

3 What other actions can you take to reduce your impact on the environment? Your actions will make a small difference, but when others join you, the effect is quite dramatic.





Material Safety Data Sheets

A **Material Safety Data Sheet** (MSDS) is a small document that:

- describes the physical and chemical properties of a substance or a material
- provides advice on the safe handling and use of that material
- gives guidance in first aid.

The Safety Data Sheets are available from:

- manufacturers and importers of chemicals
- the point of sale, such as shops and retail outlets
- online.

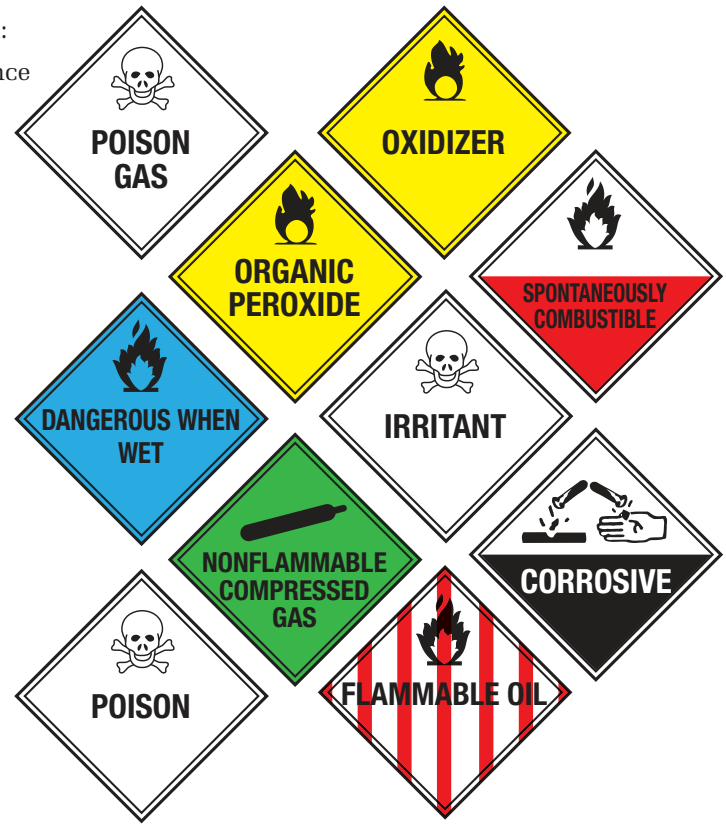
There is an MSDS for every single chemical and mixture of chemicals sold in Australia, meaning that there are over 20 million MSDS that you could read!

On the label of each substance or material, you will find the MSDS information in a condensed form.
There may be a diamond-shaped warning symbol. There is also information on the purity of the material and emergency first aid.

Many chemicals are transported by road or rail. There are warning labels on the side of tankers to guide emergency workers as to how to handle any emergencies.

Every time you use a chemical substance, at school or at home, ensure that you are familiar with any hazards it may pose. For example:

- Do you need to use it in a well ventilated area? Will it affect people with asthma?
- How do you clean up any spills?
- What should you do if you spill it on your skin?
- How do you store it safely until next time you need to use it?



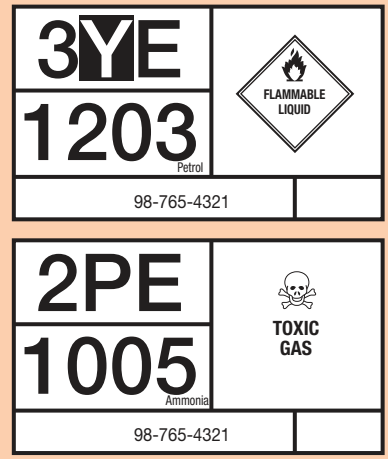
→ Fig 7.45 Warning symbols used on Material Safety Data Sheets.

What do you know about Material Safety Data Sheets?

1 What information is contained in a Material Safety Data Sheet?

2 Why are graphics used on chemical warning labels?

3 What information is shown in the label in Figure 7.46?



→ Fig 7.46 Information signs on tankers carrying petrol and liquid ammonia. The large number is the United Nations number for this substance and the small number is a phone number for emergency information.



7.3

What are the risks of using chemicals?



Remember and understand

1 What is the key difference between a fossil fuel and a biofuel?

2 How does acid rain affect objects made from limestone?

3 What is the link between CFCs and the ozone layer?

4 Why should you always have an MSDS available when working in the laboratory?

Apply

5 Why do some people say that our society's energy demands are based on carbon?

6 How is acid rain formed from the burning of fossil fuels?

7 What are some examples of green chemistry that you could apply at home?

Analyse and evaluate

8 Why is carbon dioxide—a natural product—regarded as a pollutant?

9 What is the relationship between the acidification of the oceans and the ability of living things to form bone and shell? Include equations in your answer.

Ethical behaviour

10 In the 1920s, the compound tetra ethyl lead (TEL) was developed to prevent 'knocking' in car engines. ('Knocking' is where the spark plugs fire too early, resulting in loss of power and possible engine damage.) Adding TEL saved the cost of additional refining of petrol, which resulted in lower costs for consumers and motorists. However, some people raised concerns about the use of a lead compound that was being released from the exhaust of cars. If you had been part of the debate in the 1920s, what arguments would you use against the use of TEL?

Critical and creative thinking

11 List the energy sources available to our society. Which of these are suitable as fuel for cars, trucks and buses? Which of these are renewable? Which of these do not contribute to environmental change?

CONNECTING IDEAS Interaction and change

12 In our bloodstream, haemoglobin is responsible for the transport of oxygen from our lungs to the cells in our body, where respiration takes place. The oxygen molecules interact with the haemoglobin and combine to form oxyhaemoglobin. When the blood reaches the cells (having been pumped through the heart), the oxyhaemoglobin releases the oxygen. If carbon monoxide molecules are breathed into the lungs, they can attach themselves permanently to haemoglobin molecules, thus preventing the essential transfer of oxygen. Carbon monoxide poisoning is a very real danger and many Australians are killed by it each year.

a Use a diagram to represent the transfer of oxygen from the lungs to body cells.

b Explain why the chemical changes occurring between haemoglobin and oxygen need to be reversible.

c Do you think that the reaction between carbon monoxide and haemoglobin is reversible? Explain your answer.

d Suggest two ways that carbon monoxide poisoning can be prevented.

Research

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

Rare metals

A range of rare metals is used in microelectronic devices. Many of these metals, such as tantalum and niobium, are sourced from Australia. Find out more about where these metals are found in Australia, in what form they occur naturally and what chemical processes are used to extract the pure metals.

Nanotechnology

Nanomaterials are now being used as catalysts for a range of chemical reactions, often to catalyse very specific reactions that produce valuable products. Research the products that are produced by using nanoparticles and how the use of these catalysts has improved the production method.

Minamata disease

Minamata disease is caused by people eating seafood contaminated with a compound containing mercury. The condition was called a 'disease' because when it was first described no one knew its cause. Research this disease and present your findings using the following headings:

- symptoms
- cause
- action taken
- lasting consequences (for the people affected, chemical industry and the world)

Ozone and CFCs

Although governments did act to limit the use of CFCs and hence reduce the damage to the ozone layer, it took time for many countries to recognise the risks and to act on the advice from scientists. Investigate how evidence for ozone depletion was discovered, how countries responded to the evidence and discuss implications for possible future action (or inaction) of governments based on scientific advice.

Reflect

Me

1 What do you think was the most important concept in this chapter?
2 What were the most difficult aspects of this topic? Why?
3 How has your understanding of chemical reactions improved?
4 What new science skills have you obtained from this chapter?

My world

5 Why is it important to know how chemical reactions can be used?
6 How has our increased knowledge of chemistry affected how we live?

My future

7 How do you think people will change how they use chemistry in the future?
8 Can chemistry contribute to the sustainable use of our resources?

Review

Key words

acid rain
carbon nanotube
catalyst
collision theory
combustion
decomposition
electrolysis
law of conservation of mass
Material Safety Data Sheet (MSDS)
monomer
nanotechnology
oxidation
ozone
pollutants
polymer
precipitate
precipitation
reaction rate
reduction
reversible reaction
synthesis

Clara Immerwahr

Clara Immerwahr was a Jewish–German chemist. She was the first woman to obtain a PhD at the University of Breslau in Germany. Despite this success, because of the social and cultural conventions of the time Clara was never able to fulfil her potential as a chemist and spent a lot of her time supporting her husband's work. When she was 44 years old, she pointed her husband's military pistol at her chest and fired a single bullet. Her 13-year-old son held her as she died.



→ Fig 7.47 Clara Immerwahr.



→Fig 7.48 Fritz Haber.

Her husband was Fritz Haber. He was born into a Jewish family on 9 December 1868. Haber's extraordinary life was one full of science and tragedy. Fritz Haber's mother died giving birth to him. In his university studies, Haber was guided by Robert Bunsen, who invented the Bunsen burner, and August von Hofmann, also a very famous chemist. Between 1894 and 1911, Haber worked with Carl Bosch, a chemist and engineer, to develop what became known as the Haber–Bosch process. This process was able to produce ammonia (NH_3) on a vast scale. Ammonia is essential for the production of a number of synthetic fertilisers and, as the population of the world at the beginning of the 20th century was rapidly increasing, the demand for fertilisers to promote the growth of crops was also on the rise. Haber worked to determine the best conditions for the reaction of hydrogen and nitrogen to make the ammonia, whereas Bosch, as an engineer, was able to scale up Haber's laboratory methods into an industrial process. This work enabled the economically viable production of synthetic fertilisers, which resulted in the survival of millions of people.



→Fig 7.49 Chlorine gas was first used as a weapon in World War I.

It was during this time, when he was 33 years of age, that Fritz Haber married Clara. Together, they had one son, Hermann, who would also grow up to be a chemist. In 1918, Fritz was awarded the Nobel Prize for Chemistry for this work, but before this happened his life and work took a tragic turn.

During World War I, Haber supported the German military effort. Not only were large amounts of the ammonia produced using his process being used to produce explosives, but Haber was also instrumental in designing ways to produce chlorine gas as a chemical weapon. Haber himself supervised some of the first uses of chlorine gas on the battlefields during the war. In 1915, one such attack killed 5000 French soldiers at Ypres, Belgium. It was Haber's celebration of this event that was the last straw for Clara, who had always opposed Fritz's use of science for the purposes of war. It was on this night that she took her own life. The next day Haber returned to his work with the military. He went on to help produce the poison gas Zyklon A, which was refined by the Nazis to produce Zyklon B, which was used to kill thousands of Jewish people in the gas chambers during the Holocaust.

Clara's husband eventually died at 65 years of age, having been driven out of Germany due to his opposition to the actions and philosophies of the Nazi regime, especially in relation to the treatment of Jews. But he was also shunned by many in the scientific community for his work with chemical weapons.

Your task

1. Describe how the needs of society at the time influenced the work of Fritz Haber.
2. Describe how the values and conventions of society at the time influenced the work of Clara Immerwahr.
3. If Fritz Haber's mother had survived to watch her son grow up, what do you think her opinion of him would have been? Do you think he was a good scientist?

The Haber process

Ammonia is produced in the reaction of hydrogen gas and nitrogen gas. The reaction is a reversible process and can be represented as shown here:

$$N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g)$$

It is possible to speed up the reaction by heating it, increasing the pressure of the gases and by using a catalyst. Unfortunately, what scientists found was that if the temperature and pressure were increased too much, the reverse reaction (i.e. ammonia being converted back into nitrogen and hydrogen) also occurred and it was hard to collect enough ammonia. After years of painstaking trials, Haber was able to determine the exact conditions that would produce a fast enough reaction to produce ammonia without the ammonia turning back into the starting materials. These conditions consisted of temperatures between 300°C and 550°C, with a pressure of approximately 200 atm (200 times normal air pressure). An iron catalyst was found to speed up the reaction.



Fig 7.50 Huge quantities of ammonia are produced in Australia each year.



Australia produces large amounts of ammonia each year, with the largest ammonia plant in Australia situated on the Burrup Peninsula in Western Australia. The worldwide production of ammonia is huge, with more than 100 million tonnes of ammonia currently being produced each year. An amazing fact is that half of all the nitrogen-containing proteins in the average human body have been generated from nitrogen compounds made through the Haber process.

Your task

1 Look at the equation for the Haber process.

$N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g)$

a What type of reaction is the forward reaction? Justify your answer.

b What type of reaction is the reverse reaction? Justify your answer.

2 Conduct research to locate the Burrup Peninsula. What type of environmental concerns would need to be addressed at this site?

3 Chlorine was used as a chemical weapon in World War I. Describe two uses of chlorine in society today.

4 Use your knowledge of the collision theory to explain why, in the Haber process, increasing the pressure of the gases increases the rate of the reaction.

5 Using your knowledge of the collision theory, explain why, in the Haber process, the iron catalyst used is in the form of a powder or fine mesh.



→ Fig 7.51 Many of the fertilisers used nowadays have been manufactured from compounds containing ammonium salts.

glossary

A

absolute magnitude scale scale for measuring the brightness of objects at the same distance

absorption spectrum spectrum with lines missing from the pattern; opposite of an emission spectrum because the element has absorbed its characteristic light wavelengths and removed them from the spectrum

acceleration rate of change of velocity; rate of change of speed if the motion is in a constant direction

acceleration due to gravity (*g*) acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8$ or $10\ m/s^2$

acid rain forms when raindrops dissolve pollution in the air and carry it to the ground; if the pollution is acid, then the rain will also be acid. Acid rain can dissolve limestone, marble buildings and statues, it can destroy forests and it can make lakes and rivers so acidic that fish and plants die

acquired characteristic characteristic developed during the life of an organism from a change in that organism

adaptation characteristic or behaviour of a species that allows it to survive and reproduce more effectively

alkali metals elements found in group 1 of the periodic table; have one electron in the valence shell

alkaline earth metals elements found in group 2 of the periodic table; have two electrons in the valence shell

allele different form of a gene

analogous structure structures in organisms that perform the same function but are structurally different

anemometer instrument that measures wind speed

apparent magnitude scale scale for measuring the brightness of an object when viewed from Earth

asteroid large rocky object in space, smaller than a planet but larger than 10 km in diameter

atmosphere layer of gases that surround the Earth

atomic number number of protons in the nucleus of an atom

autosome any chromosome that is not a sex chromosome

barometer instrument that measures atmospheric pressure

B

Big Bang theory theory that the Universe began from a hot, dense state at some time in the past, from when it has continued to expand and will continue to do so into the future

biosphere all the living things on Earth

black dwarf remnant formed when a white dwarf star cools and gradually fades away

black hole region in space of infinite density where gravity is so large that nothing can escape from it, including light itself

blue shift apparent increase in frequency (towards the blue end of the spectrum) of light from galaxies that are moving towards the Earth

C

carbon nanotube form of carbon molecule with a cylindrical nanostructure

carbon sink any feature of the environment that absorbs and/or stores carbon

catalyst substance that increases the rate of a reaction but is not used up in the reaction

chromatid individual strand in a duplicated chromosome

chromosome structure in a cell nucleus that carries the genes; each chromosome consists of one very long strand of DNA, tightly wound

climate weather conditions at a particular place over a long period of time based on the collection and analysis of large amounts of data

climate change any long-term change in the Earth's weather; it can be evident in changes to averages, extremes or other statistical measures

clone genetically identical organism

collision theory theory that states the particles involved in a chemical reaction must collide in order to react

combustion reaction that involves oxygen and releases light and heat energy

comet rocky body made of dust and ice that orbits the Sun; when near the Sun, has a 'tail' of gas and dust particles that point away from the Sun

constellation grid-like segment of the stars in the sky; older definition was a group of stars that appear to form a pattern

Coriolis effect influence of the Earth's rotation on the direction of air or water movement

cosmic microwave background (CMB) radiation form of electromagnetic radiation in the microwave spectrum left over from the formation of the Universe; evidence for the Big Bang theory

covalent bonding bonding formed when two atoms share one or more pairs of electrons

cryosphere part of the hydrosphere that is made up of frozen water

D

deceleration describes slowing down; also known as negative acceleration

decomposition reaction that involves the breakdown of a compound into simpler substances

delocalised electrons electrons that are free to move around the structure of a metal

denitrifying bacteria bacteria able to return nitrogen back into the atmosphere

deoxyribonucleic acid (DNA) complex giant molecule that controls all the various functions in a cell; usually organised into chromosomes and contained in the cell nucleus

diatomic molecule molecule made up of two atoms

diploid two copies of each specific chromosome; somatic cells are diploid

directional selection process of natural selection that favours a particular phenotype

displacement vector quantity that measures the change in position of an object and its direction over a certain period of time

DNA fingerprint the DNA profile for an individual; it is unique, like a person's fingerprints

dominant allele one that is always expressed

Doppler effect apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

double helix shape of a DNA molecule consisting of two strands that twist around each other creating a 'twisted ladder'

E

earthquake jolting of the Earth's surface caused by the release of built-up pressure in the Earth's plates

ecologist scientist who studies the interaction between living things and their environment

elastic potential energy (EPE) energy possessed by stretched or compressed objects

electrolysis use of electricity to provide energy for a chemical reaction

electron configuration arrangement of electrons in an atom that considers how many energy levels and how many electrons are in each level

emission spectrum pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

eutrophication process whereby excessive levels of phosphorus in our waterways lead to the excess growth of algae and bacteria and an increased consumption of oxygen, suffocating fish and other aquatic animals

evolution gradual change in the genetic material of a population of organisms over a period of time

G

galaxy huge collection of billions of stars held together by their own gravity

gamete sex cell; in humans, the sperm and egg

gene section of a DNA molecule that contains information for one characteristic

gene locus position of a gene on a chromosome

gene pool all the genes or alleles in the entire population

genetic engineering process of modifying genes in some way

genome full set of genes in a species

genotype symbolic representation of a pair of alleles

geologist scientist who studies the origin, composition, structure and history of the Earth

gravitational potential energy (GPE) energy possessed by objects raised to a height in a gravitational field

greenhouse effect absorption of heat energy by gases in the atmosphere

greenhouse gas gas that traps some heat inside the Earth's atmosphere

group vertical column in the periodic table

H

halogens elements found in group 17 of the periodic table; have seven electrons in the valence shell

haploid one copy of each specific chromosome; gametes are haploid

Hertzsprung–Russell diagram graph displaying star data with spectral class or star temperature on the *x*-axis and absolute magnitude on the *y*-axis

heterozygous when the alleles are different (e.g. *Bb*)

homologous chromosomes corresponding pairs of chromosomes

homologous structure structure that is found across organisms and has a similar plan but different function

homozygous when both alleles are the same; also known as pure breeding

hybrid organism containing heterozygous alleles for the characteristic being studied

hydrosphere collection of all the Earth's water

I

impulse product of the average force and time in a collision; also known as change in momentum

inertia tendency of an object to resist changes in its motion while either at rest or in constant motion

ion atom or group of atoms that is either positively or negatively charged as a result of the loss or gain of electrons

ionic bonding bonding formed between positively and negatively charged ions

ionic compound substance composed of positively and negatively charged ions

isobar line drawn on a weather map that joins places of equal air pressure

isolation division of a population into two groups

K

kinetic energy (KE) energy possessed by moving objects

L

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

law of conservation of mass scientific law that states the total mass of the reactants in a chemical reaction always equals the total mass of the products

law of conservation of momentum scientific law that states the total momentum in an isolated system does not change during a collision

light year distance that light travels in 1 year

lithosphere outermost rocky layer of the Earth, consisting of the mantle and crust

living fossil existing species of ancient lineage that have remained unchanged in form for a very long time

M

magma chamber region under a volcano that acts as a source of molten rock for a volcano

main sequence narrow diagonal band on a Hertzsprung–Russell diagram that includes most stars, as well as the Sun, running from top left of the graph to the lower right

Material Safety Data Sheet (MSDS) document that describes the properties of a substance, provides advice on its safe handling and gives guidance in first aid

meiosis process of cell division whereby the number of chromosomes in the cell is halved; its primary purpose is to produce gametes

metalloids elements found along the diagonal boundary between the metals and non-metals in the periodic table; exhibit properties between those of metals and non-metals

metals class of chemical elements with similar properties; lustrous, good conductors of heat and electricity, malleable and ductile; divided further into groups

mitosis process of cell division to provide growth or repair

molecular compound compound that consists of discrete molecules (e.g. water)

momentum product of an object's mass and its velocity

monohybrid cross genetic cross between two hybrids when one (mono) characteristic is being studied

monomer small molecule from which polymers are made

mutation change that occurs at the DNA level that may add, delete or rearrange genetic material

N

nanotechnology building of devices on an atomic and molecular scale

natural selection process whereby the occurrence of a particular trait in a population changes as a result of certain individuals producing more offspring than others because they are better suited to survive and reproduce in that environment

nebula cloud of gas and dust in space

net force vector sum of all the forces acting on an object; also known as resultant force

neutron star small, highly dense star, made mostly of neutrons

nitrogen-fixing bacteria bacteria able to convert nitrogen from the atmosphere into various nitrogen compounds

noble gases elements found in group 18 of the periodic table; have eight electrons in the valence shell except helium, which has two

non-metals element that does not show the set of properties common to all metals

nucleotide complex unit that makes up DNA; made up of three parts: a nitrogen base, a five-carbon sugar and a phosphate group

O

oxidation reaction that involves the combination of oxygen with a fuel or metal

ozone form of oxygen consisting of three oxygen atoms; absorbs ultraviolet light in the atmosphere that would otherwise be harmful to humans

P

palaeontologist scientist who studies fossil records and determines their relationships with different geological time periods

pedigree chart showing the phenotypes for an individual and its ancestors, usually over several generations; also known as a family tree diagram

pentadactyl limb limb with five digits

period horizontal row in the periodic table

periodic table table of the elements where they are arranged in order of increasing atomic number

permafrost permanently frozen ground

phenotype description of a characteristic (e.g. black hair)

photolysis breakdown of a chemical substance by light, one example being the breakdown of water into oxygen and hydrogen

planetary nebula glowing shell of gas formed when stars die

pollutants chemical substances that are in the wrong place or are present in the wrong amounts

polyatomic ion ion made up from more than one atom

polymer giant molecule formed by the joining of many smaller repeating molecules (monomers) together

population group of interacting individuals of a species living in a particular area

precipitate insoluble compound formed in a precipitation reaction

precipitation reaction that is used to produce solid products from solutions of ionic substances

R

reaction rate how fast or slow a reaction proceeds

recessive allele only expressed in the absence of the dominant allele

red giant large, bright star with a cool surface that forms when a star like our Sun runs out of hydrogen fuel

red shift apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

reduction reaction that involves the removal of oxygen

reversible reaction chemical reaction that can also occur in reverse

S

scalar quantity that only has size (e.g. speed, distance)

selective breeding choosing which organisms to breed in order for offspring to have particular desired characteristics

sex chromosome chromosome that differs between the sexes and determines the sex of the individual; XX in human females and XY in human males

sex linked characteristic that is coded for by a gene located on a sex chromosome

sexual dimorphism difference in appearance of males and females of the same species

sexual selection selection for traits that provide an advantage with regard to mating

shell diagram diagram used to represent the electron configuration of an atom

speciation process that results in the creation of a new species

species organisms that can reproduce sexually to produce offspring that are viable and fertile

spectral class group that a star belongs to based on its temperature

speed distance travelled per unit of time

Steady State theory theory that the Universe has always existed and that matter is constantly being created at an enormous rate, causing the Universe to expand

stellar parallax change the apparent position of a star against its background when viewed from two different positions

stem cell general cell that has the ability to change into many different types of specialised cell

supernova explosive death of a star

survival of the fittest individuals in a population that are 'fitter' or better suited to survive and reproduce in their environment contribute more to the next generation than those that are less 'fit'

synthesis reaction that involves the building up of compounds by combining simpler substances, normally elements

T

tectonic plate large area of the Earth's crust that may include continent and/or sea floor

ticker timer laboratory device commonly used to measure the speed of objects

transcription process of making a copy of DNA

transition metals elements found in groups 3–12 of the periodic table; have special properties that are not shown by group 1 or 2 metals

transitional fossil fossil or organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

V

valence shell outermost occupied shell of an uncharged atom

vector quantity that has size and direction (e.g. velocity, displacement)

vector diagram diagram where individual vectors (e.g. forces) are joined head-to-tail in order to determine the overall effect

velocity vector quantity that measures speed in a particular direction

volcano crack or hole in the Earth where molten rock, ash and gases can escape onto the surface

W

weather snapshot of what the air and conditions are like in any one place on Earth at any one time

weight force of gravity acting on an object

white dwarf small, hot star that forms when a star like our Sun runs completely out of fuel and slowly fades and cools

work occurs whenever an object is moved by a force

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acknowledgements

The research and development of the Oxford Big Ideas pedagogy was a process that involved many people. We would like to acknowledge them here:

Kristin Alford, Erin Bruns, Francesca Calati, Debbie Calder, Amanda Clarke, Craig Cleeland, Leanne Compton, Gillian Coyle, Emma Craven, John Denmead, Ellaine Downie, Karen Drought, Teresa Eva, Anita Giddings, Christina Hart, Rosemary Koina, Greg Laidler, David McGowan, Karen Marangio, Daniela Nardelli, Rebecca Paton, Peter Razos, Pam Robertson, Duncan Sadler, Maggy Saldais, Lynda Schulz, Nola Shoring, Helen Silvester, Jonathan Smith, Angela Stubbs, Mary Vail, Richard Walding, David Wilson. Students and staff at: Koonung Secondary College, Mentone Girls' Grammar School, Rosehill Secondary College and Wantirna Secondary College for participating in location photography.

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Photos: **AAP Image**, Fig 4.3, p. 172/ AFP, Fig 3.33/ AP Photo/ Javier Galeano, Fig 5.36/ EPA / Mike Trenerry, Fig 3.54 (c)/ Department of Primary Industries, Fig 3.59/ Native Fish Australia/ Michael Hammer, Fig 3.63/ Roderick Eime, Fig 5.25 bottom/ Supplied, Fig 5.87/ Kyodo News, Fig 3.8/ AP Photo/ Ronen Zilberman, Fig 4.67; **AKG Images**, Fig 6.5; **Alamy**/ Interfoto, Fig 7.48/ NASA, p. 73 (background)/ Tony Cordoza, Fig 7.15 right; **Ardea**/ John Cancalosi, Fig 3.56; Bureau of Meteorology, Fig 3.37 (b), p. 106 top/ MTSAT-1R satellite received and processed by **Bureau of Meteorology** courtesy of Japan Meteorological Agency, Fig 3.37 (a); **Burrup Fertilisers** Pty Ltd 2011, Fig 7.50; **Caltech Archives**, Fig 4.49; **Corbis**, Fig 4.79, Fig 5.15/ Roger Ressmeyer, Fig 2.17/Mark Garlick/Science Photo Library, Fig 2.14/ Karen Huntt, Fig 5.74/ Alberto Garcia, Fig 3.12/ Andy Rain/epa, Fig 5.12/ Bettmann, Fig 1.40, Fig 5.1, p. 178 top, Fig 5.10, p. 188 top, Fig 7.49/ Bob Krist, Fig 3.3, p. 109 top, p. 124 top/ Boris Roessler/dpa, Fig 2.62/ Carolina Biological/ Visuals Unlimited, Fig 5.67 left and right/ Caroline, Fig 7.5/ Darrell Gulin, Fig 5.63 (b)/ David Scharf/Science Faction, Fig 3.21/ David Watts/ Visuals Unlimited, Fig 5.28/ Dean Conger, Fig 7.7 (a)/ Dennis Kunkel Microscopy, Inc./Visuals Unlimited, Fig 4.47/ DLILLC, Fig 5.8, Fig 5.13 left, Fig 5.32/ Dr. David Phillips/Visuals Unlimited, Fig 4.48/ Frans Lanting, Figs 5.23, 5.83/ Fridrik Orn Hjaltested/ Nordicphotos, Fig 4.30/ George Steinmetz, Fig 6.23/ Hulton-Deutsch Collection, Fig 5.16/ Ian Murray/ Loop Images, Fig 3.30/ Jamal Nasrallah /epa, Fig 2.30/ Jim Borrowman/ All Canada Photos, Fig 5.68/ Jim Craigmyle, Fig 6.2/ Jim Craigmyle, p. 237/ Joe McDonald, Fig 5.63 (a)/ John Carnemolla, Fig 4.46 (tasmanian tiger)/ Jose Luis Pelaez, Inc./ Blend Images,

Fig 7.42/ Juice Images, p. 275 (bread)/ Karen Kasmauski, Fig 4.60, Fig 4.75/ Leo Mason, Fig 1.28/ M. Neugebauer, Fig 7.19/ Marcel Lam/Arcaid, Fig 7.18/ Markus Cuff, Fig 5.24/ Mike Kemp/ Tetra Images, p. 281/ Moodboard, Fig 5.38/ Najlah Feanny/ Corbis Saba, Fig 4.46 (sheep)/ NASA, Fig 3.53/ Ocean, Fig 6.21, Fig 7.39/ Paul A. Souders, Fig 5.30/ Philip Evans/ Visuals Unlimited, Fig 7.4, p. 286/ Robert Francis/Robert Harding World Imagery, Fig 3.13/ Ron Watts, Fig 7.2, pp. 275, 287/ Scott Andrews/ Science Faction, Fig 7.37/ Stocktrek Images, Fig 2.55/ Takashi Katahira/ Amanaimages, Fig 2.4/ Tim Davis, Fig 3.54 (a)/ Tim Hauf/ Visuals Unlimited, Fig 5.85/ Tom Van Sant, Fig 2.51/ Udo Richter/ epa, Fig 5.25 top/ Visuals Unlimited, Chapter 6 (1820s), Fig 6.7/ Visuals Unlimited/ Theodore Gray, pp. 224 left, 230/ W. Wisniewski, Fig 5.20/ Xu haihan/ Imaginechina, p. 257 (rocket)/ Zhang Jiansong/ Xinhua Press, Fig 3.16; **SA Department of Environment and Natural Resources**/ Steven Bourne, Fig 3.65; Photo courtesy of Dick Walker and **Gilbert's Potoroo Action Group**, Fig 3.67; **European Space Agency**/ Image by AOES Medialab, Fig 2.18, Fig 2.40; **Faber & Faber Ltd**, chapter 2 - Systems in space (book cover); **Fairfax Photos**/ Craig Abraham, Fig 3.32/ Peter Mathew, Fig 3.46/ Glen Hunt, Fig 3.51/ Glen McCurtAyne, Fig 2.42 (Penny)/ Paul Harris, Fig 2.42 (Brian); **Gemini Observatory**/ AURA, Fig 2.44, chapter 2 - Systems in space (nebula); **Getty Images**/ Michael Rosenfeld, p. 271/ Klavs Bo Christensen, Fig 3.1, pp. 88 top, 97 top/ AFP, Fig 4.46 (dogs)/David Greedy/ Stringer, Fig 4.69/ Ben Cranke, Fig 3.48/ Norbert Wu, Fig 5.40/ Science Photo Library, Fig 7.28/ AFP, Fig 5.11/ Antony Spencer, Fig 2.52/ Bloomberg, Fig 4.68/ Charles D Winters, Fig 7.9/ Charles D Winters, Fig 7.21/ Dave Einsel/ Stringer, Fig 5.86/ Eve Parry, Fig 5.51/ French School, Fig 2.38/ Image Source Ltd, Chapter 4 - Zooming in on DNA/ Jason Edwards, Fig 1.20/ Jesse Swallow, Fig 7.36/ Jon Hicks, Fig 7.40/ Lambert, Fig 7.29/ Louie Psihoyos, Chapter 1 - Finding out about inertia/ Louie Psihoyos, Fig 5.50/ Medioimages/ Photodisc, Fig 1.48/ National Geographic, Fig 5.3, pp. 200 left, 218/ Radius Images, Fig 7.7 (b)/ Reza Estakhrian, Fig 1.45/ Romilly Lockyer, Fig 1.33/ Science Photo Library, Fig 7.3/ Science Photo Library, p. 288 top, p. 297/ Sebastion, Fig 2.29/ SM/ Aiueo, Fig 1.39/ Steve Allen, Fig 5.19/ Steve Cole, Fig 4.80/ Steve Munsinger, Fig 5.79/ Tim Flach, Fig 5.34/ Tui De Roy, Fig 5.48/ Tyler Stableford, Fig 1.2, p. 19 top/ WireImage, Fig 1.1, pp. 4 left, 18, 27/ NLM/ Science Source, Chapter 4 - An incredible woman; **Hawk-eye Innovations**, Fig 1.8; **Heidas**. 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Hartmann, Courtesy of UCLA; image-NASA/MCREL, Fig 2.49/ ESA, and D. Maoz (Tel-Aviv University and Columbia University), Fig 2.26/ESA, and The Hubble Heritage Team (STScI/AURA), Fig 2.12/ESA, CXC, JPL-Caltech, J. Hester and A. Loll (Arizona State Univ.), R. Gehrz (Univ. Minn.), and STScI, Fig 2.10/ CXC/ NCSU/ S.Reynolds et al., Fig 2.64/ ESA, Fig 2.27/ JPL/ USGS, Fig 2.58/ Solar Dynamics Observatory, Fig 2.66/ ESA/ Hubble Heritage, Fig 2.25/ X-ray: NASA/ CXC/ SAO, Infrared: NASA /JPL-Caltech; Optical: MPIA, Calar Alto, O.Krause et al., Fig 2.31/Yuri Beletsky, Fig 2.2, pp. 56 top, 67; **Newspix**/ Colin Murty, Fig 6.41/ Collen Petch, Fig 7.35/ Darren Tindale, Fig 4.38; **DeepSeaPhotography.Com**/ Peter Batson, Fig 3.20; **Photolibrary**,

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AUSTRALIA & NEW ZEALAND

ISBN 978-0-19-557358-9
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