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Cambridge science for the Victorian Curriculum 10

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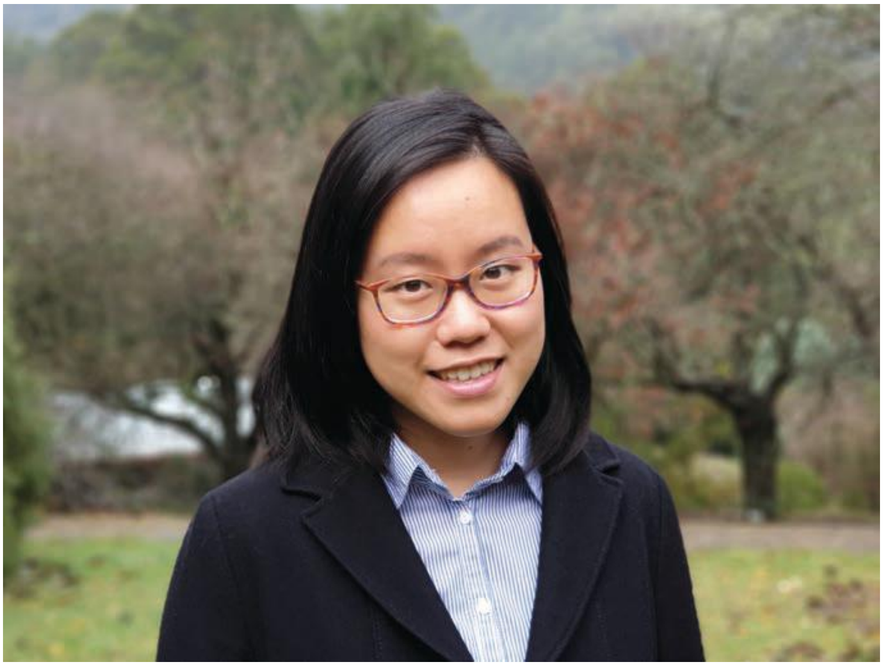
Welcome



From a young age, I found joy in studying and understanding the natural world. Science made sense and, unlike languages, the same laws of nature were applicable all over the world. I knew I wanted to work in an area related to science, so at the end of Year 10, I decided to take Physics, Chemistry and Mathematical Methods in VCE. This allowed me to do an undergraduate degree in biomedical science, in which I learned that I could not handle anatomy – goodbye medical career! However, I did discover that I loved maths and physics, so I pursued a master of engineering. Through the degree and various volunteering opportunities, I discovered my passion for education. Now I apply my engineering skills to the educational publishing field where I manage print and digital science resources for teachers and students.

Science was never the end goal, but it was the way in which I discovered all the things that I was good at and passionate about. You might have a solid idea of what you want to do in life, for which I congratulate you – keep it up! But if you don't know where you are headed, then I encourage you to keep embracing new experiences, choose to work hard through the struggles and develop your skills in whatever area of interest brings you excitement and joy.

Naomi Sutanto is a science publisher at Cambridge University Press. She graduated from her Masters of Engineering degree with first class honours, and her final year project investigated how thermal imaging could be used in preventive measures for pressure sores in wheelchair clinics. Naomi and her project partner won the departmental award for best project. During her degree, she volunteered for Engineers without Borders and was an ambassador for the Melbourne School of Engineering, which involved sharing her experiences and helping run engineering workshops for high school groups. She has also studied abroad in Beijing, China, and Delft, the Netherlands.

In her spare time, Naomi enjoys meals with friends, reading books like *Freakonomics* while curled up uncomfortably in a corner, and bushwalking on very flat ground.

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Dr Eddy de Jong has been involved with science and physics education at the secondary and tertiary level for many years. He has taught science at all levels, senior HSC/VCE Physics and university physics. He was involved in the Victorian Gifted Students Physics Network, was a Physics Study Design writer with VCAA, and is currently chair of the VCE Physics Examinations Panel. He is a successful author of numerous science and physics texts. He is passionate about seeing young minds engaging with science and physics and aims to instil in students a sense of curiosity while developing their critical thinking skills.

Kerrie Ardley

Kerrie Ardley has taught a variety of junior and VCE sciences throughout her teaching career. Currently, she is the Head of Psychology at an independent school, and she also holds a position as a VCAA assistant chief assessor. Kerrie enjoys teaching junior science and seeing students learn through making connections between theory, practical work and the world around us.

Emma Bone

Emma Bone thrives on the dynamic and practical nature of science, which led her to a first class honours in biomedical science. Her desire to enable students to maximise their potential brought about a career as a science teacher in Australia and in the United Kingdom. In the UK she was also a chemistry specialist, teaching both GCSE and A level courses.

Victoria Shaw

Victoria Shaw has been committed to sharing her love for science with Year 7–12 students for the past 18 years, having previously studied pharmacology. She was Head of Science at an independent school for a few years and volunteers as an educator for Wildlife Victoria. Victoria has also been an assessor for the VCAA and IBO and runs workshops in biology and psychology.

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Jonathan Blair graduated from the University of New South Wales with a Bachelor in Science, majoring in Pharmacology. He has worked in both research and commercial laboratories, specialising in cardiac regeneration and vaccine manufacturing, respectively. Jonathan is currently working as a laboratory technician for an independent school.

Erin Checkley

Erin Checkley has taught biology, junior science and mathematics at a Catholic secondary college for the past six years. During her Masters of Education at The University of Melbourne, she developed a passion for curriculum development, and she aims to instil a sense of curiosity and critical thinking skills in students. Erin previously worked as a cardiorespiratory and sports physiotherapist.

Sarah Chuck

Sarah Chuck teaches science in Years 7–10. She completed a biomedical science degree at Monash University and a Masters of Teaching Practice at RMIT. During her studies, Sarah worked in a genetics laboratory at the Australian Regenerative Medicine Institute modelling disease in organisms such as the zebrafish. She hopes students will find their experiences in science to be extremely interesting and rewarding.

Laura Swann

Laura Swann completed bachelor degrees in science and education at Monash University and has been teaching Years 7–12 for 13 years. Her passion is teaching physics, and she also enjoys conducting physics lessons with primary and ELC students. She has been an assessor for the VCAA and hopes to continue inspiring young people to pursue their interests in science.

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How to use this book

Overview of the print book

Did you know?
These are short facts that contain interesting information.

Quick check
These provide quick checks for recalling facts and understanding content.

Explore!
Students are encouraged to conduct research online to find and interpret information.

Try this
These are short activities to explore concepts that are currently being covered.

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

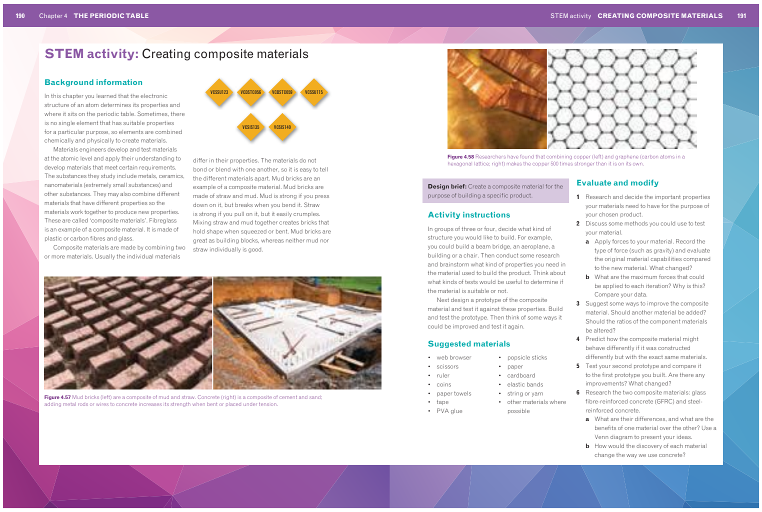
VIDEO
Videos are found in the Interactive Textbook.

WIDGET
Widgets are found in the Interactive Textbook.

Practical
Practical investigations consolidate student learning.

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

Section questions
Review questions to check students' understanding and application of the section content.



STEM activities encourage students to collaboratively come up with, design and build solutions to problems and challenges.

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Overview of the Interactive Textbook (ITB)

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

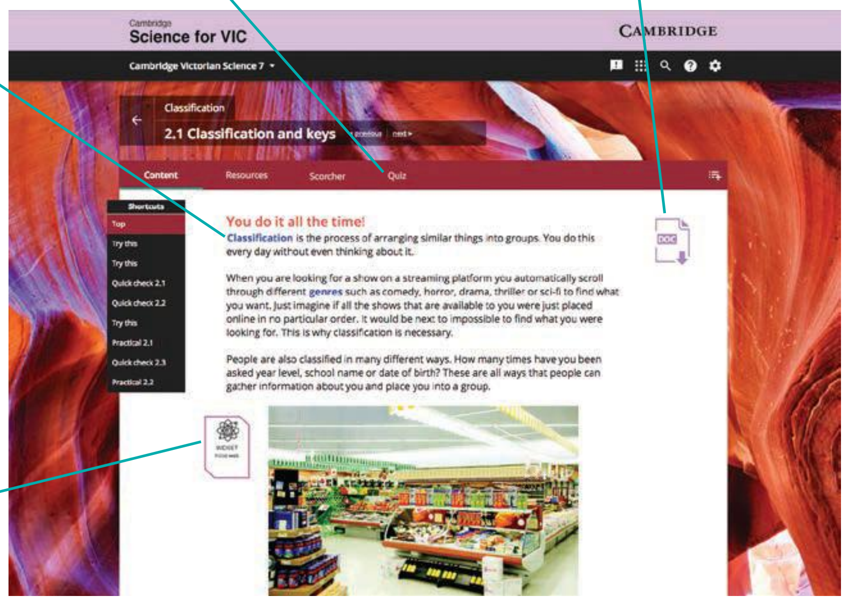
Definitions pop up for key terms in the text

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

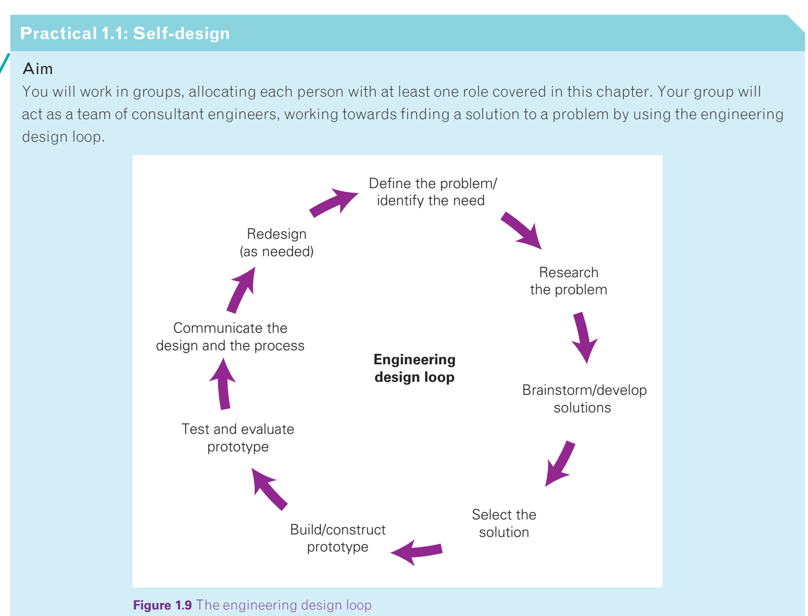
Worksheets are provided as downloadable Word documents

Videos summarise, clarify or extend student knowledge

Widgets are accompanied by questions that encourage independent learning and observations



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


Practical 1.1: Self-design

Aim

You will work in groups, allocating each person with at least one role covered in this chapter. Your group will act as a team of consultant engineers, working towards finding a solution to a problem by using the engineering design loop.

Figure 1.9 The engineering design loop

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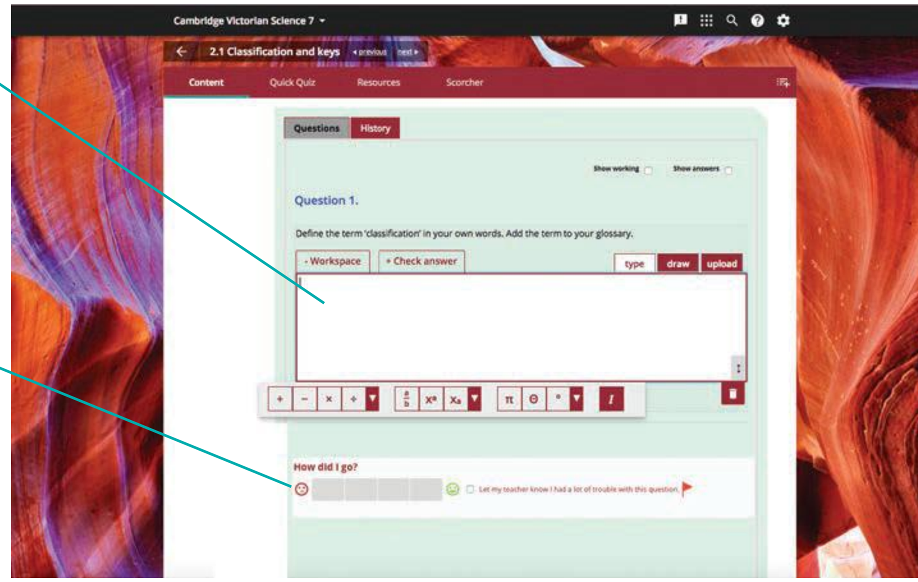
Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

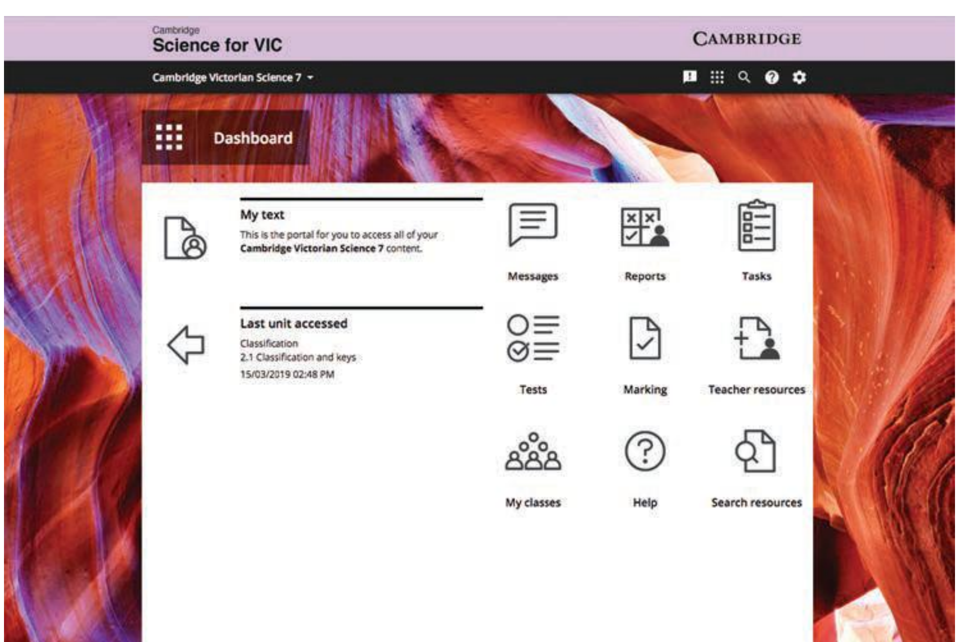
Self-assessment tools enable students to check answers, mark their own work, and rate their confidence level in their work. This helps develop responsibility for learning and communicates progress and performance to the teacher. Student accounts can be linked to the learning management system used by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



Overview of the Online Teaching Suite (OTS)

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

- **The Edjin learning management** system with class and student analytics and reports, and communication tools.
- Teacher's view of a **student's working and self-assessment**.
- **Chapter tests** and **worksheets** with answers as PDFs and editable Word documents.
- Editable **curriculum grids** and **teaching programs**.
- **Teacher notes** and downloadable Word document **guides** to Practicals and STEM activities.



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Chapter 1 Skills

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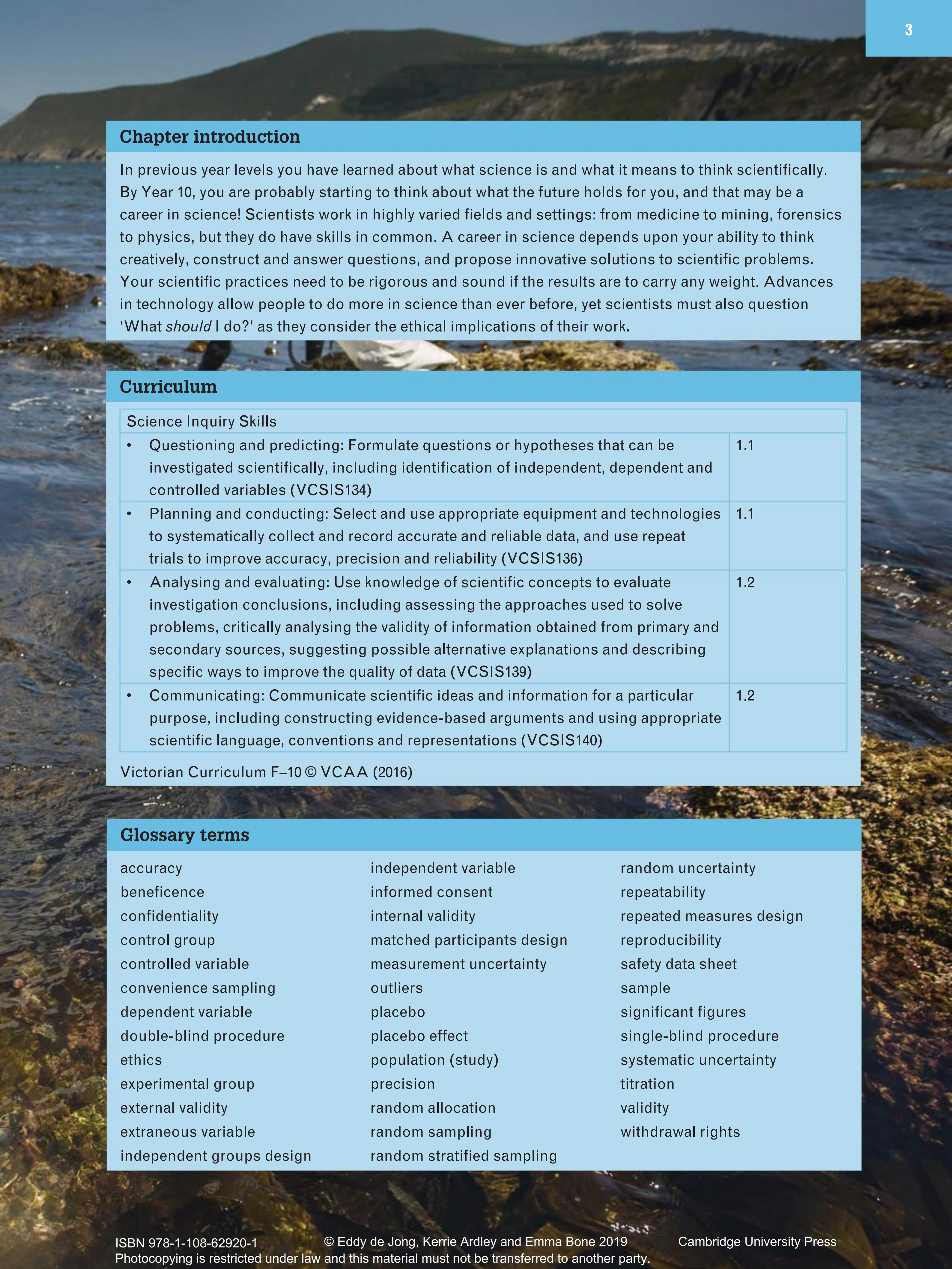

Chapter introduction

In previous year levels you have learned about what science is and what it means to think scientifically. By Year 10, you are probably starting to think about what the future holds for you, and that may be a career in science! Scientists work in highly varied fields and settings: from medicine to mining, forensics to physics, but they do have skills in common. A career in science depends upon your ability to think creatively, construct and answer questions, and propose innovative solutions to scientific problems. Your scientific practices need to be rigorous and sound if the results are to carry any weight. Advances in technology allow people to do more in science than ever before, yet scientists must also question 'What *should* I do?' as they consider the ethical implications of their work.

Curriculum

Science Inquiry Skills	
• Questioning and predicting: Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables (VCSIS134)	1.1
• Planning and conducting: Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability (VCSIS136)	1.1
• Analysing and evaluating: Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data (VCSIS139)	1.2
• Communicating: Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (VCSIS140)	1.2

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Glossary terms

accuracy
beneficence
confidentiality
control group
controlled variable
convenience sampling
dependent variable
double-blind procedure
ethics
experimental group
external validity
extraneous variable
independent groups design
independent variable
informed consent
internal validity
matched participants design
measurement uncertainty
outliers
placebo
placebo effect
population (study)
precision
random allocation
random sampling
random stratified sampling
random uncertainty
repeatability
repeated measures design
reproducibility
safety data sheet
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significant figures
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1.1 A career in science

WORKSHEET

This section addresses some aspects of a career in science: from how to generate a research hypothesis to learning safe and accurate experimental methods and communicating your findings with the world.

Remember from Year 9 Science that all scientific investigations should follow the scientific method framework.

STEP 1: OBSERVE AND ASK QUESTIONS
A research question may be identified once an area of scientific interest has been analysed.

↓

STEP 2: DO BACKGROUND RESEARCH
A scientist who is interested in conducting an experiment on a certain topic of interest will first search relevant scientific literature.

- This requires the ability to find and analyse past research articles and results.

↓

STEP 3: CONSTRUCT HYPOTHESIS
A hypothesis is a testable prediction about the relationship between two or more variables. It is formulated using the scientific knowledge obtained from the scientific literature. It is not just simply a haphazard guess without any prior knowledge – it is more of an educated guess.

↓

STEP 4: TEST BY CONDUCTING AN EXPERIMENT
An experiment may include controlled laboratory experiments, naturalistic observations, case studies, surveys and interviews. Conducting the experiment requires a specific methodology. The method usually contains at least two sections:

- Materials (lists the scientific apparatus required to conduct the experiment); and
- Method (a step-by-step procedure of how the experiment is conducted).

If human participants are used in the experiment, it also needs to include a section on participants (this states how many were used, gender, age ranges, how the participants were sampled, and the research design used). Ethics approval may need to be sought.

↓

STEP 5: GATHER DATA
Data collection is of utmost importance in any scientific experiment. This step involves organising, summarising and representing the data that was collected in the experiment (raw data) in a meaningful way. Generally, descriptive statistics are used to organise and summarise the data. Graphs and tables can be used to represent the data; calculation of means, medians or modes can be used to summarise the data.

↓

STEP 6: ANALYSE THE DATA
The tables and charts of data then need to be examined. Analysing data can reveal relationships, trends and patterns. The meaning of each of the results should be summarised.

↓

STEP 7: EVALUATE HYPOTHESIS
This step involves drawing conclusions relating back to the hypothesis using the data to back up the conclusions. Inferential statistics are needed to infer from the data and draw valid conclusions.

↓

STEP 8: REPORTING THE RESULTS
A scientific report is completed to document the research and share the finding with other scientists. Common methods used to report the research findings include: practical reports, oral presentations and poster presentations.

Figure 1.1 Scientific method framework

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From question to hypothesis: the importance of experimental variables

Let's say you have your research question: Does sleep deprivation influence stress levels?

You have done the necessary background research and have started to come up with some hypotheses. Before you can perform an experiment, you must first construct an appropriate hypothesis. To do this, you must identify the research variables.

Recall from Year 9 that the **independent variable** (IV) is what is being manipulated by the experimenter in the experiment (that is, it is the key difference in conditions between the control and experimental groups). You can further extend your understanding of the IV by 'operationalising' it. This means, you need to state exactly how it will be manipulated or measured. For example, if the independent variable within an experiment is sleep deprivation, then you need to define exactly what you mean. The two experimental conditions of the operationalised IV could be documented as amount of sleep (sleep deprivation = receiving less than six hours of sleep per night for one week; normal sleep = receiving more than six hours of sleep per night for one week).

independent variable the variable which is systematically manipulated or changed in order to investigate its effect on the dependent variable

The **dependent variable** (DV) is what is being measured in the form of the results of the experiment. You need to identify the DV and then operationalise it by stating precisely how it will be measured. For example, in the experiment mentioned, stress level is the DV, and it might be operationalised as the score on a rating scale of stress levels ranging from 0 to 10, with 10 being highest levels of stress and 0 representing no stress at all.

dependent variable the variable that is measured to see if the independent variable has had an effect

Extraneous variables refer to any variable other than the independent variable (IV) that can affect the dependent variable (DV) and thus affect the experiment in an unwanted way. The presence of extraneous variables makes it difficult to conclude that the change in the DV was solely caused by the change in the IV. Scientists seek to minimise extraneous variables through precise research design and accurate procedures. When a potential extraneous variable is eliminated by keeping it constant, it is referred to as a **controlled variable**.

extraneous variable a variable other than the independent variable that can affect the dependent variable and thereby affect the experiment in an unwanted way

controlled variable an extraneous variable that is kept constant so as not to affect the dependent variable during an experiment

Once you have identified and operationalised the experimental variables, a hypothesis can be constructed using the 'if … then … when' approach (Table 1.1).

Construct a hypothesis (a–f)					
a →	b →	c →	d →	e →	f
If (the DV)	relationship phrase (to the IV)	**then**	trend indicator (effect on the DV)	**when**	trend indicator (action by the IV)
	depends on **results from** **is affected by** **is directly related to**		**show an increase/decrease** **be greater than/less than** **be larger/smaller**		**increased/decreased** **greater/less** **large/small**
Hypothesis: If sleep deprivation is directly related to stress levels, then participants will self-report higher levels of stress on a 0–10 scale when they receive less than six hours of sleep per night for one week.					

Table 1.1 How to construct a hypothesis using the 'if … then … when' approach

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Try this 1.1

Operationalising the variables

Take the research question 'Does eating chocolate result in weight gain?'. Imagine a possible experiment you could conduct. Copy and complete the table below.

List variables here	Operationalise the variables
Independent variable	
Dependent variable	
Controlled variables	
Extraneous variables	

Quick check 1.1

1 What are extraneous and controlled variables?
2 State what it means to 'operationalise' the independent and dependent variables.

Try this 1.2

Evaluating an experiment

A student was interested in conducting an experiment to address the research question 'Does light intensity affect the growth of alfalfa sprouts?'.

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

1 The best independent variable for this research question is:
   a the total length of alfalfa sprout growth
   b light
   c length (cm)
   d level of light intensity.
2 Operationalise the IV.
3 For this research question, the dependent variable is:
   a length of alfalfa sprout growth
   b light levels
   c length (cm)
   d level of light intensity.
4 Operationalise the DV.

Figure 1.2 Scientists conducting an experiment on alfalfa sprouts

continued…

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...continued

5 Come up with a possible research hypothesis for this investigation using the 'if ... then ... when' framework. Remember, it should be a prediction of what the results will be (including the IV and DV), and as specific as possible.

6 List three variables that must be controlled in this experiment.

7 Explain why the above three variables should be controlled.

Integrity of the experimental method

If a scientific experiment is to fairly test a hypothesis, it must test what it claims to test, and yield consistent and repeatable results.

It is important that experimental results are more than one-off findings, especially if you are going to extrapolate to other circumstances or apply the conclusions more broadly. In the field of scientific research, experiments are conducted sometimes thousands of times to ensure the result is reliable. Experiments that rely on subjective data collection do not always produce reliable results, just as experiments with small sample sizes may also yield unreliable data. Imagine trying to decide if doctors should prescribe a new painkiller medication by asking one person if it reduced their pain. It would be silly to make decisions about the healthcare of all Australians based on the subjective opinions of one person!

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

repeatability
how well the results align when the experiment is repeated under the same conditions

reproducibility
how well the results align when the experiment is repeated by a different scientist

Reproducibility is how well the results match up when the experiment is reproduced by a different scientist (that is, with different equipment and in a different location), but when using the same experimental method, test material and conditions. Ensuring an experiment is reproducible is one of the reasons why writing a clear and reproducible method isso important.

In summary, the overall integrity of the scientific study depends upon both repeatability and reproducibility. Both the individual measurements within an experiment and the overall outcome of the experiment can be used to assess these two concepts.

	Repeatability measurement	Reproducibility measurement
Definition	Repeating single measurements gives the same values using the same scientist, equipment and setting.	Repeating the entire experiment gives the same final result using different scientists, equipments and settings.
How to improve	Modification of the experimental method, e.g. materials, equipment, procedure, etc.	Repetition of each test conducted and averaging single measurements.
How to test	Repetition of single measurements while noting any changes in values measured.	Repeat entire experiment and look at difference in final results.

Table 1.2 Importance of repeatability and reproducibility within experiments.

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For example, imagine detecting the core body temperature of a captured bandicoot with a thermometer. If you took the measurement when the animal was stationary and then double-checked the reading again immediately, you would expect the same result, with perhaps some small variation due to equipment or technique. The results from the repeated test can be averaged to produce a more accurate measure. In the science laboratory, repeatability of results can sometimes be improved through repetition. The more similar the repeated measurements are, the more reliable the results are likely to be.

If on the next night you captured lots more bandicoots under similar conditions and measured their core body temperatures, you would get an idea of how body temperature varies between individuals. You have replicated your test on additional subjects, so you now have a larger sample size on which to base your conclusions.

While repetition can check the repeatability of the results, it does not ensure results are reproducible. Replicating the experiment on additional samples is an important process because it gives you an idea of the natural variability (or margin of error).

Good experiments should use a sound experimental design and an experimental method that minimises experimental uncertainties.

Validity

Experimental **validity** assesses whether the experiment is suitable for the research question and whether it measures what it claims to be measuring. For example, a psychological experiment that claims to be testing memory must ensure the questionnaire does not actually measure intelligence, reading skills or emotional state. The validity of an experiment depends on both the experimental design and the procedure.

validity
the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what it says it measures

Internal validity relates to how confidently you can attribute change in the DV to the change or presence of the IV. An experiment may have poor internal validity because of poorly controlled extraneous variables. Internal validity can be improved by better identifying and controlling the extraneous variables, using accurate and appropriate measuring equipment, and using standardised instructions and procedures.

internal validity
the confidence we have that the change in the dependent variable was solely due to the change in the independent variable

External validity relates to the extent to which the results of an experiment can be extrapolated (generalised) to other contexts or populations. For example, will the conclusions hold for participants of a different age, species or in a different location? External validity can be improved by conducting experiments in natural settings, accurately analysing the results and ensuring that a representative sample is used.

external validity
the extent to which results can be generalised and extrapolated to other contexts or populations

In summary, the validity of an experiment relates to how appropriately the experiment addresses the overall aim. Is the experiment suitable for testing what it is meant to test so that it can measure what it is claiming to measure? The equipment used, experimental design, experimental method and method of analysing the results all contribute to the validity of an experiment. It is essential that only one variable is changed at a time if you want to determine the effect on the dependent variable. If other variables are introduced, or extraneous variables are not adequately controlled for, then you cannot draw a valid conclusion, because you cannot distinguish which variable has actually had the impact.

To sum it up, research with high internal and external validity enhances the integrity of the experimental method.

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Quick check 1.2

1 Using the same set of scales when measuring the weight of a beaker on Day 1 and Day 2 of an experiment is a factor relating to the ______________ of an experiment.
2 The likelihood that another scientist performing exactly the same experiment under the same conditions will generate the same results depends on ______________.
3 Why is it important to reproduce experiments in the field of science?

Accuracy, precision and outliers

Experimental **accuracy** refers to how closely the experimental results match the 'true' values. For example, if you record the mass of a product of a chemical reaction as 1.55 g, but the chemical equation suggests that based on the amount of reactants you should only have 1.20 g, then you have a measurement error of 0.35 g. Choosing the best equipment and using a method that avoids systematic errors will improve the accuracy of the experiment as a whole. For example, you could use an electronic timer system to record measurements at given time intervals rather than rely on a human to use a hand-operated stopwatch.

accuracy
how closely measures match the 'true' or accepted values

Experimental **precision** refers to how closely repeated measurements agree with each other. For example, let's say you record the mass of a product of a chemical reaction, and you repeat the experiment four times, getting results of 1.54 g, 1.55 g, 1.55 g, 1.54 g. The data shows low variation from the mean (it is clustered tightly) and can be said to be precise. Note that, even though this data is precise, it is not necessarily accurate. Precision does not give us an indication of how 'true' the data is; that is, how accurately it matches the actual values.

precision
how closely repeated measures agree with each other

Outliers are extreme data values that do not appear to fit with the other recorded values. These values are often situated a long way from the mean, and may represent an experimental error, such as human error in reading the scale or a fault in measuring equipment. It is important that outliers are investigated and accounted for in the discussion of your results. Sometimes, repeating the experiment eliminates the outlier, but you need to mention that this has occurred. The most common causes of outliers in a data set, within the scientific laboratory are:

- data entry faults (human miscalculation)
- measurement inaccuracies (instrument faults)
- data extraction or experiment planning/executing deficiencies.

outliers
extreme data values that do not seem to fit the rest of the data

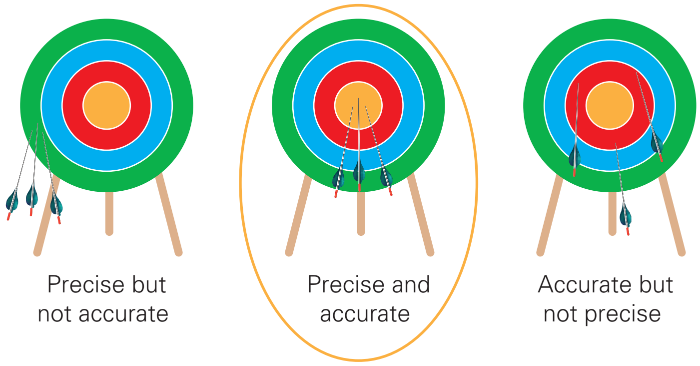

Figure 1.3 A faulty piece of measuring equipment might consistently give wrong values, like the target on the left. This measurement would be precise but the results are inaccurate and do not measure what they claim to measure, therefore, have low validity.

Quick check 1.3

1 Define an outlier.
2 If a data set had a number of outliers, would the data be said to have high or low precision?
3 An experiment is conducted and the results align very closely with the true values. This experiment could be said to have high ______________.

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Using specialised equipment

Specialised equipment can often give accurate and precise results, thereby enhancing the reproducibility and internal validity of the experimental data.

Titration equipment

Titration is a specialised procedure used in the study of Chemistry to determine the concentration of an acid or alkali solution. It involves measuring the amount of one solution (an acid or an alkali) that is needed to neutralise a carefully measured amount of a second solution. Titrations require specialised equipment such as: a pipette, a burette, a pH probe or data-logging devices.

titration
a procedure used to determine the concentration of an acid or alkali solution

A pipette is an important tool to use within the laboratory, as very precise amounts of solution can be measured out accurately.

A burette is a long, thin, glass tube used to measure the volume of solution needed for neutralisation. A burette can release the solution by turning the tap. To release the solution, the tap is placed in a vertical position and to stop the flow the tap is placed into a horizontal position.

Figure 1.4 A pipette filler pump (left) and a volumetric pipette (right)

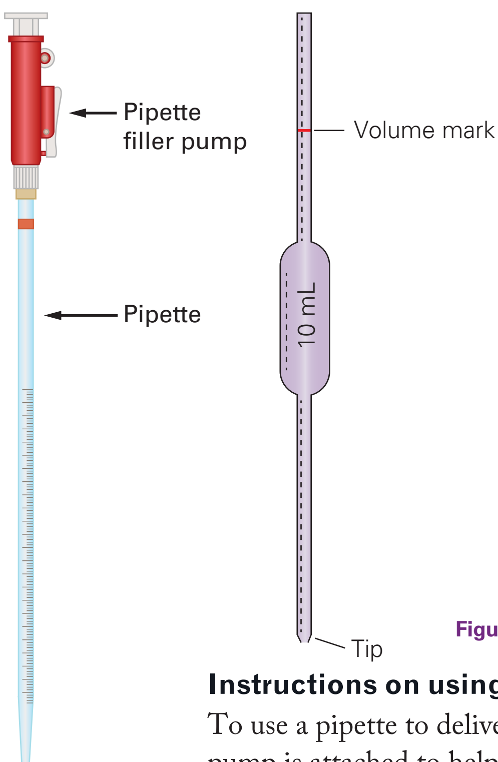


Figure 1.5 A burette is set up in a retort stand to perform a titration.

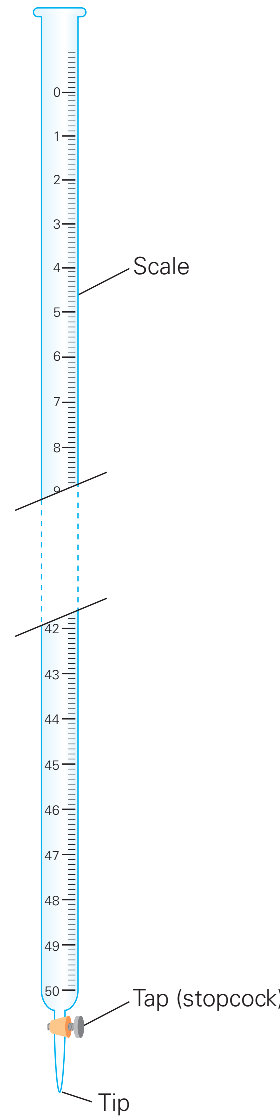
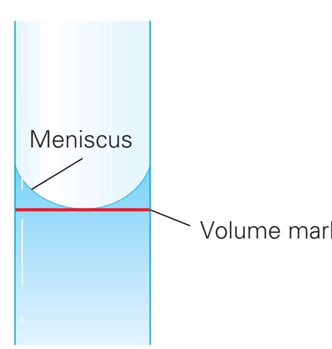


Figure 1.6 A burette

Instructions on using the pipette

To use a pipette to deliver a fixed volume of solution, a pipette filler pump is attached to help fill and empty the pipette with solution.

1 Never use your mouth to suck solution up into the pipette.
2 Attach the pipette filler pump to the end of the pipette by gently twisting and securing it.
3 A thumb wheel found on the pipette filler pump can be turned to allow the solution to be drawn into the pipette.
4 Rinse the pipette using a small amount of the solution being used.
5 It is easiest to draw the solution up above the mark of the pipette.
6 Release the solution from the pipette until the bottom of the curve of the meniscus sits just on top of the volume mark.
7 Now you are ready to deliver a precise amount of your solution.



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Handy hint: when drawing the solution up into the pipette, make sure the tip is in the solution at all times to prevent bubbles from occurring within the solution.

A pipette bulb may also be used with a pipette to withdraw and deliver solutions.

They can be quite tricky to use and a pipette can be easily damaged if it is not used the right way.

Things to remember when using a bulb type pipette filler:

- When inserting the pipette, hold the pipette close to the end being inserted so that the pipette does not break.
- To create a seal, the pipette should not be inserted too far into the bulb (1 cm should be enough).
- Never allow solution to enter the bulb. Tell your teacher immediately if this occurs.
- Make sure there is more than enough solution in the beaker to draw up into the pipette.
- Be careful when removing the pipette from the bulb at the end of an experiment. A gentle twisting motion will help, to allow the pipette to be removed safely without breakage.

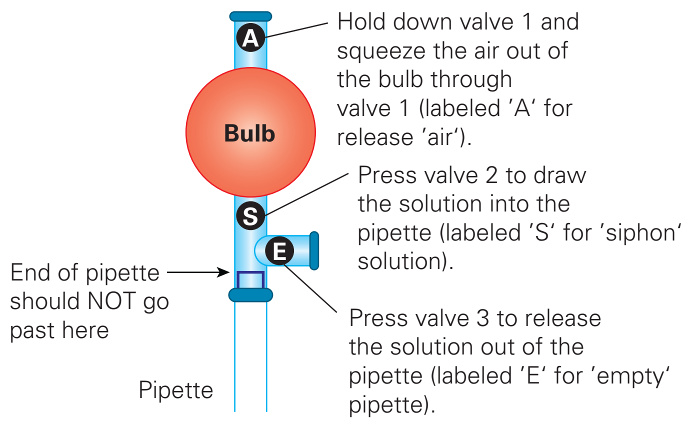


Figure 1.7 This diagram shows the correct way to use the three valves.

Practical 1.1

Titration skills

Be careful

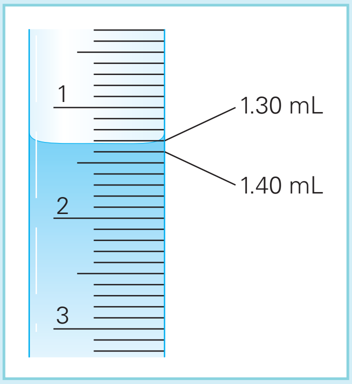
Extreme care needs to be taken when handling all equipment. Ensure appropriate personal protective equipment is worn.

Materials

- burette
- pipette
- funnel
- retort stand
- clamp
- 100 mL 0.5 M sodium hydroxide solution
- 20 mL 0.5 M hydrochloric acid solution
- 2 x beaker
- volumetric flask
- white tile (to help detect colour change)
- 2–3 drops phenolphthalein indicator

Part 1 – Practicing reading from a burette

1. When reading from the burette, always record volumes to two decimal places. For example, if a reading is exactly on the 2.7 mL mark then it should be recorded as 2.70 mL
2. Try this example – it would be read as 1.32 mL
3. To calculate the titre volume, write down the initial and final burette readings and then subtract the final titre volume from the initial titre volume.



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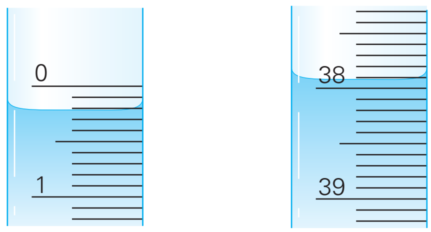
4 Calculate the titre volumes in the following examples:

Example 1:

Titre = final reading – initial reading

Titre = 37.91 mL – 0.21 mL

Titre = 37.70 mL



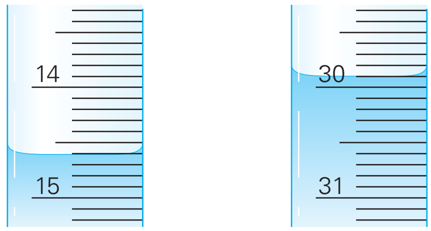
Initial reading: 0.21 mL Final reading: 37.91 mL

Example 2: Try this one yourself.

Titre = final reading – initial reading

Titre =

Titre =



Initial reading:________ Final reading:________

Part 2 – Using a burette

1 Measure 100 mL of 0.5 M sodium hydroxide solution into a clean beaker.
2 Use a clamp to secure the burette.
3 Making sure the tap of the burette is closed, add approximately 5 mL of the sodium hydroxide solution from the beaker to the burette using a funnel.
4 Open the burette tap to drain this solution into a waste beaker.
5 Using a funnel, add the 0.5 M sodium hydroxide solution to the burette, getting close to the 0.00 mL marking line. (Make sure the burette's tap is shut).
6 To eliminate any bubbles in the burette tip, allow several drops of the solution to rinse through.
7 Slowly release the solution and try to get as close to 0.00 mL as possible.
8 Record the precise scale reading from the burette. Be as accurate as possible by using 2 decimal places. This is your initial scale reading.
NOTE: For practicing purposes, 0.00 mL has been chosen, but it is not necessary to start a titration at 0.00 mL, as long as your initial reading is accurate.

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Part 3 – Using a pipette

1 Rinse the pipette using a small amount of the 0.5 M hydrochloric acid by drawing the solution up above the volume mark of the pipette.
2 Carefully release the hydrochloric acid from the pipette until the bottom of the curve of the meniscus sits just on top of the volume mark.
3 Pipette the 20 mL hydrochloric acid solution into a volumetric flask.

Part 4 – Titration

1 Add 2–3 drops of phenolphthalein to the hydrochloric acid solution in the flask.
2 Place the volumetric flask on the white tile under the burette.
3 Open the tap (stopcock) and start releasing the solution into the flask.
4 If working in pairs, one can gently swirl the flask and the other can control the release of the solution from the burette.
5 Once the colour pink starts to appear, start adding the sodium hydroxide solution drop by drop and keep swirling the volumetric flask.
6 Once the solution maintains a constant pink colour, close off the stopcock. This is called the endpoint. It is worth noting that the lighter the shade of pink, the more accurate your titration.
7 Record the final reading from the burette to calculate the volume of hydrochloric acid solution that has been added.
8 Repeat for another three trials.
9 Record the volume of sodium hydroxide solution for these trials to then calculate the average titre volume. The table below can be used.

	Initial reading from burette	Final reading from burette	Titre (Final reading – Initial reading)
Trial 1			
Trial 2			
Trial 3			
Trial 4			
Average titre			

Example of titration set up from this experiment.

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Data loggers and probes

A data logger is an electronic measuring tool that accurately records data over time. It features a built-in instrument, such as a probe or sensor, that can measure a physical stimulus such as temperature, light, pressure, humidity or pH. The device is connected to a computer and converts the stimulus into a readout on the screen. This means the experimenter does not have to manually take a reading at set intervals, as the data logger takes very frequent (almost continuous) readings over time.

The benefits of using a data logger in scientific experiments include:

- highly accurate measurements
- an automated process that can be programmed and left to take readings regularly over a long period of time (for example, overnight) or many readings over a very short period of time
- removing the risk of human faults or miscalculations in interpreting a measurement scale and recording data.

The data collected from the experiment can be processed by specialised software or placed into a spreadsheet to allow for further analysis at a later point. This allows scientists to easily generate tables of values and graphs.

Practical 1.2

Titration using pH probe

Be careful

Extreme care needs to be taken when handling all equipment. Appropriate personal protective equipment should be worn.

Aim

To complete a titration using a pH probe linked up to a data-logging program to produce a graph showing pH changes as an alkali (base) is added to an acid.

Materials

Four different combinations of acid and alkali solutions are supplied for the class to test. Such combinations include: strong acid-strong alkali; strong alkali-weak acid; strong acid – weak alkali; weak alkali – weak acid.

- pipette
- pipette bulb
- burette
- burette funnel
- burette clamp
- retort stand
- boss head
- clamp
- conical flask
- wash bottle
- pH probe
- computer
- computer software

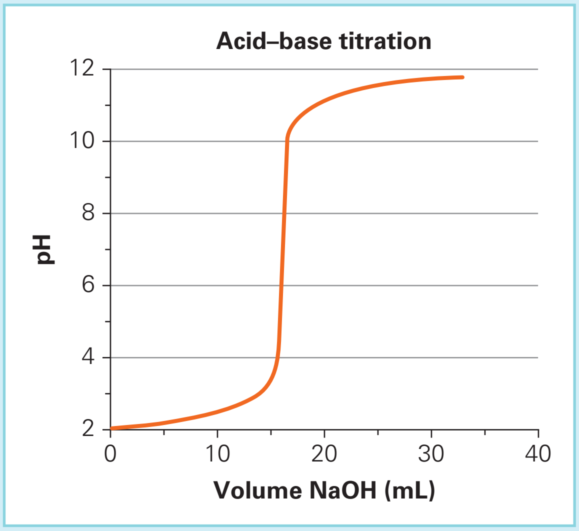

Figure 1.8 A graph showing how the pH (concentration) changes as a volume of sodium hydroxide (a base) is titrated into an acid

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Method

Each lab pair will be provided with one of the four different combinations of acid and alkali solutions to titrate. Decide who will be in charge of the continual stirring of the solution within the beaker and who will be in charge of releasing the alkali into the beaker using the burette.

1 Set up the burette and apparatus as shown in the diagram by using a clamp and a retort stand to secure the pH sensor.
2 Rinse the burette throughly with a few millilitres of the alkali solution.
3 Fill the burette using approximately 50 mL of alkali solution and record the precise volume in your logbook.
4 Add 50 mL of distilled water to a 250 mL beaker.
5 Pipette 10 mL of the acid into the beaker of distilled water.
6 Connect the pH sensor to the computer and open up the relevant 'Acid-Base' titration program.
7 Monitor the pH for approximately 20 seconds and wait for the reading to stabilise.
8 Enter 0 mL as the first data point of alkali added in the computer program.
9 Slowly start to add some of the alkali solution until the pH has risen approximately 0.2 units.
10 Wait for a stable pH reading and record the burette reading (volume of alkali left in the burette) to the nearest 0.01 mL.
11 Repeat steps **9** and **10** until the pH starts to get close to 3.5.
12 Start adding smaller equal volumes of approximately 0.1 mL of alkali solution to the beaker, making sure to record the burette reading into the software after each increment.
13 When the pH reaches close to 10, add larger amounts of alkali solution that raise the pH approximately 0.2 units.
14 Continue the adding of alkali solution until the pH remains constant and stable.
15 Click stop on the software and save copies of the table and graph.
16 Dispose of the beaker contents as directed by your teacher and the safety data sheet.

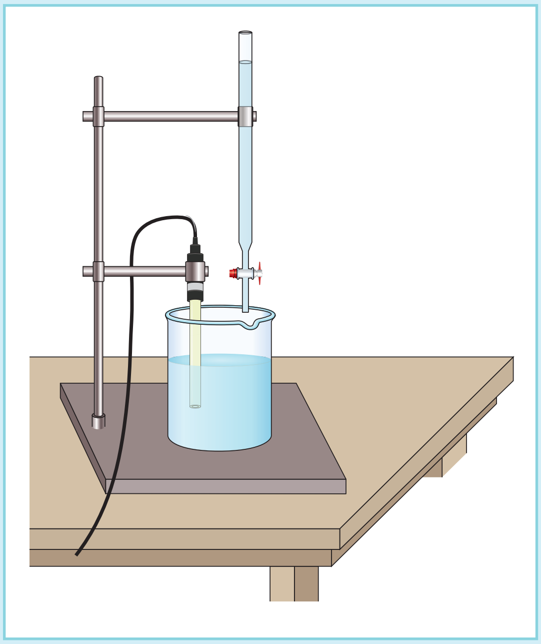

Figure 1.9

Results

1 Print out your table and graph and paste these into your logbook.

Evaluation

1 Compare your results to the class results. Comment on the different shapes of curves that were produced in relation to the strength of the acid and alkali combinations used.
2 Would this experiment have been possible without the use of a data logger?

Conclusion

1 Make a claim about the usefulness of data loggers in titrations based on this experiment. What claim can be made regarding the pH when an alkali is titrated into an acid?
2 Support your statement by using the data you gathered and include potential faults with the experiment.
3 Explain how the data supports your statement.

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Minimising experimental error

Systematic and random errors

Measurements are never perfect; for example, even though you may try to measure a mass at exact 15 second intervals, the best you can do is measure time correct to the nearest second. So, when a value of 15 seconds is recorded in the table, the actual time the measurement was taken could be anywhere between 14.50 and 15.49 seconds. Such errors in collecting data are called **random uncertainties**. The first reading could be an underestimate and the next an overestimate, and so on without any pattern.

random uncertainty error that occurs through inaccurate measurements (slightly high or slightly low)

If, on the other hand, the scale used to measure the mass was not calibrated, so that all the readings were 3.00 grams greater than they should be, then all the measurements of mass (for example, 150.00, 148.25 and 145.17) would be consistently overestimated by 3.00 grams. This would be a **systematic uncertainty** because the data is all wrong by the same amount each time a measurement is taken.

systematic uncertainty error that occurs through a poorly calibrated device (consistently high or consistently low)

Random uncertainties are an unavoidable part of doing experiments and can only be reduced by repeating the experiment and taking average values. Systematic errors can be avoided by carefully calibrating measuring instruments. If systematic errors are discovered, the data can be corrected.

Using more accurate measuring instruments can improve the **measurement uncertainty**. In the example given, the measurements of mass (to five **significant figures**) would normally have a smaller measurement uncertainty than than the measurements of time (to two significant figures).

measurement uncertainty the range of values within which lies the true value

significant figures the number of digits needed to be as exact or consistent as required

Random uncertainties need to be taken into account during experiments when accurate measurements are important. Note that experimental uncertainty is not the same as mistakes or carelessness. Misreading a scale, or spilling chemicals, are just mistakes. Experimental uncertainty is an estimate of the range of values within which the actual value may fall, that still remains in an experiment that has been done very carefully and with no mistakes.

Quick check 1.4

1 What sort of uncertainty does each of the following scenarios represent?
   a A measuring tool is incorrectly calibrated and regularly underestimates the mass.
   b A measuring tool is not very precise and the temperatures vary by approximately 0.5 of a degree in either direction.
2 How can the effect of random uncertainty be reduced?

Figure 1.10 Measurement tools vary in their precision.

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Practical 1.3

Reproducibility and repeatability: does mass change in a chemical reaction?

Be careful

Appropriate personal protective equipment should be worn.

Aim

To consider the accuracy of measurements before and after a chemical reaction in determining whether there has been a change.

Materials

- 8 mL sodium hydroxide solution
- 4 mL ferrous sulfate solution
- conical flask with stopper
- test tube
- thread
- balance

Part 1: Reaction between ferrous sulfate and sodium hydroxide solutions

1. Copy the results table below.
2. Using a measuring cylinder, measure 10 mL of *sodium hydroxide* solution and pour into the conical flask.
3. Add 5 mL of *ferrous sulfate* solution into a test tube that has a piece of thread tied around the upper lip.
4. Place the test tube carefully into the conical flask, ensuring that the thread around the lip of the test tube is secure and that the end of the thread is pulled through out of the flask.
5. Insert the stopper on the conical flask and carefully weigh the whole apparatus.
6. Record the mass in the table below.
7. Invert the conical flask which allows the mixing the two solutions thoroughly.
8. Wait for the complete reaction to occur, and try not to let any of the contents of the flask escape.
9. Reweigh the flask and contents on the same balance as before.

Results

	Mass of flask and contents (g)	Range of possible values (±0.08 g)
Before reaction		
After reaction		

Evaluation

Consideration needs to be taken before drawing valid conclusions from results. If you and your partner measure the mass of the same object (or even if you measure it twice), there's a good chance that you will not get exactly the same result. This is because of slight differences in technique or in the conditions in which the measurement was taken. These moment-to-moment fluctuations are called random uncertainties.

1. What may influence the measurement accuracy of an object or mass?
2. What is the range of possible values for a measurement of 87.26 with an experimental uncertainty of ±0.06 g?
3. How confident can you be of a change in mass occurring during this reaction? Could the mass change be simply caused through experimental uncertainties?
4. Compare your individual results to the class results.

Part 2: Reaction between calcium carbonate and hydrochloric acid

1. Copy the results table into your logbook.
2. Use the same apparatus as was used for Part **1** of the practical. Place a few lumps of calcium carbonate into the flask.
3. Fill the small test tube with hydrochloric acid solution (about 3/4 full), and suspend the test tube inside the flask by means of the thread.
4. Stopper the conical flask.
5. Weigh the whole apparatus and record the mass in the results table.

continued…

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...continued

6 Remove the stopper and pour the contents of the test tube onto the calcium carbonate. Do not put the stopper on the flask during the reaction.
7 Wait for the complete reaction to occur.
8 Once the reaction is complete, do not remove the test tube and replace the stopper on the conical flask.
9 Reweigh the whole apparatus and record the weight in your table of results.

Results

	Mass of flask and contents (g)	Range of possible values (±0.08 g)
Before reaction		
After reaction		

Evaluation

1 What evidence was there to suggest that a chemical reaction was taking place in this experiment?
2 Suggest reasons for the possible change in weight of the flask before the reaction and after the reaction.
3 Describe the key difference in experimental procedure between Part **1** and Part **2** of this experiment.
4 Relate the findings of this experiment to your understanding of the law of conservation of mass.

Conclusion

1 Make a claim about the accuracy of your measurements in detecting changes in mass based on this experiment. Did the method influence your accuracy or precision?
2 Support your statement by using the data you gathered and include potential experimental faults or sources of measurement uncertainties.
3 Explain how the data supports your statement.

Comparing the effect of stomach powders

Try this 1.3

Background

We already know from Year 9 that the stomach is an essential organ involved in the breakdown and digestion of food. It achieves this by creating a highly acidic environment (pH of approximately 2 or 3) through the production of hydrochloric acid. However, an excess of acid in the stomach can cause painful ‘indigestion’.

Antacids are a common treatment option as they are alkaline, allowing for the excess stomach acid to be neutralised. Now that you have a much more accurate way of measuring volume, design an experiment that will compare three different antacids (A, B and C) to determine which is most effective in relieving indigestion.

Materials

- titration equipment
- 3 × antacids
- hydrochloric acid (1 M)
- electronic balance
- spatula
- Congo red indicator
- watch glass

Method

Design the method: Plan out your experiment with a lab partner, taking into consideration:

- your aim
- the independent variable and dependent variables
- the variables that will be controlled in this experiment
- how you will document the results.

Carry out the experiment and derive your conclusion. Consider how you could improve the accuracy of your results in future.

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Safe experimental practices

Experiments sometimes require the use of hazardous chemicals. A **safety data sheet** (SDS) must be provided during all experiments. The SDS is a document that provides both teachers and students relevant information about the health risks and safety of products (such as chemicals) that are classified as being dangerous goods or hazardous substances. Ultimately, the safety data sheet provides precise information about how to use a substance during and after the experiment,

> **safety data sheet**
> a document that provides information regarding hazardous chemicals and substances

Standard Operating Procedure

Science – General

Personal Protective Equipment (PPE)

Safety glasses, gloves, fully enclosed shoes, lab coat

Procedure:

Science Experiments – general SOP

Step	Procedure	Photo
1	**Pre-start checklist:** • Is all PPE worn appropriately? • Is the spill kit available? • Has long hair been tied back? • Have you checked you're not wearing loose clothes? • Has the risk assessment been completed? • Have you been trained in the operation of any relevant equipment? • Have you read the SDS for specific chemicals used? DO NOT COMMENCE TASK IF UNSAFE	
2	**Prepare equipment** Pre-use inspection – No physical damage to equipment being used – Electrical leads in good condition and tested within date	*Before the experiment, ensure all equipment is in working order.*
3	**Chemical use:** Identifies that chemicals involved should only be used in well ventilated areas. CAUTION: Use air vents, do not breathe vapour	
4	**Dispose of waste chemical** Do not place harmful chemicals down the sink. Appropriate disposal of chemicals in place.	
5	**Wash hands** and exposed skin with soap and water	

This SOP does not cover all possible scenarios.

Figure 1.11 An example standard operating procedure sheet

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including the associated health risks and how to dispose of waste products.

A standard operating procedure sheet details the PPE (personal protective equipment) that is required when conducting a specific experiment. It also provides five steps to follow before conducting any form of experiment.

Quick check 1.5

1 What does SDS stand for?
2 Why are SDSs essential within the science classroom?

Documenting and communicating experimental findings

Within all Science classes, writing up experiments or investigations is a common form of assessment. Students who undertake any experiment will be involved in collecting primary data (qualitative and/or quantitative), analysing and evaluating data, identifying limitations, developing a valid conclusion and deriving suggestions or further investigation which may be undertaken.

You can document the scientific method from start to finish in a logbook. You can record the background research, development of a research question, identification of variables and construction of a hypothesis, use of method and materials, data and analysis, and conclusions. You can also document in your logbook questions relating to the safety and ethical aspects of your experiment.

Logbooks

The logbook is a record of practical work and resultant data. It may include records of teacher demonstrations, experiments and research activities and formal practical reports. Entries should be dated and have clear titles. It is also important to recognise the input of partners and appropriately reference secondary data. Essentially, the logbook is a dated workbook of scientific information that can be drawn upon at a later date. It acts as a record of practical work for authentication and assessment purposes.

Scientific posters

The scientific poster is a prerequisite form of assessment for all VCE Science subjects: Biology, Chemistry, Environmental Science, Physics and Psychology. Experimental results can be communicated in a scientific poster format according to the following possible template. The specifications of size, word count and content of a scientific poster depends on the context in which it is to be displayed. The content may include the sections shown in Figure 1.13.

Figure 1.12 A scientist records the results of an experiment in a logbook.

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Title: A concise version of the research question

Name:

Introduction

A 1–2 sentence overview of the purpose of the investigation linked with background information from theory and past research. Include definitions and relevant formulas to enable peers to understand the investigation, and can include a diagram or photograph.

Methodology

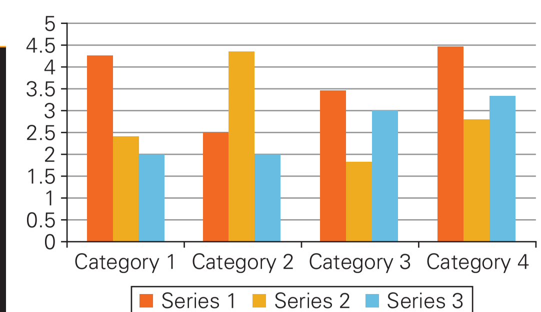
Materials (apparatus) and procedure need to be described in sufficient detail that someone could replicate the experiment exactly. The level of detail in a formal practical report is not needed, e.g. can use a diagram to show experimental set-up.

Discussion

Approximately 3–4 paragraphs addressing:
Did the data support the hypothesis? Discuss the relationship between the IV and DV.
Compare the results with expected results, discussing controlled and extraneous variables. Relate your findings to previous findings.
What are the implications of the findings?
What were the limitations in the experimental design?

Results

Display a selection of descriptive statistics (not yet analysed) generated from the experiment, in a table, a graph or percentages/ratios. It is a waste of space to show the results in *both* a table and a graph. Ensure the graph clearly shows any trends. This section should also include a few sentence summary of the results.



Conclusion

State the main result from the investigation. It should answer the research question with reference to whether the hypothesis was supported or refuted. Some justification based on the results might be necessary.

References and acknowledgements (section not included in the word count)

Only list references you have cited (referred to) in the body of the poster, not all the sources you have accessed in your background research. Use an appropriate format such as Harvard, Oxford or APA referencing styles. This is the appropriate place to thank individuals such as lab partners, experts who provided assistance etc.

Figure 1.13 An example template for a scientific poster

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Try this 1.4

Summarise as a poster

Analyse the information provided in the article below and summarise the data presented in this article in a scientific poster format.

New Method Helps You Learn Skills Twice As Fast (R. Andrews, February 2016)

What's the best way to learn a new skill, such as playing the guitar? Multiple hours spent doing the same task over and over is thought to be the optimal strategy – practice makes perfect, as many would say. However, a new study in *Current Biology* has revealed that varying your training regime, and not making it so repetitive, may actually double the speed at which you learn.

Eighty-six volunteers were recruited by a team of researchers from Johns Hopkins University [in Baltimore, United States] and asked to learn a new skill: Moving a cursor around a screen by squeezing a small, touch-sensitive device, rather than using a traditional mouse.

The volunteers were segregated into three groups. The first (the controls) were only given one 45-minute-long training session. The second group were given one training session, then asked to wait six hours before they repeated the same exercise. The third group had the same experience, but their second training session modified the sensitivity of the controlling device, meaning they had to quickly adapt to the new conditions.

The next day, all three groups were asked to repeat the first training session with the original device sensitivity restored. At the end of each group's sessions, they were scored on how accurately and rapidly they were able to move the cursor around the screen.

Intuitively, one would expect the third group to perform worse than the second group, with the changing parameters of their gaming sessions increasing the overall difficulty of the task. Remarkably, the situation was reversed, and the third group did twice as well by the end of the experiment than the second group did. The control group performed the worst.

"What we found is if you practice a slightly modified version of a task you want to master, you actually learn more and faster than if you just keep practicing the exact same thing multiple times in a row," said lead researcher Pablo Celnik, from Johns Hopkins University, in a statement.

The secret lies in the six-hour gap between training sessions that the groups were given. The memory of their new skill is "consolidated" within the brain during this time period, wherein the neural connections in the brain form and "preserve" the memory. With this memory consolidated, the volunteers could reactivate it during the second training session in order to perform the task with increased ease.

However, these consolidated memories can be modified. Changes to the parameters of a second session practicing any motor skill – attempting a video game level with different obstacles, for example – "reconsolidates" these memories, slightly altering then reinforcing the original neural connections. This allows them to become more adaptive and flexible to future changing conditions.

This explains why the third group performed best in this study. Celnik noted that a massive change in the parameters of the game would not produce the same beneficial effects, however. "The modification between sessions needs to be subtle," he added.

Although this study tested only one specific skill, its finding could hopefully be applied to many other situations. Amputees could be taught to learn to use their prosthetics more rapidly by using memory reconsolidation techniques, for instance.

Source: 'New Method Helps You Lean Skills Twice As Fast, Robin Andrews, *IFLScience!*, February 5, 2016

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Quick check 1.6

1 Why is a logbook an essential part of the scientific student's life?
2 List the components that should be included in a scientific poster.
3 A student was interested in determining whether the cup colour influences the taste perception of coffee. What could be a possible title for this research?

Section 1.1 questions

QUIZ

Remembering

1 Name one specialised piece of equipment used in a titration.
2 State two pieces of information that should be included in a logbook.
3 What is an outlier?

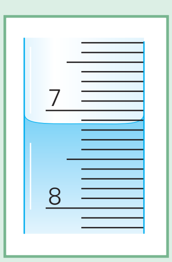
Understanding

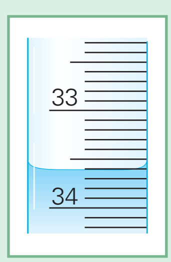
4 Explain how the use of a data logger can be beneficial to an experiment.
5 Classify the following errors as either random errors or systematic errors.

Scenario	Random or systematic uncertainty?
Instrument fault: A burette is leaking so every reading taken is 0.1 mL lower than the actual value.	
Human fault: When recording the data, the researcher has a poor understanding of rounding decimals and consistently rounds them up to the nearest whole number.	
Instrument fault: A set of scales is not very precise and the displayed mass is often out by around 1–3 grams in either direction.	

Applying

6 Take the readings from the burette below to determine the overall titre.





Initial reading: ______________ Final reading: ______________ Titre: ______________

7 You are constructing a scientific poster. Select and describe one situation when it would be appropriate to include a line graph (instead of a table of data) in the results section.

continued…

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...continued

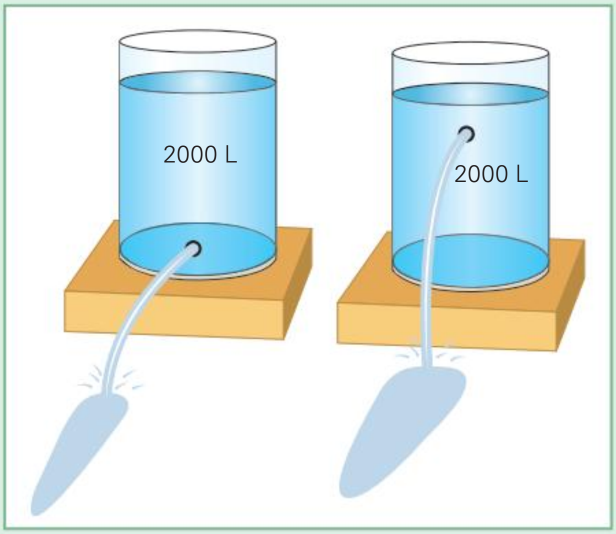
8 Biology students were learning that, on a hot day, plants lose water out of pores (called stomata) in the underside of their leaves. The students were asked to design an experiment that would test how factors of their choice influence the rate of water loss. After conducting some background research, one student identified that humidity and temperature should affect the rate at which water is lost out the stomata. She set up the experiment below:

Figure 1.14 The three experimental conditions

- **a** What are the two independent variables manipulated in this experiment?
- **b** What would be a relevant dependent variable in this experiment?
- **c** Which set-up acts as a control with which to test all three factors?

Analysing

9 A farmer noticed that his leaky tanks seemed to lose water quicker if the hole is closer to the top of the tank. He designed the research question: Do tanks leak water faster when the hole is positioned higher on the tank?



- **a** What was the independent variable of this experiment?
- **b** List three variables that must be controlled.
- **c** The farmer repeated his experiment on five different occasions and found the same result: that the water flows more strongly from the highest hole in a water drum. Infer whether this is showing high or low repeatability.

Evaluating

10 Jake took 12 identical pots and 12 identical plants. In four pots he placed soil and 10 grams of fertiliser A and one plant. In another set of four pots he placed in each a plant, 15 grams of fertiliser B and the identical amount of soil as in the previous four pots. In another four pots he placed the same amount of soil with a plant but provided no fertiliser. All 12 pots were placed in the same location and received the same amount of water and sunlight every day. Plants with fertiliser B grew much larger than all the others. Jake concluded that fertiliser B was better than fertiliser A. Is his conclusion a valid one?

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1.2 The human side of science

Science is done by humans for humans. Humans also play a role as participants in some experiments, and this raises a number of ethical issues that need to be addressed. **Ethics** refers to the principles and standards upheld by scientists that guide them to display acceptable and appropriate conduct during experiments.

ethics
the standards used to appraise and guide what is considered as acceptable conduct

Ethical implications of human participants

In fields such as psychology, using people as participants is a critical source of data in experiments. Before the commencement of any research involving humans, a research plan is submitted to an ethics committee for discussion and approval. This ensures that the participants' physical and psychological welfare is considered by a team of medical and non-medical professionals. Any scientist who conducts research on human participants must follow two sets of guidelines.

The national statement on ethical conduct in research involving humans

The *National Statement on Ethical Conduct in Human Research* was issued by the National Health and Medical Research Council in 2007 and updated in 2018. The statement aims to protect the welfare and rights of human participants and to ensure that the research conducted benefits the community and does not harm the participant.

All researchers – often they are psychologists or scientists – who are using human participants (regardless of the area being studied) most follow these four principles:

i Research merit and integrity – the research must be worthwhile and justifiable (have merit), and the researcher should be committed to behaving in an honest and ethical manner when conducting the research and disseminating and communicating on the findings of research (have integrity).

ii Respect – the researcher has a responsibility to show consideration for the privacy, welfare, rights, beliefs, customs and cultural heritage of the participants involved in the research.

iii **Beneficence** – the researcher has a responsibility to maximise benefits and minimise risk of harm to participants. The dignity and welfare of the participants must have a higher priority than the expected benefits to knowledge of the research.

iv Justice – the researcher has a responsibility to ensure there is a fair distribution of the benefits and burdens of the research within a population of research interest.

WORKSHEET

beneficence
the responsibility of a researcher to maximise benefits and minimise harm to participants

Australian Psychological Society code of ethics

The Australian Psychological Society (APS) is a highly esteemed professional organisation to which most Australian psychologists belong. The *APS Code of Ethics* describes the researcher's responsibilities to not bring into disrepute the profession of psychology, and the rights of participants to not be harmed either physically or psychologically by their involvement in the research.

The *APS Code of Ethics* outlines the ethical rights of all participants in a study, including:

i No harm – the welfare of participants must be the researcher's priority, and no physical or psychological harm must be caused by the participants' involvement in the research.

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ii Voluntary participation – participants' involvement must be voluntary and people must not be placed under any pressure to participate in a study.

iii **Informed consent** – where possible, participants must be informed of relevant important information about the experiment; for example, their ethical rights, a brief description of any risks involved, an outline of the procedure, and the purpose and nature of the experiment (provided the experiment does not require deception). The participant (or a parent or guardian) must sign a document to indicate they agree to participate and that they are fully aware of what is required of them in the study.

informed consent
where possible, participants are informed about the risks and procedures involved in an experiment and they sign to say they agree to participate

iv **Confidentiality** – participant's data (such as test results) must be kept private unless their written consent is given. Before the experiment begins, the experimenters must explain how the data will be stored.

confidentiality
participants' data and results must be kept private

v **Withdrawal rights** – a participant has the right to withdraw from (leave) a study at any time for any reason. They also have a window after the experiment to have their results excluded from the study if they wish.

withdrawal rights
the right for a participant to leave a study at any time for any reason

vi No distress from deception – sometimes it is necessary to deceive participants about the true purpose or nature of a study in order to yield accurate results. The experimenter must ensure the participants do not experience any distress as a result of being deceived, and that they are offered the chance to debrief after the experiment.

Debriefing is a process in which the experimenter informs the participants about the nature and purpose of the experiment, after it has been completed. This aims to alleviate any confusion or misconceptions they have. Participants should be directed towards counselling services afterwards if required.

Explore! 1.1

When ethics goes wrong

Unfortunately, some very distressing research has been conducted on participants in the past. One of the most infamous experiments is the Stanford Prison experiment, conducted by Professor Philip Zimbardo and his colleagues in 1971 at Stanford University. Research what exactly took place in this experiment and outline the ethical rights that were followed and the ones that were breached. Present these findings in a table.

1 Why is an ethics committee important when using humans as participants?
2 If a scientist carries out an experiment using humans as participants, list the six ethical rights of the participant.
3 When would deception be used within an experiment?

Figure 1.15 Phillip Zimbardo at the 2015 opening night of *Stanford Prison Experiment*, a movie based on true events that happened during the 1971 experiment

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Quick check 1.7

1 Define the term 'beneficence'.
2 Define the term 'informed consent'.
3 Define the term 'withdrawal rights'.

The effects of human participants

If you are using participants in a scientific study, it is important that they do not know whether they are part of the control condition or the experimental condition. Participant expectations can act as an extraneous variable within an experiment. For example, participants may try harder than they usually would if they believe they belong to the experimental condition or to please the experimenter. Conversely, they may be very nervous and not able to perform at their usual ability level.

The placebo effect

To counteract the effect that participant expectations may have within scientific experiments, especially those that deal with medications (drugs), both groups of participants will receive some form of treatment. However, only one of the groups – the experimental group – will receive the actual treatment (such as a new drug), and the other group – the control group – will receive a placebo (a fake drug). A **placebo** is a fake or false treatment used so that none of the participants know whether they belong to the control or experimental condition.

placebo
a fake or false treatment

The **placebo effect** is a strange and misunderstood phenomenon that occurs during scientific studies. It occurs when a patient who is given a placebo (fake) treatment is tricked, by their own mind, into thinking that the treatment has beneficial effects. The improvement a patient may experience cannot be attributed to the treatment, but rather to the patient's belief in the treatment. In some studies, the placebo effect is so strong that the control group can improve as much as the experimental group!

placebo effect
a phenomenon where participants who receive a placebo perceive a benefit or improvement

Did you know? 1.1

Here are some unusual examples of how the placebo effect has been documented.

Dogs believe in placebos too!

In a canine study (the participants were dogs) a pharmaceutical company allocated epileptic dogs to either the placebo or experimental group. The experimental group received an anti-epileptic drug being trialled and showed positive results. However, the control group also responded positively, indicating the placebo effect is not just limited to humans!

Were they actually drunk?

Researchers tricked participants who believed they were drinking vodka (it was actually just tonic water and lime) into feeling drunk! Participants had impaired judgement and performed worse on simple memory tests.

Figure 1.16 A dog receives a check-up from a veterinarian.

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Placebo pills

Humans are visual creatures, and the colour and shape of a tablet actually influences our belief in how effective the medication is. Studies have found that yellow placebo pills are rated as the most effective in treating depression, while white pills are perceived as soothing stomach issues. Pills with a brand name stamped on them are rated as more effective than generic unlabelled pills. Some studies have suggested the placebo effect still exists even when the participant knows they are in the placebo medication group!

Figure 1.17 Medications come in a range of colours, shapes and sizes.

Figure 1.18 Single and double-blind procedures do not literally mean blindfolds!

Controlling for the placebo effect

A **single-blind procedure** can be used to control for the placebo effect. This occurs when the experimenter ensures that none of the participants know which group they have been assigned to – the control or the experimental group. This reduces the chance of participant expectations playing a factor in the results.

single-blind procedure an experimental design where the participants are unaware of whether they are in the experimental or control group

double-blind procedure an experimental design where the participants and researchers are unaware of which experimental group the participant is in

A **double-blind procedure** is when the experimenter collecting the data also does not know who is in which group. This is considered the 'gold standard' when conducting an experiment, as it controls for both experimenter bias and participant expectations; both the experimenter and participant are unaware as to which group each participant has been assigned to.

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Quick check 1.8

1. In a study measuring the impact of a new drug on attention deficit hyperactivity disorder (ADHD), the placebo group is usually also known as the ____________ group, whereas the participants exposed to the independent variable and taking the medication being tested for ADHD are part of the ____________ group.
2. List one way in which the placebo effect could occur.
3. How can you control for the placebo effect?

Experimental designs with human participants

Aside from the ethical issues, using human participants demands certain experimental designs and processes. It is essential that our sample of participants represents the population we hope to generalise the results to.

Sampling participants

In scientific research, a **population** is considered to be the entire group of people of research interest, which usually depends on the research question. It is rarely possible to perform an experiment on every member of the population so a **sample** (subset) is selected for the experiment. The purpose of a sample is to make the research manageable.

population (study)
the entire group of people who form the larger group of research interest

sample
a subset of participants selected from the population

For the research to be meaningful, the sample must be representative of the population of research interest. That is, it should reflect the characteristics of the population. Therefore, the procedure for selecting the sample should take into account relevant personal characteristics, so they occur in the same proportion in the sample as they do in the population.

There are a variety of ways to obtain a sample of participants from a population of research interest. These include convenience sampling, random sampling and stratified sampling.

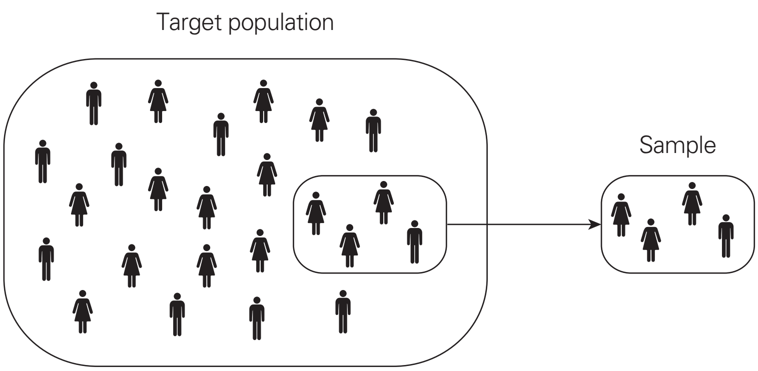

Figure 1.19 A sample is a smaller version of the target population.

Convenience sampling

In **convenience sampling**, the sample comprises of participants selected from a group or region that is readily available for the experimenter. Example: testing the students in your Year 10 Science class.

convenience sampling
selecting opportunistic samples based on the ease of accessibility to the experimenter

random sampling
selecting samples that had an equal chance of being selected from the population

Random sampling

In **random sampling**, the sample comprises participants selected from the wider population using a random procedure (such as a random number generator app or pulling names out of a hat). This technique is better than convenience sampling as it tends to avoid bias because it makes sure every individual within the population has the same chance of being selected for the study. Example: allocating all population members a number and using a random number generator app to generate a list of random numbers to select the sample.

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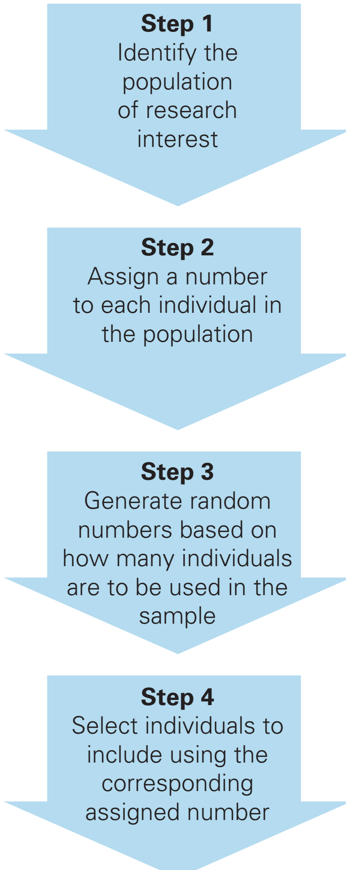

Figure 1.20 A flow chart showing the process of selecting a random sample for research from a population

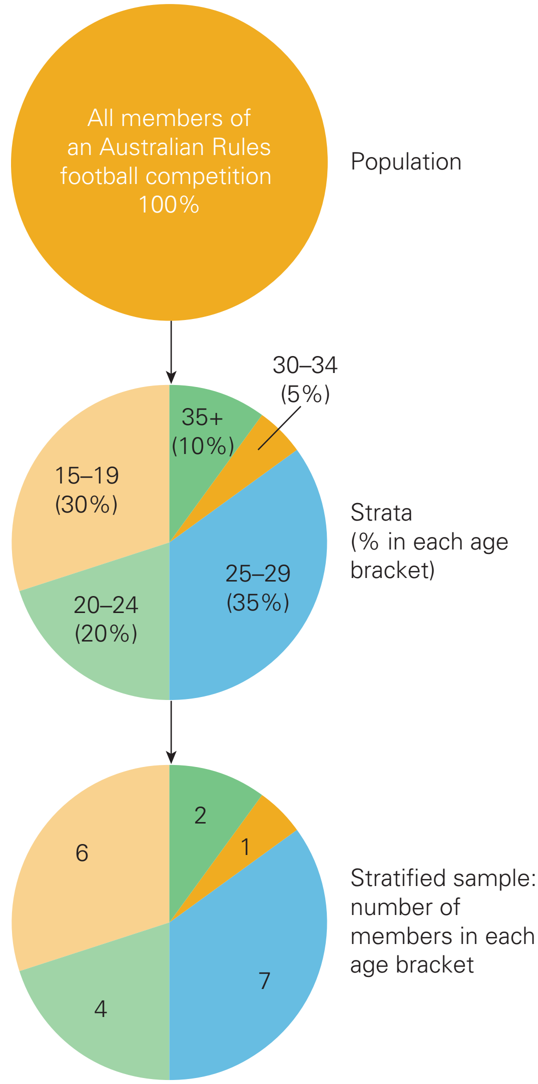

Figure 1.21 An example of a stratified sample using 20 participants that reflect the accurate proportion of age ranges within an Australian Rules football competition. The size of the sample from each age range reflects the proportion of the whole football population made up by that age range. (For example, more participants needed from the 15 – 19 age range and the 25 – 29 age range).

Stratified sampling

Purely random sampling still involves a chance that the sample (particularly if it is small) does not accurately represent the entire population. For example, by chance you may select the only two people from a pool of 1000 that have a heart condition, and this could skew the data.

One way of getting a more representative and unbiased sample is by using stratified sampling. The population of research interest is divided into distinct subgroups (called strata). For example, they can be grouped by age or gender, IQ, salary or political ideologies. Then a random sample is selected from each stratum in the population in the same proportion as they occur in the population. This method is called **random stratified sampling** because all members of each stratum have an equal chance of being selected as part of the sample.

random stratified sampling the population is organised into sub-groups (strata) and then a random sample is selected from each group

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Here is an example of a stratified sampling process:

A researcher was interested in investigating the student's attitudes towards the morning starting times at a particular school. The researcher decided to obtain a stratified sample based on the distance that students travelled to their school every morning. There were 300 students in the school and the researcher wanted to sample 30 participants.

Knowing the number required from each group, you can then use a random number generator to select students in each group, resulting in a random stratified sample.

Method	Less than 5 km	5–10 km from school	10–20 km from school	More than 20 km
Identify the number of students in the population in each distance lived from school	60	90	120	30
Calculate the percentage of the students within the population	20%	30%	40%	10%
Calculate the number of students in each stratum, given a sample total of 30.	20% of 30 = 6	30% of 30 = 9	40% of 30 = 12	10% of 30 = 3

Table 1.3 Calculating the percentage of each stratum

Try this 1.5

Sampling M&Ms

M&Ms are a favourite confectionery worldwide. Figure 1.22 shows the proportions of each colour produced in the factory.

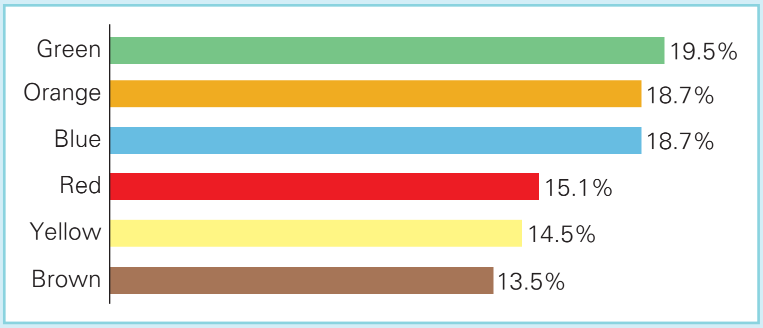

Figure 1.22 The proportion of different colours of M&Ms

Your teacher will give you a snack pack size of mini M&Ms.

1 Copy the table below and complete the following information by counting out the total numbers of M&Ms and distributing them into the colour groupings below.
Original sample size of snack pack: ______________

	Blue	Brown	Green	Orange	Red	Yellow
Number of M&Ms						
Proportion (%)						

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...continued

2 Within the class, calculate the total population of M&Ms by collating everyone's data.
Total population of M&Ms: ______________

	Blue	Brown	Green	Orange	Red	Yellow
Number of M&Ms						
Proportion (%)						

3 Graph the results of the total population of M&Ms of the class. Make sure you label the axes and complete a valid title.

4 How do the percentages of colour proportions from your graph compare to the graph obtained using the colour breakdown from the factory?

Analysis

1 How could you gather a convenience sample of 50 M&Ms from our population of M&Ms?

2 How could you gather a random sample of 50 M&Ms from our population of M&Ms?

3 How could you gather a random stratified sample of 50 M&Ms from our population of M&Ms?

4 What do you think would happen as your sample size increased?

5 What is the best sampling method? Explain.

Figure 1.23 Take your pick!

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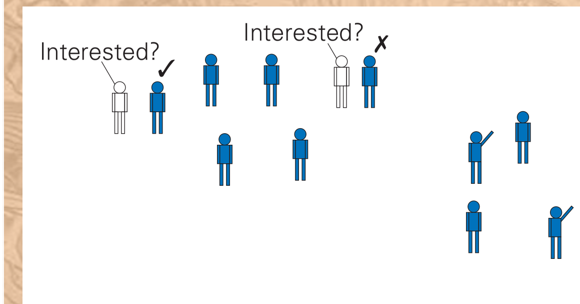
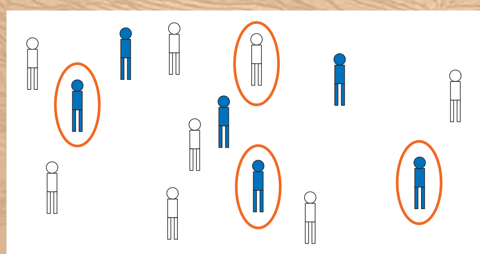
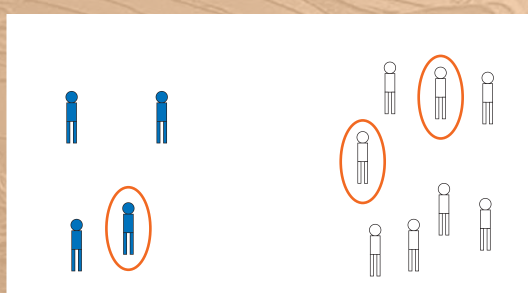
Type of sampling	Definition	Advantages	Disadvantages
Convenience sampling 	A sample is selected in the simplest way possible – for example, asking people that you know if they are interested to take part in the experiment or not.	It can be quick and easy to pick people who are easily accessible.	Only people known to the experimenter or people that are easily accessible are used, which may cause a biased sample group.
Random sampling 	A sample is selected by ensuring that every member of the population has an equal chance of being picked to take part in the experiment – for example, use a random number generator or pick names out of hat.	This is a fair way to select the sample as each member of the population has an equal chance of being chosen. It can also be quick and easy to assign each member of the population a number and to then use a random number generator.	This method may not be practical or representative of the population of research interest.
Stratified sampling 	A sample is selected by dividing the population into groups (strata) from which the participants are then selected in the same proportion as what is seen within the population.	This accurately reflects the population of research interest.	It may be time consuming to divide the population of research interest into appropriate groups (strata) to then select the correct proportion of participants from.

Table 1.4 An overview of sampling

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Participant allocation

After a sample has been selected, participants are **randomly allocated** to either the control or experimental group. The systematic random allocation of participants to groups ensures that the personal characteristics of participants that may affect the results are evenly distributed across the different groups. In other words, it allows for extraneous variables to be spread out across the groups.

random allocation participants are randomly placed in the control group or the experimental group

Random allocation can be generated by selecting names from a hat, assigning the participants a number and using a random number generator, or flipping a coin.

Remember that the **experimental group** is the group of participants that are exposed to the experimental condition where the independent variable is present, and the **control group** is the group of participants that are not exposed to the experimental condition (the independent variable). The control group provides the comparison or baseline performance on the dependent variable against which the performance of the experimental group can be compared.

experimental group the group of participants who are exposed to the independent variable (the experimental condition)

control group the group of participants who are not exposed to the independent variable (the experimental condition)

Figure 1.24 Cows on the left trial the fortified food. They were randomly allocated to the experimental group.

Quick check 1.9

1. What is the difference between random sampling and random allocation if you are using participants in your experiment?
2. What is similar about random sampling and random allocation if you are using participants in an experiment?
3. What is a convenience sample?

Practical 1.4

Do brands influence taste?

Aim

Food packaging and brand names can influence how consumers perceive the quality and/or taste of a food product. Consumers make judgements based on intrinsic cues (such as taste) and extrinsic cues (such as brand name, packaging quality and product price). The following information relates to a study that sought to analyse the effects these cues have on brand preference. Read the background, and then conduct an experiment of your own.

Be careful
No food items are to be consumed in the laboratory. Another setting should be used.

Background

Home brand food products are commonly perceived by consumers to be lower quality than products from famous brand names, even though they sometimes come out of the same factory! However, in recent years, the

continued…

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…continued

difference in perceived quality between the cheapest and most expensive brands has narrowed, as retailers have devoted more effort to marketing their own brands. You have probably seen many different brands of food in the supermarket. It is not a coincidence that the big food brands (including the supermarket's own brand) are given pride of place at eye level!

In a 2011 study, a team of psychologists investigated how brand packaging and taste affect brand preferences in consumers. The participants were all regular supermarket shoppers, and were chosen through a stratified process according to gender (70% females and 30% males) and occupation (70% employed, 30% not currently employed).

Data was collected from 93 participants. The median age category was 35–49 years. Participants were given three biscuits to taste: two were from leading manufacturing brands and one was a home brand product. Preference was measured on a Likert scale with a range of seven points, where the value 1 corresponded to very low preference and 7 to very high preference.

NOTE: A Likert scale is a rating scale that provides participants with a series of statements about a topic, by allowing them to express how much they agree or disagree with a particular statement.

For example: The following statements can be answered by ticking your level of agreeance using a scale of 1 – 5 (with 1 representing strongly disagree through to 5 representing strongly agree). There is no right or wrong answer as it is based on opinion.

	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
Monday is my favourite day of the week	✓				
Friday is my favourite day of the week				✓	

Participants were asked to rank the biscuits on their taste. The participants were then shown the packaging for each product and asked to rank the products for a second time.

The results showed that when the participants were not aware of the brand or packaging, they generally ranked the products according purely to taste. However, when shown the brand packaging, some participants who had previously rated the home brand product highly for taste, adjusted their rating down. Extrinsic cues were found to clearly affect consumers' taste preferences.

Your task

Create a scientific poster addressing the following research question:

Does knowing the brand of a food affect a consumer's taste perception?

On the cola market within Australia, the leading brand, Coca-Cola, is considered to lead the way in both taste and brand-packaging influence. The participants gave all cola categories lower preference ratings during blind taste testing than when they knew the brand. Participants rated the manufacturer-branded colas higher on the branded taste test and overall preferred the well-known manufacturer brand Coca-Cola.

Blind taste test	Mean	Branded taste test	Mean
Coca-cola	5.01	Coca-cola	6.32
Pepsi	3.86	Pepsi	5.03
Home brand	3.65	Home brand	3.68

continued…

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...continued

You will use this information as background information on the effects of the brand of food on the perception of taste. As this is quite a subjective experiment, every participant will conduct both the blind taste test and the branded taste test. You will also be expected to obtain informed consent from all participants. If every member of the class can recruit and test at least two participants, then the combined data from each can be used as part of the class results.

Materials

- Smith's brand original flavoured potato chips
- Woolworths or other home brand original flavoured potato chips
- plate
- cup of water (to clean palate during taste test)
- taste preference data sheet
- pen
- informed consent sheet

Method

1. Copy the results table below for the class results.
2. Choose two participants to perform the taste test. Consider sample size and demographics of your study.
3. Inform participants about the experiment and provide an informed consent sheet for further explanation and their signature. See the example sheet on page 37. Copy the sample data record sheet (see page 38) for each participant.
4. Present the participant with chips that they do not know the brand of. Ask them to rate the flavour in the blind taste test section of the sample data record sheet. Repeat with the second brand of chips.
5. Then present the participant with chips that they know the brand of. Ask them to rate the flavour in the brand taste test section of the sample data record sheet. Repeat with the second brand of chips, again showing the participant what brand they are.
6. Record the age and gender of each participant.
7. Collate the data in class and summarise it in the results table to determine whether the taste preferences varied when the brands were known versus unknown.

Results

	Average numerical score for taste quality (from a scale of 1–6) during blind test	Average numerical score for taste quality (from a scale of 1–6) during known brand test	Difference in taste quality score
Smith's			
Home brand			

1. Summarise the class results in table.
2. Represent the data as a graph with relevant axis labels and title.

Evaluation

1. List and explain two possible extraneous variables that may affect the results.
2. List and explain two possible limitations that may affect the results.
3. What future improvements would you recommend should this experiment be reproduced?

Conclusion

1. Make a claim about the effect of knowledge of brand on taste preferences in a food product based on this experiment.
2. Support your statement by using the data you gathered and include potential faults with the experiment or measurement uncertainties.
3. Explain how the data supports your statement.

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Sample informed consent form for experiments using people as participants

Dear Participant,

Year 10 Science students are required to complete research as a part of their scientific studies. Part of the requirements of their assessment is to obtain appropriate, clear and informed consent from potential participants. We thank you for your time in assisting our students with the research.

Informed Consent Form to Participate in Research

Project Title: Is taste perception influenced by knowing the brand being tasted?

I, ______________________________, accept the invitation to participate in this study conducted by a Year 10 Science student of ________________________ school.

The purpose of the study is to investigate the impact of brand awareness on taste perception. On the day of data collection, I will be asked to complete a short taste test of some original flavoured potato chips and to rate them on taste quality.

This research will take approximately ____two____ minutes in total.

- I understand the purpose, procedure, expectations and commitment required of this study.
- I understand that the project may not benefit me directly.
- To the best of my knowledge, there is nothing hindering me from participating in this study, and I have no allergies.
- I understand that all results I provide will remain confidential.
- I understand that I can refuse to consent or withdraw from the study at any time without explanation, as well as withdraw my results from the survey if I wish.
- I understand that my results will be published in the student's report and my identity will not be revealed.
- I understand that at the completion of the research I can discuss any concerns I may have with the researcher.

I have read the above and hereby voluntarily consent and offer to take part in this study.

Signature of Participant: ________________________ Date: ________

Signature of Parent: *________________________ Date: ________

*(*required if participant is under 18 years of age)*

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Try this 1.6

Water taste test

Create an experiment that tests different brands of water for taste quality. Evaluate the cost per litre and taste quality rating. Do this test on people who are not in your class to make sure that your study participants have no prior knowledge or expectations.

OR

Create an experiment where you trick or deceive the participants to taste test different brands of water. In fact, just use tap water at each taste station, but place bottles of branded water next to some stations to determine whether the perceived brand of the water affects the perceived taste quality of the water.

Be careful

No food items are to be consumed in the laboratory. Another setting should be used.

Sample data record sheet

Participant:

Gender ______________________________

Age ______________________________

Blind taste test:

Taste rating	Very Low	Low	Adequate	Satisfied	Good quality	Very High
Sample A	1	2	3	4	5	6
Sample B	1	2	3	4	5	6

Brand taste test:

Taste rating	Very Low	Low	Adequate	Satisfied	Good quality	Very High
Home brand	1	2	3	4	5	6
Smith's	1	2	3	4	5	6

Sample A for this participant was ______________________________

Sample B for this participant was ______________________________

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Research designs with human participants

Three different experimental designs are used to minimise the effect of extraneous variables when using humans in experiments.

independent groups design a design in which two separate groups of participants are used in an experiment

repeated measures design a design that uses the same participants for both/all conditions in the experiment

An **independent groups design** uses two or more entirely separate groups of participants, with each participant exposed to only one of the different conditions tested.

A **repeated measures design** uses the same participants for each condition in an experiment; for example, half the group is first allocated to the control group and the other half is allocated to the experimental group – then they swap over and complete the experiment again, but this time under the different condition being tested.

A **matched participants design** pairs participants who are similar (in age, gender, fitness, IQ, or baseline performance on a test), and then randomly allocates them to the different groups in an experiment. Each participant will only be exposed to one condition, and their matched partner will be exposed to the other condition.

matched participants design a design in which similar participants are paired and then allocated to different groups

Table 1.5 summarises the differences.

Experimental design description	Advantages of design	Limitations of design	Example of procedure: When testing the effects of sleep deprivation on driving ability
An *independent groups design* allocates each participant randomly to one of two or more entirely separate groups, usually an experimental and control group.	Each participant is only exposed to one condition, so they cannot do better or worse the second time they conduct the experiment (known as an order effect). Quick (time-efficient) and easy to set up	Less control over participant-related extraneous variables (like IQ or age) than other designs – especially if the sample of participants is small – as different participants are exposed to only one of the different conditions	Randomly allocate participants into two separate groups – usually an experimental (sleep deprived) or control group (not sleep deprived).
A *repeated measures design* is where each participant is involved in both the experimental and control conditions in the experiment.	Controls participant-related extraneous variables because the same participants are used in all conditions tested. Fewer participants are required than in the other experimental designs.	May have order effect (the improvement or decline in the participants' performance on a task due to the practice and experience gained in the first task or condition in an experiment).	1 Administer driving simulator test to participants. 2 Match and pair participants on the basis on scores obtained from the driving test. (Participants with the highest scores are paired, then the next two participants with the next highest scores, and so on. 3 Randomly allocate one person in pair to the control condition, the other person to experimental condition.

Table 1.5 Summary of the procedures and advantages and disadvantages of three experimental designs

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Experimental design description	Advantages of design	Limitations of design	Example of procedure: When testing the effects of sleep deprivation on driving ability
A *matched participants design* first selects pairs of participants who are very similar in terms of characteristics which could affect the DV (IQ, age, etc.), and then randomly allocates each member of the pair to the different groups in the experiment.	Limits the control over participant-related extraneous variables because the experimental and control groups are matched on important participant-related variables likely to affect the DV, such as IQ and age. No order effects to control	As pre-testing and pairing of participants is involved, this design can be time consuming and costly. Only controls specific participant related extraneous variables – not all.	1 Participants complete driving simulator test sleep deprived. 2 The same participants do the same driving simulator test on another day without being sleep deprived. Counterbalancing could be used to control for the effects of order.

Table 1.5 *(Continued)*

Drawing conclusions and generalising

When drawing conclusions, a judgement is made based on whether the results of the experiment support or do not support the hypothesis. The conclusion can be generalised to the wider group of research interest if certain criteria are met. These criteria include:

- The results are statistically meaningful (and valid); for example, sufficient participants were tested and any differences are statistically significant.
- There are no limitations that mean that the results for the sample cannot be generalised to the population of research interest; for example, the sample was truly representative of the population of research interest and the sampling method was appropriate.
- Wherever possible, all extraneous variables are controlled.

Therefore, while you can always draw a conclusion from a study by either accepting or rejecting the hypothesis, it is much harder to go further and generalise these results to the wider population of research interest when humans are used as the participants in a study.

Quick check 1.10

1 List the three different experimental designs that may be used with humans.
2 List one limitation of a matched participants design.
3 What three criteria must be met in order to generalise results using humans?

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Section 1.2 questions

QUIZ

Remembering

1 What is the importance of sampling in scientific research?
2 What are some branches of science that of science usually requires human participants?

Understanding

3 Explain the differences between random sampling and random allocation.
4 What is one key advantage of using a stratified sample in an experiment?

Applying

5 Pauline was interested in conducting research on humans to look at the effect of extreme temperature on memory recall. What three key pieces of information should be included in an informed consent form?
6 Outline one procedure that could be used to obtain a random sample of 30 participants from your school, which is the population of research interest.

Analysing

7 If deception is to be used within an experiment using humans, what must be done to combat any negative effects that may have been experienced by the participant?
8 Why would a matched participant design be considered a better research design than an independent groups design when looking at the effects of stress on memory ability?

Evaluating

9 A researcher was interested in investigating how driving ability was affected if people were sleep deprived and under the influence of alcohol – specifically with a blood alcohol content (BAC) reading of 0.05. She tested 30 participants who responded to an advertisement on Facebook. They were tested in a driving simulator in one of three conditions: control, sleep deprived and BAC 0.05. Results are shown in Figure 1.25:

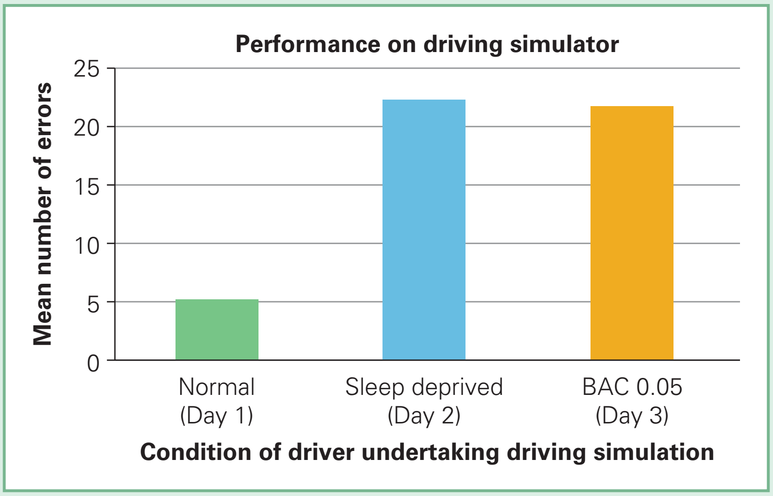

Figure 1.25

a What research design was used?
b Why would this design be the best to use in this study?
c Summarise the results found, using data from graph.

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Review questions

SCORCHER

Remembering

1 Name two ethical principles that must be upheld by a scientist conducting research using humans.

2 Define the following:
 a independent variable
 b dependent variable
 c extraneous variables
 d controlled variables.

3 What is the placebo effect?

4 What information is located on an SDS?

Understanding

5 How can the placebo effect be eliminated?

6 Explain why a repeated measures design is considered to control for most participant-related extraneous variables.

Applying

7 The table below shows results that a changing pH of a pond has on the number of tadpoles that are found there.

pH of water	Number of tadpoles
8	45
7.5	69
7	78
6.5	88
6	43
5.5	23

 a Identify the IV and DV of this study.
 b Which pH is the optimum for tadpole growth?
 c Construct a scatterplot with correctly labelled axes and title, to display this data.

8 A researcher wants to gather information about the reflex times of senior high school students. A local high school obtains informed consent from all guardians and the researcher is provided with the following enrolment information from the school:

	Year 10	Year 11	Year 12
Males	65	52	38
Females	68	65	50

If the researcher wants a sample of 40 students, suggest a method for stratified random sampling she could employ, and state the number of students that would be selected for each subgroup.

Analysing

9 A faulty burette is being used during a titration and this causes the results to all be overstated by around 0.5 mL each time.
 a What type of error does this represent?
 b Discuss the effect in terms of accuracy, precision, validity and repeatability.

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10 Read the following excerpt from a recent study and answer the questions below.

> Research studies using mice and rats have shown that just 10 minutes of mild, almost easy exercise on a daily basis can immediately alter how certain parts of the brain communicate and coordinate with one another and improve memory function. The findings suggest that exercise does not need to be prolonged or intense to benefit the brain and that the effects can begin far more quickly than many experts had thought. Multiple studies with mice and rats have found that the animals develop more new brain cells if they run on wheels or treadmills than if they remain sedentary. Many of the new cells are clustered in the hippocampus, a portion of the brain that is essential for memory creation and storage. The active animals also perform better on tests of learning and memory.
>
> Equivalent experiments examining brain tissue are not possible in people. But some past studies have shown that people who exercise regularly tend to have a larger, healthier hippocampus than those who do not, especially as they grow older. Even one bout of exercise, research suggests, can help most of us to focus and learn better than if you sit still.

Source: 'Even a 10-Minute Walk May Be Good for the Brain', Gretchen Reynolds, *The New York Times*, October 24, 2018

a Identify a possible independent variable and dependent variable from this study.
b Construct a testable hypothesis.
c What issues arise when generalising the results from this study to humans?

Evaluating

11 A student was interested in testing the effects of sleep deprivation on memory recall in secondary school students, so decided to conduct a study. He chose four of his friends to be the participants. Two of them went without sleep for a whole 24-hour period and were then given 20 three-letter nonsense words (for example, tuf, pud, wes) to memorise for two minutes and then recall.

The other two of his friends were allowed to sleep for their usual time period and were given the same memory test: 20 three-letter nonsense words to memorise for two minutes and then recall.

Results are shown below:

	Average recall score of three-letter nonsense words (out of 20)
Sleep deprived group	3
Non–sleep deprived group	7

a Construct a testable hypothesis for this experiment.
b Which experimental design was used?
c Graph the results.
d Outline two possible extraneous variables.
e Discuss whether this experiment was ethically sound.
f What conclusion can be drawn from the results obtained.
g What limitations exist in this study?

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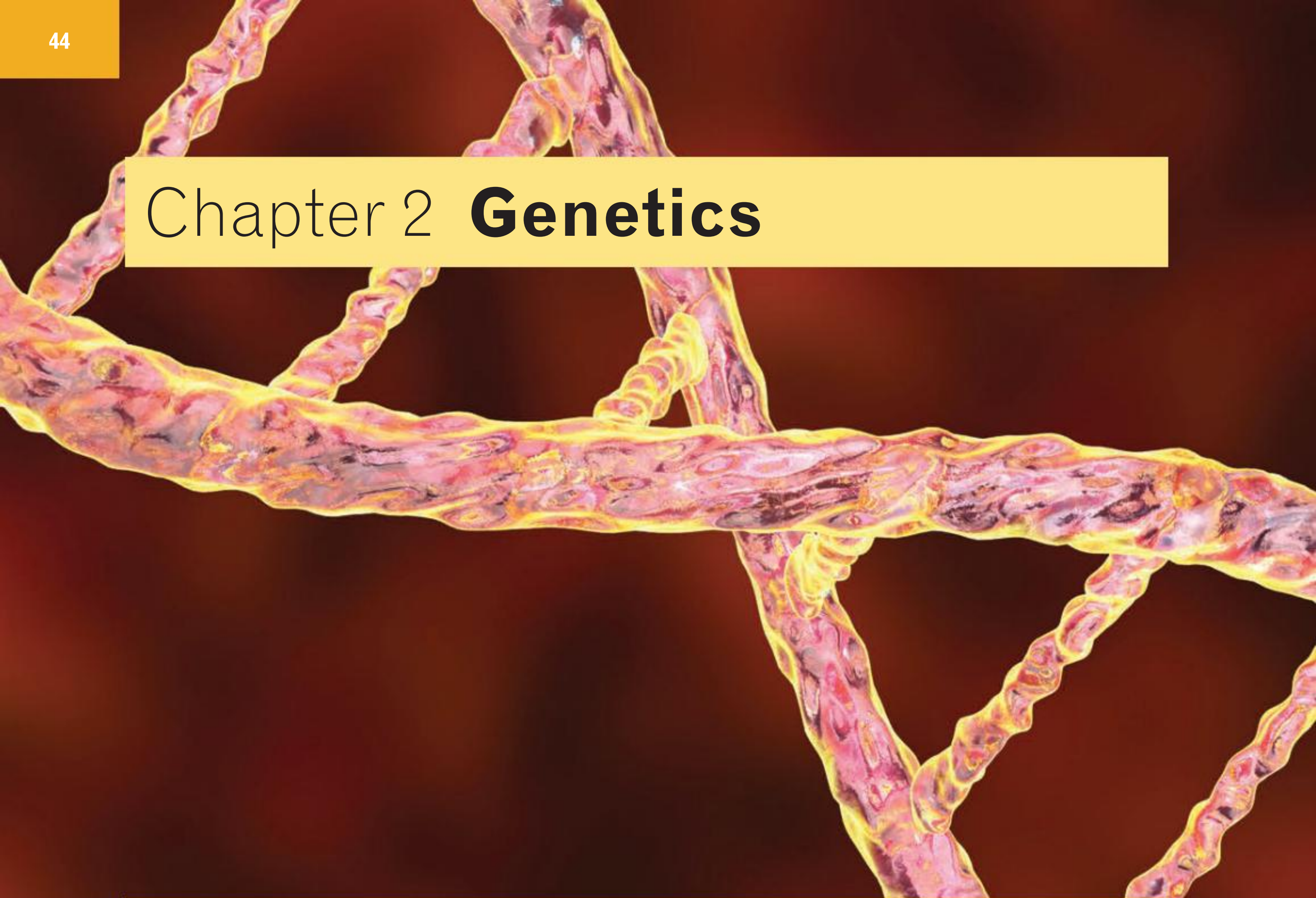
Chapter 2 Genetics



Chapter introduction

Everyone is unique. That is thanks to the genetic make-up we all have within us, known as DNA. DNA carries the important instructions that make us who we are. This chapter delves into the DNA molecule and the important role that genes play in the inheritance of the characteristics that make us who we are. Geneticists rely upon DNA in many different areas; for example, to examine the probability of passing on traits to offspring and to assist with forensic investigations by using DNA profiling. You will also examine the structure of DNA and the effect of mutations.

Curriculum

The transmission of heritable characteristics from one generation to the next involves DNA and genes (VCSSU119)	
• using models and diagrams to represent the relationship between DNA, genes and chromosomes	2.1
• describing mutations as changes in DNA or chromosomes and outlining the factors that contribute to causing mutations	2.4
• recognising that genetic information passed on to offspring is from both parents and involves the processes of fertilisation and meiosis	2.2
• representing patterns of inheritance of a simple dominant/recessive characteristic through generations of a family	2.3

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Glossary terms

allele
aneuploidy
autosomes
bioinformatics
chromosome
chromosome mutation
codominance
complementary pairing
deletion
diploid
DNA
Down syndrome
embryo
fertilisation
gametes
gene
gene therapy
genetic engineering
genetic screening
genetically modified organism
genetics
genome
genotype
germline mutation
gonads
haploid
heterozygous
homologous chromosomes
homozygous
hydrogen bonds
incomplete dominance
induced mutation
insertion
inversion
karyotype
locus
meiosis
mitosis
mutagenic
mutation
non-disjunction
non-homologous chromosomes
nucleotide
ova
pedigree
phenotype
point mutation
Punnett square
reduction division
sex chromosomes
sexual reproduction
somatic cells
somatic mutation
spontaneous mutation
substitution
test cross
transgenic organisms
triplet
trisomy
zygote

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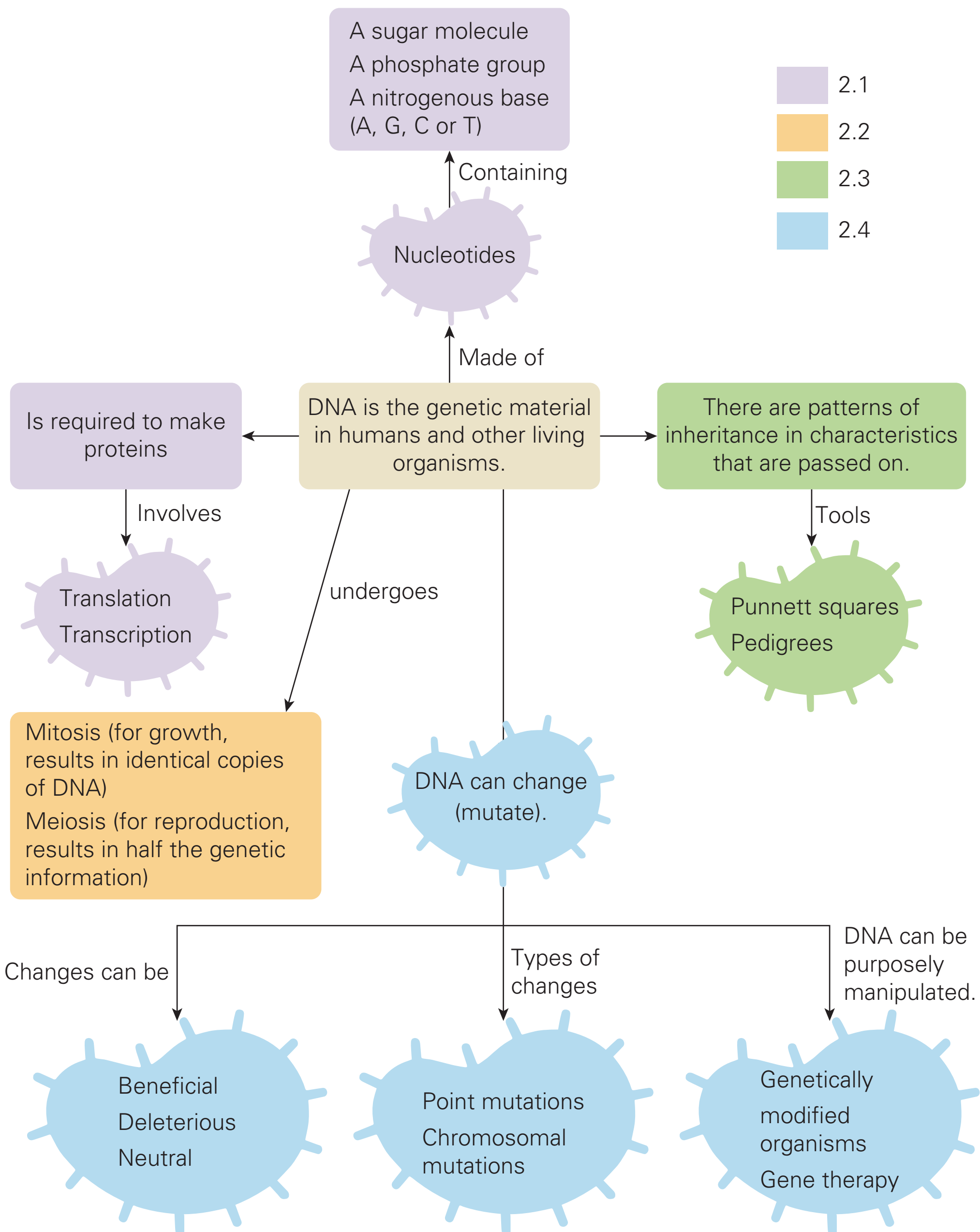
Concept map



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2.1 Introduction to genetics and DNA

Genetics

Genetics is the study of inheritance. Genetic information is passed on from generation to generation. This results in traits or specific characteristics being passed on from parents to offspring, and occurs in all species – including humans.

genetics
the study of inheritance

You may recall from when you investigated cell structure that genetic information is contained in the nucleus of cells. This genetic information is called deoxyribonucleic acid, or **DNA** for short.

WORKSHEET

DNA
genetic make-up that carries the instructions for life (deoxyribonucleic acid)

Practical 2.1

Extracting DNA from cells

Be careful
No food items are to be consumed.

Aim
To investigate and extract the DNA from wheat germ.

Materials
- raw wheat germ
- 100 mL beaker
- stirring rod
- plastic pipette
- bent glass rod
- 30 mL of warm water (~50°C)
- dishwashing detergent
- alcohol (70–95% isopropyl or ethyl alcohol)

Method
1 Place one level tea spoon of raw wheat germ into a 100 ml beaker.
2 Add 30 mL of warm water (~50°C) to the beaker.
3 Use a stirring rod to stir the mixture for 2–3 minutes.
4 Add 1 mL of detergent to the beaker and continue to stir, very gently, for 5 minutes. Avoid creating foam or bubbles.
5 Use a plastic pipette to remove any foam or bubbles that may have formed.
6 Decant the water/detergent mixture into a clean test tube. Make sure the wheat germ remains in the beaker and is not transferred to the test tube.
7 Tilting the test tube at an angle of about 45 degrees, carefully and slowly pour some cold alcohol into the test tube until there are equal amounts of the DNA mixture and alcohol. The alcohol should form a separate layer on top; do not allow the layers to mix.
8 Wait several minutes for the DNA to appear in the alcohol. Look for a white precipitate to form where the mixture and alcohol meet (called the interface).
9 Using a bent glass rod, gently and slowly lift the precipitate. It is fragile and looks like thread.

You now have some DNA that has been extracted from the wheat germ.

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...continued

Results

Sketch the test tube as it appears, labelling the DNA that became visible.

Evaluation

1 Describe the DNA as it appears in the alcohol.
2 Suggest why the alcohol is used and explain what happens when it is added.
3 Suggest some improvements for this experiment.

Conclusion

1 Make a claim about DNA based on this experiment.
2 Support the statement by using observations and include potential sources of error.
3 Explain how the observation supports your statement.

VIDEO
What is DNA?

Structure of DNA

DNA is a double-stranded molecule that forms a 'double helix' shape, like a twisted ladder.

nucleotide
a subunit of DNA

DNA is a polymer (poly means 'many') as it is made up of numerous amounts of subunits called **nucleotides**.

A nucleotide has three major components:

- a five-carbon sugar molecule called deoxyribose
- a nitrogenous base – one of adenine (A), guanine (G), cytosine (C) or thymine (T)
- a negatively charged phosphate group.

The nucleotides bind together in the middle (using **hydrogen bonds**) to form two long strands, and then twist to form the double helix (twisted ladder shape). The sugars and phosphates form what would be the side of the ladder (and are called the sugar–phosphate backbone), while the nitrogenous bases align towards the centre and form the rungs of the ladder.

hydrogen bonds
chemical bonds that hold the two strands of DNA together

Figure 2.1 A simplified illustration of the DNA double helix

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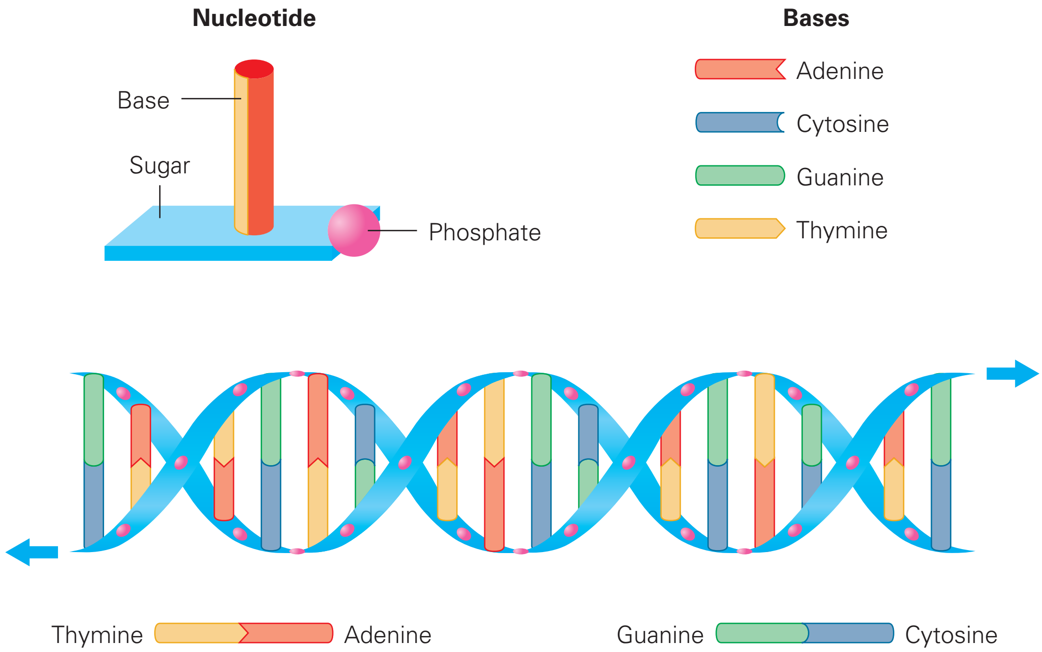

Figure 2.2 The structure of DNA: the subunits called nucleotides all join up to form the double-stranded DNA. Note the sugar–phosphate backbone on the edge of the DNA molecule and the nitrogenous bases joining in the centre.

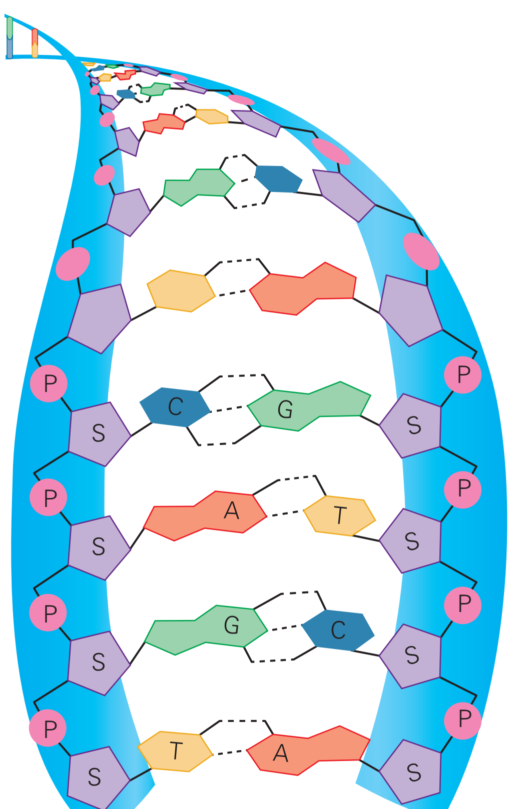

Figure 2.3 A closer look at the structure of DNA. The sugar–phosphate backbone forms the edge and the nitrogenous bases form complementary pairs in the centre. Hydrogen bonds hold the two strands together.

What do you notice about the pairing of the nitrogenous bases in the previous diagram? We can see that the bases on one strand pair with the bases on another strand. You can also see that adenine (A) always pairs with thymine (T) and guanine (G) always pairs with cytosine (C). This pairing is called **complementary pairing** and has to do with the shape of the nitrogenous bases and the number of hydrogen bonds they need to form to hold the strands together. For example, you can see in Figure 2.3 that guanine and cytosine both form three hydrogen bonds, while adenine and thymine only form two hydrogen bonds.

complementary pairing adenine only binds with thymine and cytosine only binds with guanine

Both guanine and adenine have a double-ring structure, which means they are in the group of chemical molecules called purines. Cytosine and thymine have a single-ring structure and are in the group called pyrimidines. A purine (which is larger) always pairs with a pyrimidine (smaller) to achieve a more stable molecule.

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Try this 2.1

Modelling DNA using lollies

Remember not to consume the lollies in the classroom, and beware of allergies.

Materials

- liquorice ribbons or sour strips
- a handful of jelly babies
- cocktail sticks

Method

1. Sort the jelly babies into four groups of colours.
2. Pair up the jelly babies so that one particular colour always goes with another particular colour; for example, red with yellow and orange with green.
3. Place a pair of jelly babies onto each cocktail stick as if you were making lolly kebabs. Ensure that the pairs are always of matched colours.
4. Attach your lolly kebabs to the long strips of liquorice.
5. Keep doing this until you have about 5–7 horizontal cocktail sticks attached and it starts to look a bit like a ladder.
6. The paired coloured sweets represent the base pairs, while the liquorice is the sugar–phosphate backbone.
7. Pick up your lolly ladder and twist it to represent the double helix shape of DNA.

Did you know? 2.1

How long is DNA?

The DNA found in only one cell, if fully unravelled, would be around two or more metres long! The length of a piece of double-stranded DNA is commonly expressed as the number of complementary nitrogenous base pairs it contains. The DNA in an average human cell has an estimated 63 000 000 base pairs.

Quick check 2.1

1. List the three key components that make up a nucleotide, the basic building block of DNA.
2. Describe the overall shape of DNA.
3. If a strand of DNA was to contain the bases seen below, what would the bases in its complementary strand be?
   One DNA strand: ATATAGATAGAT CAGACA

Explore! 2.1

The discovery of DNA

Friedrich Miescher was a German biochemist who first observed DNA in 1869. However, it took almost a century for scientists to understand DNA's structure, the mechanisms by which it carries genetic information, and what it is made of.

Research the following scientists who, among many others, contributed to our understanding of DNA. Put their contributions on a timeline.

- Friedrich Miescher
- Erwin Chargaff
- James Watson
- Francis Crick
- Rosalind Franklin
- Maurice Wilkins

Figure 2.4 The structure of DNA was discovered by Francis Crick and James Watson while working in the Medical Research Council Unit for Research on the Molecular Structure of Biological Systems at the Cavendish Laboratory in Cambridge. In 1953 they constructed a molecular model of the complex genetic material deoxyribonucleic acid (DNA).

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What is a chromosome?

The DNA found in the nucleus of cells usually looks like a bowl of spaghetti. However, when it is time for the cell to replicate, the DNA winds up tightly around proteins called histones to form structures called **chromosomes**. Each molecule of DNA forms one chromosome. Along each length of the chromosome are structures called **genes**, which are the units of inheritance. Genes are actually just sections of DNA or chromosome that, like a recipe book, hold the specific instructions required for making all of the proteins in our bodies! Proteins are fundamental to all of the chemical reactions in an organism, and also form much of its structure.

chromosome
a structure of tightly wound DNA

gene
a length of chromosome

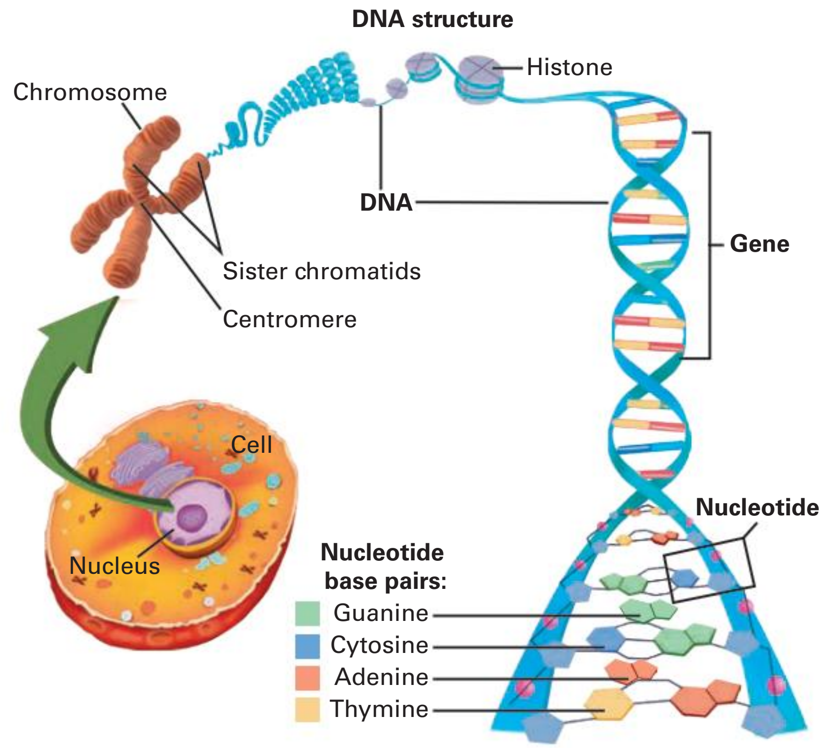

Figure 2.5 The relationship between DNA and chromosomes

You may realise that the chromosome has a familiar X-shape. But, before replication (when DNA is copied), the chromosome appears as a single structure. After replication, two chromatids are joined together by centromeres to form the distinct X-shape, then these are known as sister chromatids. They belong to the same chromosome. Figure 2.6 shows this.

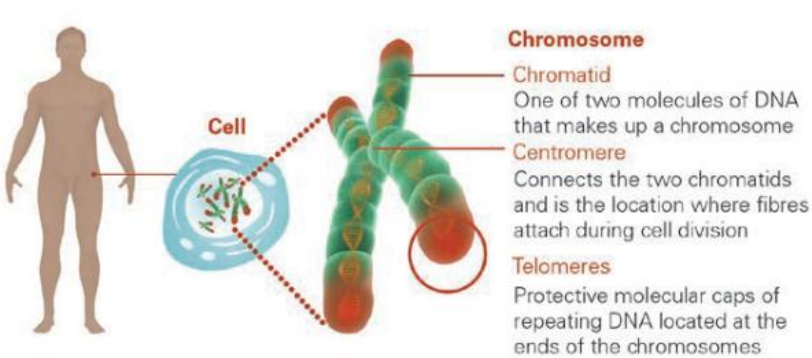

Figure 2.6 The distinct X-shaped chromosome, showing the two chromatids and the centromere

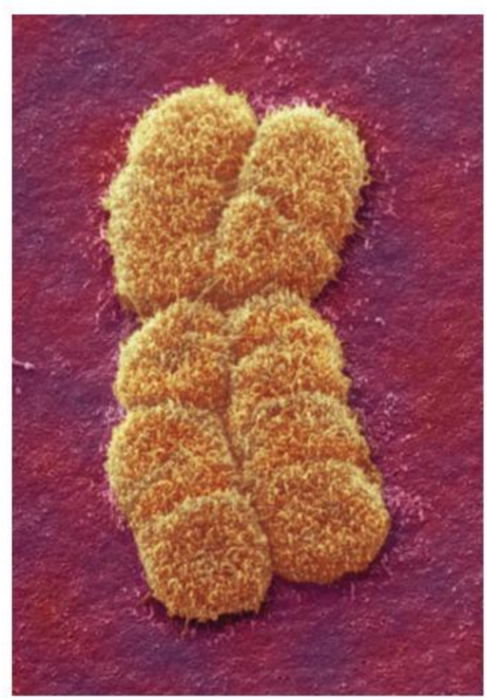

Figure 2.7 A scanning electron micrograph of a human chromosome. Notice the two identical chromatids joined at a centromere.

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Science as a human endeavour 2.1

Professor Elizabeth Blackburn

Born in Hobart in Tasmania, Australia, Professor Elizabeth Blackburn took an early interest in nature and studied biochemistry at the University of Melbourne. She completed her PhD at Cambridge University, United Kingdom, and then went on to work in the United States. Through her research, she and her colleagues discovered that the ends of DNA, called telomeres, have a particular DNA that prevents chromosomes from breaking down. The enzyme telomerase produces the telomeres' DNA. Elizabeth Blackburn was awarded the 2009 Nobel Prize in Physiology or Medicine together with her colleagues Jack W. Szostak and Carol Greider.

Figure 2.8 Nobel Prize Laureate Professor Elizabeth Blackburn was integral to the research on telomeres.

Different forms of nucleic acids

There are four types of biomacromolecules: proteins, carbohydrates, lipids (fats and oils) and nucleic acids. You would have already learned about several of these biomacromolecules in Year 9, but may not have realised that DNA is in the group of nucleic acids. Nucleic acids are found in two forms: DNA and ribonucleic acid (RNA). There are key differences between the two types of nucleic acids, which are outlined in Table 2.1.

	DNA	RNA
Number of strands	Two	One
Type of sugar	Deoxyribose	Ribose
Nitrogenous bases	Guanine Cytosine Adenine Thymine	Guanine Cytosine Adenine Uracil
Where is the molecule found?	In eukaryotes, DNA is found in the nucleus, mitochondria and chloroplasts In prokaryotes, DNA is not found in specialised organelles, rather they are found within the cytoplasm	Cytoplasm Nucleus Ribosomes
Different forms	DNA	Messenger RNA (mRNA) Transfer RNA (tRNA) Ribosomal RNA (rRNA)

Table 2.1 The main differences between the two nucleic acids DNA and RNA

Quick check 2.2

1. Describe the relationship between chromosome, genes, DNA and base pairs.
2. List three key differences between DNA and RNA.

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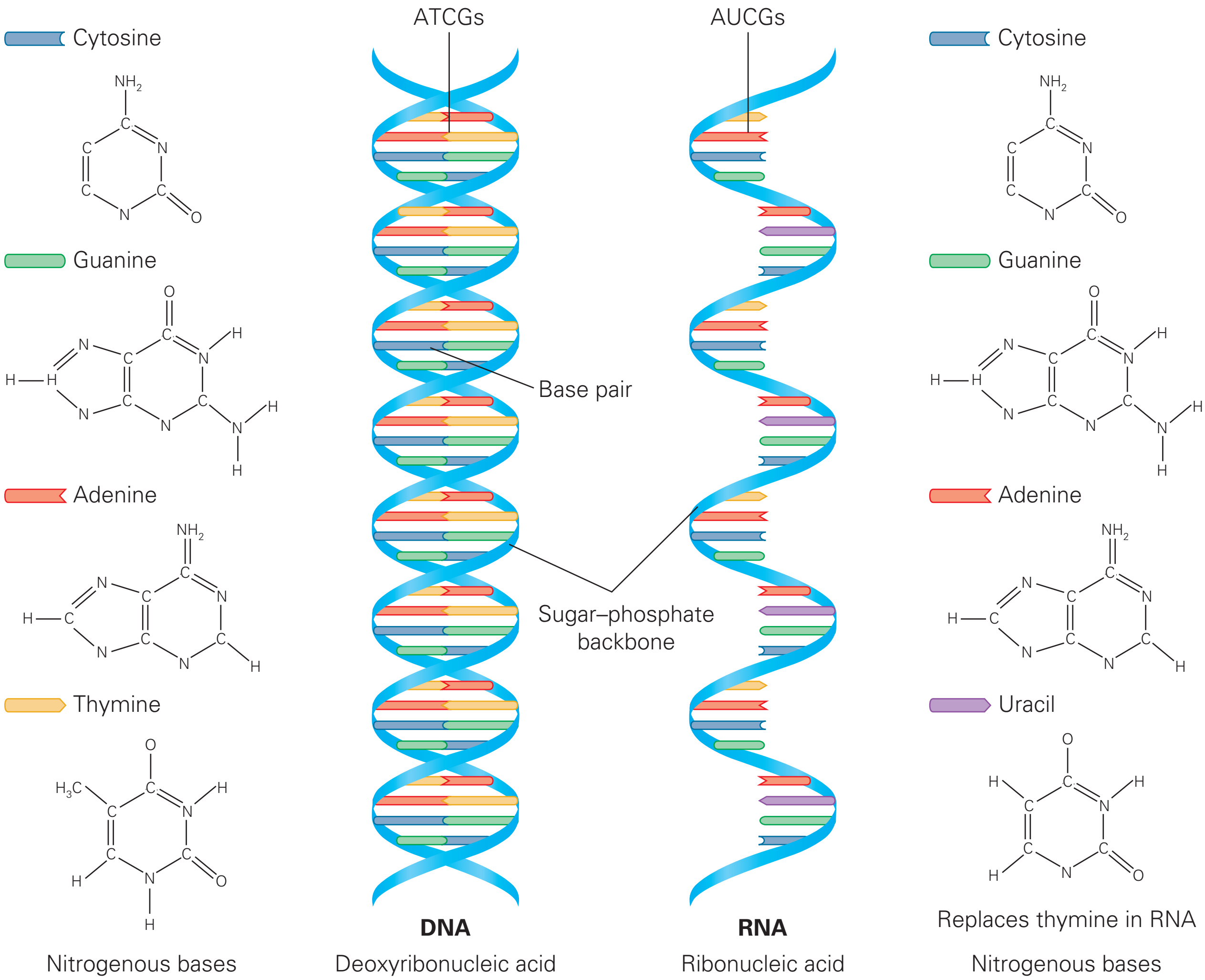

Figure 2.9 DNA and RNA

The purpose of DNA: making proteins

Why do we need proteins?

We need proteins to stay alive. We need to make use of approximately one billion proteins every day, just to function normally. Proteins are the main structural component of cells, and they can build and repair tissue, and may include enzymes to break down substances. Protein molecules play varied roles in the body; they include the haemoglobin molecule that carries oxygen around our body and the hormones that regulate our glucose levels and development. Other proteins help us fight invaders, speed up reactions and move our muscles.

Protein functions — **Explore! 2.2**

Proteins' many roles include structural, contractile, transport, catalytic, regulatory and immunological functions. Research the following proteins and determine their function.

Protein	Function
Collagen	
Actin	
Haemoglobin	
Amylase	

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The link between DNA and proteins

Remember that genes are sections of DNA or chromosome that hold the specific instructions required for making all of the proteins in our bodies. The order of the nitrogenous bases in the gene provides these instructions (or code) for proteins. Each group of three nitrogenous bases in DNA is called a **triplet** and codes for a particular amino acid to be assembled. Amino acids are the subunits of proteins. The order of the triplets specifies the sequence of amino acids that forms a particular protein.

triplet three DNA bases that code for an amino acid

Quick check 2.3

1 Why are proteins important?
2 What is the relationship between DNA, amino acids and proteins?

Making proteins using the DNA code

To build proteins using the DNA code in genes, the gene must be expressed. This means two processes need to occur: transcription and translation.

To transcribe means to put into written form, so in this process the DNA code for a specific protein is 'written down' in the form of mRNA (messenger RNA). You could liken this to having a website full of wonderful delights to bake, but you only want to make chocolate brownies. So you make a copy of the page you need to make that one specific dish.

To translate means to convert into another form, so in this process the code (written down as mRNA) is converted into a chain of amino acids. In the same way, your copy of the instructions for making brownies are converted into the most amazing brownies to eat.

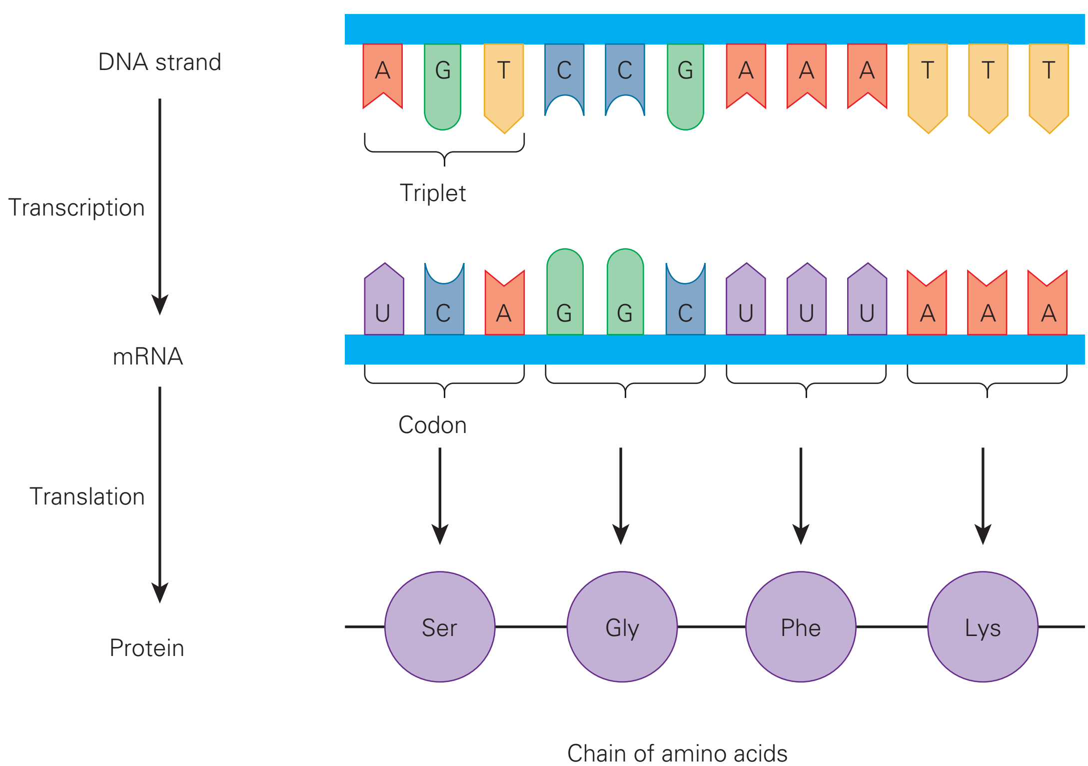

Figure 2.10 The process of transcription and translation from the DNA molecule

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Transcription

Transcription happens in the nucleus of the cell. The transcription process requires getting access to the DNA code in the genes, otherwise the code cannot be copied. This is like you having to open the recipe website before you can copy the brownie recipe. To access the DNA code, the double strand of DNA needs to be 'unzipped'. Then, an enzyme can come in and read the code on one of the DNA strands (called the DNA template strand). As the enzyme reads the code, it builds a copy of the gene using RNA nucleotides. The cool thing is that the RNA follows the same complementary pairing as DNA, with one exception. Where DNA has the nitrogenous base thymine, RNA has uracil. The resultant single-stranded RNA formed is called messenger RNA (mRNA). When the mRNA peels away from the template strand, the DNA double strands rejoin. The mRNA can then leave the nucleus and go to the site of protein production, the ribosomes.

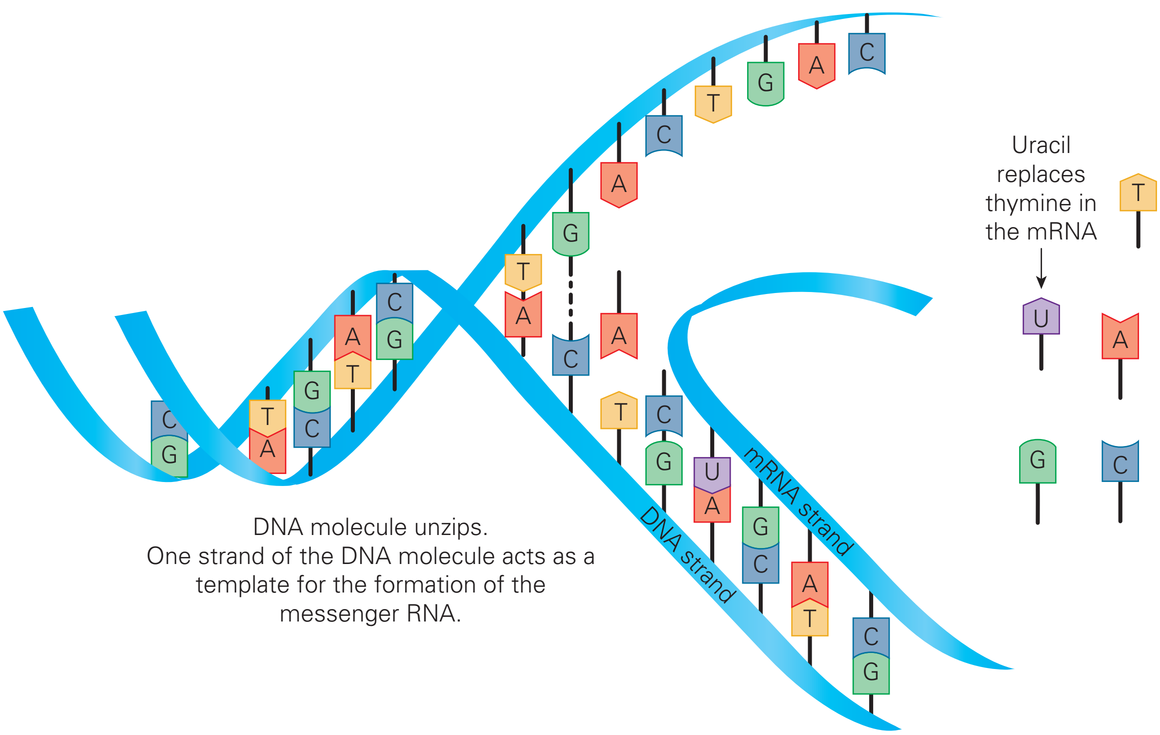

Figure 2.11 When the DNA double helix unwinds and unzips, one strand of the DNA acts as the template on which messenger RNA strand is formed.

Try this 2.2

Base pairings

Complete the base sequence of the DNA complementary strand and then the mRNA strand formed from the DNA template strand given below.

Complementary DNA												
DNA template	T	A	C	C	C	G	A	A	A	G	T	G
mRNA												

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WIDGET
Building a protein

Translation

Once mRNA reaches the ribosomes in the cytoplasm, it must be 'decoded' or translated so that the necessary protein can be made. The nitrogenous bases in the mRNA are decoded in groups of three (called codons in mRNA and triplets in the original DNA template strand). Each codon in the mRNA specifies an amino acid – remember it is a chain of amino acids that we call a protein. The process of translation is a bit tricky and involves several enzymes and another type of RNA called transfer RNA (tRNA). It occurs at the ribosomes, which may be freely floating in the cytoplasm or attached to the endoplasmic reticulum (ER) as rough ER. Each tRNA molecule is responsible for transporting one amino acid towards the ribosome, for delivery.

Table 2.2 shows the 20 different amino acids that make up the amazing range of proteins we have in our world. To use the table, and see what happens during translation, let's say your first codon in your mRNA is AUG. First, you look up the A on the left and the U at the top and find where they intercept. At that spot is a box containing four different codons. You then read across from the G on the right and you will see your codon AUG. Next to the codon it says Met, which means AUG codes for the amino acid methionine. The codon AUG is unique as it can also be called the START codon. This means that it is the first codon in the transcribed mRNA that undergoes translation. In eukaryotes, AUG codes for methionine (Met) and is also the only START codon.

2nd letter in the codon

1st letter in the codon	U	C	A	G	3rd letter in the codon
U	UUU, UUC: Phe (F) UUA, UUG: Leu (L)	UCU, UCC, UCA, UCG: Ser (S)	UAU, UAC: Tyr (Y) UAA: STOP UAG: STOP	UGU, UGC: Cys (C) UGA: STOP UGG: Trp (W)	U C A G
C	CUU, CUC, CUA, CUG: Leu (L)	CCU, CCC, CCA, CCG: Pro (P)	CAU, CAC: His (H) CAA, CAG: Gln (Q)	CGU, CGC, CGA, CGG: Arg (R)	U C A G
A	AUU, AUC, AUA: Ile (I) AUG: Met (M) START	ACU, ACC, ACA, ACG: Thr (T)	AAU, AAC: Asn (N) AAA, AAG: Lys (K)	AGU, AGC: Ser (S) AGA, AGG: Arg (R)	U C A G
G	GUU, GUC, GUA, GUG: Val (V)	GCU, GCC, GCA, GCG: Ala (A)	GAU, GAC: Asp (D) GAA, GAG: Glu (E)	GGU, GGC, GGA, GGG: Gly (G)	U C A G

Table 2.2 Table of amino acids showing that the genetic code is degenerate. This means that more than one codon can code for a single amino acid. Due to this redundancy, the 64 codons code for the 20 amino acids.

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Quick check 2.4

1 The following codons are found in a strand of DNA: TAA TTA TCG ACT ACT AGC.
What would the complementary mRNA strand be?
2 List two differences between transcription and translation.
3 Explain why you do not need to read the code on both strands when transcribing DNA into RNA.

Section 2.1 questions

QUIZ

Remembering

1 What are the basic building blocks or subunits of DNA called?
2 Where in the cell are proteins created (synthesised)?
3 Recall the name for the shape of DNA.
4 Draw and label a nucleotide.
5 Recall the purpose of DNA.

Understanding

6 Describe the key differences between mRNA and DNA.
7 Name the four bases found in DNA and explain the complementary base pair rule.
8 Explain the relationship between DNA, genes and chromosomes.
9 Explain why all mRNA strands start with the codon AUG.
10 Explain how the body produces so many different proteins with only four different nitrogenous bases.

Applying

11 Explain how the genetic information found in the chromosomes within the nucleus of a cell reaches the ribosomes for protein synthesis?
12 Differentiate between a structural protein and a catalytic protein, providing examples of each.
13 A template strand of DNA is found to contain the following bases:
TAC GGA TCA TCG TGG GAA GCA GGC ATT
a What would the complementary DNA strand be?
b Using the above template strand of DNA, what would the mRNA strand look like?
c Using the table of amino acids earlier in the chapter, list the amino acids that this strand of DNA would code for.

Analysing

14 Make a flow chart summarising the key steps in transcription and translation.
15 Propose what may occur if there was a problem with a certain protein in your body.

Evaluating

16 A template strand of DNA is found to contain the following bases:
TCC TGA TGA TGG GGG GCA AAA CGC GTA
Something went wrong during the transcription of this template strand and the mRNA strand contains the following bases:
AGG ACU ACU ACC CUC CGU UUU GCG CAU
a Circle the mistake in the mRNA strand above.
b Predict the outcome of this mistake on the protein produced.

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2.2 Passing on genetic information

WORKSHEET

sexual reproduction
reproduction involving sex cells

gametes
sex cells that combine to produce new offspring

gonads
the sexual organs: testes in males and ovaries in females

ova
eggs

zygote
a fertilised egg produced by the fusion of male (sperm) and female (ovum or egg) gametes

embryo
a zygote eventually turns into an embryo

Two different forms of reproduction occur among organisms: asexual and **sexual reproduction**. You may recall from Year 8 that sexual reproduction requires two organisms of the same species to each contribute a special cell, which combine to produce a new unique offspring. These cells, called **gametes**, are formed in the **gonads** of the male (testes) and the female (ovaries). Each gamete contains half the genetic information needed to form a new organism of the same species. When the gametes – sperm and **ova** (eggs) – meet and fertilise, they form a **zygote** with the full set of genetic information. The zygote divides into smaller cells, and as the number of cells increases they begin to take on special functions. Eventually the zygote turns into the **embryo** of the organism.

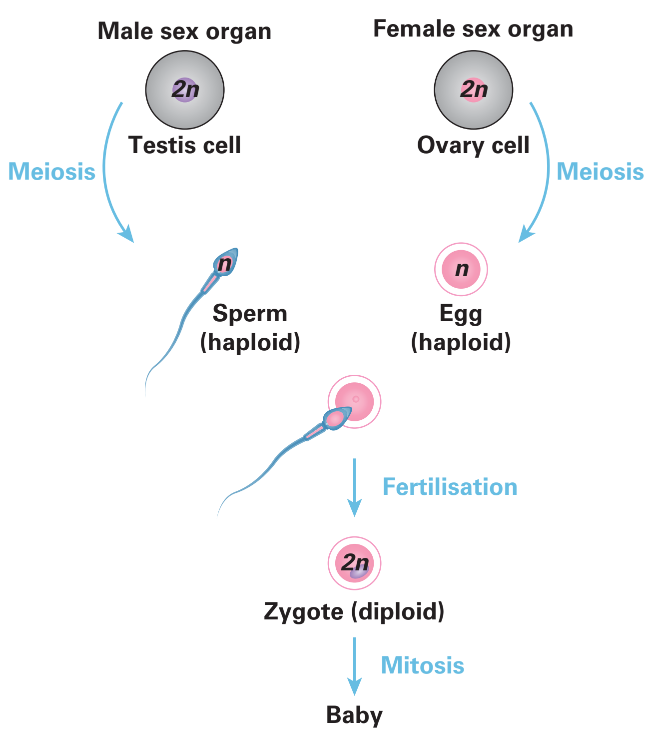

Figure 2.12 Sexual reproduction involves a gamete from a male and a female combining to form a zygote.

You will notice that Figure 2.12 has some new terms. Let us have a look at them:

- When we talk about a cell containing only one set of chromosomes, we call it **haploid** and use the symbol *n*. Gametes like sperm and eggs are haploid.
- When we talk about a cell containing two sets of chromosomes, we call it **diploid** and use the symbol *2n*. **Somatic cells** (body cells) and the zygote are both diploid.
- **Meiosis** is the name of the process by which the gonads make the haploid gametes.
- **Mitosis** is the name of the process by which diploid somatic cells make identical diploid copies of themselves to grow and repair.

In humans, the haploid number (*n*) – the amount of genetic information carried by the sperm and eggs – is 23 single chromosomes. When the egg and sperm meet and fertilise, the two haploid parts come together and form the diploid cell (*2n*) called the zygote. The zygote contains 23 pairs of chromosomes, and therefore the diploid number (*2n*) in humans is 46. The haploid and diploid numbers vary between species, but always remain the same for all of the organisms within that species. For example, a common garden snail has a diploid number (*2n*) of 24, which means it has 12 pairs of chromosomes in its somatic body cells. This also means the egg and sperm of the snail contain half this amount of genetic information, so its haploid number (*n*) is 12 chromosomes.

VIDEO
Sexual reproduction

haploid
a cell containing only one set of chromosomes.

diploid
a cell containing two sets of chromosomes.

somatic cells
the body cells of an organism

meiosis
the process by which the gonads make the haploid gametes

mitosis
the process by which diploid somatic cells make identical diploid copies of themselves to grow and repair

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Did you know? 2.2

Interestingly, the diploid number of chromosomes in a species is not related to whether an organism is bigger or more complicated. For example, a koala, a particular species of kangaroo and garlic all have a diploid number of 16, but are clearly very different!

Figure 2.13 Different organisms contain a different number of diploid chromosomes.

Quick check 2.5

1 Differentiate between the terms 'haploid cell' and 'diploid cell', providing an example of each.
2 If a sheep contained 54 chromosomes in all body (somatic) cells, how many chromosomes would be found in their sex cells?

How does DNA copy itself?

Before a cell divides, the DNA has to be copied (replicated) to provide two copies of each chromosome. This occurs before mitosis and meiosis. This process of DNA replication has to occur perfectly, otherwise the code in the DNA might be affected and faults in replication before meiosis can lead to mutations. The steps involved in DNA replication are summarised below and in Figure 2.14:

1 The DNA molecule untwists with the help of an enzyme.
2 The DNA then 'unzips' down the middle between the nitrogenous bases, breaking the hydrogen bonds. Again, this step happens with the help of an enzyme. Unzipping is a good description because the bases are left exposed, hanging as two strands, each on the DNA backbone, just like the teeth on an open zipper.
3 Another enzyme then very quickly attaches new nucleotides to the exposed nitrogenous bases. The enzyme follows the complementary pairing rule, where adenine can only join with thymine, and cytosine can only join with guanine. This simple rule is of great importance because it means the two new strands of DNA will be identical to the one that unzipped.
4 The newly added nucleotides are connected together with new bonds, which results in two identical strands of DNA being formed. Each new strand is one-half of the original strand and one-half that was newly built. For this reason, replication is sometimes described as being semi-conservative.

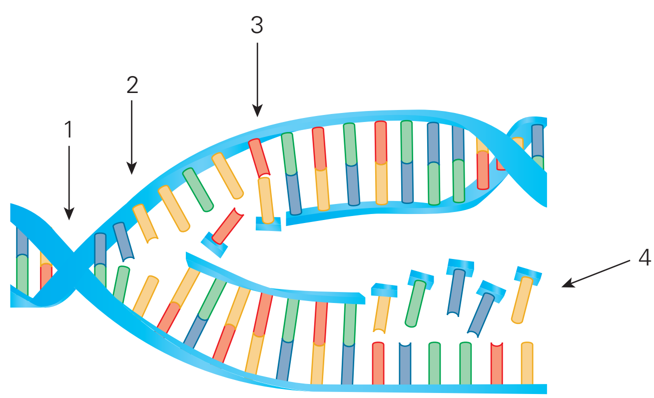

Figure 2.14 DNA replication: the DNA must first untwist and unzip and then the new DNA nucleotides can be added following complementary pairing rules. This results in two identical strands of DNA.

Quick check 2.6

1 Explain the purpose of DNA replication.
2 Summarise the steps of DNA replication.

Mitosis

Mitosis, you may recall, is a form of cell division that occurs during the growth and repair of cells, and also during asexual reproduction when identical copies of cells need to be made. The diploid parent cell divides into two cells that are genetically identical (so also diploid), called daughter cells. Within the human body, every cell is produced via this process, with the only exception being the formation of gametes, or sex cells.

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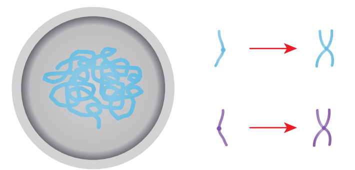
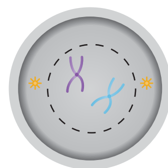
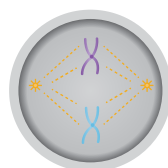
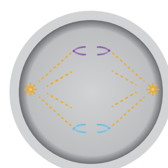
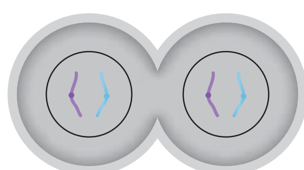
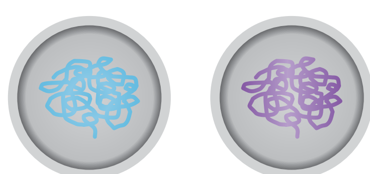
The stages of mitosis			
Before mitosis	Interphase *2n*		• Parent cell is diploid • DNA replication occurs. • Chromosomes are not visible.
Stages of Mitosis	Prophase		• The nucleus 'disappears', DNA winds up and become distinct chromosomes. • Spindle fibres begin to form.
	Metaphase		• Chromosomes are arranged along the centre of the cell. • Each chromosome is attached to a spindle fibre by the centromere.
	Anaphase		• The chromatids split at the centromere and are pulled to either end of the cell by the spindle. • Spindle fibres then begin to disappear.
	Telophase		• The nuclear membrane reappears and the chromosomes are no longer visible.
After mitosis	Cytokinesis 2 × *2n*		• Division of cytoplasm starts, the cell pinches in half, and cell divides into two diploid daughter cells.

Table 2.3 The stages of mitosis

Figure 2.15 Plant cells in the process of mitosis viewed under a light microscope. The central image shows the chromosomes moving to each end of the cell in anaphase. Can you identify some of the other stages?

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Quick check 2.7

1. State which cells undergo mitosis.
2. Summarise the steps of mitosis.

Practical 2.2

Observing cells in a dividing root tip

Be careful

Ensure that the microscope is carried appropriately. Carry with one hand holding the arm and one hand under the base. Ensure big changes in magnification do not occur, so as not to damage the glass slide.

Aim

To observe cells carrying out mitosis in a growing onion root tip.

Materials

- prepared, stained slide of the growing section of an onion root tip caught at different stages of cell division
- microscope

Method

1. Using the lowest magnification, place a prepared slide of a growing onion root tip on the stage of the microscope.
2. Position the slide so that the pointed narrow end of the root tip is clearly visible.
3. Look for a cluster of rapidly growing cells near this region.
4. Observe several different cells at various stages of cell division under the highest magnification of the microscope.

Results

Carefully choose one cell that clearly outlines the cell wall showing chromosomes in certain stages of cell division. Sketch a copy of what you observed, labelling the cell wall and the chromosomes. Remember to use a pencil and to document the magnification the sketch is taken at.

Evaluation

1. Explain how you could tell which cells were dividing.
2. Describe the hallmarks of each stage of cell division. Could you use these to identify the stage of mitosis for a particular cell?
3. List the structures in the cells you could observe. Which structures were present that you could not observe. Why might this be the case?

Conclusion

1. Make a claim about mitosis based on this activity.
2. Support the statement by using observations and include potential sources of error.
3. Explain how the observation supports your statement.

Meiosis

Meiosis is the process by which animals and plants produce gametes (egg and sperm cells) for sexual reproduction.

In animals, this process occurs in the gonads of the male and female, that is the testes in males and the ovaries in females. Like animals, plants also produce gametes (sex cells)

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but they are called pollen (males) and ovules (females) that need to fuse together in order to produce a zygote, or fertilised egg. Unlike humans, however, many plants produce both types of these cells. The ovary of the plant produces the female ovule, or egg cell. A plant's male cell is generally encased by some sort of cover, like a pollen grain.

The process of meiosis itself begins with a parent cell, which is diploid, and results in four 'daughter' cells (the gametes), which are haploid. Because of this reduction in genetic material between the parent and daughter cells, meiosis is also known as a **reduction division**.

reduction division cell division in which there is a reduction in the genetic material between parent and daughter cells

Just like in mitosis, meiosis consists of a number of distinct stages. The process of meiosis involves two divisions, called meiosis I and meiosis II. These steps are further subdivided, as shown in Table 2.4, into a number of distinct stages.

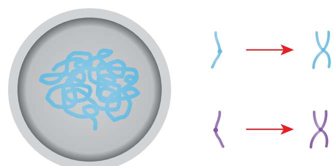
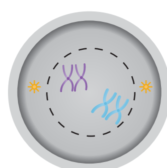
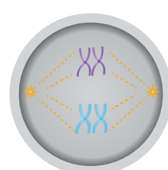
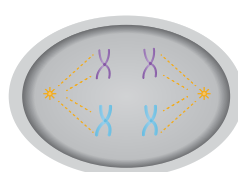
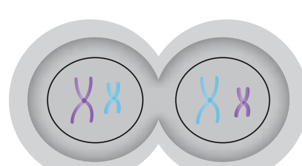
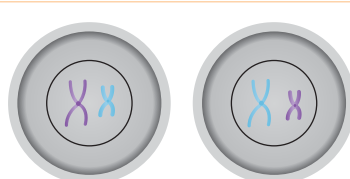
Meiosis I		
Interphase *2n* (Before meiosis)		• Parent cell is diploid. • The DNA is replicated and copied.
Prophase I		• The nucleus 'disappears', the DNA winds up and chromosomes become visible. • Crossing over can occur.
Metaphase I		• Spindle fibres attach to the centromere of each homologous (matching) chromosome pair and pull the matching chromosomes into a line in the centre of the cell.
Anaphase I		• The matching chromosomes of a homologous pair are pulled to opposite ends of the cell by the spindle fibres. • Spindle fibres disappear.
Telophase I		• The cell membrane pinches in. • The nuclear membranes re-form. • Two separate nuclei form.
Cytokinesis		• Cell pinches completely into two daughter cells. • Note that each daughter cell has half the genetic information of the parent cell.

Table 2.4 The stages of meiosis I and meiosis II

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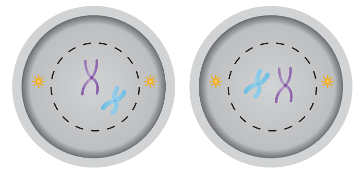
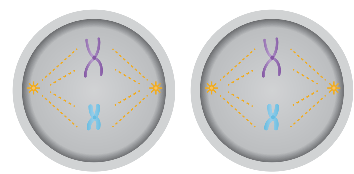
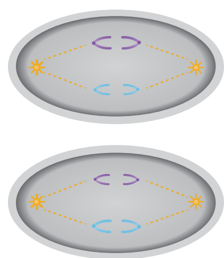
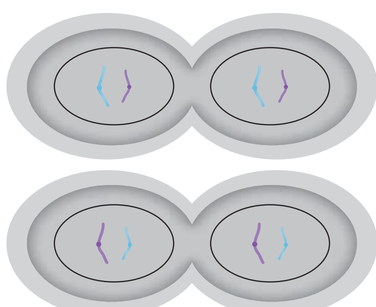
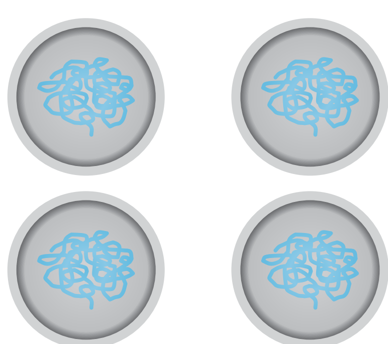
Meiosis II		
Prophase II		• Nuclear membranes disappear and spindle fibres reform in both cells.
Metaphase II		• Chromosomes move into the centre of the cell where spindle fibres attach to each chromatid. • The centromeres start to divide.
Anaphase II		• The chromosomes are pulled apart and the chromatids are pulled to opposite sides of the cell. • The spindles disappear.
Telophase II		• The nuclear membrane re-forms. • The chromosomes are no longer visible.
Cytokinesis $4 \times n$		• Both cells pinch in half to produce four haploid daughter cells, each containing half the amount of DNA as was in the parent cell. • One member of a chromosome pair is present in each gamete.

Table 2.4 *(Continued)*

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Did you know? 2.3

Creating variation

You might have noticed in Table 2.4 that at prophase I of meiosis I it says 'crossing over can occur'. What is crossing over? Crossing over occurs when **homologous chromosomes** (matching pair of chromosomes) get so close together that some of their genetic material gets tangled and swaps. It results in the chromosomes being recombined with a new combination of alleles. This means that, when gametes are being made, the process of meiosis can lead to more variation or difference between the gametes.

homologous chromosomes matching chromosomes

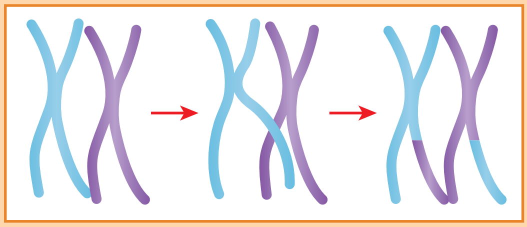

Figure 2.16 Crossing over during prophase I results in the formation of recombinant chromosomes with new combinations of alleles.

Quick check 2.8

1 State why the process of meiosis is also known as 'reduction' cell division.
2 Recall where meiosis occur in humans.
3 Explain why crossing over is an important process involved with meiosis.

Practical 2.3

Modelling meiosis

Aim

To use a model to demonstrate some details of meiosis.

Materials

Per pair of students

- 200 Poppit beads: 100 white, 100 black
- 6 pipe cleaners
- pencil and eraser
- large sheet of paper (such as butchers paper)
- permanent marker and liquid paper

Method

Part 1: Making the chromosomes

For this exercise you will 'invent' an organism with just six chromosomes arranged in three pairs; that is $2n = 6$.

1 First make two 'chromosomes', one white and one black, each consisting of two 'chromatids' which are 20 beads long. Tie the chromatids together with a pipe cleaner 'centromere'.
2 Make a second pair of 'chromosomes', one white and one black, with each 'chromatid' about 16 beads long.
3 Make a third pair of 'chromosomes', one white and one black, with each 'chromatid' about 10 beads long. You should have six chromosomes in three pairs as shown on the next page.
4 In each pair of chromosomes, one chromosome was inherited from the maternal parent (represented by the white beads) and one from the paternal parent (black beads).

continued…

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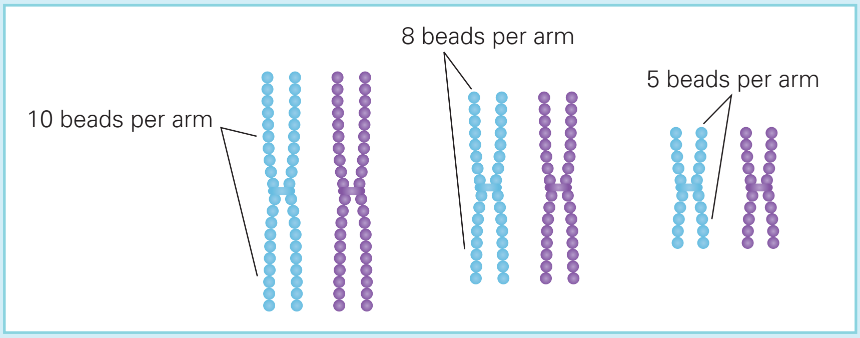
...continued



Part 2: The process of meiosis

1 Place the chromosomes on the large sheet of paper and draw a small circle in pencil around them to represent the nuclear membrane, and a larger circle outside to represent the cell membrane. Move the three pairs of *matching* chromosomes on the sheet of paper to simulate the following stages of meiosis.

2 a Appearance of the chromosomes and spindle (**prophase 1**):
   i Erase the inner circle.
   ii Draw lines to represent spindle fibres.
 b Arrangement of chromosomes at the equator (**metaphase I**):
   i Arrange the chromosomes randomly as matching pairs across the equator attached to the spindles at their centromeres.
 c Separation of chromosome pairs (**anaphase I**):
   i Move each member of the pair of chromosomes in opposite directions of the paper.
   ii Erase the lines.

This completes the first division of meiosis. Now the second division begins.

 d Separation of the chromatids:
   i Draw pencil lines to represent spindle fibres.
   ii Arrange the chromosomes across the equator attached to the spindles at their centromeres (**metaphase II**).
   iii Undo the pipe cleaners.
   iv Move the chromatids to opposite poles of the spindles (**anaphase II**).
   v Erase the pencil lines and draw a new inner circle around the chromosomes.

3 Note the type of chromosomes (colour of bead and length) present in each of the four cells.

4 Repeat the simulation, but for metaphase 1 change the arrangement of the maternal or paternal member of the homologous pairs across the equator. Note the difference this makes to the chromosomes present in the gametes now formed.

Results

Draw a diagram to represent what occurred at each stage of the practical.

Evaluation

1 Which cells were, represented by this model undergoing meiosis.

2 Your model cell had three pairs of chromosomes. How many pairs of chromosomes would a human body cell represented by your model cell contain?

3 How many chromosomes were present in each daughter cell produced in the simulation? How does this compare with the number present in the parent cell?

4 Would it be possible for all the maternal chromosomes to be on one side of the equator in metaphase 1 and all the paternal chromosomes on the other?

continued...

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continued…

5 What factors contribute to the different combinations of chromosomes (and therefore genes) that can be present in gametes?
6 Outline the processes that occur during meiosis that contribute to the variety of gametes produced.

Conclusion

1 Make a claim about meiosis based on this activity.
2 Support the statement by using observations and include potential sources of error.
3 Explain how the observation supports your statement.

Fertilisation

We know that the haploid gametes produced during the process of meiosis are called sperm and ova (eggs). In humans, each sperm or egg has 23 single chromosomes, so the haploid number is 23. After **fertilisation**, the zygote (which becomes the embryo that grows into the fetus) has 23 pairs (or 46 single) chromosomes, so the human diploid number is 46. Keep in mind that the zygote has received half of its genetic information from the mother's egg, and half of its genetic information from the father's sperm.

fertilisation
the fusing of an egg and sperm

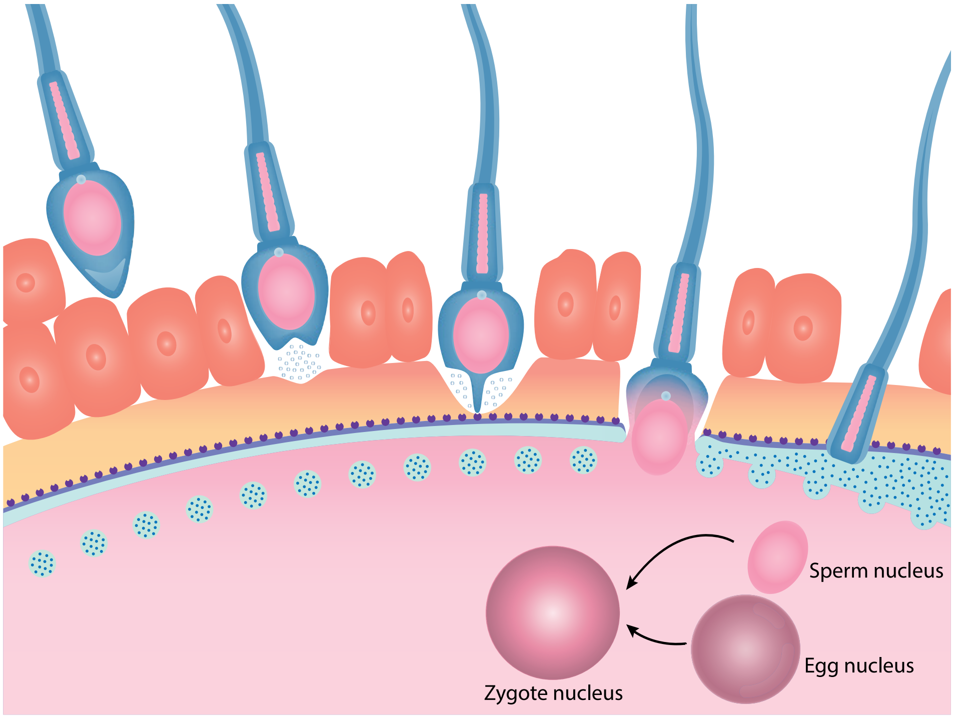

Figure 2.17 Once the sperm fertilises the egg, the nucleus of the sperm and the egg fuse.

Two types of twins **Explore! 2.3**

You, or someone you know, might have a twin sister or brother. There are two different types of twins which vary greatly in the way they form!

1 Name the two types of twins and how they are formed.
2 Draw a diagram to show how the two different types of twins are formed.
3 Describe the differences between the two types of twins.

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Quick check 2.9

1 Copy the table below and complete the definitions.

Term	Definition
Meiosis	
Fertilisation	
Zygote	
Haploid	
Diploid	

2 Male gametes are called __________ whereas female gametes are called __________.

Meiosis versus mitosis

Although the processes of meiosis and mitosis have similarities, two distinct differences remain:

- In meiosis, the genetic material in chromosomes is reshuffled by crossing over, producing chromosomes with new combinations of genes. In mitosis, chromosomes are replicated to make identical copies of themselves.
- Meiosis produces four daughter cells containing unique genetic material and half the number of chromosomes of the parent cell. Mitosis produces two daughter cells with identical genetic material to the parent cell just like the copies produced by a photocopier.

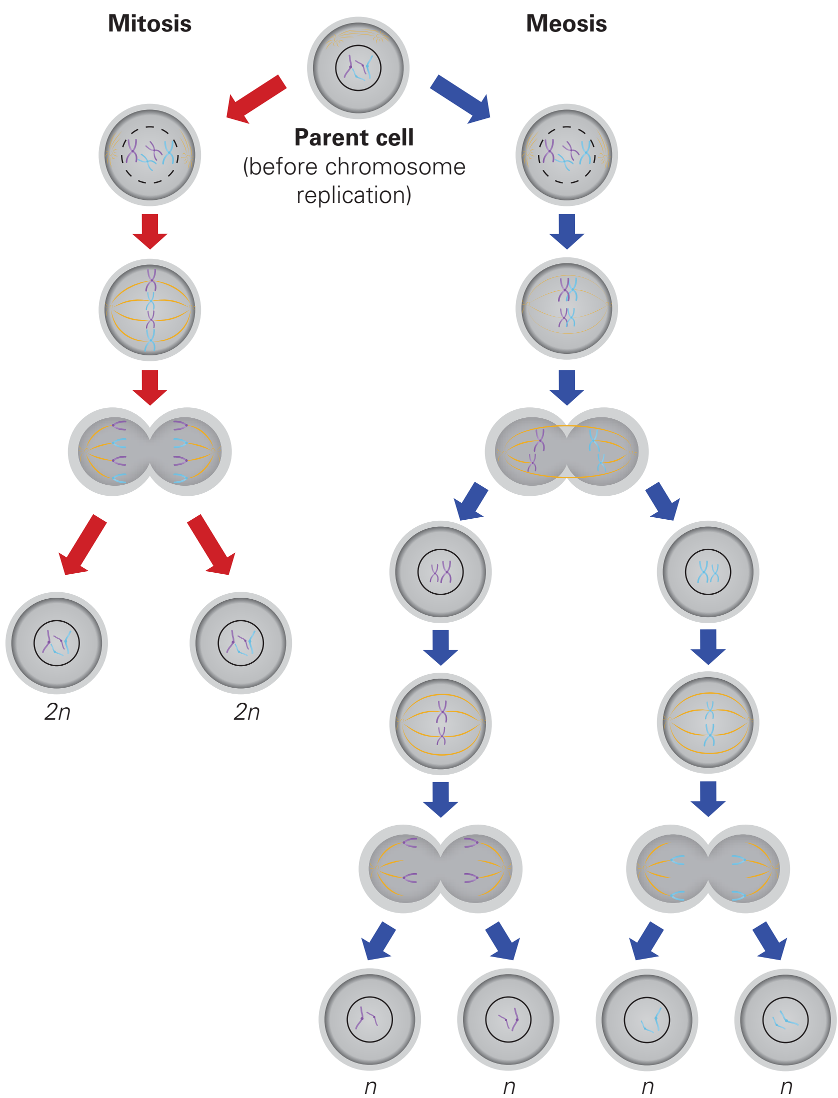

Figure 2.18 A diagram summarising the processes of meiosis (making gametes) and mitosis (making copies of somatic cells)

Karyotypes

Although each species has its own particular number of chromosomes, the chromosomes in each body cell always occur as pairs. For example, we know humans all have a total of 46 chromosomes, or 23 pairs of chromosomes in every nucleus of every body cell. However, within the gametes, we know there are only half of this amount: 23 chromosomes. We can take a photo of a cell when it has undergone DNA replication and clearly see the chromosomes.

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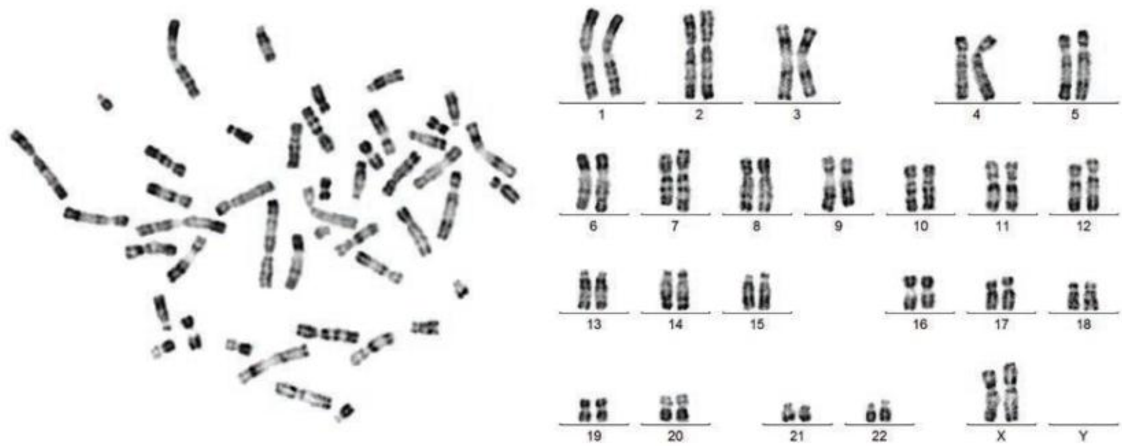

Figure 2.19 The chromosomes seen under a microscope (left) can be arranged and paired up according to size and gene band patterns in a pictorial representation known as a karyotype (right).

The chromosomes can then be arranged and paired up according to their size and gene band patterns in a pictorial representation known as a **karyotype**.

karyotype
a pictoral representation of an organism's chromosomes

The chromosomes always exist in pairs within the body cells because one was received from the male parent via the sperm, and one was received from the female parent via the egg. We call the chromosome pairs that are matching homologous chromosomes, while those that do not match (for example, chromosomes from different pairs) are called **non-homologous chromosomes**. Notice in Figure 2.19 how homologous chromosomes (paired chromosomes) have the same length, centromere position and pattern.

non-homologous chromosomes
non-matching chromosomes

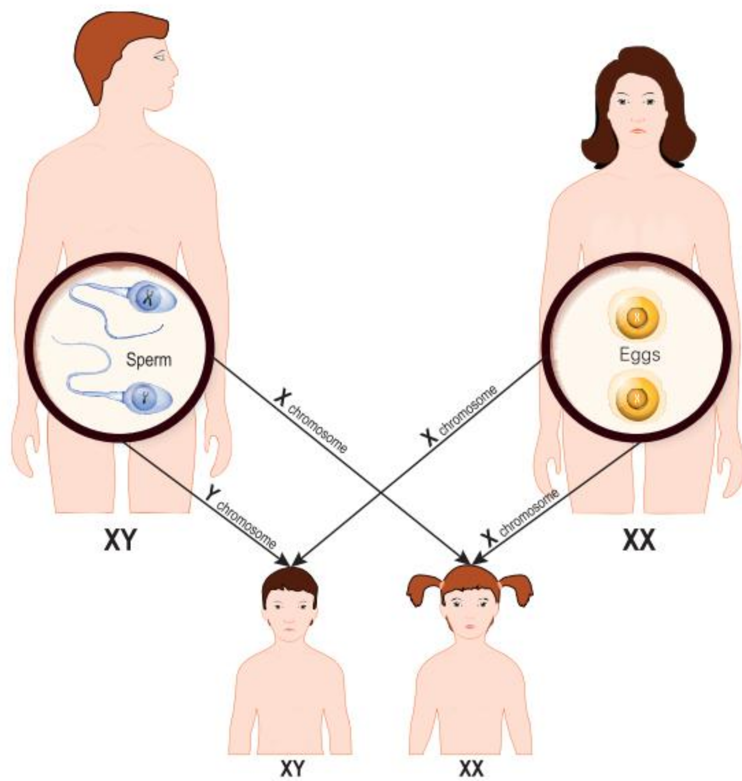

Figure 2.20 If an egg is fertilised by an X-carrying sperm, the child will be female. If an egg is fertilised by a Y-carrying sperm, the child will be male. Therefore, it is the male's sperm that fertilises the egg that determines the sex of the child.

Autosomes

Of the 23 pairs of chromosomes, pairs 1 to 22 are known as **autosomes**. These 44 chromosomes are found in both males and females.

autosomes
in humans, chromosome pairs 1 to 22

Sex chromosomes

In humans, the chromosomes of the 23rd pair are the **sex chromosomes**. They contain genes that determine the sex of the individual. Females receive two X chromosomes (one from each parent), whereas males receive one X chromosome (from the mother) and one Y chromosome (from the father).

sex chromosomes
in humans, the 23rd pair of chromosomes that determines the sex of a person

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Practical 2.4

What are the chances?

Aim

To investigate the chances of conceiving a male or female at fertilisation.

Materials

- coin

Method

1 Copy the results table into your logbook.
2 Predict the number of times you will toss heads and the number of times you will toss tails in 50 coin tosses. Justify your prediction.
3 Toss the coin 50 times, recording the number of heads and tails in the table.
4 Calculate the percentage chance of tossing heads and tails.
5 Average the class results and record them in the results table.

Results

	Number of heads	Percentage heads	Number of tails	Percentage tails
Individual results				
Class results				

Evaluation

1 Did your results differ from your prediction?
2 Did your results differ from the class results? Explain why?
3 If heads represents the Y chromosome and tails represents the X chromosome, explain how accurately this models the process of fertilisation. What would the coin represent?
4 Suggest one limitation of this model and provide an improvement.

Conclusion

1 Make a claim about the chances of conceiving a male or female based on this activity.
2 Support the statement by using data obtained and include potential sources of error.
3 Explain how the data supports your statement.

Did you know? 2.4

Sex chromosomes in the animal kingdom

In some other animals, such as birds, females have two different sex chromosomes (ZW) while males have two of the same (ZZ). In some reptiles, the sex of the organism is determined by the temperature of the incubating environment of the developing embryo. In some insects, females are XX and males have just one X chromosome (written XO).

Figure 2.21 A male and female insect

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Try this 2.3

Can you sort chromosomes into a karyotype?

Go online and find an online karyotype activity. There are many interactives that allow you to sort chromosomes into order, and ones that allow you to analyse karyotypes.

Quick check 2.10

1 Draw a Venn diagram to compare and contrast mitosis and meiosis.
2 Explain why karyotypes are useful.

Science as a human endeavour 2.2

Genetic counselling and karyotypes

When a woman is pregnant, the doctor will conduct a number of tests to screen for genetic and chromosomal abnormalities. Creating a karyotype lets the doctor check for abnormalities in the number or length of chromosomes. If anything looks abnormal, the doctor can do follow-up tests to check for specific disorders. One such test is chromosomal microarray (CMA) testing, which is much more detailed genetic testing than karyotyping. Chromosomal microarray testing detects around one abnormality in every 70 foetal samples that had a normal karyotype. Scientists think that CMA testing will replace karyotyping for prenatal testing.

Explore! 2.4

Chromosomal abnormalities

Many things can be wrong with a karyotype. One of the best known abnormalities is trisomy 21 or **Down syndrome**, where the foetus has three copies (instead of two) of chromosome 21.

Down syndrome a genetic condition in which the individual has three copies of chromosome 21

1 Research other chromosomal abnormalities that lead to syndromes associated with it.
2 Choose one other syndrome and describe the symptoms associated.

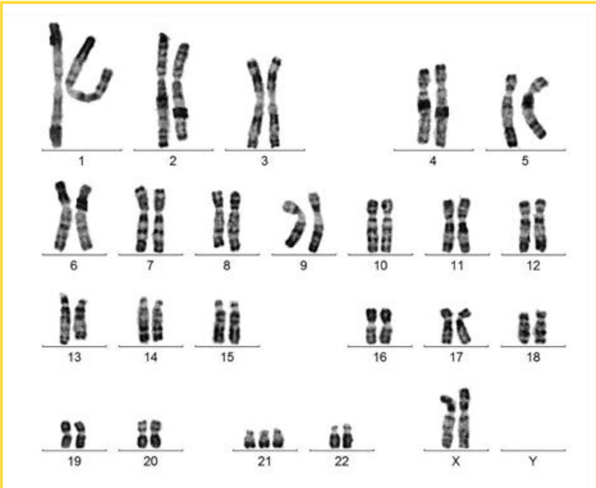

Figure 2.22 Karyotype of a female with Down syndrome. Note the three chromosomes in position 21.

QUIZ

Section 2.2 questions

Remembering

1 List one key difference between mitosis and meiosis.
2 What are the differences in daughter cells produced in mitosis vs. meiosis?
3 In which phase of meiosis are the pairs of matching chromosomes separated?
4 Draw a diagram to represent the steps of mitosis for a cell with two pairs of chromosomes. Be sure to use a different colour for each pair of chromosomes.
5 State the name of the syndrome that arises from trisomy 21.

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...continued

Understanding

6 State what the term 'homologous chromosome' means.

7 Explain why gametes need to be haploid.

8 Explain what is meant by the term 'reduction division'.

9 Explain why missing part of a chromosome may lead to a disorder or syndrome.

Applying

10 Why are the cells produced during meiosis considered to be unique?

11 Complete the following table.

	Where it is used	Purpose of use	Features of daughter cells
Mitosis			
Meiosis			

Analysing

12 Explain the key difference between anaphase I in meiosis and anaphase in mitosis?

13 How does prophase I differ from prophase II in meiosis?

Evaluating

14 Evaluate the following claim: 'It is the male that determines the sex of his child.'

15 Evaluate the chances of a woman giving birth to a girl if she has already given birth to three boys. Justify your response.

2.3 Patterns of inheritance

Inheriting traits from our parents

We now know that our genetic instructions (genes) come from our parents. This is called heredity or inheritance. We also now know that chromosomes are made up of DNA and that genes are found within the DNA. Chromosomes exist in pairs, so it is also reasonable to suggest that genes must exist in pairs. Therefore, each characteristic or trait that we inherit is controlled by a pair of genes, which are found at the same location on their respective chromosomes. This is called the **locus** of a gene – another name for the location of the gene.

locus
the location of a gene on a chromosome

We know genes are sections of DNA or chromosome that code for a particular protein which contributes to our characteristics, such as a gene for eye colour. However, not all forms of the gene are the same; for example, someone might have blue eyes and someone else might have brown eyes. We use the term **allele** to describe the different forms of a gene. Because we get one copy of each chromosome from each parent, the genes we inherit are all the same, but the alleles may not be. The combination of alleles for a gene inherited from the parents is known as the organism's **genotype**. If two identical alleles are present in a person's genotype, they are known as **homozygous** (or pure-breeding) for that particular trait. However, if there are two different alleles present for the same trait, then the person is known as **heterozygous** (or hybrid) for that trait.

WORKSHEET

allele
different forms of the same gene

genotype
the combination of alleles for a gene inherited from our parents

homozygous
having two identical alleles at a locus

heterozygous
having two different alleles at a locus

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Did you know? 2.5

The genome

The **genome** refers to the full set of genes found within an organism. The human genome is made of approximately 3.2 billion nitrogenous bases, which make up about 20 000 genes on 23 pairs of chromosomes. Other organisms have different genome sizes.

genome
the full set of genes in an organism

Figure 2.23 DNA base pairs that code for specific genes make up the genome of an organism.

For example, take the trait of the ability to roll your tongue. This trait is controlled by a single gene that is represented using two alleles: the allele of the dominant trait, which is the ability to roll your tongue (we can assign it the capital letter 'R' to show it is dominant), and the allele for the recessive trait, which is the lack of ability to roll your tongue (we can assign this allele a lower case 'r' to show it is representing the recessive trait). If you inherit the rolling allele from both parents, you are said to be homozygous dominant for that trait and your genotype will be RR. If you inherit the non-rolling allele from both parents, you are said to be homozygous recessive for that trait and your genotype will be rr. If you inherit a rolling allele from one parent and a non-rolling allele from the other parent, you are heterozygous for that trait and your genotype will be Rr.

A trait or characteristic is described as dominant if you only need 1 allele for it to be expressed (RR or Rr). For a recessive characteristic, the allele needs to be inherited from both parents in order for it to be expressed (rr).

Figure 2.24 The ability to roll your tongue is an example of a dominant trait.

The interaction of an organism's genotype with the environment results in its **phenotype**, or its physical appearance. So in this example, the ability to roll or not roll the tongue is the person's phenotype for that trait. Always remember that genes and alleles refer to the genotype, and the appearance of the trait refers to the person's phenotype.

phenotype
the way an organism appears

To determine whether an allele represents a trait that is dominant or recessive, scientists look at the phenotype of a heterozygous organism. If the trait is expressed in this phenotype it must be the dominant trait.

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Quick check 2.11

1 Copy the table below and complete the definitions.

Term	Definition
Locus	
Allele	
Genotype	
Phenotype	

2 Your genotype says you will have pale skin but your phenotype is red skin. Explain why this may be.

Practical 2.5

Inherited features

Aim

To determine whether some key characteristics are dominant or recessive traits.

Materials

- mirror

Method

Copy the results table on the next page and record your findings and those of the class in the table as you answer the following questions.

1 Identify whether or not you possess each of the inheritable features described below.
   a Attached ear lobes: are your earlobes attached or unattached to the side of your head?
   b Darwin's point: do you have a point on your ear? It looks like a small bump on the inside of your upper ear.
   c Widow's peak: do you have a v-shaped peak in the centre of your hairline?
   d Tongue roll: can you roll your tongue as shown in Figure 2.24?
   e Front tooth gap: is there a definite gap between your two top front teeth?
   f Mid-digital hair: is there any hair on the second joint of at least one of your fingers?
   g Long second toe: is your second toe longer than your big toe?

2 Find out how many members of your class share the same features as you do. Record your results in the table.

3 Find out how many members of your family share the same features as you do. Record your results in the table.

Figure 2.25 This girl has an example of a widow's peak (v-shaped peak) in the centre of the hairline.

Figure 2.26 This man has an obvious gap between his top front teeth.

Figure 2.27 The second toe is longer than the big toe on this foot.

continued…

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...continued

Results

Feature	Present in you?	Present in the family	% presence in family	Present in the class?	% presence in class
a					
b					
c					
d					
e					
f					
g					

Evaluation

1 Graph the class results of % presence for each trait.
2 Do your findings support the idea that a feature such as tongue-rolling is inherited? Explain your answer.
3 Using data from your results table, comment on whether you share more traits with your family members or class mates. Why do you think this is the case?
4 Suggest another trait that would set two people apart.

Conclusion

1 Make a claim about dominant and recessive traits based on this activity.
2 Support the statement by using data obtained and include potential sources of error.
3 Explain how the data supports your statement.

Determining chances of inheritance

Gregor Mendel

Figure 2.28 Gregor Johann Mendel (1822–1884) was the founder of heredity, using pea plants to show dominant and recessive traits within the field of genetics.

Gregor Mendel is known as the father of genetics. He was an Austrian monk who carried out experiments in his garden using pea plants and discovered some of the fundamental laws of heredity we still rely on today.

Mendel looked at the features of pea plants, which could be tall or short (dwarf). He assigned the following letters to represent these alternative characteristics (which we call alleles today): T = tall and t = dwarf. Mendel bred the plants and observed the height of the plants in the next generation. He discovered that tall pea plants could be either pure either pure breeding (TT or homozygous dominant) or hybrid (Tt or heterozygous). The dwarf plants would be tt (homozygous recessive). Today, we call this the plant's genotype.

Mendel also used the following notation to represent different levels of generations:

- P = parent generation
- F_1 = 1st filial generation
- F_2 = 2nd filial generation.

An easy way to predict the outcome of crossbreeding plants with certain traits is to use a **Punnett square**, a specialised grid invented by Reginald Punnett. To use a Punnett square, you need to know the genotype of the parents and then work out what genetic information they could pass onto their offspring via the gametes. For example, we know a heterozygous tall pea

Punnett square a specialised grid to show crosses

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plant has the genotype Tt. This means that when the plant makes its gametes, they could contain either a T or a t, as gametes only carry one of the alleles from the parent. In contrast, a homozygous tall pea plant has the genotype TT, so its gametes will all contain a T.

Worked example 2.1

Cross between a pure-breeding tall plant and a pure-breeding dwarf plant

Parents: TT × tt

gametes	T	T
t	Tt	Tt
t	Tt	Tt

You will notice that all the predicted F_1 offspring (shaded) have the genotype Tt. We can write this as:

F_1 genotype: 100% Tt

We can also see that offspring with Tt would all look tall, as T stands for the tall allele which is dominant over the dwarf allele (t). So we can write this as:

F_1 phenotype: 100% tall plants.

Worked example 2.2

Cross between two of the hybrid F_1 plants from worked example 2.1

F_1: Tt × Tt

gametes	T	t
T	TT	Tt
t	Tt	tt

F_2 genotype: 25% TT; 50% Tt; 25% tt

F_2 phenotype: 75% tall plants; 25% dwarf plants

We can also write the predicted outcomes as ratios. In this case, when two heterozygous tall pea plants were crossed, there was a genotypic ratio of 1TT : 2Tt : 1tt and a phenotypic ratio of 3 tall : 1 dwarf.

Huntington's disease

Huntington's disease is inherited as a dominant trait on an autosome. It usually appears in an affected person as neurological symptoms that develop around 30–50 years of age. The disease is lethal in the womb if an individual is homozygous for the abnormal protein.

If we let H = abnormal Huntington protein allele (Huntington's disease) and h = 'normal' protein allele (unaffected), then we can use these notations to help work out probable outcomes in the offspring.

Worked example 2.3

Cross between two individuals unaffected by Huntington's disease

Parents: hh × hh

gametes	h	h
h	hh	hh
h	hh	hh

F1 genotype: 100% hh

F1 phenotype: 100% unaffected

Worked example 2.4

Cross between an individual with Huntington's disease and an unaffected individual

Parents: Hh × hh (Remember, someone with two H alleles will not survive birth so the Huntington's disease individual must be Hh).

gametes	H	h
h	Hh	hh
h	Hh	hh

F_1 genotype: 50% Hh; 50% hh

F_1 phenotype: 50% with Huntington's disease; 50% unaffected

Try this 2.4

Punnett squares

1 A black mouse mates with a brown mouse. Of a large number of offspring, all of them are black.
   a Which trait is dominant?
   b Draw a Punnett square and determine the genotypes of the offspring.

2 A recessive gene causes the condition cystic fibrosis. If a homozygous recessive female mates with a heterozygous male, what are their chances of producing offspring with cystic fibrosis?

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Quick check 2.12

1 Explain the difference between genotype and phenotype.
2 Brown eyes is dominant to blue eyes.
  a Assign letters for the brown eye and blue eye alleles.
  b Draw a Punnett square for a couple who are both heterozygous.
  c State the genotypic and phenotypic ratios of the offspring.
  d State the chances of this couple producing a blue-eyed child.

Test cross

test cross
a special type of cross-breeding test that can be used to identify whether an organism is homozygous or heterozygous for a dominant trait

A **test cross** can be used to test whether an organism showing a dominant trait is homozygous or heterozygous. It involves mating or crossing the individual in question with a homozygous recessive individual (for example, aa). This essentially means mating the individual of unknown genotype with an individual of known genotype. Then, by looking at the offspring ratio, we can deduce the genotype of the individual in question.

For example, in mice, coat colour may be B = black and b = white. A black mouse was found by a student and she wanted to know if the mouse was homozygous black (BB) or heterozygous black (Bb). A test cross can be used to answer the question, so she crossed the black mouse with a white mouse (bb).

Quick check 2.13

1 Explain why a test cross is important to use in genetics?
2 Silky feathers in a bird species is caused by a gene whose trait is recessive to normal feathers. If you had a normal-feathered bird, what would be the easiest way to determine whether or not it is heterozygous or homozygous? Use Punnett squares to help with your answer.

If the unknown black mouse is BB, the cross would look like this:
Parents: BB × bb

gametes	B	B
b	Bb	Bb
b	Bb	Bb

F_1 genotype: 100% Bb
F_1 phenotype: 100% black
This means if all the offspring are black, the unknown black mouse is probably BB (or homozygous dominant).

If the unknown black mouse is Bb, the cross would look like this:
Parents: Bb × bb

gametes	B	b
b	Bb	bb
b	Bb	bb

F_1 genotype: 50% Bb; 50% bb
F_1 phenotype: 50% black; 50% white
This means if half the offspring are black and half are white, the unknown black mouse is probably Bb (or heterozygous). Note that these are the expectations on the basis of large numbers of offspring.

Practical 2.6

Positive or negative

One vital gene located on chromosome 1 in humans, is the gene controlling for Rhesus blood type. Due to Rhesus positive blood being dominant to Rhesus negative blood, we can assign the alleles D (Rhesus positive) and d (Rhesus negative). Therefore, a Rhesus positive person can be either DD or Dd with respect to this gene, but a Rhesus negative blood type can only be homozygous, dd.

continued…

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...continued

Aim

To model the passing of Rh alleles from heterozygous individuals, to their offspring.

Materials

- coloured counters
- felt-tipped pens

Method

1. Copy the results table below.
2. Choose one coloured counter. Print D on one side and d on the other to represent the alleles of the chromosomes. This counter represents an individual who is Dd for Rhesus blood type; that is, able to produce gametes (eggs or sperm) of the type D and d in equal proportions.
3. Find a partner in the room with a different coloured counter.
4. Make an unbiased toss of your two counters to produce an offspring. The labels facing uppermost on the counters will represent the alleles of the gametes, produced by the parents. Record the genotype of the offspring in the Family 1 row of the table below. Repeat this step three more times to produce a total of four children.
5. Generate a total of four families (by pairing up with three different students) with each having produced four children.
6. Record the number of each child's genotype in each family in the table below. Pool your total results with those of the class.

Results

	Genotype of children		
	DD	**Dd**	**dd**
Family 1			
Family 2			
Family 3			
Family 4			
Total numbers across the class			

Evaluation

1. How many different kinds of sperm with respect to the Rhesus gene can the male parent produce? State the probability of each kind being produced.
2. Does the mother's production of a D gamete affect the probability that her next gamete will be a d?
3. What are the probabilities for obtaining the offspring genotypes:
   a. DD
   b. Dd
   c. dd?
4. Explain why variation exists between each different family of four offspring.
5. What are the proportions of the different genotypes in your group of 16 children compared to those generated across the whole class. Discuss whether or not this was expected.
6. A woman with Rhesus positive blood insisted that she was the daughter of a rich, elderly couple who both had Rhesus negative blood. Use a punnet square to show your working out to explain whether this woman's statement could be valid or not?

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...continued

Conclusion

1 Make a claim about the Rhesus alleles based on this activity.
2 Support the statement by using data obtained and include potential sources of error.
3 Explain how the data supports your statement.

Sex linkage

As we have seen, in humans the sex chromosomes are considered to be the 23rd pair. They contain genes that determine the sex of the individual. Daughters get two X chromosomes (one each from the mother and the father), whereas sons receive one X chromosome (from their mother) and one Y chromosome (from their father). Human females are therefore homozygous and males are not. It is also reasonable to conclude that the determination of sex in humans depends on the presence or absence of the Y chromosome.

Therefore, the father is responsible for determining the sex of the child, by passing on either an X or Y chromosome. The mother can only pass on an X chromosome to the child.

The X chromosome also has many genes not related to sex determination (the Y chromosome has very few). Characteristics that do not necessarily have anything to do with the sex of the individual but are coded by genes on the X chromosome are said to be X-linked. When we predict X-linked traits using a Punnett square, we have to use the sex chromosomes in the Punnett square and use letters superscripted above the sex chromosomes to represent the trait. For example, haemophilia, a disorder where the blood does not clot properly, is inherited as an X-linked recessive trait. The genotype for an unaffected female would be X^HX^H, a carrier female would be X^HX^h, and a haemophilic female would be X^hX^h. On the other hand an unaffected male would be X^HY and haemophiliac male would be X^hY. As there is no gene for this condition found on the Y chromosome, we do not write a H or h next to the Y.

Worked example 2.5

Cross between a heterozygote normal vision female (carrier) and a normal vision male

Colour blindness is inherited as an X-linked recessive trait. The genotype of a normal vision (carrier) female is X^BX^b and of a colour-blind male is X^bY.

Parents: $X^BX^b \times X^BY$

gametes	X^B	X^b
X^B	X^BX^B	X^BX^b
Y	X^BY	X^bY

F_1 genotype: 25% X^BX^B; 25% X^BY; 25% X^BX^b; 25% X^bY

F_1 phenotype: 25% normal vision female; 25% normal vision male; 25% carrier normal vision female; 25% colour-blind male

Try this 2.5

Sex-linked inheritance

Now it is your turn to practise. Remember that the gametes need to include the sex chromosomes, and the genotype and phenotype both need to include the sex chromosomes or gender as well.

1 Cross: normal vision female (homozygote) with colour-blind male
2 Cross: colour-blind female with normal vision male
3 Can you explain why more males than females have colour blindness?

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Codominance

When you have two alleles for a trait that are equally dominant, they will both show up in the heterozygote. We call this **codominance** – both the alleles in this situation are expressed equally in the phenotype. Look at the picture of the chickens in Figure 2.29. The colours black and white are equally dominant (their alleles are both given capital letters), so when you cross a pure black chicken with a pure white chicken, you get a heterozygote. In the heterozygote, both colours are expressed equally, so you get a chicken with black feathers and white feathers!

codominance
both alleles are expressed equally in the phenotype

VIDEO
Give an example of codominance

Phenotype	White	Black	Speckled
Genotype	WW	BB	BW

Figure 2.29 White and black are equally dominant alleles and are said to be codominant. The evidence of this is their heterozygote offspring that has black and white feathers.

Blood types

In humans, our blood type is a codominant trait. Our red blood cells have little proteins on the surface called antigens, and it is these antigens that determine whether our blood is A, B, AB or O. Remember that the code for building proteins, like the antigens, is in our DNA, and the processes of transcription and translation are responsible for building the protein. So, your genetic code, which you inherit from your parents, is responsible for your blood type.

Each person has two copies of the ABO blood type gene, one from their mother and one from their father. The blood type gene is found on chromosome 9, and there are three alleles (versions) of the gene:

- I^A = production of antigen A (type A blood) is dominant.
- I^B = production of antigen B (type B blood) is dominant.
- i = production of neither antigen (type O blood) is recessive.

However, because we only have two copies of chromosome 9, we can only have a maximum of two versions at one time:

- Type A blood can have genotypes I^A I^A or I^A i.
- Type B blood can have genotypes I^B I^B or I^B i.
- Type AB blood has the genotype I^A I^B.
- Type O blood can only have genotype ii.

IA an IB are both dominant over i, but equally dominant when together.

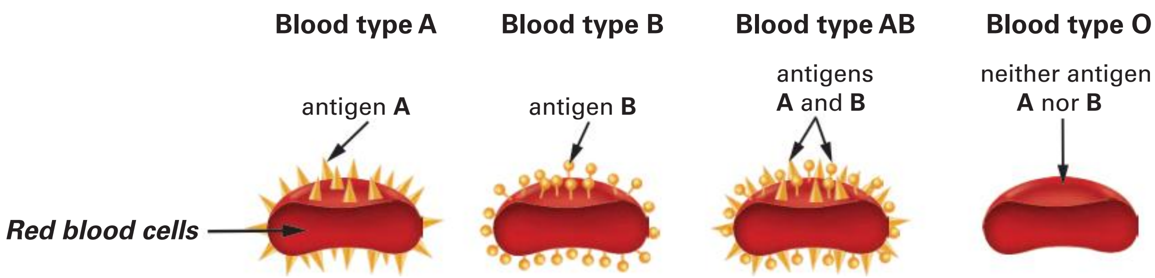

Figure 2.30 Illustration of the differences between the antigens on the surface of red blood cells of different types

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Worked example 2.6

Cross between heterozygous blood type A and heterozygous blood type B

Parents: $I^Ai \times I^Bi$

gametes	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

F_1 genotype: 25% I^A I^B; 25% I^B I; 25% I^A i; 25% ii

F_1 phenotype: 25% AB blood type; 25% B blood type; 25% A blood type; 25% O blood type

Explore! 2.5

Incomplete dominance

incomplete dominance a form of inheritance in which neither allele is dominant over the other

Incomplete dominance is a form of inheritance in which neither of the alleles is dominant over the other. The phenotype of the offspring is a combination of both alleles.

1. Flower colour of snapdragons is an example of incomplete dominance. Draw an example of a cross for a white flower and a red flower.
2. Research some other examples of incomplete dominance.

Quick check 2.14

1. Explain why males are much more affected by X-linked disorders than are females.
2. Explain how codominance works.

Pedigrees

One way of finding out how a trait is inherited is to follow the inheritance pattern over two or more generations. This technique is called pedigree analysis. To study patterns of inheritance in humans, geneticists investigate the frequency and occurrence of a particular gene over many generations and so determine whether the traits are dominant or recessive. The chart formed is called a **pedigree** and it is just like a family tree.

pedigree a chart formed to study patterns of inheritance over generations

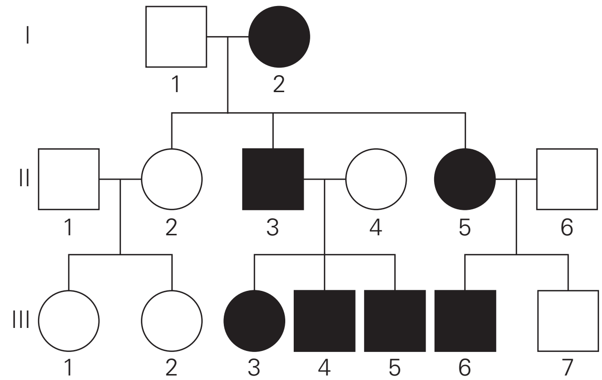
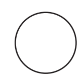
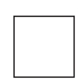
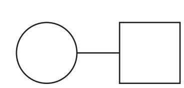


Figure 2.31 An example of a pedigree showing three generations of a family. Individuals affected by a particular trait are shown in black. Note how male I-1 and female I-2 had three children, and their eldest is an unaffected female (II-2).

You can see in Figure 2.31 that each generation (numbered in roman numerals) forms a row on the pedigree, with individuals numbered (using arabic numbers) from left to right on each row. The symbols used are:

- Unaffected females 
- Unaffected male 
- Female with the trait being investigated 
- Male with the trait being investigated 
- Mated represented by a horizontal line as shown: 
- Vertical line connects offspring to parents as shown: |

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Reading a pedigree

There are some points to keep in mind when reading a pedigree and determining inheritance:

- A trait that is common in a population is not necessarily dominant.
- If you are asked to determine a genotype in a pedigree, first you will need to work out the mode of inheritance. You can use Punnett squares to help you.
- Remember that if a couple has four male offspring it does not mean their next child is going to be female. Every time the parents have a child, the chance of getting a male or female is the same 50/50. The same goes for the chance of inheriting traits.

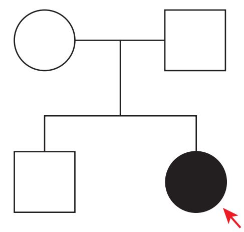
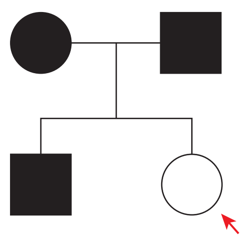
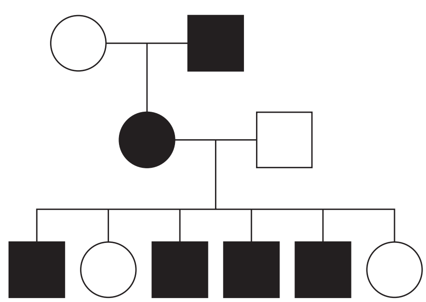
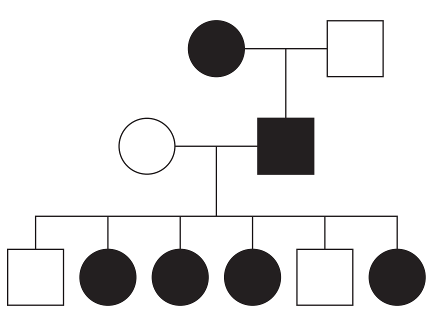
Type of inheritance	Pedigree chart	What to look for	Examples
Autosomal recessive		If two unaffected parents have an affected child, the trait cannot be dominant. Males and females can be equally affected. The trait may disappear from a branch of pedigree and then reappear in later generations. Two affected recessive parents must have all affected recessive children.	Albinism, cystic fibrosis and thalassaemia
Autosomal dominant		If two affected parents have an unaffected child, the trait must be dominant. With a dominant trait, a person only needs one allele to show the trait. Males and females can be equally affected, yet all of the affected individuals must have at least one parent affected.	Huntington's disease and a form of Alzheimer's disease
X-linked recessive		If an affected mother has all affected sons, the trait could be carried on the X chromosome and be recessive.	Colour blindness, haemophilia and muscular dystrophy
X-linked dominant		If a father is affected and all his daughters are affected, this suggests the trait is X-linked and dominant. Also an affected father *cannot* pass the trait to his sons, yet an affected homozygous female will pass the trait on to all of her daughters and sons. And an affected heterozygous female has a 50% chance of passing the trait onto her daughters and sons.	Vitamin D deficient form of rickets

Table 2.5 Different modes of inheritance and how to identify them in a pedigree chart

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Did you know? 2.6

Famous people have genetic disorders too!

Chopin was a famous composer born in 1810. He was sick for most of his life from what they thought at the time was tuberculosis. It is now thought that it was due to an autosomal recessive condition called cystic fibrosis.

Queen Victoria was a carrier of haemophilia B, which is X-linked recessive. She passed this gene on to two daughters and one son.

Figure 2.32 Chopin and Queen Victoria both had genetic disorders.

Quick check 2.15

1 Study the pedigree in Figure 2.33. It illustrates the inheritance of achondroplasia (dwarfism) in humans.

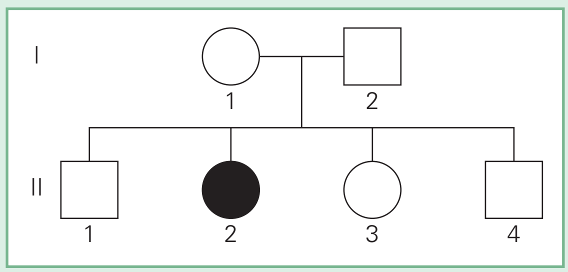

Figure 2.33

a What evidence suggests that this condition is recessive and not dominant?

b Write down the genotype of individuals I-1, I-2, II-1 and II-2.

c Suppose individual II-2 marries a man who does not have achondroplasia but is a carrier for the condition. What is the chance of having a child with achondroplasia and the chance of having a child without achondroplasia? Use a Punnett square to show how you arrived at your answer.

QUIZ

Section 2.3 questions

Remembering

1 State how many copies of each gene we have and where they come from.
2 Recall the name of the person known for being the father of genetics.
3 Describe what pedigrees are useful for.
4 Outline the difference between codominance and incomplete dominance.
5 Provide an example of codominance and incomplete dominance.

Understanding

6 Explain how sex linkage is different to other types of inheritance.
7 Explain why for a particular characteristic two homozygous recessive individuals can only produce homozygous recessive children.
8 Explain what is meant by the term 'carrier'.
9 Explain why a test cross is useful.

continued…

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...continued

Applying

10 Dimples is dominant to no dimples.

- **a** Assign letters for these alleles.
- **b** Write the genotypes and phenotypes of:
  A person homozygous recessive for dimples
  A person heterozygous for dimples
  A person homozygous dominant for dimples.
- **c** Circle the person above who would be considered a carrier for dimples.

11 In fruit flies, eye colour is determined by an autosomal gene. The red eye allele is dominant over the white eye allele.

- **a** Assign letters to the alleles.
- **b** Draw a Punnett square for a male heterozygous fly that mates with a female homozygous recessive fly.
- **c** State the genotypic and phenotypic ratios of the offspring.

12 In mice, black hair is dominant to brown hair. Mice with black hair can be either homozygous or heterozygous. Describe how you would find out if a mouse with black hair was homozygous or heterozygous. Justify your response with a Punnett square.

Analysing

13 The pedigree in Figure 2.34 shows the inheritance pattern of a disease that is caused by a single gene.

- **a** Identify the sex of the person labelled 7.
- **b** State whether the disease is dominant or recessive. Justify your response.
- **c** Identify the genotype of individual 7. Justify your response.

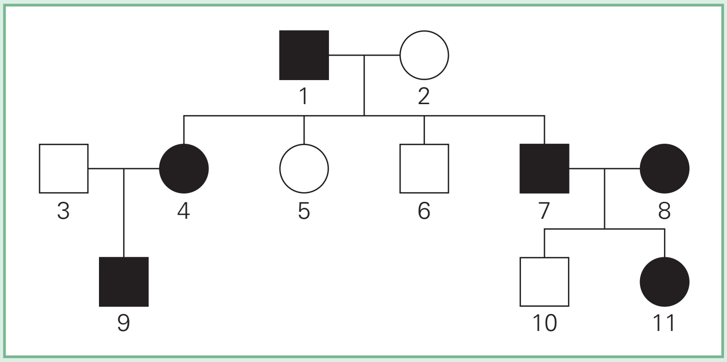

Figure 2.34

14 The pedigree in Figure 2.35 shows the inheritance patterns for haemophilia. Haemophilia is an X-linked recessive disorder.

- **a** State how many children couple 1 and 2 had.
- **b** Use evidence from the pedigree to demonstrate that haemophilia is recessive.

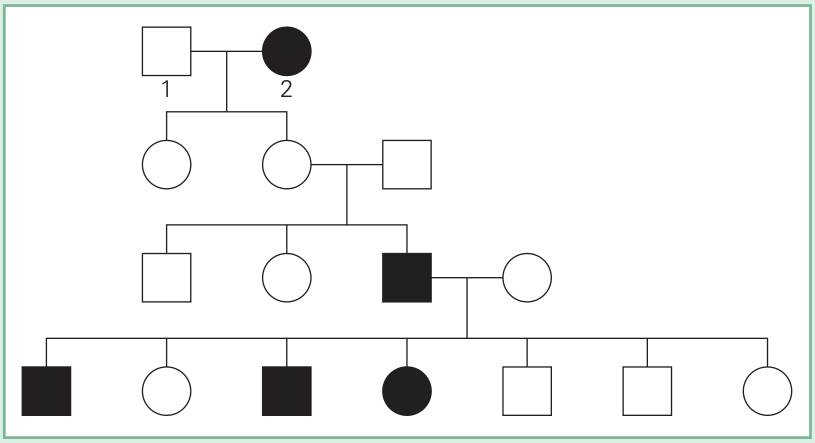

Figure 2.35

Evaluating

15 Explain what is meant by the statement 'nature versus nurture'.

16 If a brown-eyed male and a blue-eyed female produced all blue-eyed children, does that mean that blue eyes is the dominant trait? Justify your response.

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2.4 Changes in DNA

WORKSHEET

We know that the DNA code of an organism is replicated during cell division. It is this code that determines what the cell will do and when it will do it. The genetic code is translated into proteins that then determine cellular function.

Sometimes, however, this process makes errors and causes changes to the genetic code of a cell. Often these errors are quickly repaired by the cell, but when they are not, they become permanent changes in the genome of the cell and are known as **mutations**. Mutations may be small, such as the changing of a single nucleotide (**point mutations**), or large, involving huge segments of DNA within a chromosome (**chromosome mutations**).

mutation a change in the genetic code of a cell

point mutation a mutation in which a single nucleotide is changed

chromosome mutation a mutation involving large segments of DNA

A mutation can be described as being **spontaneous** (naturally occurring) or being **induced** due to exposure to **mutagenic** agents like radiation (X-rays, ultraviolet or nuclear) or chemicals. The mutations that occur within the gametes can be inherited and will influence the next generation. These are called **germline mutations**. If the mutation occurs within the body cells (somatic cells), this will only affect the individual and not be passed down to future generations. This form of mutation is known as a **somatic mutation**.

spontaneous mutation a naturally occuring mutation

induced mutation a mutation produced by environmental factors

mutagenic causing mutations in DNA

germline mutation a mutation of DNA in gametes

somatic mutation a mutation that occurs in somatic (body) cells

Did you know? 2.7

Agent Orange

Agent Orange was a chemical used during the Vietnam War. It contained a chemical 2,3,7,8-tetrachlorodibenzodioxin (TCDD), which is a dioxin that causes birth defects. If a pregnant mother is exposed to the chemical, the embryo will be affected via the bloodstream.

In the years following the Vietnam War, there were higher rates than usual of miscarriages, premature births and congenital birth defects in regions where Agent Orange was used. Male Vietnam veterans who were exposed to the chemical during the war had a higher than average

Figure 2.36 Plane spraying Agent Orange

continued...

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...continued

chance of having children with neural tube defects, such as spina bifida. This was because Agent Orange induced a germline mutation within the sperm, and consequently this mutation could be passed to the next generation.

Figure 2.37 The stunted leg of a two-year-old child, a victim of Agent Orange

Explore! 2.6

Mutagens

Many factors in the environment are known as 'mutagens' – that is, they cause mutations.

1 Research environmental mutagens and create a list.
2 From the list created in question **1**, divide your mutagens into categories according to their source, such as chemical mutagens, radiation, mutagens in food.

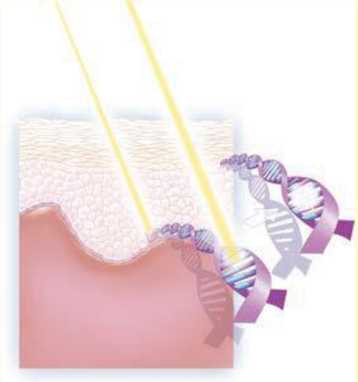

Figure 2.38 Radiation from the Sun can cause mutations in the DNA of skin cells.

Beneficial, deleterious and neutral mutations

There are three possible consequences of mutations:

- No effect – neutral. Neutral mutations are non-lethal and make no difference to the organism's ability to survive and reproduce in its environment. Such mutations accumulate in the gene pool and give rise to genetic variation within a population.
- Negative effect – deleterious. Deleterious mutations may cause the death of the organism or in some way make it less likely that the genetic material will be passed on to the next generation.
- Positive effect – beneficial. Beneficial mutations give rise to variations that increase the chance that the organism will survive and reproduce to pass its genetic material to the next generation.

Quick check 2.16

1 If a mutation is to be passed on to the next generation, state where it must occur and why.
2 State what usually results when mutations occur in somatic cells.

Point mutations

Point mutations involve changes to any of the four nitrogenous bases in the nucleotides (ATCG) which make up the genes. Changing the nucleotides could change the message

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carried by the gene so that there may be a change in the order of amino acids making up the protein.

There are four types of point mutations:

- A **substitution** mutation occurs when one nucleotide is swapped for another (for example, ATG becomes ACG). This mutation only changes the DNA code for one amino acid. Or it could code for the same amino acid (this is called a silent mutation). An example of a type of substitution mutation is sickle cell anaemia.

substitution
a type of point mutation in which one nucleotide is swapped for another

- An **insertion** mutation occurs when an extra nucleotide (or more than one) is inserted into the DNA sequence (for example, ATG becomes ATCG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a type of insertion mutation is fragile X syndrome.

insertion
a point mutation in which an extra nucleotide (or more than one nucleotide) is inserted into the DNA

- A **deletion** mutation occurs when a nucleotide is deleted from the sequence (for example, ATG becomes AG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a type of deletion mutation is Duchenne muscular dystrophy.

deletion
a point mutation in which a nucleotide is deleted from the sequence

- An **inversion** mutation occurs when two nucleotides reverse their order in the DNA (for example, ATG becomes AGT).

inversion
a point mutation in which two nucleotides reverse their order

Try this 2.6

Remembering deletions

Find a way to remember the different types of mutations using normal words.

For example:

- normal code: WING
- deletion: WIG
- insertion: WRING.

Explore! 2.7

Sickle cell anaemia

Sickle cell anaemia is a disease caused by a mutation in a gene that codes for a subunit of haemoglobin. Haemoglobin is a protein found in red blood cells, and the mutation causes the red blood cells to be misshapen and block blood vessels.

1 Which amino acid is changed?
2 It is an example of both a deleterious and a beneficial mutation. Explain what these terms mean.
3 Why is it deleterious in a non-malarial zone and beneficial in a malarial zone?

Figure 2.39 Red blood cells are misshapen in people with sickle cell anaemia.

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Science as a human endeavour 2.3

Savant Thakur

Savant Thakur commenced his PhD in 2015. The interesting thing is that he is researching his own condition! Savant was born with Duchenne muscular dystrophy (DMD). DMD is characterised by the progressive breakdown of muscles and is caused by a mutation in an X-linked gene. This gene codes for the protein dystrophin, which is responsible for keeping muscles intact. The disorder is recessive, so it is much more common in males, who inherit only X chromosome, than in females, who inherit two X chromosomes. Thakur is determined to help improve the lives of other affected by muscular conditions and has received The Lionel Murphy Endowment Postgraduate Scholarship in 2016 for his contribution to research on skeletal muscle biology.

Figure 2.40 Savant Thakur with Dr Nikki Cranna, a support researcher who helps Thakur set up lab experiments

Chromosomal changes

Chromosomal mutations

If a mutation occurs in a gene on one of the pair of homologous chromosomes, there will still be a normal copy of the gene on the other chromosome. The same applies with chromosome mutations – the insurance is that they occur as homologous pairs, so if one chromosome is abnormal the other is still likely to be normal. There are different types of chromosomal mutations:

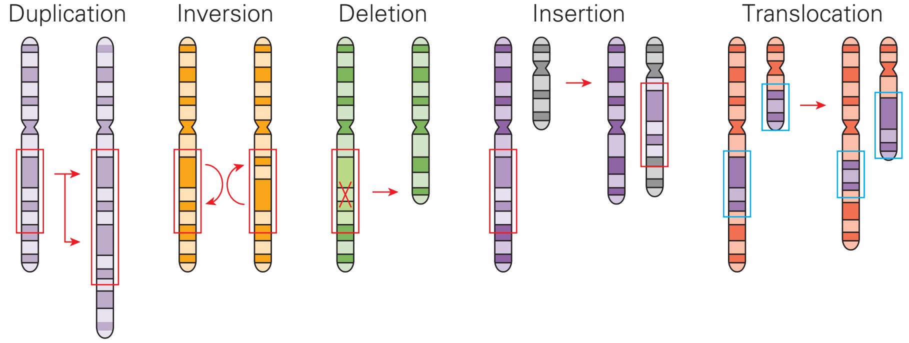

Figure 2.41 The five different types of chromosome mutation. Can you identify what is changing in each type?

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Chromosome number abnormalities

Certain individuals may have one more or one less chromosome (**aneuploidy**) as a result of **non-disjunction** during meiosis. Non-disjunction means that the chromosomes failed to separate correctly when making gametes, so the gametes end up with an abnormal number of chromosomes.

aneuploidy when an individual has one more or less chromosome

non-disjunction when the chromosomes failed to separate correctly in meiosis

Trisomy occurs when an organism has a third copy of a chromosome that should only be present in two copies and is therefore an example of aneuploidy. The most common trisomy among embryos that survive to birth is Down syndrome, or trisomy 21. People with this inherited disorder have short stature and digits, facial distinctions including a broad skull and large tongue, heart problems, and developmental delays.

trisomy when an organism has a third copy of a chromosome

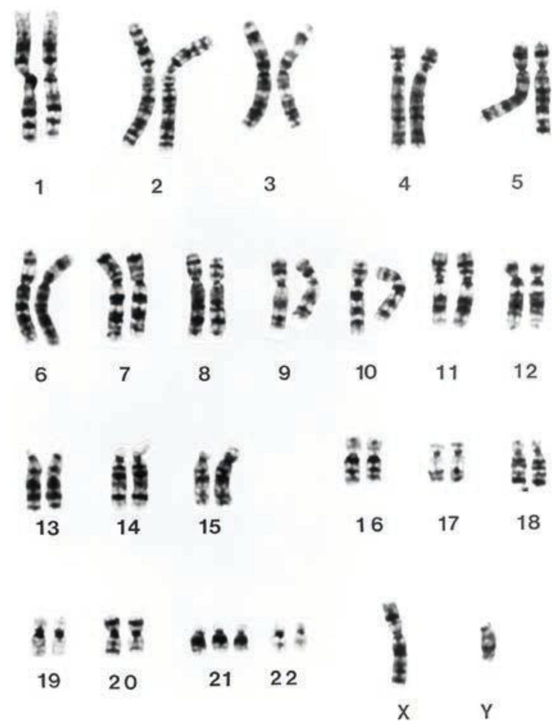

Figure 2.42 Karyotype of a Down syndrome male. Note the presence of three chromosome number 21s.

Madeline Stuart

Did you know? 2.8

Madeline Stuart is the first professional model with Down syndrome, and she is Australian! Although the fashion industry has a long way to go in terms of diversity, Madeline is one of the women who is changing the game. As well as being a model, she has also represented Queensland at the Special Olympics in cricket and basketball.

Figure 2.43 Madeline Stuart models at the Los Angeles Fashion Week for a Spring Summer 2019 collection.

Quick check 2.17

1 What is a substitution point mutation?
2 Recall what the term 'aneuploidy' means.

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DNA testing for mutations

A person's DNA can provide information relating to their risk of developing certain diseases. Genetic testing can be performed to analyse a person's DNA to find out whether they carry a gene which confers higher risk for a disease, and whether they are at risk of passing a genetic mutation on to their children.

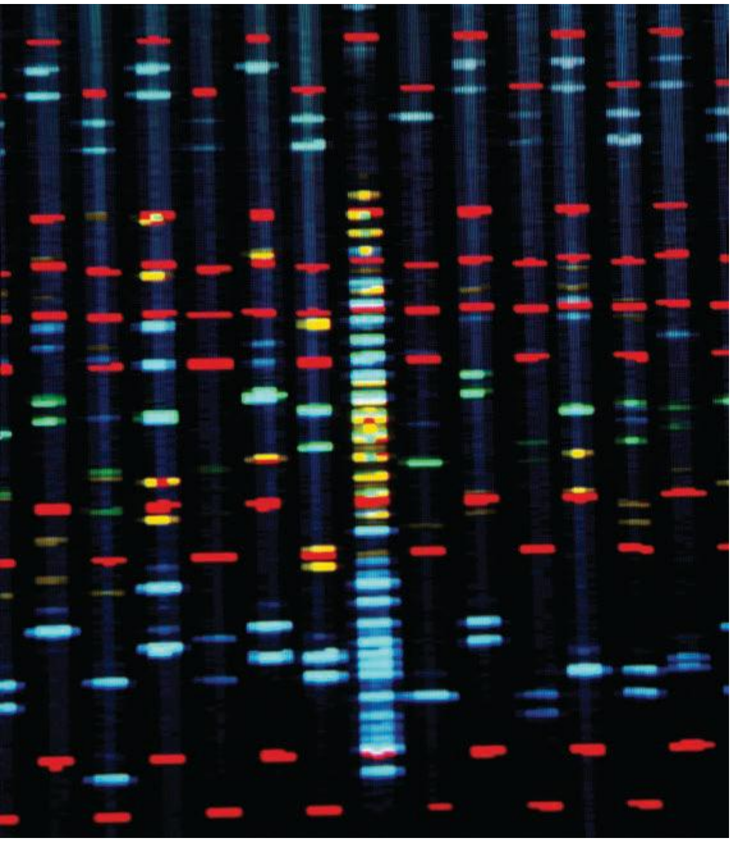

Figure 2.44 DNA sequence or 'genetic fingerprint' on a computer monitor screen. Each coloured band represents one of the bases that make up the genetic code of this sample of DNA.

Types of testing

If an individual has a family history of a disease, they may be able to be genetically tested for that specific disease or condition.

genetic screening
genetic tests that are available for anyone in the population

Genetic screening refers to tests routinely done for anyone in the population, even if they have not shown a family history of the disease. This screening is usually done during pregnancy and at birth. Pregnant women are able to have their foetus screened for Down syndrome and neural tube defects, and all newborn babies are tested for cystic fibrosis, phenylketonuria and hypothyroidism. Some parents choose to abort a foetus that is carrying a serious mutation – over time the frequency of these conditions may decline. On the other hand, early diagnosis of a genetic condition like phenylketonuria means that action can be taken to treat or manage the condition – this allows some people to live longer and healthier lives than they would have without the appropriate intervention.

bioinformatics
an analysis tool that is able to sort biological data using computers

Bioinformatics involves using very powerful computers to sort and analyse biological data. DNA chips are used to detect the presence of particular genes in a person's genome. Short fragments of genes are attached to a chip, and by adding a person's DNA, an area of the chip will light up if a certain gene is present.

Figure 2.45 A scientist analysing a DNA profile

With increasing knowledge about the human genome and disease-causing genes, we can gain more and more information about an individual. However, with this information comes some important questions. For instance, what happens with your genetic information once the tests have been completed? Who has access to that information? Could the results of these genetic tests affect things like health insurance?

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Try this 2.7

The great debate!

Split your class into teams and engage in a debate surrounding genetic testing.

You may wish to consider the following scenario to your debate:

A woman who is 12 weeks pregnant attends a clinic and expresses her concern about her husband's family history of Huntington's disease (HD). Her sister-in-law tested positive last year, although she is not yet showing symptoms of the disease, but the woman's husband refuses to be tested. Due to this, the woman is asking for her unborn baby to be screened to determine whether it carries the HD gene. If the test comes back positive, which means that her husband carries the HD gene, the woman will discuss terminating the pregnancy with her husband.

Discuss the legal and ethical issues surrounding this scenario. Consider the view point of all people involved.

Explore! 2.8

Non-invasive prenatal testing

When a woman is pregnant, some of the baby's DNA passes into the mother's bloodstream. This DNA can be used to screen all of the baby's chromosomes for abnormalities. Because the baby's DNA is obtained from the mother's blood, this is a safe and non-invasive test.

1 What are the main disorders that a non-invasive prenatal test (NIPT) looks for?
2 How early in a pregnancy can this test be performed?
3 What advantage does NIPT have over other prenatal screening tests?
4 Why might you choose to have NIPT?

Science as a human endeavour 2.4

Going mainstream!

Genetic testing is going mainstream, with companies like *Ancestry.com* and *23andme* giving insight into an individual's genetic make-up. However, new research is indicating that up to 40% of widely available genetic testing contains incorrect readings in the raw data. This can obviously be very stressful if unexpected inaccurate information is obtained. The advice from researchers is that these sorts of tests still need to be interpreted by professionals.

Figure 2.46 Genetic screening can identify risks for certain cancers.

Quick check 2.18

1 Explain why an individual might choose to be screened for genetic diseases.
2 List some ethical issues with genetic testing.

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Manipulating DNA

Genetic engineering technology allows scientists to manipulate genetic material and transfer genes between two different species. Scientists have transferred human genes into bacteria and cows, and bacterial genes into cotton plants. **Transgenic organisms** (TGOs) are organisms that possess a 'foreign' gene, or a segment of 'foreign' DNA, in their genome as a result of human experimentation. They are an example of a genetically modified organism. Prokaryotic cells with foreign DNA are called transformed cells, whereas eukaryotic cells with foreign DNA are called transfected cells.

genetic engineering technology that allows genetic material to be manipulated and enables genes to be transferred between any two species

transgenic organisms organisms that possess a 'foreign' gene or segment of 'foreign' DNA in their genome as a result of human experimentation

Genetically modified organisms

A **genetically modified organism** (GMO) is an organism whose genome has been altered by humans. Many foods come from genetically modified organisms, and we call them GM foods. For example, some plants have been genetically engineered to grow with less water so that they are more resistant to changing weather patterns. Genes from other organisms have also been inserted into the genome of some plants to make them resistant to pests. This means that farmers can reduce their use of pesticides.

genetically modified organism an organism that has had its genome altered by humans

Human genes have been engineered into other mammals in order to supply the protein products of those genes, usually for medical purposes.

For example, transgenic hamster cells have been genetically engineered to contain the human gene that codes for the production of follicle-stimulating hormone (FSH). FSH is commonly used in in vitro fertilisation (IVF) treatments. Some women do not produce enough FSH to allow their eggs to mature so may have difficulty becoming pregnant. Fertility drugs must contain FSH to stimulate the eggs to mature in the ovary, thus allowing for optimum chance of pregnancy.

The supply of this recombinant FSH is more reliable, larger and purer than FSH derived from human urine. Another example is the use of transgenic cows with the gene for human serum albumin, which is often given in blood transfusions. These cows produce large amounts of recombinant human serum albumin in their milk; much more than can be extracted from human blood donations.

Figure 2.47 A researcher analysing genetically modified corn

Gene therapy

Gene therapy is a process by which a copy of a functional gene is introduced into an organism. The gene is then switched on to produce the functional protein that is missing. This technique aims to treat inherited disorders like cystic fibrosis by directly targeting the genotype (unlike symptomatic treatments that target the phenotype). Technical difficulties may arise when trying to specifically target the cells of affected tissue, and when targeting one specific gene without interfering with the function of other essential genes. Ethical issues also arise. Some people argue that gene therapy should be restricted to somatic tissue only, so the introduced gene is not transmitted through to the next generation. What do you think about this issue?

gene therapy a process by which a copy of a functional gene is introduced into an organism

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Quick check 2.19

1 What does GMO stand for?
2 What is the underlying feature of gene therapy?

Try this 2.8

A great debate continues to rage within society regarding the health risks associated with eating GM food. Research two advantages and two disadvantages of the use of GM food, and be prepared to debate with your classmates.

Figure 2.48 A scientist analysing the colour of a GM corn cob

Section 2.4 questions

QUIZ

Remembering

1 If a mutation is to be passed on to the next generation, where must it have occurred and how do you know?
2 Define the term 'mutagen'.
3 Describe the difference between a spontaneous mutation and an induced mutation.
4 Recall the definition of a genetically modified organism.

Understanding

5 Explain what will happen if a nucleotide is deleted from the sequence of nucleotides within a gene.
6 Explain what usually results when mutations occur in non-germ cells.
7 Explain whether or not all mutations are detrimental/harmful.
8 Explain how a mutated gene can lead to a genetic disorder.
9 Explain the difference between a genetically modified organism and a transgenic organism.

Applying

10 Why is the substitution of one nucleotide not as critical to the functioning of the protein as is a deletion or insertion of a nucleotide?
11 Draw a diagram to outline how non-disjunction may occur and cause aneuploidy.
12 Using the DNA sequence ACAATTGGTAGCTGAGTTGGCCCGTA, demonstrate an example of a:
   a substitution
   b inversion
   c deletion
   d insertion.

continued…

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...continued

Analysing

13 Using the table below, answer the following questions.

1st letter in the codon		2nd letter in the codon: U	C	A	G	3rd letter in the codon
	U	UUU Phe (F) UUC Phe (F) UUA Leu (L) UUG Leu (L)	UCU Ser (S) UCC Ser (S) UCA Ser (S) UCG Ser (S)	UAU Tyr (Y) UAC Tyr (Y) UAA STOP UAG STOP	UGU Cys (C) UGC Cys (C) UGA STOP UGG Trp (W)	U C A G
	C	CUU Leu (L) CUC Leu (L) CUA Leu (L) CUG Leu (L)	CCU Pro (P) CCC Pro (P) CCA Pro (P) CCG Pro (P)	CAU His (H) CAC His (H) CAA Gln (Q) CAG Gln (Q)	CGU Arg (R) CGC Arg (R) CGA Arg (R) CGG Arg (R)	U C A G
	A	AUU Ile (I) AUC Ile (I) AUA Ile (I) AUG Met (M) START	ACU Thr (T) ACC Thr (T) ACA Thr (T) ACG Thr (T)	AAU Asn (N) AAC Asn (N) AAA Lys (K) AAG Lys (K)	AGU Ser (S) AGC Ser (S) AGA Arg (R) AGG Arg (R)	U C A G
	G	GUU Val (V) GUC Val (V) GUA Val (V) GUG Val (V)	GCU Ala (A) GCC Ala (A) GCA Ala (A) GCG Ala (A)	GAU Asp (D) GAC Asp (D) GAA Glu (E) GAG Glu (E)	GGU Gly (G) GGC Gly (G) GGA Gly (G) GGG Gly (G)	U C A G

The original DNA strand is GTC GGG ATA CGG CTC.

A point mutation occurs, whereby the C in the first codon is replaced with a T, resulting in GTT GGG ATA CGG CTC.

- **a** State the name of this point mutation.
- **b** Write out the mRNA strand that was copied from the original DNA strand.
- **c** Write out the new mRNA strand produced from the mutated DNA strand.
- **d** State whether the amino acids stay the same or change.
- **e** Another mutation occurs, whereby a C was added to the beginning of the above original DNA strand: CGTC GGG ATT CGG CTC
  State the name of this mutation and describe how it would affect the subsequent amino acids that it codes for.
- **f** Write out the mRNA code for this mutation and identify the corresponding amino acids.

Evaluating

14 Suggest an explanation for the relationship between increased rates of skin cancer and the thinning of the ozone layer.

15 Construct a mind map that shows the different types of mutations that may occur.

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Review questions

SCORCHER

Remembering

1. State the name of the position on a chromosome where a particular DNA sequence is located.
2. Name two autosomal recessive inheritable traits.
3. Name the structure formed when DNA condenses and becomes visible before cell division.
4. Construct a simplified drawing of a nucleotide.
5. State where transcription and translation occur.

Understanding

6. Explain why males have more chance than females of inheriting an X-linked recessive trait.
7. Assuming eye colour in humans is controlled by a single pair of genes, and that brown eyes are dominant to blue eyes, identify the genotype of a brown-eyed man who marries a woman with blue eyes and has a baby with blue eyes.
8. Draw a diagram to show how two nucleotides join together with hydrogen bonds.
9. Explain why chromosomes are not always visible.
10. State how many chromosomes you would expect to find in a:
    - a human somatic cell
    - b human gamete
    - c human somatic cell with Down syndrome.

Applying

11. When cells reproduce themselves, the DNA is replicated. Explain why this is necessary.
12. Show, using a Punnett square, the probability of the genotype and phenotype of the children if a normal female carrier of colour blindness has children with a normal vision male.

		Normal carrier female (X^BX^b)	
	gametes	X^B	X^b
Normal vision male (X^BY)	X^B		
	Y		

13. Construct a pedigree with the following information.
    A woman with Huntington's disease marries a man who does not have Huntington's disease. They have three children. The first child is a male, the second child is a female and both do not have the disease. The third child, a male, does get the disease. Remember that Huntington's disease is an autosomal dominant genetic disorder.

Analysing

14. An abandoned baby was handed in to the police station. Later, two different women claimed to be the baby's mother. Blood studies revealed that woman 1 had blood type A, and that woman 2 was blood type AB. The baby was blood type O. Which woman could possibly be the baby's mother, and which woman can be ruled out completely? Show your working.
15. Chondrodystrophy is an autosomal recessive condition that is governed by a single gene with two alleles. In turkeys, affected embryos die approximately 16 days after fertilisation, so they do not survive long enough to hatch. Two turkeys that are heterozygous for the condition are crossed. Show all of your working to determine the phenotypic and genotypic ratios of the offspring.
    Let C = normal turkey; c = turkey with chondrodystophy.

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16 The table below shows a number of different organisms with their chromosome number.

Organism	Chromosome number
Chimpanzee	48
Human	46
Horse	64
Onion	16
House fly	12
Worm	20

a Identify the organism with the highest number of chromosomes.
b State the haploid number of the onion.
c Explain whether the chromosome number of an organism reflects its intelligence. Justify your response.

Evaluating

17 Personal genome screening can be readily ordered over the internet. Evaluate the pros and cons of having DNA testing so readily available for an affordable cost.

18 You had genome screening and found out that your genes conferred a 25% chance of developing a disease. However, you also know that environmental and lifestyle factors play a large role in whether or not you develop the disease.
a Evaluate how this information would affect your life.
b Discuss how this scenario is different from knowing about a disease that is not influenced by lifestyle factors.

Figure 2.49

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STEM activity: Designing and prototyping an assistive device for individuals with a genetic disease

VCSSU119 VCDSTS055 VCDSTC059 VCDSCD061 VCDSCD064 VCDTCD050 VCMMG343

Background information

Genetics forms the foundation of all life on Earth. It differentiates one species from another, and one individual from another within a species. Look around and you will notice everyone is unique.

This genetic ‘encyclopaedia’ is not perfect. As with ancient scribes who transcribe texts, errors are made each time a copy is produced. Errors in the genetic 'encyclopaedia', or genetic code, are known as mutations. The different types of mutations can be thought of as spelling, punctuation or grammar errors. Mutations create variations within a species and allow for evolution.

However, when a mutation occurs that is not beneficial, complications occur. An example of a disease with genetic causes is scoliosis. Scoliosis is a sideways curvature of the spine that usually occurs before puberty. Genetic diseases such as cerebral palsy and muscular dystrophy can cause scoliosis, but the cause of most scoliosis is unknown.

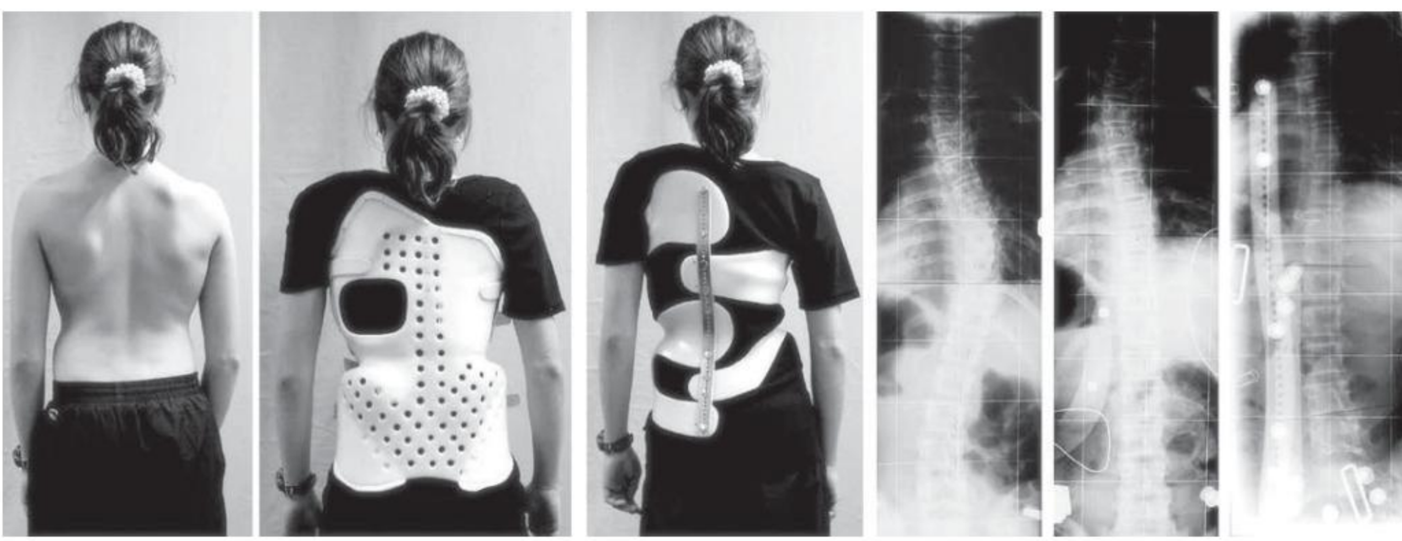

Figure 2.50 Various brace designs can be used for the treatment of scoliosis.

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Design brief: Research a genetic disease. Design and build an apparatus that can help to prove the quality of life for people with the selected disease.

Activity instructions

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life for people with that condition. Consider how the product would be built and marketed. Each team member needs to have a clear role but must be able to contribute to all aspects of the project.

Suggested materials

- computer
- pencil
- paper
- ruler
- balsa wood
- plaster
- papier mâché
- chicken wire
- 3D printer
- cardboard
- poster paper

Evaluate and modify

1 Identify the genetic disease and describe its cause and effects.

2 Find pictures or diagrams of current equipment used in treatment(s), if any, and annotate with features and characteristics that relate to treating the disease.

3 Sketch potential design solutions (at least two), and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current treatments (if any).

4 Develop a marketing strategy.

  a How would you present your design solution?

  b Who is the customer; for example, the end user, doctor or someone else?

  c Present supporting evidence that your apparatus would not be just a placebo solution.

5 Propose how some design constraints or limitations might apply to engineers developing real-world apparatus for genetic diseases.

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Chapter 3 **Evolution**

Chapter introduction

How can there be so many different species on Earth? How are species suited to particular environments? Biodiversity is the key and can be explained through evolution. Evolution refers to the genetic changes in a species' population over a very long period of time. The theory of evolution is supported by the evidence we see in the fossil record, genetics and other fields of science. In this chapter we will look at the significant evidence that supports the theory for evolution and evaluate the key processes involved.

Curriculum

The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (VCSSU120)	
• describing biodiversity as a function of evolution	3.1
• outlining processes involved in natural selection including variation, isolation and selection	3.2
• investigating changes caused by natural selection in a particular population as a result of a specified selection pressure, for example, artificial selection in breeding for desired characteristics	3.2
• evaluating and interpreting evidence for evolution, including the fossil record, chemical and anatomical similarities, and the geographical distribution of species	3.3

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Glossary terms

absolute dating
adaptation
analogous structures
artificial selection
biodiversity
biogeography
biostratigraphy
direct (evidence)
DNA hybridisation
endangered
evolution
evolutionary tree
extinct
fertile
fossil
fossil record
fossilisation
gene flow
genetic drift
half-life
homologous structures
index fossil
indirect (evidence)
isotope
natural selection
population (ecological)
relative dating
reproductively isolated
selection pressure
selective breeding
speciation
species
stratigraphy
trace fossil
variation
viable

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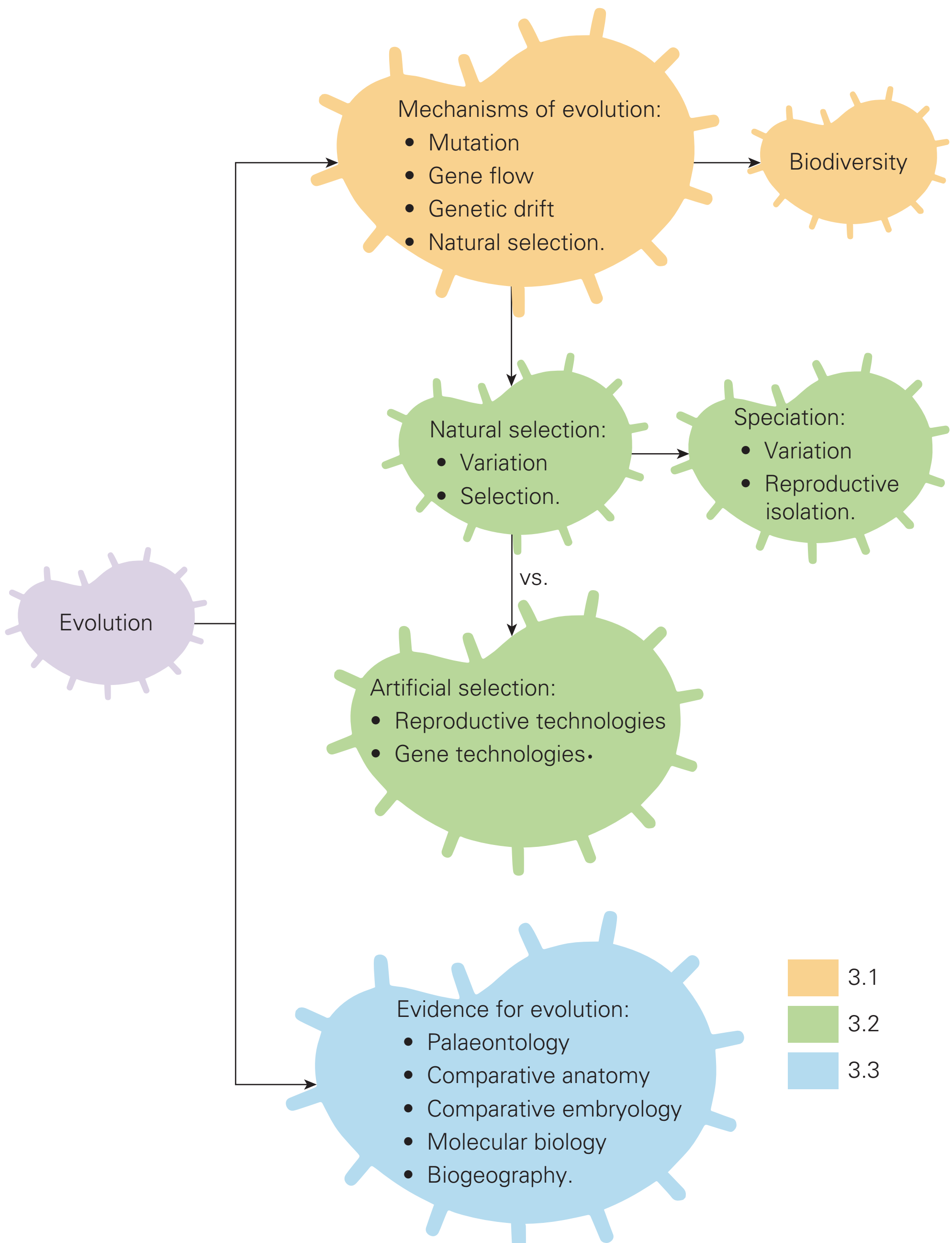
Concept map



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3.1 Evolution

Evolution refers to the genetic changes in a population over a very long period of time. When we talk about a **population**, we mean the members of a single species living in the same region (geographical area) at the same time. So evolution is understood by looking at a population of a particular species, not at individuals.

> **evolution**
> the genetic changes in a population over a long period of time
>
> **population (ecological)**
> a group of a particular species living in the same geographical area at the same time
>
> **variation**
> genetic differences within a population

When we talk about evolution we often refer to the variation that exists within a population. **Variation** occurs when members of a population differ in one or more characteristics. For example, we can notice many types of variation in humans, such as skin and hair colour, height, blood types, fast or slow metabolism, and food preferences.

Variations that contribute to an organism's ability to survive and reproduce in their environment are called **adaptations**.

WORKSHEET

> **adaptation**
> characteristic that contributes to a species' suitability for its environment

Mechanisms of evolution

Evolution can take place through five key mechanisms. Remember, evolution is all about the change in genetic composition of a particular species' population over time. So each of these processes changes the genetic make-up of a population in some way:

- mutation
- gene flow
- genetic drift
- natural selection
- sexual reproduction – including the processes of 'crossing over' in meiosis and the random combination of genetic information from two parents (as discussed in Chapter 2).

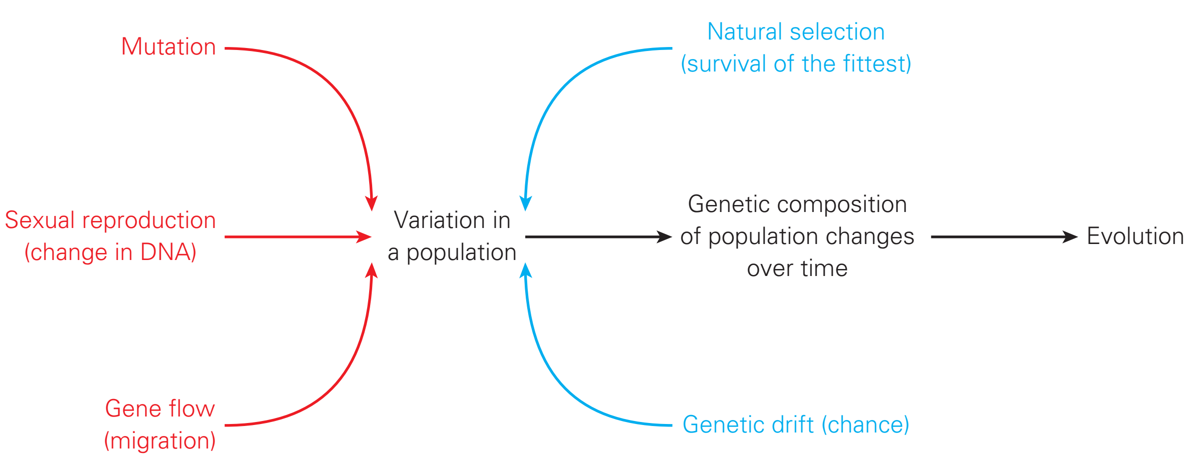

Figure 3.1 Changing genetic information changes the variation within a population and this leads to an overall change in the genetic composition of a population, which means evolution is occurring.

Mutation

For evolution to occur, there must be a change in the genetic make-up of at least one individual. Recall from Chapter 2 that a mutation is a spontaneous or induced change in the genetic sequence of an organism's DNA. A mutation, if present in gamete cells, can be passed down to future generations.

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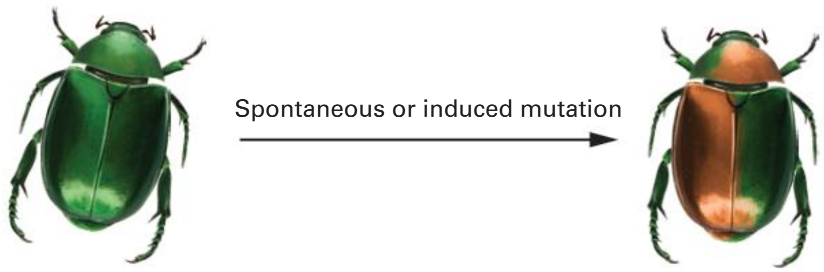

Figure 3.2 A spontaneous or induced mutation in a gamete can cause a change in the DNA code passed onto the next generation and so contributes to evolution.

Mutations may have various effects on the phenotype of organisms, ranging from no change at all through to small changes or large changes. Mutation is a random process in that the change can occur anywhere in a length of DNA. For this reason, most mutations are harmful or detrimental, and will not be passed on to future generations. Large changes include genetic diseases that are associated with a loss of function and negatively affect the individual. However, some mutations that are usually detrimental or harmful can produce a positive outcome in some circumstances.

Genetic disease	Some of the outcomes
Albinism	No or little colour in skin, hair and eyes Reduced Sun protection
Cystic fibrosis	Thicker mucus lining organs Respiratory and other health problems Fatigue
Duchenne muscular dystrophy	Progressive muscle weakness
Haemophilia	Blood cannot clot properly Abnormal bleeding
Sickle cell anaemia	Sickle-shaped red blood cells can interrupt blood flow Pain and fatigue Resistance to malaria, which is beneficial in areas where malaria is common

Table 3.1 Some examples of genetic mutations and their outcomes in humans

As a mechanism of evolution, it is mutations that introduce the variations in new alleles. If the mutation happens to be advantageous and occurs in the gametes, it may lead to a shift in the genetic composition in the population of a species. This links to another mechanism of evolution called natural selection, which we will cover later. In conjunction with natural selection, mutations are one of the main drivers of evolution and without it, evolution cannot occur.

Gene flow

gene flow
the movement of genetic information from one population to another

Another way genetic variation can be introduced to a population is through migration, also called **gene flow**.

Migration is the movement of individuals from one population to another, while gene flow specifically refers to the movement in genetic material the individuals carry from one population to another. However, gene flow can only occur between separate populations that are still part of the same species because they must be able to reproduce.

Migration can occur through different kinds of events, such as seed dispersal, animals moving to different areas, or movement forced by natural disasters such as earthquakes or floods.

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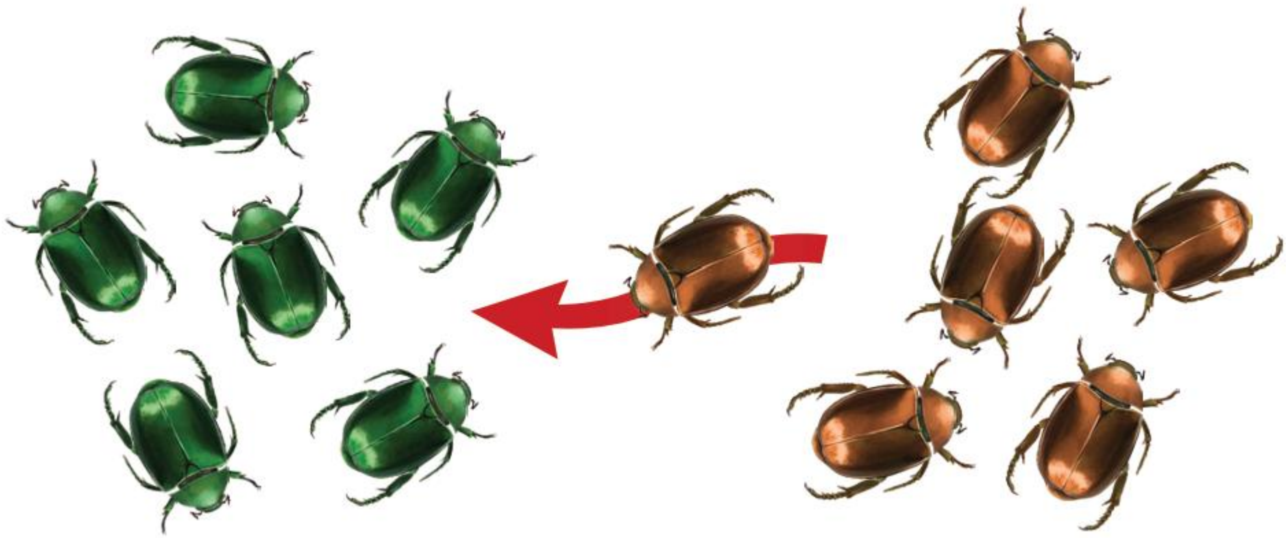

Figure 3.3 Unlike mutations, variations brought in by gene flow already exist within the species, but for one reason or another, some populations do not have a particular variation of a gene.

Did you know? 3.1

Dugongs and gene flow

Dugongs live in tropical areas around northern Australia and feed on seagrass, which means they are only found in areas where seagrass grows. Satellite tracking has recently shown that dugongs move long distances along the coast and often mate in their new location. This means there is a high level of gene flow across large distances. Interestingly, scientists found it is a male-biased gene flow, meaning that it is mostly the males that migrate and then mate and pass on their genetic information in the new population.

Figure 3.4 A dugong feeding on sea grass

Genetic drift

Genetic drift is the process by which the genetic information in a population changes at random or due to a chance event. When we say by chance, we are referring to factors that are unpredictable like bushfires and floods. Therefore, genetic drift alters the genetic make-up of a population in a random way. The key requirement for genetic drift is a small population. A population 'bottleneck' reduces the size of at least one generation of the population. The bottleneck event may be caused by chance, such as habitat destruction or an environmental disaster that results in the deaths of many organisms. Because the remaining population is much smaller than the original population, it contains much less genetic diversity. In this way, genetic drift can cause a large loss of genetic variation in small populations. This loss of genetic variation may result in the new population becoming more genetically distinct from the original population.

genetic drift
a random change in the frequency of an existing gene in a population

And what do we know happens when the genetic composition of a population changes over time? Evolution!

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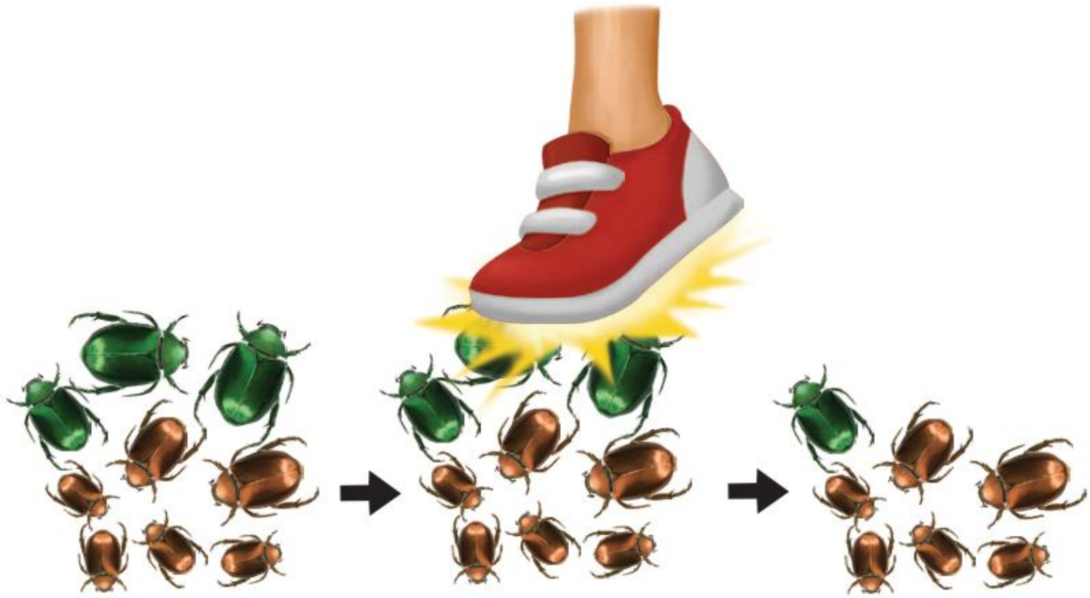

Figure 3.5 Someone standing on some beetles by accident is a random or chance event that can change the genetic composition of the beetles' population. This can then contribute to evolution.

VIDEO
Give an example of natural selection

natural selection
the process that when applied to a population results in the continued existence of only the organisms that are best suited to the conditions in which they live

Natural selection

You may have heard the saying 'survival of the fittest'. This is what **natural selection** is all about. It means that those organisms that are best suited to their environment – that is, have the best adaptations – will survive and are more likely to pass on their genetic information. So 'fittest' does not mean who can do the most push-ups, it means the organisms that have the best genetic information for survival in a particular environment and fitter individuals have more offspring. For example, look at Figure 3.6. These beetles live in the leaf litter on the forest floor and natural variation in their colour: they can be green or brown. The birds eat more green beetles, not because they prefer them but because they are easier to spot. So being green is a disadvantage if you want to survive and not be eaten for dinner by the birds. The brown beetles have the best colour for surviving (adaptation), which means they will be more likely to pass on their genetic information to their offspring. We will cover this in more detail in the next section.

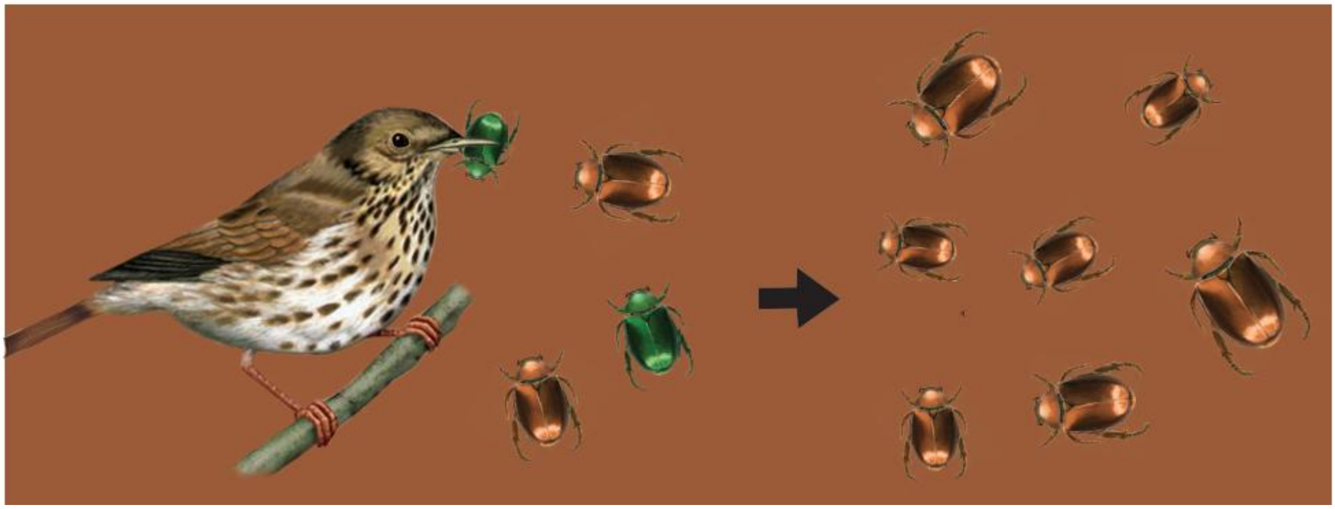

Figure 3.6 Some variations within a species are less likely to be passed on to the next generation because they cause a disadvantage.

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Try this 3.1

Summarise the five mechanisms of evolution you have learned by copying and completing the following table.

Mechanism	Definition	Contribution to evolution?
Mutation		
Gene flow		
Genetic drift		
Natural selection		
Sexual reproduction		

Quick check 3.1

1 Define the key terms 'evolution', 'population', 'variation' and 'adaptation'.
2 Identify the five mechanisms of evolution.
3 What does evolution act on, and what property does that thing need to have?

Biodiversity as a consequence of evolution

Biodiversity (biological diversity) refers to the immense variety of life on Earth. It includes both species diversity (the number of different species within an ecosystem) and genetic diversity (range of genetic traits within a species). Over time, populations within a species can become so different as to become a different species, increasing biodiversity. Therefore, it is evolutionary processes that have resulted in the biodiversity we see today.

biodiversity the variety of species, eco-systems and genes that exist in a particular area

Australia's unique biodiversity is best explained as the result of our plants and animals being isolated over a long period of time from the plants and animals of other continents and land masses. Australia was once part of a great southern supercontinent called Gondwana that even earlier was the southern portion of the giant Pangaea

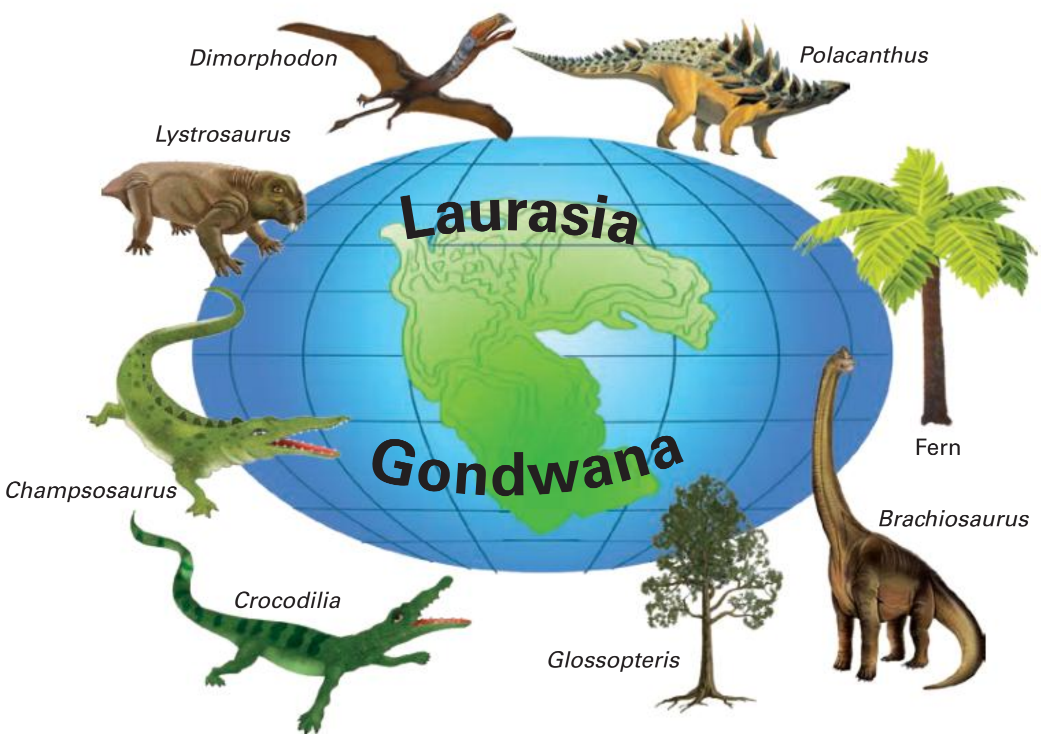

Figure 3.7 This map shows the supercontinent Pangaea before it separated into a northern Laurasia and a southern Gondwana.

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land mass. Gondwana was made up of the continents and countries that we know today as South America, Africa, Australia, India and Antarctica. Gondwana is thought to have begun breaking up approximately 140 million years ago.

As the continents moved across the surface of Earth, so too did their assemblages of plants and animals. This not only created geographical barriers (like oceans, mountain ranges and large rivers), but over time it also brought new combinations of species together.

Quick check 3.2

1. What is meant by the term 'biodiversity'?
2. What supercontinent was Australia once part of?
3. How did the movement of continents lead to the biodiversity among species?

Biodiversity through time

Our understanding of the origin of life on Earth is based upon the scientific evidence of the fossil record and genetic comparisons to modern life forms. The most primitive cells lived some 3.5 billion years ago. Although life appeared early in Earth's history (Earth is approximately 4.5 billion years old), evolution beyond the simple cell stage did not occur until much later – approximately 600 million years ago. Since then, the biodiversity that exists on Earth has fluctuated depending on changes in the environment. Figure 3.8 shows a timeline of the major stages in the development of life on Earth.

Historically, one of the best-known causes of a mass extinction on Earth is an asteroid impact that may have killed off the dinosaurs. However, the asteroid is suspected to be implicated in just one case, while volcanic activity has been implicated in at least four mass extinctions. Here are some hypothesised causes for the biggest mass extinctions on Earth:

- volcanic activity
- climate change
- changes in deep ocean oxygen levels
- changes in sea level.

A combination of the above causes may have contributed to mass extinctions, which caused major and rapid changes in the Earth's biota.

If there is sufficient genetic biodiversity in a species when an environmental change occurs, some organisms within a population will be better suited to that new environment than others. The survival of the well-adapted individuals will result in a change in the genetic composition of the species' population resulting in their evolution over time.

When did humans arrive in Australia?

Many researchers believe that humans first arrived in Australia 60 000 years ago. The fossil record indicates that Australia's megafauna were present at the start of the last glacial cycle and survived for the first 70 000 years of the cycle, but were probably extinct by 45 000 years ago.

An ice age occurs when the temperatures on Earth become relatively cold for a long period of time (millions of years). This results in ice sheets and alpine glaciers covering large parts of Earth. During an ice age, there are short periods of warm temperatures when glaciers retreat; these are called 'interglacial cycles'. Colder temperatures when glaciers advance are called 'glacial cycles'.

It is hypothesised that at least five major ice ages have occurred on Earth. The earliest ice age is thought to have occurred over two billion years ago, and the most recent one began approximately three million years ago – and continues today. So, we are currently living in a warm interglacial cycle that began about 11 000 years ago.

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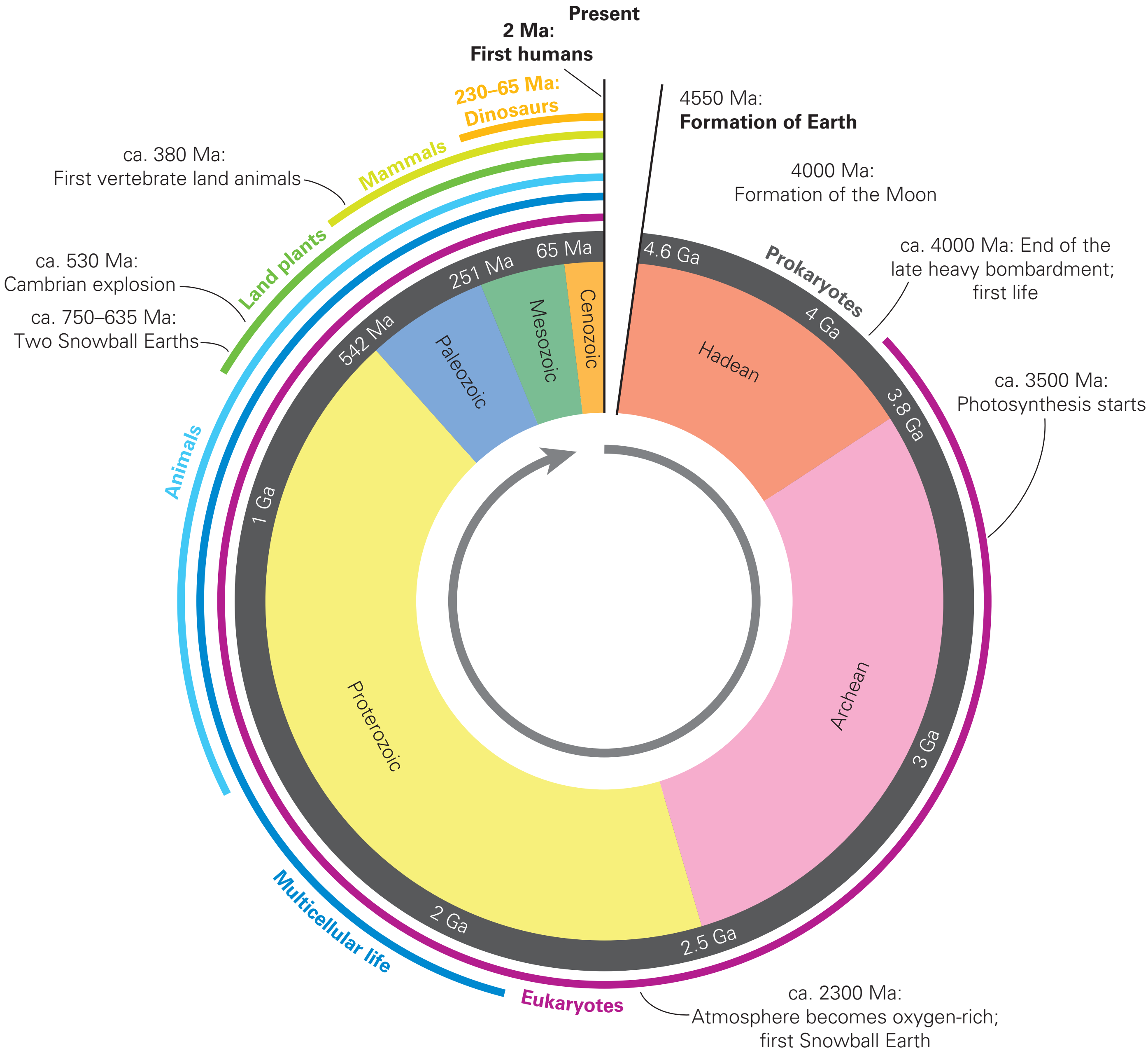

Figure 3.8 A timeline of Earth's history (ages are abbreviated from Latin: Ga (giga-annum) represents a billion years, Ma (mega-annum) is a million years)

The fossil record suggests that the Australian megafauna went extinct very soon after the arrival of Indigenous Australians. Is the timing of these two events a coincidence, and the extinction of the megafauna perhaps caused by a changing climate, or did one cause the other? How could people cause the extinction of these large animals?

There are examples of species hunted to extiction such as (but not limited to) the dodo, the passenger pigeon, the great auk, and quaggas.

Figure 3.9 Australia's megafauna included the largest known marsupial, *Diprotodon optatum*.

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Could the megafauna of Australia have been hunted to extinction by a small population of hunter-gatherers? Modern humans, the most formidable predator on the planet, first appeared in Africa around 200 000 years ago. Our ancestors had been evolving, first as omnivores in the middle of the food chain and later as top predators in Africa, for over three million years, and in Europe and Asia for around 1.5 million years. This allowed the megafauna in these areas, such as elephants and lions, to gradually adapt to survive in the presence of the increasingly formidable human hunters (although the modern agricultural and industrial world is now threatening these species).

Giant marsupials (mammals who carry their young in a pouch), reptiles and birds once roamed Australia too. One such marsupial is known as the *Diprotodon optatum* – with a shoulder height of 1.7 metres and weighing close to a whopping three tonnes – was the largest marsupial ever to have lived. The arrival and spread of modern humans in Australia and climate change are believed to have led to its demise.

We are interested in the influence of humans on the megafauna and today's organisms because we are affecting (or have affected) the evolution of these species. By clearing forests, overfishing, polluting the environment, consuming animals and introducing new species, we have caused the extinction of many species. We have also changed the genetic composition of populations of native plants and animals, and thus altered the course of evolution and affected species diversity.

Maintaining biodiversity

Maintaining biodiversity is extremely important, and loss of it due to human actions can cause huge impacts on ecosystems and result in loss of species beneficial to us. Maintaining diversity means keeping the full range of species in our ecosystems in order to conserve the variety of organisms on Earth. Species are considered **endangered** if they meet the criteria set by the International Union for the Conservation of Nature (IUCN). These include species whose numbers have experienced a reduction of 70% in a decade and species with fewer than 250 mature individuals living in a single population.

endangered a species that is in danger of becoming extinct

Endangered species are at risk of becoming **extinct**, especially if there is not enough genetic variation in the population. Species can be at risk even if their population is still large. Changes in the environment that may cause extinction include new diseases, new predators, competition with another better adapted species and loss of habitat.

extinct no longer existing

Did you know? 3.2

The genetic diversity of the platypus

Australia's wonderfully unique platypus, like the koala, is at risk of becoming locally extinct (extinct in a particular area) due to disease. Platypuses found on the mainland and in Tasmania have a good level of genetic diversity, so it is not likely that a disease would wipe out every individual in the population. However, platypus populations on two islands, King Island in Bass Strait and Kangaroo Island off the South Australian coast, face a greater danger of extinction. These populations have become so inbred that they have low genetic diversity. If a disease comes along that can kill one individual, all of the others could also be at risk as they are so genetically similar.

Figure 3.10 A platypus swimming in a creek

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Many zoos have captive breeding programs in which they breed captive animals to help the survival of endangered species. Such programs aim to reintroduce the species back into the wild, which would aid in keeping population numbers up and limiting inbreeding.

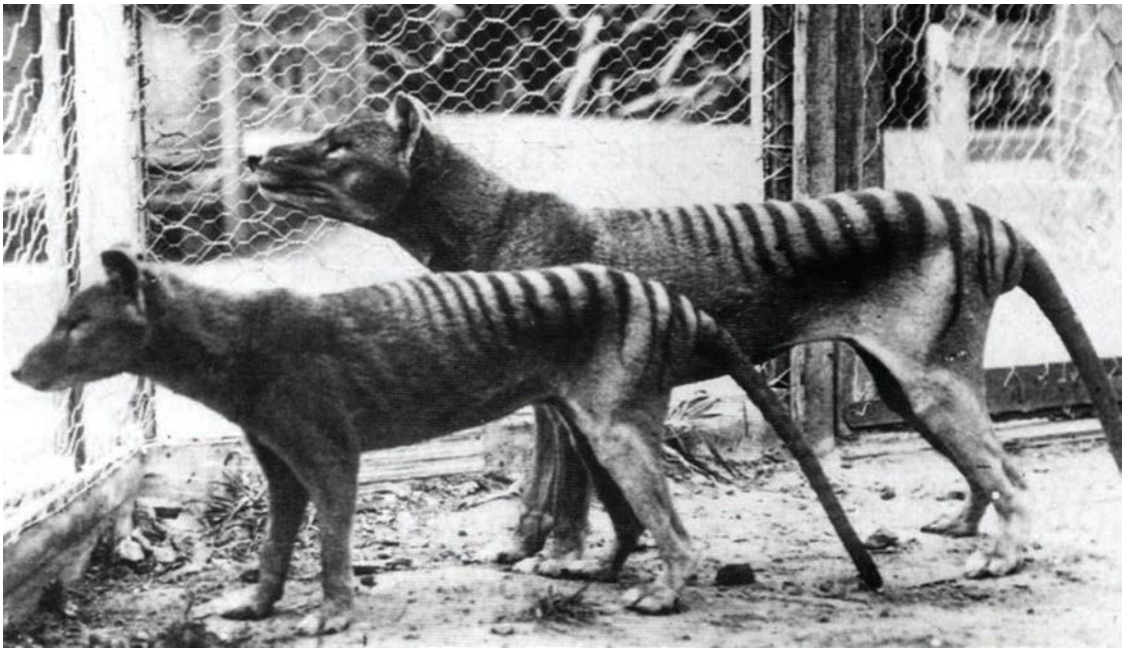

Figure 3.11 The now extinct Tasmanian tiger (thylacine) is pictured in an enclosure at the Hobart Zoo Tasmania in 1933. This is an example of an extinct Australian species.

Explore! 3.1

Conservation of Australian species

Australia has more than 80 critically endangered species, including the northern hairy-nosed wombat and the mountain pygmy possum. Conduct some research to answer the following questions.

1 Choose an endangered Australian species and research conservation efforts put into place for the species. These may include education programs, captive breeding, legal protection of habitats and ecosystems created artificially.

2 Many of today's species have survived by adapting where other species, less well adapted, died out. Why do you think we should try to protect endangered species to preserve biodiversity?

Science as a human endeavour 3.1

Australia has the world's worst mammal extinction rate

Australia has the highest mammal extinction rate in the world: 30 mammal species have disappeared since European settlement. At least 25 of these extinctions were due to feral cats and foxes. New research published in 2018 by scientists at La Trobe University has revealed which mammal species are now most vulnerable to cats and foxes. The scientists hope that their research can help governments by helping direct conservation efforts to prevent these vulnerable species from becoming extinct in coming years. Their findings can also inform communities and land managers where cat and fox control is most needed. Sadly, the researchers found that one-third of our mammal species, including some of our beloved potoroo, eastern quoll, bandicoot and bettong species, are highly susceptible to predation by cats and foxes. With prompt action we might be able to turn these numbers around in the next decade.

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Figure 3.12 Two vulnerable mammal species: long-nosed potoroo (left) and eastern quoll (right)

Quick check 3.3

1 Define the terms 'biodiversity', 'endangered' and 'extinct'.
2 Explain the link between biodiversity and evolution.
3 Name one change in the environment that may lead to the extinction of a species.
4 How have humans affected biodiversity and therefore evolution?

QUIZ

Section 3.1 questions

Remembering

1 Define the terms 'evolution' and 'population'.
2 Name one extinct Australian species.
3 Name one species deemed critically endangered within Australia.
4 Define the term 'variation' and give four different examples of variation within a species not provided in the text.
5 List where variation in a population comes from.

Understanding

6 How does an extinct species differ from an endangered species?
7 Outline how mutations contribute to variation within a species and consequently evolution.
8 Explain how gene flow can contribute to a change in the genetic composition of a population.

Applying

9 Summarise how a change of only one nucleotide in DNA can result in a different phenotype and eventually cause evolution.
10 Identify an example of variation in a species that:
  a increases the species chances of survival
  b decreases the species chance of survival
  c does not affect the species chance of survival.

Analysing

11 Distinguish between species diversity and genetic diversity.
12 In your own words, explain how extinctions can stimulate new biodiversity among species.

Evaluating

13 Give reasons as to why genetic biodiversity is important for the survival of a species.
14 In Earth's past, some species have been wiped out after an environmental change. Explain if this suggests the species had low or high genetic biodiversity, and give reasons why this would occur.

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3.2 Natural and artificial selection

WORKSHEET

Recall from Section 3.1 that there are five mechanisms of evolution: mutation, gene flow, genetic drift, natural selection and sexual reproduction (crossing over). In this section we will look in more detail at natural selection. Recall from the previous section that evolution and natural selection applies to populations not individuals, and that genetic variation must be present in the population. Furthermore, although the term 'survival of the fittest' has been used to describe natural selection, it is not popular with biologists because it is often misunderstood.

In 1831, the young naturalist Charles Darwin boarded the ship called the HMS *Beagle* and set out on a five-year voyage around the world to study and collect animal, plant and rock specimens. The HMS *Beagle* visited the remote Galapagos Islands off the coast of Ecuador, and it was here that Darwin observed that, although the different islands had similar animals and plants, many seemed to have specialised features that adapted them to their local environments. For example, the finches on each island had uniquely shaped beaks. Each species' beak was suited to eating the particular seeds that were available in the habitat they occupied on their island. It was Darwin's detailed observations of the finches, their physical characteristics and habitat, that formed the basis for his theory of evolution. Darwin explained how species change over time, using the theory we know today as 'natural selection'.

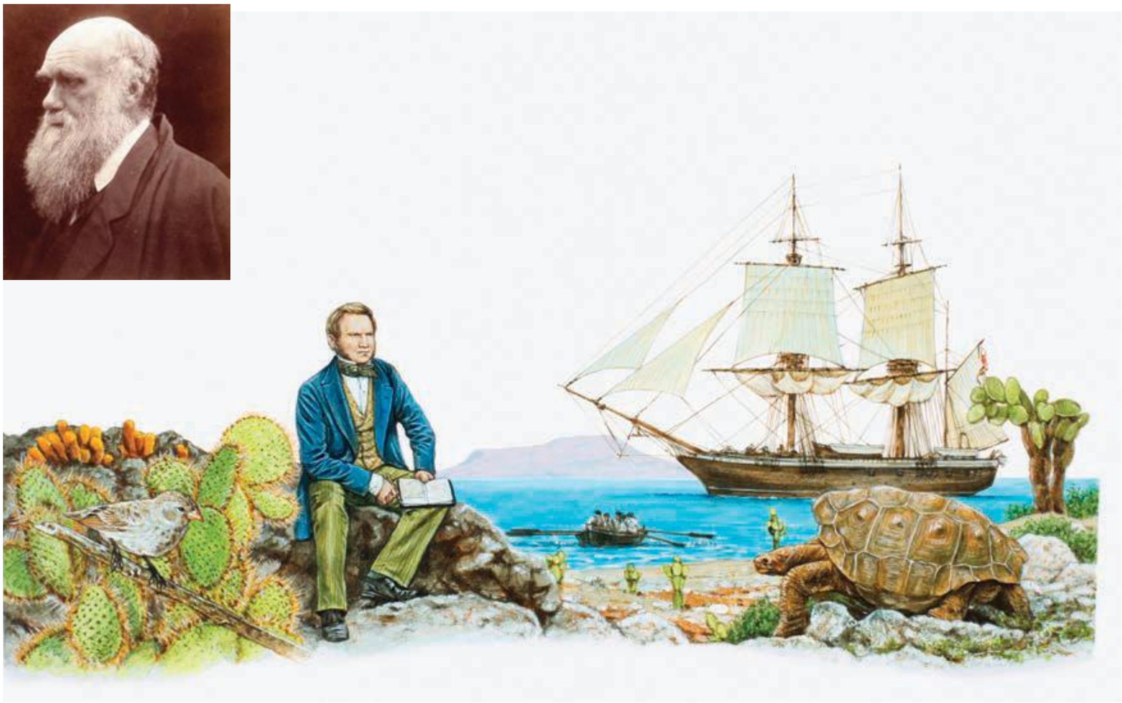

Figure 3.13 An illustration of Charles Darwin observing the Galapagos finches and tortoise, with HMS *Beagle* in background. Inset: a photograph of Charles Darwin

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Explore! 3.2

Research the different varieties of Darwin's finches and investigate how the variations of beak shape is related to the diet of the different finch species.

WIDGET
Natural selection

The process of natural selection

It is important to note that the process of natural selection cannot occur without a selecting agent or a selection pressure (e.g. predator). With this is mind, the following steps outline the process of evolution through natural selection.

1. Variation naturally exists in the population due to processes such as sexual reproduction, crossing over, mutations and gene flow.
2. The genetic information of some of the organisms in the population is expressed in favourable traits.
3. Individuals with favourable traits are more likely to survive and reproduce than others of their species. We say those favourable traits are 'selected for' – that is the process of natural selection.
4. Over time, the individuals with the favourable traits become more numerous in the population. That is the process of evolution by natural selection.

A fascinating example of natural selection is the case of the light and dark peppered moths in Britain. There are two varieties within the one species – one is light coloured, the other is dark coloured – and the colour is genetically determined. Look at the moths in Figure 3.14 – the light-coloured variety of the peppered moth initially had the favourable trait (we can say the light moth was at a selective advantage) as it blended well with the light-coloured bark of the trees. This meant when a hungry bird (the selecting agent) came by it would only see the dark-coloured moth and ate them more often. Consequently, the dark-coloured moths were rare. The light-coloured moths were best adapted to survive and reproduce, so they were able to pass on their genetic information to the next generation.

However, during the Industrial Revolution, the bark of trees became darkened because of the pollution. This gave the dark-coloured moths a selective advantage, as they were better camouflaged against the trees and not as easily spotted by predators. Now the roles were reversed: the light-coloured moths were at a survival disadvantage and their numbers fell.

Figure 3.14 There are two variations of peppered moth: light and dark coloured. Can you see both moths in each image? The picture on the left shows the moths against a light tree bark. The picture on the right shows the moths against a dark tree bark.

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The darker moth was the 'fittest' or best adapted in this new environment and so was able to survive, reproduce and pass on its genetic information to the next generation. The proportion of dark moths rose. Interestingly, cleaner air in recent decades has seen the light-coloured moths favoured once again.

Quick check 3.4

1 Where did Charles Darwin observe the adaptation differences among finches?
2 Draw a flow chart of the four steps involved in the process of evolution by natural selection. Then, annotate your flow chart with how each step relates to the peppered moth example.

Variation

Natural selection occurs when an environmental factor acts on the phenotype. That is, some individuals in the population need to be different from others, and those differences need to give an advantage or disadvantage for survival and reproduction. All around us, organisms are producing offspring that vary. Many of these variations make the individual better suited or less well suited to the environment. Those organisms best suited to an environment where there is a selection pressure, are more likely to survive and produce offspring.

Can you recall where this variation may come from? In Chapter 2 we saw that meiosis involves crossing over and the gametes produced are all different. We also learned that sexual reproduction and the random combination of genetic information from two parents increases the chance of variability. What are the additional sources of variation we have looked at in Section 3.1?

Selection

Those organisms that are best suited to the pressures of their environment are the ones that are more likely to survive, reproduce and pass on their genetic information to the next generation. We call these pressures **selection pressures** because they determine which variations provide individuals with better survival chances.

Figure 3.15 Some variations of adult males of the frog species *Pristimantis leopardus*

selection pressure an external agent that affects an organism's chances of survival depending on their genotype (genetic variations)

Selection pressures can be biotic (living) or abiotic (non-living) conditions that affect an organism's survival chances in a given environment. Selection pressures can increase or decrease the occurrence of a trait in a population and may change with time or with other changes in the environment.

VIDEO Selective pressures

Category	Examples of selection pressures
Resources	Food availability (biotic) Shelter (abiotic) Availability of mates (biotic)
Physical environment	Temperature (abiotic) Weather (abiotic) Geography (abiotic)
Biological factors	Predators (biotic) Diseases (biotic)

Table 3.2 Selection pressures can be grouped in various categories.

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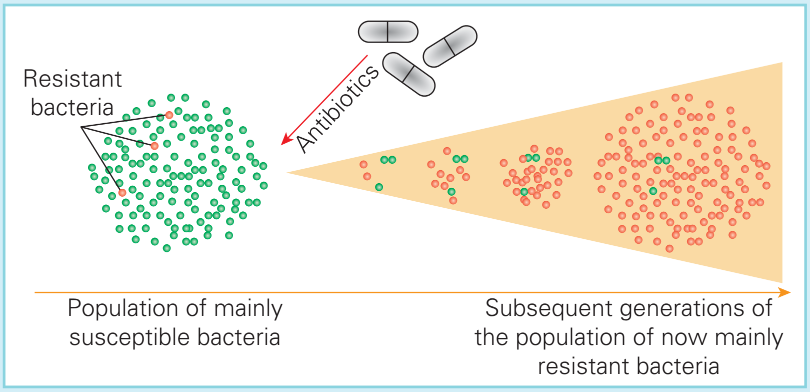
Try this 3.2

Drug resistant bacteria and natural selection

Antibiotics are synthetic drugs used to kill bacteria that are causing an illness. Consider the following diagram carefully and then answer the questions below.



1 What variation between bacteria can you see in the original population?
2 Which variation is selected for (the fittest)? And which was selected against?
3 Which variation will contribute less to the next generation?
4 Which variation will survive in greater numbers, to reproduce and pass on its genetic information to the next generation?
5 Identify the selecting agent.

Practical 3.1

Modelling natural selection

Aim

To simulate natural selection by means of modeling a beetle population and some of its consequences.

Background

Let us make the following assumptions about a beetle population:

- The original population of 30 beetles consist of 10 red, 10 yellow and 10 green.
- Each year the beetles mate once at random, and each pair produces one offspring (30 beetles produce 15 offspring – increasing the total population to 45 beetles).
- The colour of the offspring is determined by these rules:

Parent colour		Offspring colour
Parent 1	Parent 2	
Red	Red	All red
Yellow	Yellow	All yellow
Red	Yellow	All green
Green	Yellow	½ green: ½ yellow
Green	Red	½ green: ½ red
Green	Green	¼ red: ½ green: ¼ yellow

- After the beetles have produced their offspring, a predator kills one-third of the total population (15 beetles) each year. Therefore the population of beetles returns to 30 at the beginning of each breeding season.
- On average, the colour ratio of beetles lost to predation is:
  3 red: 2 orange: 1 yellow (this ratio is reflected in the coloured sides of the dice).
- Other than the death caused by the predator mentioned, there will be no further deaths or migration.

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Materials

- Small circular coloured stickers to add to the sides of a die (three red, two green, one yellow)
- 60 coloured cards of each type (20 red, 20 green and 20 yellow)

Method

1. Copy the results table below.
2. To create your original population of 30 beetles, take 10 red, 10 yellow and 10 green cards.
3. Shuffle these 30 cards to model the process of random mating and deal them out into 15 pairs.
4. Using the rules from the table, determine the colour of the offspring for each of the 15 pairs. Use the die to decide the colour if there is more than one possibility of colour produced. For example, if the offspring combination has the possibility of being one of two colours, let the even numbers on the die represent one of these colours, and the odd numbers represent the other colour.
5. Take a beetle card that represents the colour produced for each of the 15 offspring and add them to the population, creating an overall population size of 45.
6. Due to predation, 15 beetles will die and be removed each year. This will be modelled by rolling the coloured die on 15 different occasions and removing the corresponding beetle colour from the population each time. If a particular colour of beetle has disappeared altogether from population, roll the die again.
7. After one year of mating and predation, complete the table below showing the total number of red, green and yellow beetles that remain in the population of 30.
8. Repeat the process of mating and predation by repeating steps **3–7** for as many trials as possible (up to a maximum of 10 trials, modelling 10 years).

Results

Record the total number of red, yellow and green beetles for each year in the results table.

	Number of beetles after year									
Colour of beetle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Red										
Green										
Yellow										
Total	30	30	30	30	30	30	30	30	30	30

Evaluation

1. Within the population of beetles that you created, identify the beetle's phenotypic trait that was observed, and its variations.
2. Explain the crucial role that variation plays in order for natural selection to occur.
3. Based on your observations, did any particular beetle colour have a greater survival value than other colours in the population? Explain your answer using the data from your results table.
4. Describe how the process of natural selection relates to genetics.
5. Was there any evidence of natural selection taking place in your population of beetles? Refer to your results in your answer.
6. Did your results show any coloured beetle becoming extinct in your population over the generations?
7. a. Provide another colour possibility of a beetle predation ratio other than the original 3 red: 2 green: 1 yellow as observed in this experiment.

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- **b** Using the predation ratio of beetles you outlined in part **a**, write a hypothesis for this experiment.
- **c** What results would refute your hypothesis?

8 Another group of students obtained a beetle population of 10 red: 10 green: 10 yellow after completing the same experiment and modeling the same mating and predation rules for 10 trials. What possible explanation could be given for these results?

Conclusion

1. Make a claim about natural selection based on this experiment.
2. Support the statement by using your observations and include potential sources of error.
3. Explain how your observations support the statement.

Quick check 3.5

1. Variation is essential for the process of natural selection to occur. Explain what 'variation' means and where variation comes from in a population.
2. Define the term 'selection pressure' and outline how it contributes to natural selection.

Speciation

We now know how natural selection is a mechanism for evolution. Interestingly, sometimes natural selection can lead to a new species forming, which is called **speciation**. For this to occur, there needs to be one extra step in the process of natural selection: reproductive isolation.

Before we look at speciation, we need to be clear about what a species is. A **species** is a group of organisms that are phenotypically similar and are capable of interbreeding with each other to produce **fertile** and **viable** offspring. For example, the offspring of a male and female horse will be a horse that is able to mate and produce offspring with another horse. However, the offspring of a female horse and a male donkey is a mule. A mule is infertile, which means it is unable to produce offspring. This is evidence that horses and donkeys are two different species – they cannot produce fertile and viable offspring.

speciation
the process by which new types (species) of living things are thought to develop from existing ones by evolution

species
a set of animals or plants in which the members have similar characteristics to each other and can breed with each other

fertile
able to reproduce

viable
able to survive and reproduce

Figure 3.16 The offspring of a female horse and a male donkey is a mule, which cannot reproduce. This is ev dence that horses and donkeys are two different species.

Variation

We know natural selection only works if there is variation within a population, and natural selection that leads to speciation requires this too.

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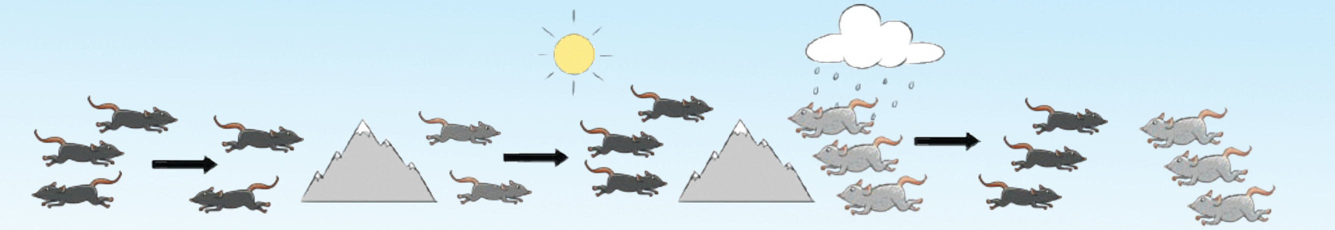

Figure 3.17 Natural selection can cause speciation.

Geographic isolation

An essential feature in speciation is isolation of populations from one another. Isolation is not required for natural selection to occur but is necessary for speciation to result. Isolation may be caused by a geographical or physical barrier (for example, a large river, a desert or mountain range) or even a natural disaster like a fire, flood or volcanic eruption. The consequence is the original population is divided into two populations, not necessarily the same size.

Selection

The isolated populations may now be exposed to different selection pressures; for example, one environment may be cooler than the other. Just like we saw in the process of natural selection, those organisms that are best suited to their environment are the ones that will survive, reproduce and pass on their genetic information to the next generation. On the cold side of the mountain, individuals with thicker fur will be selected for, while on the sunny side of the mountain, those with a thinner coat will be selected for.

Reproductive Isolation

Over time, the different selection pressures on the two populations will change the genetic composition of the two populations in different ways. Eventually, enough differences may accumulate between the two populations so that individuals cannot interbreed with one another to produce fertile and viable offspring. The two populations are now **reproductively isolated**. This is when we know that we have a new species.

reproductively isolated unable to breed successfully with related species due to genetic differences

Science as a human endeavour 3.2

Rock wallabies

Did you know there are 16 species of rock wallaby? Six of these rock wallaby species live in north-east Queensland and have different numbers of chromosomes. They are different species, meaning that they cannot reproduce to create fertile and viable offspring. However, scientists recently found that gene flow somehow occurs between them, meaning that despite being six different species with different numbers of chromosomes, they *can* interbreed. Scientists now know that their evolution is a lot more complex than previously thought, and the way that new species form may need to be reinvestigated as a consequence.

Figure 3.18 A yellow-footed rock wallaby

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Quick check 3.6

1 Define the term 'species'.
2 Speciation can occur as a consequence of natural selection with one additional step. What must also occur and what is its role in speciation?
3 How could you determine if two populations were the same species?

Try this 3.3

Speciation story time

With a classmate, take turns telling stories of speciation. You may like to use the images below as inspiration. To tell a story of speciation, use all the scientific terms you have learned that relate to natural selection and speciation. Begin by talking about the possible variation that naturally exists in your organism's population, then a possible geographic barrier that could divide and isolate the population, finishing up with the process of selection and how this leads to the creation of a new species.

Figure 3.19 These Australian animals are perfectly suited to their environment and so are able to survive, reproduce and pass on their genetic information to the next generation.

VIDEO What is artificial selection?

Artificial selection

Artificial selection, as the name suggests, is selection that does not happen naturally and therefore does not occur randomly. In other words, humans purposefully choose the characteristics they want passed onto the next generation, so only breed those organisms with favourable traits. Thus, humans select who reproduces, not the environment. For example, a farmer wants her cows to produce lots of milk so she selectively breeds the best milk-producing cows and prevents the poorer producers from mating. Artificial selection is also called **selective breeding**, and humans have been using these techniques for thousands of years. Can you think of any other examples?

artificial selection intentional breeding of plants and animals to produce desirable traits

selective breeding artificial selection

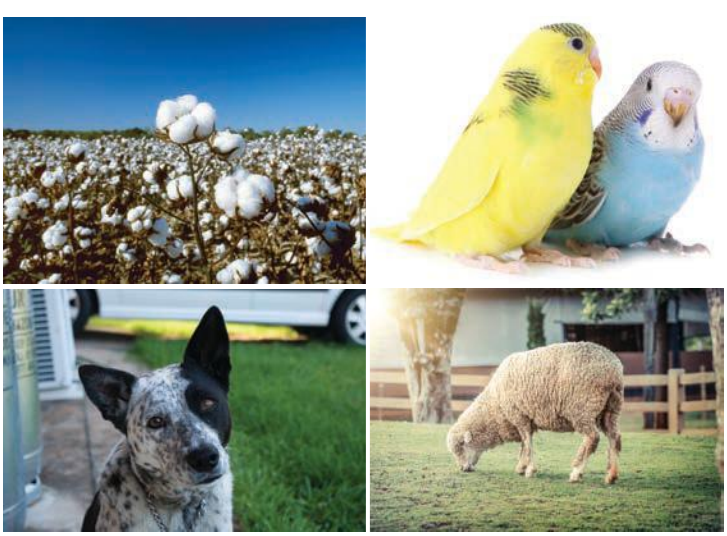

Figure 3.20 Artificial selection in action: each of these organisms was selectively bred for particular characteristics.

Artificial selection is certainly beneficial for humans who want plants and animals to show particular traits, but how does this manipulation affect biodiversity and evolution? Sadly, biodiversity is often reduced. The outcome is often a population that is genetically very similar and has low

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variation. For example, there is a worldwide decline in agricultural crop diversity. In Mexico, farmers are cultivating only 20% of the corn types that were grown there in 1930. Chinese farmers are producing only 10% of the 10 000 varieties of wheat that were recorded there in 1949, and more than 95% of known apple varieties that existed in the United States in 1900 are no longer being cultivated.

Did you know? 3.3

Broccoli and kale are the same?

Did you know that broccoli, kale, cabbage, Brussels sprouts, cauliflower and gai lan are all the same plant species? The plant is of the genus and species *Brassica oleracea*. There are more variations of this plant, and each of the variations is called a 'cultivar', which is a plant variety produced by selective breeding.

Figure 3.21 Some of the many varieties of the plant *Brassica oleracea*.

Explore! 3.3

Like cats, all domestic dogs belong to one species, *Canis familiaris*. How can they appear so different? Go online to answer the following questions.

1 Choose one dog breed and identify its unique characteristics.
2 Critique some of the ethical considerations involved in breeding a dog for a particular characteristic that may be detrimental for their health. For example, the dachshund's short legs and long back makes it particularly susceptible to knee and spinal problems. The pug's wrinkled face is susceptible to infections resulting from dead skin cells and moisture being trapped in the folds of skin.

Figure 3.22 (Left to right) British bulldog, greyhound, chihuahua, chihuahua, Leonberger, chihuahua, King Charles spaniel, schnauzer, Yorkshire terrier, schnauzer: they are all the same species!

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These crops are artificially selected for their production values, but what are the chances of the population surviving if it is exposed to a change in environment or a new disease? Reduced variation in the population may mean the population is more susceptible to threats like these.

Human reproductive technologies

To assist human reproduction today, we use many reproductive technologies that involve artificially selecting the genetic information that is passed to the next generation. In this way, we humans are affecting the biodiversity of the human race and consequently affecting evolution.

For example, in vitro fertilisation (IVF) involves selecting viable sperm and combining them with eggs in a test tube. After fertilisation, the best embryo is selected for development and the remainder frozen.

Medical technology is amazing – it lets us genetically test embryos prior to implantation, test for the genetic cause of a disease and genetically screen babies. Using these technologies can change the genetic composition of the human population in the next generation. Remember, evolution takes an extremely long time so we will not actually see the impact of our actions for thousands to millions of years!

Gene technologies

You may recall from Chapter 2 that today we can acquire the traits we desire by using gene technology, rather than relying on selective breeding. Gene technology lets us transfer genes from one individual or species to another. We looked at gene therapy (in which a faulty gene found in an organism is replaced by the normally functioning gene) and genetically modified organisms (an organism that has had its DNA altered or modified in some way through genetic engineering).

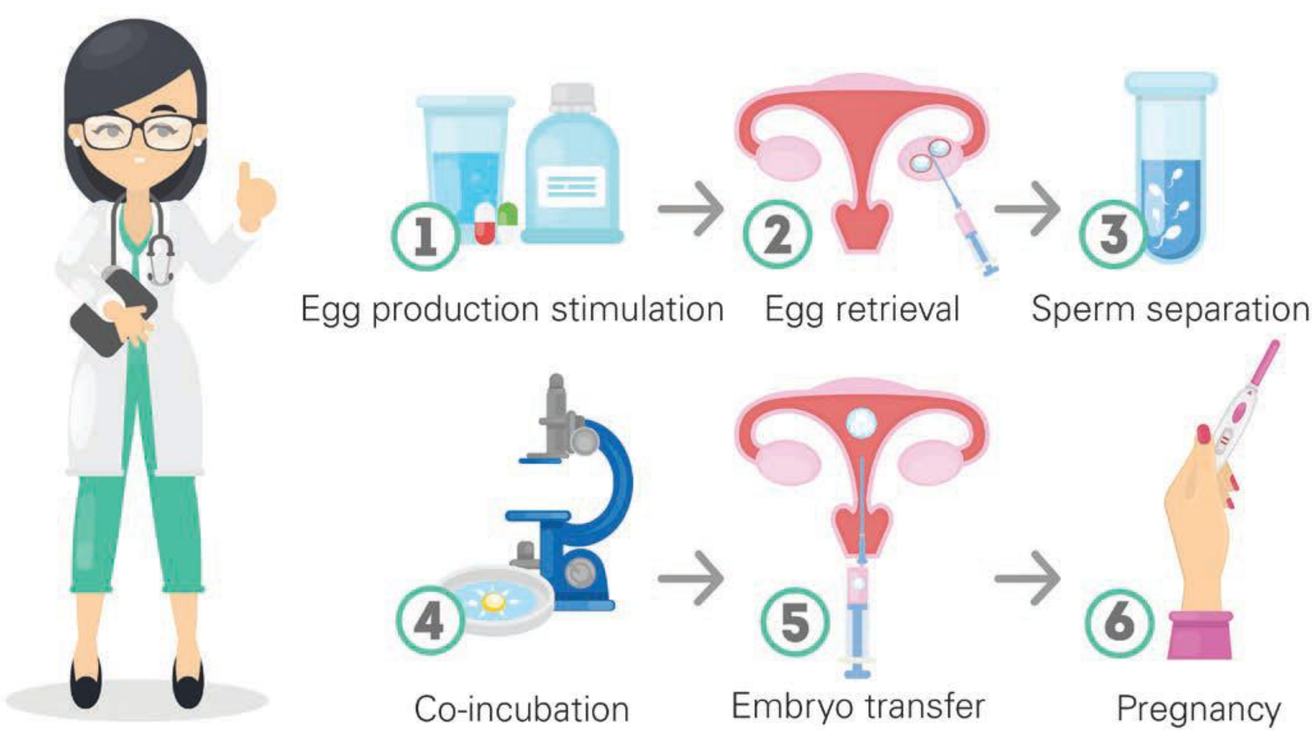

Figure 3.23 The process of IVF artificially selects the eggs, sperm and embryos that have the best chance of survival.

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Can you work out how gene therapy would change the biodiversity of the human population? Would there be more or less variation? And what would this mean for the process of evolution? What about GMOs? Consider blue carnations, which were created by genetic engineering – are they contributing to reduced biodiversity? Might we end up creating a new species? Do GMOs affect the biodiversity of the naturally occurring organisms? And what of their evolution?

Figure 3.24 Four types of genetically modified blue carnation are grown and sold in Australia.

Science as a human endeavour 3.3

Editing 'bad' genes out

A team of researchers in Switzerland has used a new gene editing tool to correct gene mutations. They have only been successful in mice at this stage, but their success means a lot for suffers of genetic conditions like phenylketonuria (PKU), which is caused by a mutation in the gene that codes for the enzyme phenylalanine hydroxylase. The hope is that babies with PKU can have this mutation fixed, so that they can live a normal life. Currently, people with PKU need to eat a special diet so that the amino acid phenylalanine does not accumulate in the body. Excess phenylalanine delays mental and motor development. If left untreated, PKU can cause permanent mental disability, which is why all babies are screened at birth. Incredibly, this gene technology might be able to eradicate PKU in all future newborn children! What would that mean for biodiversity and evolution?

Figure 3.25 Testing a newborn baby for PKU involves taking several drops of blood from their heel.

Quick check 3.7

1. Define the term 'artificial selection' and provide an example.
2. Outline the differences between natural selection and artificial selection.
3. Does artificial selection increase or decrease variation and therefore biodiversity?
4. Explain how reproductive technologies can affect human biodiversity.

Section 3.2 questions

QUIZ

Remembering

1. What are the key processes involved in natural selection?
2. Identify a geographical barrier that could divide a bird population, an eel population and a mammal population.

continued...

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...continued

3 List the different sources of variation in an individual and in a population.
4 Identify three examples of abiotic selection pressures and three examples of biotic selection pressures.

Understanding

5 Describe what is meant by the term 'selective advantage'?
6 Summarise the three processes in speciation.
7 Tomato breeders have created the most sweet and juicy tomato ever. Summarise how they would have done this, given that they started with a not-so-sweet and not-so-juicy crop of tomatoes.

Applying

8 Explain why variation is necessary for natural selection to occur.
9 Explain why isolation is necessary for speciation to occur.
10 Identify the different ways that technology can affect the biodiversity of the human population.

Analysing

11 Distinguish between artificial and natural selection, providing examples for each.
12 The Galapagos finches share similar features but are recognised as distinct species. What test could be used to identify if two similar kinds of finches are different species or subspecies of the one species?
13 Determine how speciation, biodiversity and evolution are linked.

Evaluating

14 Determine if humans are evolving by natural selection.
15 Predict what will happen if a particular species has low genetic variation and there are changes in the environment in which they live.

3.3 Evidence for evolution

WORKSHEET

Evolutionary theory is supported by a multitude of evidence and findings from observations and experiments, including the sources in Table 3.3.

Field of science	Evidence
Palaeontology	The study of fossils, including their identification and interpretation
Comparative anatomy	The study of the structure of specific organs and limbs of different organisms
Embryology	The study of the development of the embryo in different organisms
Molecular biology	The ability to sequence DNA to indicate the degree of relatedness between organisms
Biochemistry	Similarities and differences in the biochemical make-up of organisms that can help distinguish differences and similarities
Biogeography	The study of the geographic distribution of organisms which can help ascertain where a species may have originated from

Table 3.3 Sources of scientific evidence for the theory of evolution

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Palaeontology

fossil
the shape or impression of a bone, a shell, or a once living organism that has been preserved in rock for a very long period

direct (evidence)
evidence that supports an assertion without intervening inferences

indirect (evidence)
evidence that requires inferences to be made

trace fossil
a trace of an animal, such as footprint or imprint, that has become fossilised

fossilisation
the process of becoming a fossil

fossil record
the record of past life and evolution inferred from fossils

The term **fossil** refers to any parts of, or impressions made by, a plant or animal that survives following death. Normally an organism decomposes after it dies, and after a time no trace remains. On rare occasions, evidence of the organism is preserved in the form of a fossil. Fossils may be the hard parts of an organism, like its bones and teeth (called **direct** evidence), or evidence of an organism's presence, like footprints, burrows and faeces (called **indirect** evidence). Fossil footprints or tracks are known as **trace fossils**. The process of forming a fossil is called **fossilisation**. However, the fossil record is far from complete. Because fossilisation is rare, and usually only organisms with hard parts tend to form fossils, there are a lot of gaps in our **fossil record**. There is also the problem that we cannot dig up everywhere looking for fossils, so many go undiscovered.

Fossils are most likely to be found in sedimentary rock. Where the sediments have not been disturbed by later events, they nearly always show an age sequence, with the oldest fossils deepest under the ground and youngest at the top. Often these fossil sequences allow us to see the change in a species over time. This highlights how the fossil record is amazingly valuable for collecting evidence of evolution. For example, fossils have provided evidence for the evolution of modern horses from the ancient four-toed mammal, and the discovery of *Archaeopteryx* gave us evidence for the link between reptiles and birds. The fossil record also tells us more about organisms that are now extinct and what Earth was like when particular species existed.

Figure 3.26 A marine reptile fossil of the Triassic period, named *Pachypleurosaurus*, which was found high in the Swiss Alps

Fossilisation

VIDEO
What is Paleontology?

For an organism to be fossilised, the following special circumstances must be met:

- Rapid burial: organisms must be buried quickly in oxygen-poor sediments. Usually this happens when organisms die in seas, lakes, floods or mud slides. Organisms can also be preserved in ice or amber or buried under ash from volcanic eruptions (lava will usually incinerate any remains).
- Decomposition is prevented: bacteria, which normally cause the decay of organisms, needs to be reduced. For example, many bacteria that cause decomposition will die in the absence of oxygen or water, or in conditions of high acidity or extreme cold. Soft tissue and organs break down chemically, so they do not usually get fossilised.
- Remains lie undisturbed: predators and scavengers do not dig up the remains.

If all of these conditions are met, which is rare, over millions of years the sediments or material covering the dead organism become more and more compressed and eventually form rock, preserving the fossil within.

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Figure 3.27 A fossil of the fish *Diplomystus dentatus*

Figure 3.28 Trace fossil marks of an extinct sea scorpion in Kalbarri National Park, Western Australia

Types of fossils

Trace fossils are important tools in understanding extinct animals as they give some insight into their behaviour, how they lived and how they interacted with the environment. The best preserved megafauna trackways in Australia were identified in south-west Victoria in the early part of this century. Dr Stephen Carey of Federation University Australia discovered them on a lake bed during a prolonged drought (the site is usually under water). A trace fossil can provide important information relating to the size and walking or running posture of an extinct species.

Explore! 3.4

Fossil terminology

There are many different types of fossils and many different terms we use to categorise fossils. Copy the following table and carry out some research online to complete it.

Term	Description	Example (include picture where possible)
Mould		
Cast		
Body fossil		
Replacement fossil		
Carbon imprint		

Quick check 3.8

1. List two sources of evidence for evolution.
2. List some of the evidence for evolution that you can find out from fossils.
3. Explain why it is rare to find fossils.
4. Summarise the circumstances required for fossilisation.
5. What is a trace fossil?

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Did you know? 3.4

Living fossils?

Charles Darwin coined the phrase 'living fossils' and, despite not being a scientific term, it has remained in use. It describes modern species of plants and animals that are almost identical to species that lived in ancient geological ages. This means they have survived mass extinctions, the various ice ages and comets hitting Earth! Examples include the Wollemi pine, the Queensland lungfish, mountain shrimp and the Australian ghost shark.

Figure 3.29 The Queensland lungfish is a 'living fossil' as it resembles ancient organisms found only in the fossil record.

Dating fossils: relative dating

Until last century, **relative dating** was the only method available for dating fossils. As the term suggests, relative dating techniques only work out how the age of a fossil compares in relation to other fossils. For example, it can tell you that fossil X is older than fossil Y, but it cannot tell you the actual numerical age of the fossil. Relative dating is used to order rocks and geological events into a time sequence. The study of the order of the layers of rock (strata) is called **stratigraphy**.

relative dating determining the order of past events without the specific age

stratigraphy the branch of geology studying the rock layers

Try this 3.4

Stratigraphy

The diagrams in Figure 3.30 represent the strata (rock layers) found at two different locations (1 and 2). Each layer has a letter associated with it, and also you can see the different fossils found in each layer. Knowing that the youngest layers are on the top and the oldest down below, work out the relative age of all of the layers in both locations from oldest to youngest. Then list the clues you used to work this out.

For example, layer G is younger than layer B, but older than layer A.

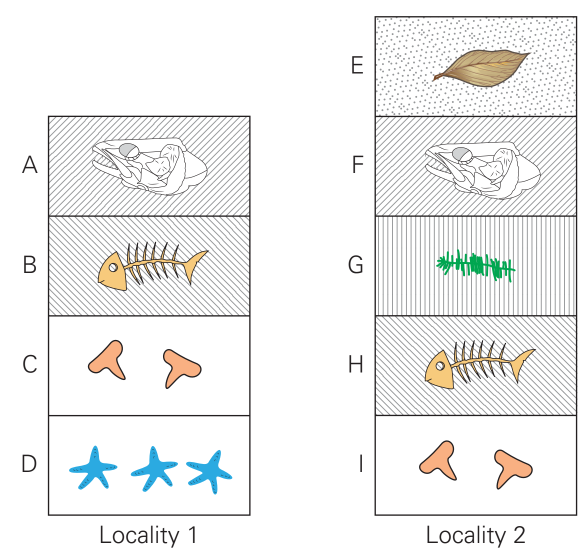

Figure 3.30 Relative dating: the different strata and their relative positions at locations 1 and 2 help us date the fossils in each layer relative to other fossils.

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Fossils are important for working out the relative ages of sedimentary rocks too. Fossils can help to match rocks of the same age, even when you find those rocks a long way apart. This matching process is called correlation, and it has been important in constructing geological timescales. Throughout the history of life, different organisms have appeared, flourished and become extinct. Many of these organisms have left their remains as fossils in sedimentary rocks. Geologists have studied the order in which fossils appeared and disappeared through time and rocks. This study is called **biostratigraphy**.

biostratigraphy a branch of stratigraphy focused on dating rock layers using the fossils found in them

To help identify matching strata, and to compare strata in different locations, indicator or **index fossils** can be used. An index fossil is a fossil of known age found in a particular type of sedimentary rock layer. It can be used to indicate the age of any deposit in which it is found, at any locality. For example, trilobites are wonderful index fossils as they were very common at the time they existed (between 488 and 225 million years ago), there were large numbers of them, they were easy to recognise, they were well preserved as fossils because of their hard exoskeleton and they evolved rapidly, which means there were different species present at different times.

index fossil a fossil used as the base for dating the strata it occupied

Figure 3.31 Fossil of a trilobite, *Albertella helena*

Dating fossils: absolute dating

Absolute dating is where a precise age (within certain error margins) is obtained for a fossil or more commonly for the rock or soil in which the fossil is found. For example, you can work out that fossil X is 233 million years old and fossil Y is 100 million years old. Absolute dating uses radiometric techniques, which means looking at the level of radioactivity detected in rocks containing certain naturally-radioactive **isotopes**. These isotopes are known to exist in living things, so if we measure the speed of breakdown of the isotope (called radioactive decay), we can work out how long an organism has been dead. The time in which half of the sample of the radioactive isotope (parent) has decayed to a more stable form (daughter), is known as its **half-life**. Knowing this helps us determine the best isotope to use to work out the absolute age of a fossil. The longer the half-life, the older the fossil or rock that can be dated.

absolute dating determining the actual age of a material

isotope an atom of the same element but with differing number of neutrons and hence differing atomic mass

half-life the length of time needed for the radioactivity of a radioactive substance to be reduced by half

Radioactive isotopes (parent to daughter)	Half-life (years)	Estimated age range of fossils they can date
Carbon-14 to nitrogen-14	5730	Up to 60000 years ago
Uranium-235 to lead-207	710000000	1000 to 1 million years ago
Potassium-40 to argon-40	1300000000	500000 million years and older

Table 3.4 Each radioactive isotope has a different half-life. The longer the half-life, the older the fossil or rock that can be dated.

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Practical 3.2

Looking at half-lives

> **Be careful**
> Food should not be consumed in the laboratory.

Aim

To model radioactive decay using M&Ms and draw a decay curve.

Materials

- 100 M&M's (or counters with one side marked)
- graph paper
- plastic container with lid
- plastic tray
- gloves

Method

1. Copy the results table below.
2. Place all 100 M&M's parent isotopes on your plastic tray with the 'm' side up.
3. Record your original number of parent isotopes in your results table for time 0.

4. Place all the isotopes in the plastic container and shake for 10 seconds.
5. Pour your isotopes back onto the plastic tray.
6. With your gloves on, remove all the stable daughter isotopes from the tray and set them aside.
7. Count the remaining M&Ms (parent isotopes), which will be a percentage of the original number since that was 100, and record this in your results table for time 1.
8. Repeat steps **4–7** another eight times.
9. Collate the class results on the board and calculate averages for each time.

Results

1. Complete the results table.

Time	Per cent undecayed parent isotopes
0	100
1	
2	
3	
4	
5	
6	
7	
8	
9	

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...continued

2 Draw a graph of the time (*x*-axis) versus % undecayed parent isotopes (*y*-axis) using the class results.

Evaluation

1 Compare your results to the class averages you calculated. What was the importance of calculating the class average? Do you think your individual results or the class averages were more accurate?
2 The half-life of your isotope can be calculated. This can be achieved by using your graph to identify the time that half of the parent isotopes had decayed into daughter isotopes. Identify the half-life of your isotope.
3 It was expected that, each time, there is a 50% chance of the M&Ms being M side up; therefore, time 1 should represent one half-life. Explain why this prediction may differ to what was observed in your graph.
4 Absolute dating is an important method used by scientists. Discuss why scientists would use absolute dating when relative dating techniques are more simple.
5 List possible sources of error, and make suggestions on how the experiment could be improved.

Conclusion

1 Make a claim about radioactive decay based on this experiment.
2 Support the statement by using your observations and include potential sources of error.
3 Explain how your observations support the statement.

Quick check 3.9

1 What is relative dating?
2 Define the terms 'stratigraphy' and 'index fossil'.
3 What is absolute dating?
4 Name one isotope that could be used to accurately measure the absolute age of a fossil.

Science as a human endeavour 3.4

The latest fossil finds

In 2018, an international team of palaeontologists identified the world's oldest lizard. They found a 240-million-year-old fossil, *Megachirella wachtleri*, which is believed to be the oldest known ancestor of all modern lizards and snakes. Scientists used computed tomography (CT) scans, DNA analysis, and data from living and extinct lizards to work out that this fossil lizard is 75 million years older than previously thought.

Figure 3.32 New fossils are providing key insights into the evolution of modern lizards and snakes.

Also in 2018, researchers found what they believe are fossilised lungs preserved inside a 120-million-year-old bird. Scientists have previously found four fossils of this ancient bird, *Archaeorhynchus spathula*, but never with plumage or suspected lungs. As you know, it is extremely rare for soft tissues to survive the pressure, heat and chemical changes needed for fossilisation to occur. But nowadays, scientists are increasingly reporting finding fossilised skin and even brain material preserved along with bones.

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Comparative anatomy

As we have learned by looking at variation, there can be a remarkable diversity of forms amongst closely related organisms. But have you ever thought about how some animals display remarkable physical likeness despite not being closely related at all? Think about a bird and a bat, a dolphin and a shark, a sugar glider and a flying squirrel. The members of each pair, despite not being closely related, share some very obvious structural characteristics. For example, sugar gliders and flying squirrels look remarkably alike, sharing similar characteristics such as size, big eyes and a distinctive white belly. They have thin, loose skin between their limbs which keeps them stable when stretched while they glide.

However, sugar gliders (native to Australia) and flying squirrels (native to Asia, central and North America, and Europe) also have many differences. Sugar gliders are marsupials so they have a pouch to protect their tiny babies, whereas flying squirrels are placental mammals, having larger babies and no pouch.

By studying their genes and other traits, biologists discovered that sugar gliders and flying squirrels are not very closely related at all. So why do they share some common physical characteristics?

The characteristic 'wings', which are flaps of skin, are what is known as **analogous structures**. These are structures that have a similar function but have evolved independently. The two organisms have evolved from different ancestors but in similar environments, so the same selection pressures have caused the same feature to be selected for. The fin shape of sharks (a fish), penguins (a bird) and dolphins (a mammal) is another example of an analogous structure (Figure 3.34 on the following page). The shape of their fin (or the wing of the penguin) is adapted for swimming through water. The three types of animals faced similar selection pressures in their aquatic environment, and evolved into a similar shape, but they do not share a recent common ancestor.

analogous structures structures that have a similar function but evolved separately

Figure 3.33 A sugar glider (top) and a flying squirrel (bottom) have many common characteristics, but they are not closely related.

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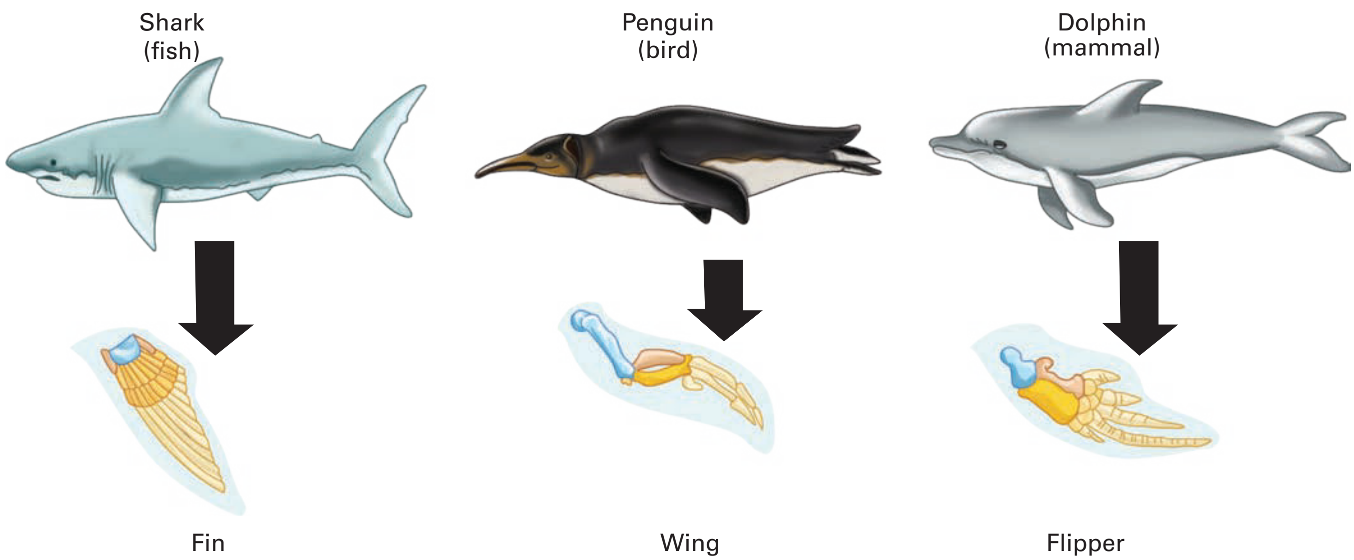

Figure 3.34 The shark, penguin and dolphin have analogous structures; that is, structures with the same function. These arose because they live in similar environments and face similar selection pressures.

homologous structures structures that are similar because they have evolved from the same ancestor

Homologous structures are structures that organisms inherit from a common ancestor. 'Homo' in science means 'same', hence they inherited the same general body plan from the same ancestor.We say these structures have a common evolutionary origin. Homologous structures have similar underlying anatomy, but have evolved in different ways over time due to different selection pressures. For example, the forelimbs of different mammals show basic similarities in the bones present and how they are arranged, even though the limbs may serve different functions. They are the same bones arranged for different uses. If homologous structures can be found in different organisms, that suggests they had a relatively recent common ancestor, which helps to explain their evolutionary path.

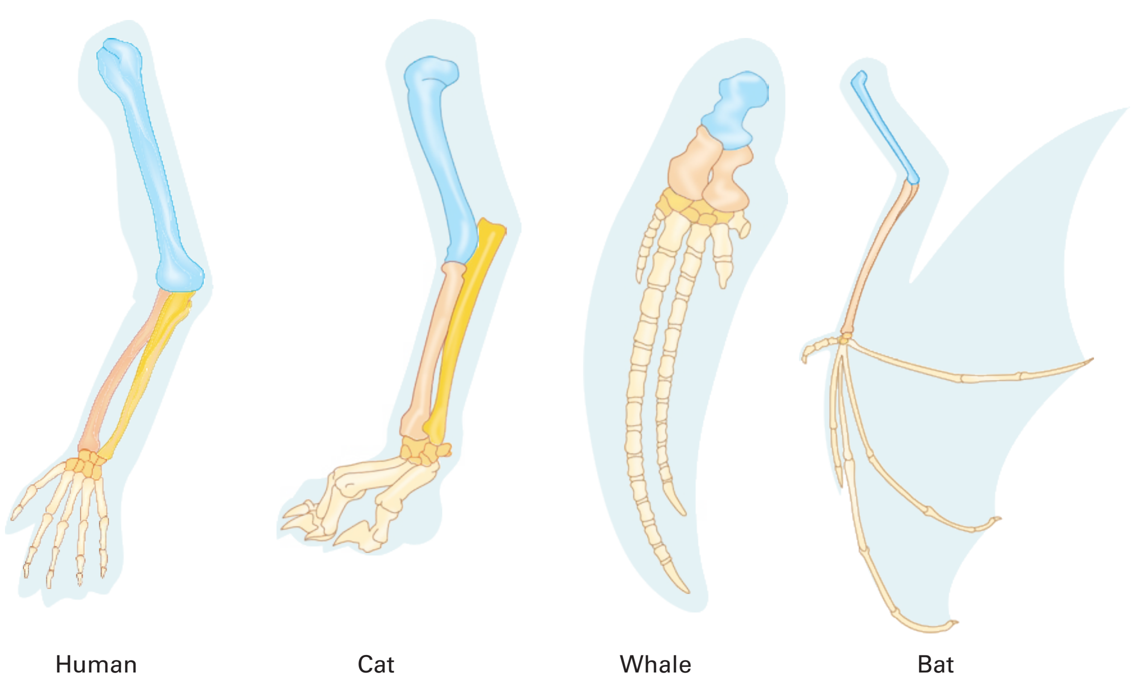

Figure 3.35 The forelimbs of different mammals have a common structure and are called homologous, despite having different functions.

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Did you know? 3.5

Vestigial structures

A vestigial structure or organ is part of an animal that is significantly reduced in size or lacks functionality compared to the animal's ancestors. It differs to both homologous and analogous structures but still provides evidence for evolution. An example of a vestigial structure within humans is the coccyx. It holds little to no importance to the functioning of humans these days. Some mammals use tails for balance, whereas humans walk on two feet, not requiring a tail. So in humans the 'tail' structure is instead just some fused vertebrae that is called the coccyx. Other organisms have different vestigial structures, as shown in the image below.

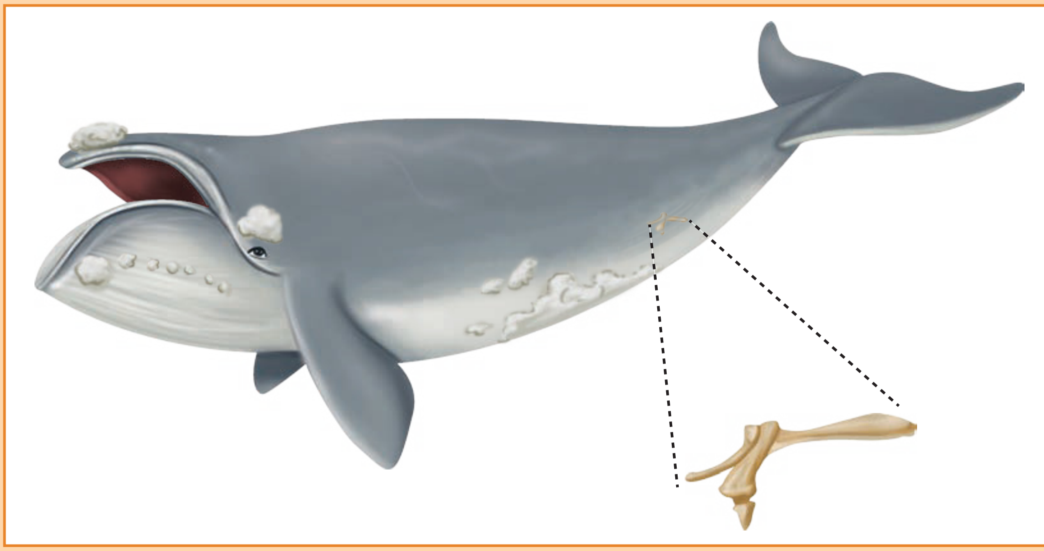

Figure 3.36 The whale skeleton shows evidence of a pelvis and hind limbs but has no need for these structures, so we call them vestigial structures.

Quick check 3.10

1 What are analogous structures? Provide an example.
2 What are homologous structures? Provide an example.
3 What are vestigial structures? Provide an example.

Practical 3.3

Dissection of a chicken wing

Be careful
Ensure benches are cleaned and hands are washed before leaving the laboratory.

Aim

To compare the structure of a chicken wing to the structure of a human arm.

Materials

- dissecting board
- dissecting scissors
- probe
- disposable gloves
- fresh chicken wing
- human skeleton model

Method

Part 1: Examining the chicken wing

1 Hold the chicken wing at the shoulder and the tip and then stretch out the wing. Identify where the joints are and in which direction they bend.
2 Use your fingers to feel the bones and muscle under the skin.
3 Using dissecting scissors, carefully remove the skin from the chicken wing, taking care not to cut the muscles, ligaments and tendons.

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4 Then identify the muscles of the wing and see if you can work out how each one is attached to the bones of the wing.
5 Look for the tendon, which is white and tough and attaches the muscle to the bone.
6 Try squeezing the muscle in the wings and observe what happens to the bones. You may notice there are two muscles which can flex or extend the wing.
7 Look at the surface of each bone where it forms a joint. It should appear white, shiny and slippery – this is called cartilage. Can you find the cartilage at the joint between the humerus and the radius and ulna?

Part 2: Examining your arm

1 Identify the humerus, ulna and radius in your arm. What other features of the chicken wing and your arm are similar?
2 Bend your arm at the elbow and hold it tight. Notice that your bicep muscle shortens. Now, extend your arm and feel your bicep lengthen.
3 Now, look at your hand and identify where the muscles are that move your fingers. You may need to press on your wrist or forearm to figure this out.
4 With a partner, raise and lower a textbook by bending your arm at the elbow. Which muscles were acting as you raise and lower?

Results

Take a photo of the finished dissection of the chicken wing and compare it to the skeletal bones of the human ulna and radius.

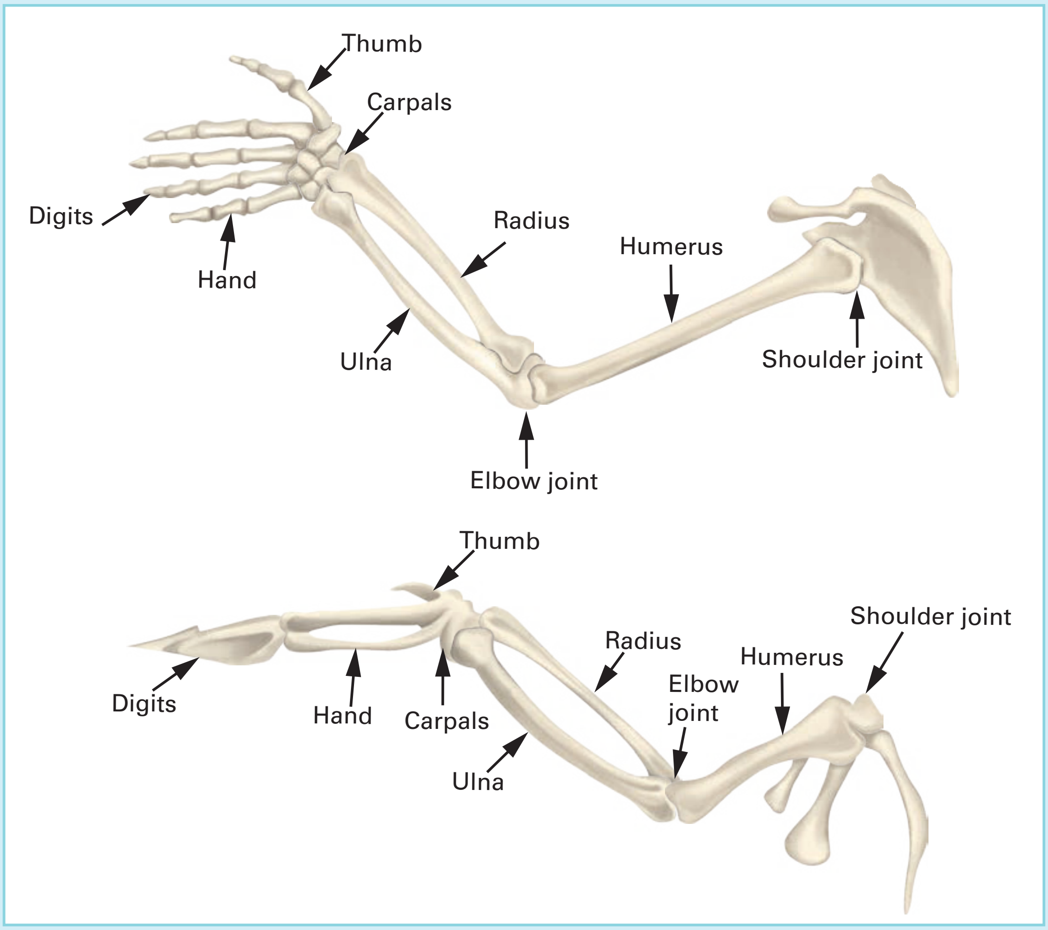

Figure 3.37 A human arm and a chicken wing

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Evaluation

1 List the similarities between the structure of the chicken wing and the human arm.
2 List the differences between the structure of the chicken wing and the human arm.
3 Define the term 'analogous structures' and explain what they can tell us about the evolution of a species.
4 Define the term 'homologous structures' and explain what they can tell us about the evolution of a species.
5 Would the chicken bones and human bones be considered homologous or analogous structures? Discuss.

Conclusion

1 Make a claim about chicken and human skeletons based on this activity.
2 Support the statement by using your observations and include potential sources of error.
3 Explain how your observations support the statement.

evolutionary tree a diagram used to represent evolutionary relationships between organisms

Scientists can construct **evolutionary trees** using fossil evidence and radiometric dating to estimate when different groups of species diverged from a common ancestor. Evolutionary trees can be constructed when scientists have studied the anatomy of different species to determine which ones have homologous structures. Only homologous traits are evidence of a shared ancestry. An example of an evolutionary tree is shown in Figure 3.38.

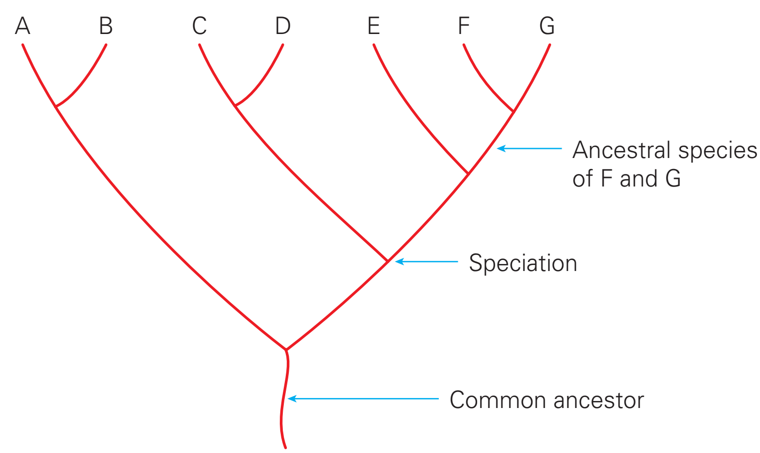

Figure 3.38 An example evolutionary tree

For example, humans, chimpanzees and gorillas all have thumbs that are very similar anatomically and are considered to be homologous. The giant panda also has a thumb, but it has been found to be analogous to these primate thumbs. This suggests that humans, chimpanzees, and gorillas are much more closely related to one another than any of them is related to giant pandas.

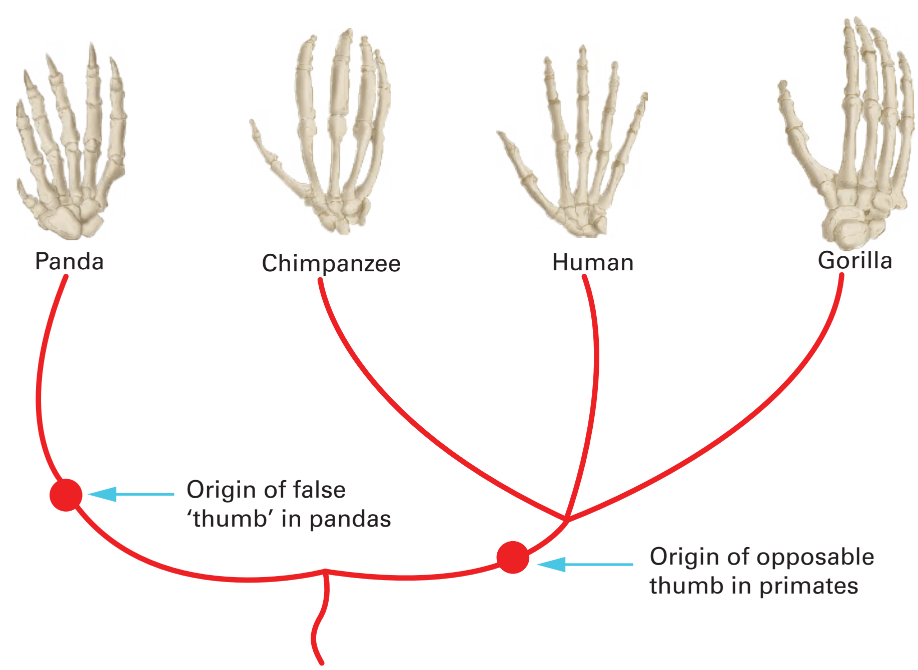

Figure 3.39 An evolutionary tree showing how their homologous opposable thumbs mean that humans, chimpanzees and gorillas have a recent common ancestor

Comparative embryology

The embryos of vertebrate animals look very similar in the early stages, which suggests that they share some of the genetic information that contributes to embryo development.

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The explanation is that this genetic information has been inherited from a common ancestor. For example, a very early stage human embryo has gill slits, a tail and a simple heart, similar to that of a fish. At later stages, the human embryo develops body proportions similar to the embryos of reptiles and then apes.

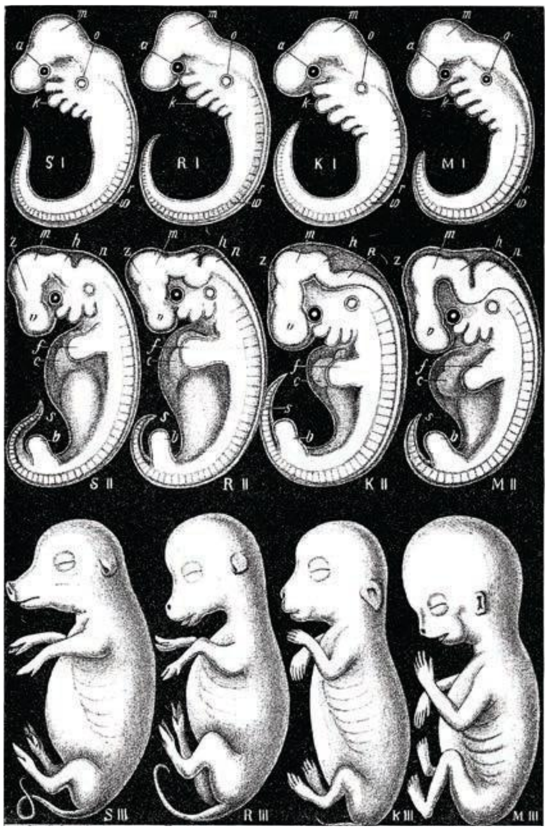

Figure 3.40 Comparative embryology drawings of embryos at three stages from (left to right) a pig, cow, rabbit and human

Comparative embryology also finds evidence for evolution in the circulatory system of fish and mammals. Adult fish and mammals have quite different circulatory systems. However, during embryonic development you can clearly see that the circulatory systems are based on the same pattern. This suggests that the genetic information responsible for the development of the fish and mammalian circulatory systems has been inherited from a common ancestor.

Quick check 3.11

1 What is an evolutionary tree?
2 Explain how embryology provides evidence for evolution.

Molecular biology

Substances that are found in most or all living things are very useful in the investigation of evolutionary relationships. For example, all living things contain DNA so it is commonly used to compare organisms. This is what the study of molecular biology is all about – investigating DNA, its code and the proteins it codes for. Molecular biology lets evolutionary scientists:

- trace ancestors of species
- estimate how long ago one species diverged into two
- discover how closely related two species are.

DNA analysis

DNA hybridisation a technique that measures genetic similarity between two organisms

DNA hybridisation is a technique to compare the DNA sequences of two species to find out how closely they are related. First, the DNA from each organism is extracted and heated so it forms two single strands. When the single strands from the two organisms are mixed together and allowed to cool, complementary nitrogenous bases will bind together (or hybridise). The degree to which the single strands form a stable double-stranded DNA molecule is an indication of the relatedness of the species. For example, if there is a lot of hybridisation, there must be a lot of complementary bases, which means the organisms are similar; and therefore, have a recent common ancestor.

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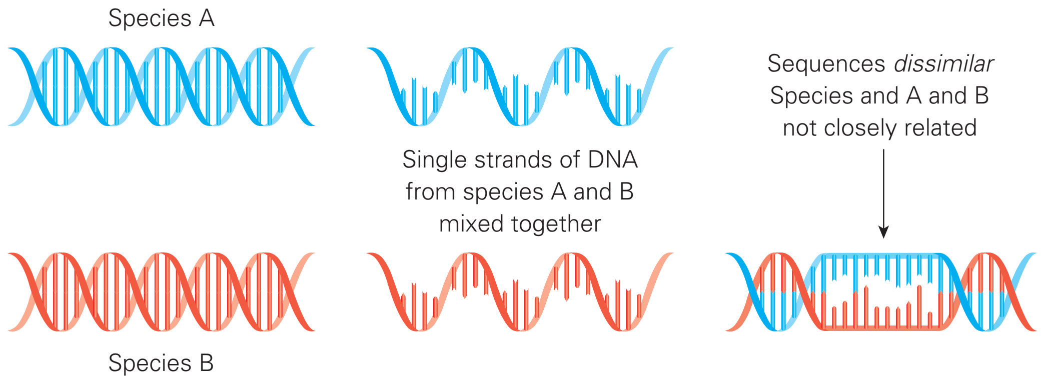

Figure 3.41 The process of DNA hybridisation allows scientists to determine the relatedness of two organisms by comparing their DNA.

Did you know? 3.6

Molecular clocks

Mitochondrial DNA (mtDNA) is DNA found in the mitochondria. It is particularly useful because some sections of the mtDNA have a relatively constant mutation rate. Because this rate of change is reliable, scientists can calculate the time of divergence according to the number of differences in mtDNA. This is why we often refer to mtDNA as a 'molecular clock'.

Figure 3.42 In the same way that a clock tells the time, a molecular clock allows scientists to determine how long ago two species diverged.

Protein analysis

As we know, proteins are made up of building blocks called amino acids. Scientists can analyse the differences in the amino acid sequences, knowing that this relates to how similar proteins are in the different organisms. The number of different amino acid sequences in the proteins of different species is an indicator of the number of mutations and hence the degree of separation of species. In other words, a large difference in amino acid sequences between two organisms means they had a distant common ancestor, while a small difference in amino acid sequences mean they had a recent common ancestor. The cytochrome c protein is often studied as it is involved in cellular respiration and found in most eukaryotic organisms. Table 3.5 shows the differences in the amino acid sequence for cytochrome c between humans and other organisms.

Note that it is also possible to predict amino acid sequences from the DNA code, and the latter also tells you the relationship between organisms.

Organism	Number of differences in the amino acid sequence for cytochrome c compared to humans
Horse	12
Chicken	13
Dog	11
Moth	31
Tuna	21
Monkey	1

Table 3.5 The differences in the amino acid sequence for cytochrome c between humans and other organisms

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Quick check 3.12

1 What is DNA hybridisation and how does it provide evidence for evolution?
2 Why can the number of differences in the amino acid sequence for cytochrome c be used to establish the relationship in evolutionary terms between organisms?

Biogeography

biogeography the study of the geographical distribution of plants and animals

Biogeography is the study of the distribution of organisms, both today and in the past. Biogeography provides us with additional evidence for evolution. For example, ancient fossils in one area may resemble modern organisms in that same area, and have a similar pattern of distribution (for example, fossil and modern platypuses are both found in Australia). The similarity of fossil and modern organisms suggests that the modern organisms have descended from ancestors living in same areas.

Remember that the continents were once grouped together in one big supercontinent, and ancestral organisms were distributed across more than one continent. When the continents split up and drifted apart, the separated populations evolved into different but related organisms. For example, the emu of Australia, the ostrich of Africa, the cassowary of Papua New Guinea and northern Australia and the rhea of South America are all large, flightless birds. Despite being found on different continents with oceans between them, one possible explanation for their similarity is that they descended from a common ancestor that occurred on the ancient Gondwana supercontinent.

Figure 3.43 (Left to right) The emu, rhea and ostrich live on different continents.

Quick check 3.13

1 Define the term 'biogeography'.
2 Explain how biogeography provides evidence for evolution.

Evolution of humans: bringing it all together

In order to understand human origins, we need to first look at what humans are. Humans are in the Animal Kingdom, Phylum Chordata, Class Mammalia, Order Primates, Family Hominidae, genus *Homo* and species *Homo sapiens*.

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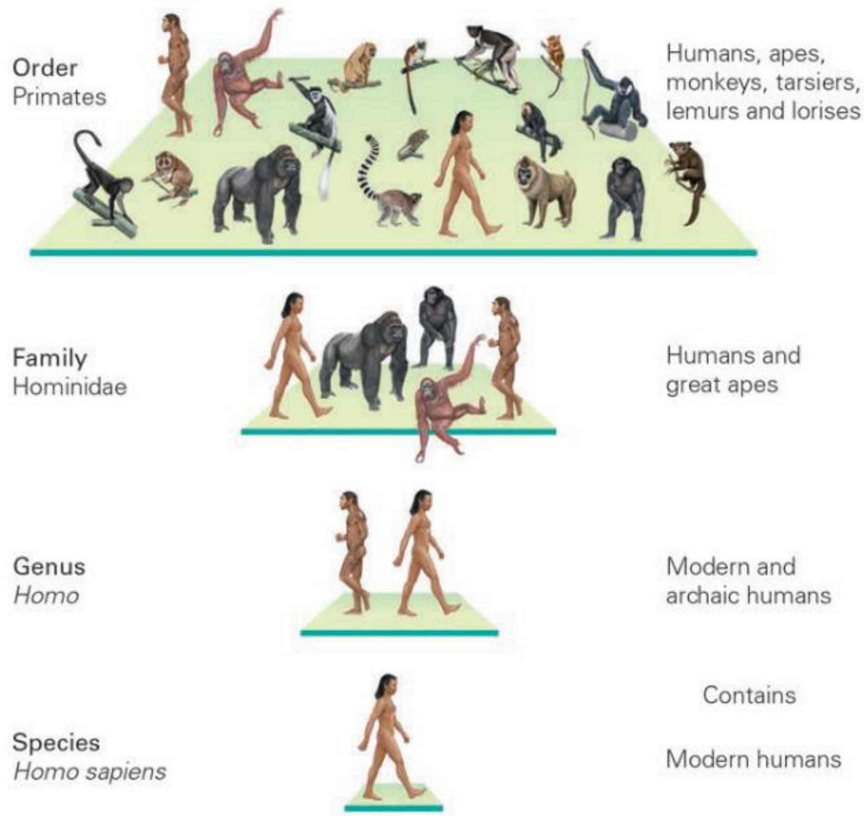

Figure 3.44 Classification of *Homo sapiens* within the order Primates

The primates living today gradually evolved over 65 million years from ancestral primates that were small tree-dwelling mammals. We did not evolve from apes and monkeys, but we share a common ancestor with them. About six million years ago, the line that led to humans is thought to have diverged from the chimpanzee line due to different habitats and different selection pressures.

Over the course of human evolution there have been two main genera, the earlier genus *Australopithecus* and the later genus *Homo*. Modern humans are more similar to other species in the genus *Homo* than to any *Australopithecus* species.

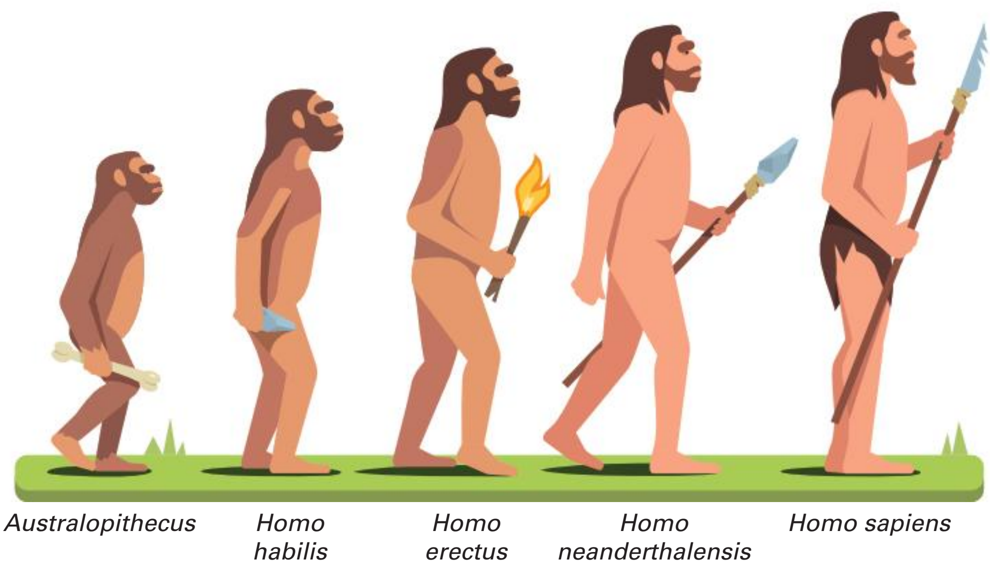

Figure 3.45 Darwin was the first to suggest that humans and other species were related.

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Evidence for human evolution

Explore! 3.5

In this section you have learned all about the different ways that we can gather evidence about evolution: palaeontology, comparative anatomy, embryology, molecular biology and biogeography. However, we have not investigated how they have informed us about human evolution.

1 Research the fossil evidence of human evolution. Summarise what fossils teach you about the evolution of humans and use pictures to illustrate what you find.
2 Research homologous and analogous structures related to human evolution. Summarise what comparative anatomy teaches you about the evolution of humans and use pictures to illustrate what you find.
3 Research the DNA evidence of human evolution. Summarise what DNA teaches you about the evolution of humans and use pictures to illustrate what you find.

QUIZ

Section 3.3 questions

Remembering

1 List the five sources of evidence for evolution.
2 What is meant by the term 'fossil'?
3 What does biogeography refer to?

Understanding

4 What is an analogous structure? Provide an example.
5 Why would the scales of reptiles and the feathers of birds be considered homologous structures?
6 Explain how DNA hybridisation can show that two organisms share a common ancestor.

Applying

7 Summarise why fossils of soft-bodied organisms are relatively rare.
8 Figure 3.46 represents the layers of rock found within a cave. In which layer (1 to 5) would you expect to find the oldest group of fossils? Why?

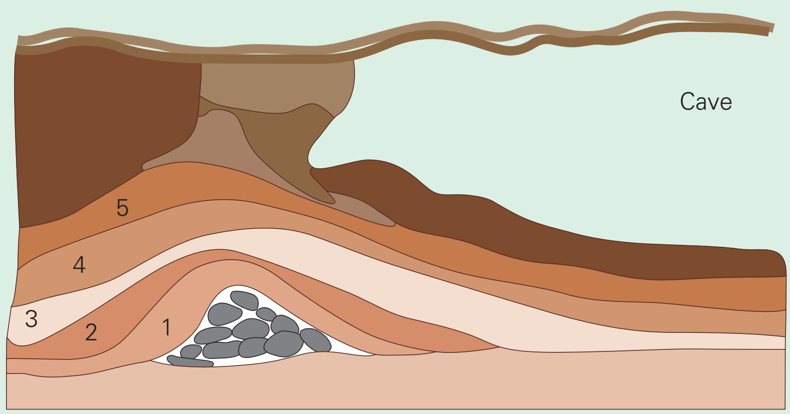

Figure 3.46 Layers of rock within a cave

9 Distinguish between absolute and relative dating techniques.

Analysing

10 Figure 3.47 on the next page shows a timeline for the evolution of some dinosaurs. The average mass of each dinosaur is shown in brackets under its name.
  a The dinosaur that lived the longest time ago is the ____________
  b The dinosaur/s that evolved from *Agilisaurus* is/are the ____________

continued...

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...continued

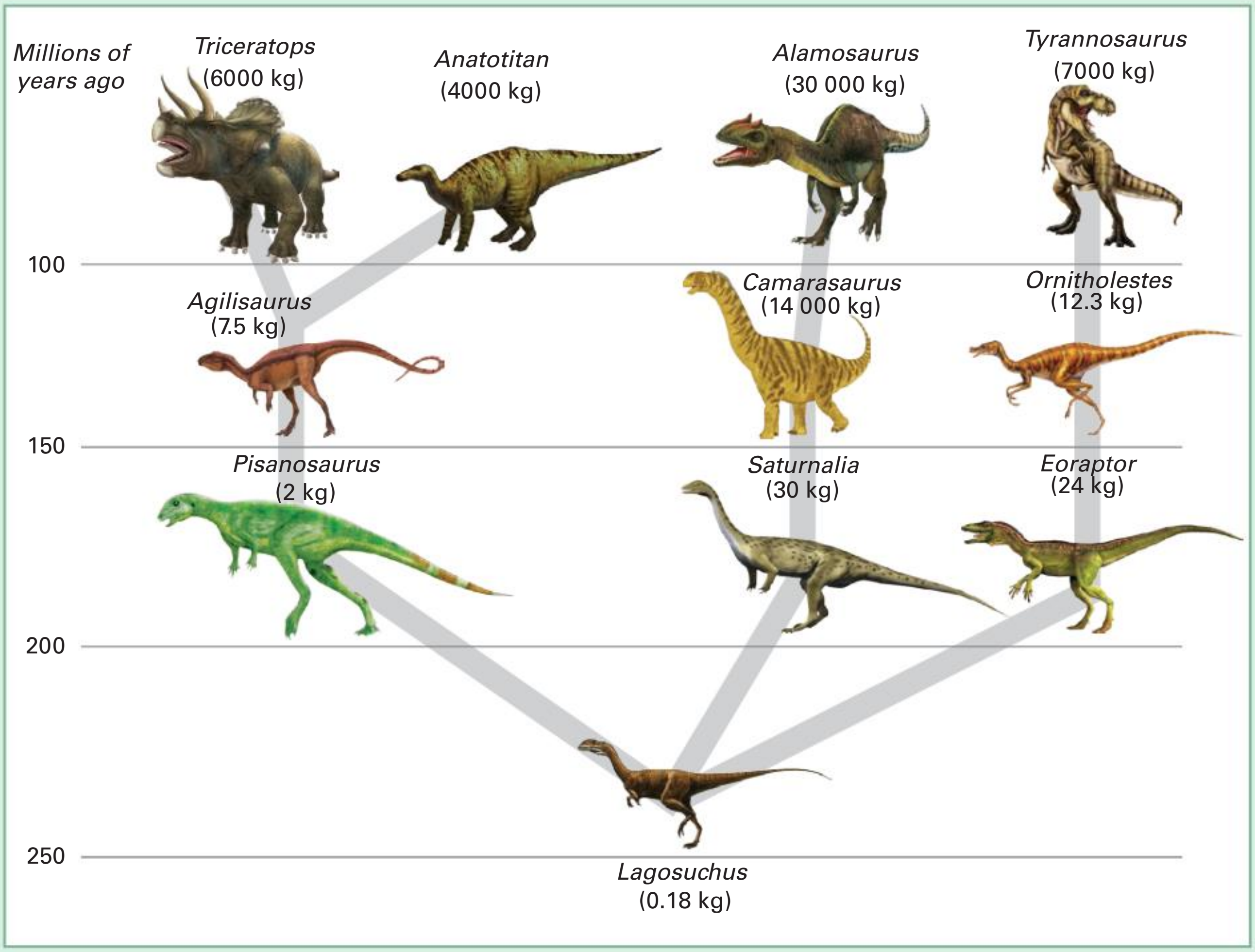

Figure 3.47

c The dinosaur from which *Camarasaurus* evolved is the ____________________

d The dinosaur with the largest average mass is the ____________________

11 Refer to Figure 3.48 of the possible evolutionary relationships between chimpanzees and the various genera of humans to answer the following question.
The most recent common ancestor of *Homo* and *Kenyanthropus* is represented on the diagram at letter ____________________

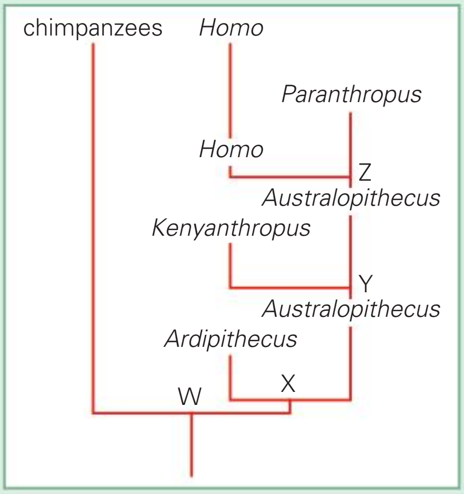

Figure 3.48

12 The table on the following page shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees and a Neanderthal.

continued...

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...continued

	Human 2	Chimpanzee 1	Chimpanzee 2	Neanderthal
Human 1	15	77	76	20
Human 2		79	80	27
Chimpanzee 1			23	72
Chimpanzee 2				71
Neanderthal				

a Based on the table, which organism is most closely related to the Neanderthal?
b Based on the table, which organism is the least closely related to the Neanderthal?
c Decide which method could be used to estimate the absolute age of the Neanderthal fossil?
d Decide which method could be used to estimate the relative age of the Neanderthal fossil?

Evaluating

13 Propose how you would investigate whether birds are more closely related to mammals or reptiles. Include what evidence you would expect if the organisms were related or not related.

14 Draw a concept map that shows the links between the different ways we can gain evidence for evolution. Please include how each method sheds light on evolution.

Review questions

SCORCHER

Remembering

1 What is meant by the concept of variation in the field of evolution?

2 Define the terms 'index fossil', 'gene flow', 'species', 'adaptation', 'isolation' and 'comparative embryology'.

3 How does the camouflage of organisms support the idea of natural selection?

Understanding

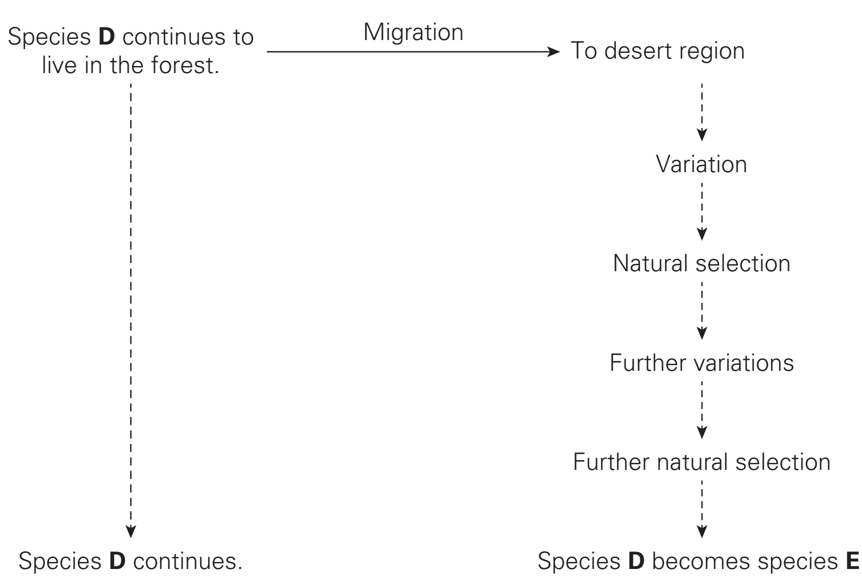
4 Outline the main causes of variation among organisms.

5 Explain why 'survival of the fittest' does not necessarily mean survival of the biggest and strongest.

6 Explain how amino acid sequences can provide evidence for evolution.

Applying

7 The following diagram is representing the process known as speciation.



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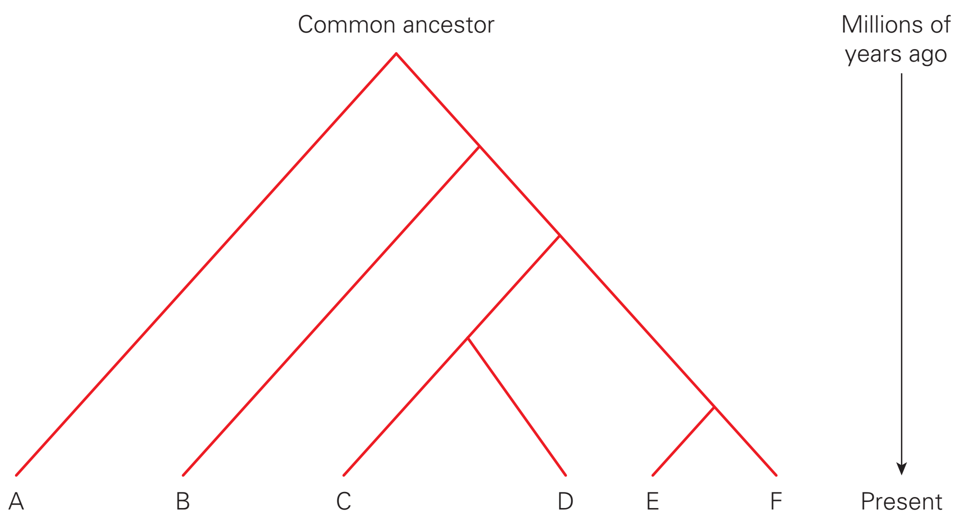
- **a** Explain, using the information from the diagram, the key forces behind the creation of the new species E in the desert.
- **b** Members of new species E cannot breed successfully with species D. Suggest a reason for this.

8 Scientists excavated an abandoned quarry and found a set of dinosaur footprints that could be up to 145 million years old. The trails of 90 uninterrupted prehistoric footprints are thought to have been made by a sauropod – a class of heavy dinosaurs with long necks and tails. Identify what type of fossil a dinosaur footprint is known as, and summarise how they are formed.

9 Identify how mutations contribute to the process of evolution.

Analysing

10 The following figure shows the evolutionary tree for six organisms from a common ancestor.



- **a** According to the diagram, identify the present day organism that is least closely related to the others. Justify your response.
- **b** Determine which two organisms have the most recent common ancestor and justify your response.

Evaluating

11 Using diagrams, explain how rabbits may have become resistant to the deadly virus *Myxomatosis*, which was released in Australia to try to control the rabbit plagues.

12 Demonstrate the advantages and disadvantages of artificial selection.

13 Propose how scientists use information gained from sedimentary rock to arrange fossils into some kind of evolutionary sequence over time.

14 Give reasons why scientists want to find out about evolution.

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STEM activity: Designing a wheelchair to aid dogs with genetic problems

VCSSU120 VCDSTC048 VCDSCD049 VCDSCD051 VCSIS113

Background information

Individuals in a species become perfectly suited to their environment by the process of natural selection. In this process, individuals with characteristics that allow them to thrive in the environment are selected for, and they pass their suitable genes onto subsequent generations. However, the individuals within a species being too similar genetically can be detrimental to the species' survival. If the environment changes, genetic variation within a species gives it a better chance of survival because there are individuals that can cope better with the changed environment. A lack of genetic variation can result in a population being wiped out entirely from an environmental change.

Inbreeding occurs when genetically similar individuals from a species breed with each other. There are many examples of inbreeding in humans and other species that are bred selectively, like dogs. In these cases, the problem is not that a population could be wiped out by an environmental change, but that genetic conditions that would be very rare in wider populations continue to be passed onto subsequent generations.

A famous example of this occurred with haemophilia, a condition resulting from a mutation on the X-chromosome. In people with this condition, blood does not clot properly so injury can cause excessive bleeding. Haemophilia spread throughout European royal families in the nineteenth and twentieth centuries because of arranged marriages among the related royal families.

Humans have bred dogs for thousands of years, originally to serve a specific purpose or job like herding and hunting. All modern dog breeds exist as a result of human selective breeding. Unfortunately, many pure breed dogs suffer from genetic conditions because of inbreeding. For example, purebred dachshunds commonly suffer from knee problems as a result of their short legs and non-ideal angle for the knees. They also often have hip dysplasia and spinal problems because of their long bodies, and eye problems like cataracts.

Figure 3.49 Dachshunds are prone to numerous genetic diseases because of their signature long bodies and tiny legs.

While dog owners can take preventive measures to reduce the effects of these disorders, often reactive treatment is the method used to give affected dogs a good quality of life. Wheelchairs are a potential solution to help with mobility for dachshunds that have hip and knee problems.

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Design brief: Design a wheelchair to aid dachshunds with genetic knee and hip problems

Activity instructions

In small groups, research the features of dog wheelchairs. You may like to put together a collection of different designs to help you decide which features you would like to include in your own design.

Draw your chosen design and label its features and the materials you intend to use. You will need to consider the method of attaching the wheelchair to the dog and whether the dog's legs will hang down or be supported on a platform. You will also need to think about the best way to make it comfortable for the dog. Some research into the specific genetic problems occurring in dachshunds may be necessary to make sure you are catering for the dogs' needs.

Your wheelchair will need to be sturdy, so remember to use appropriate shapes and bracing to achieve the right strength for your design.

Suggested materials/presentation formats

- cardboard
- fabric/felt
- glue
- scissors
- wheels
- paddle pop sticks
- elastic bands
- straws
- sticky tape

Evaluate and modify

1. List the features you used to make the wheelchair comfortable. Explain how these features cater for the specific needs that you researched.
2. Research problems people have found with a current model or solution they are using. What changes or adaptations could you make to solve their problems?
3. Describe any difficulties you came across when constructing your model. Explain how you overcame these difficulties.
4. Propose some improvements to the design of your wheelchair to improve comfort and functionality.
5. Depending on the size of your model, you may be able to test it by using your wrist or palm as the back of the dog and your index and middle fingers as the front legs to pull it along. Test it with different amount of downward pressure to represent different dog sizes and weights. Comment on how your wheelchair fared in your tests.

Figure 3.50 Dachshunds are not the only dog breed that may need the aid of a wheelchair.

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Chapter 4 The periodic table

Chapter introduction

For hundreds of years, since the discovery of elements, scientists have been trying to classify them into groups based on how they behave. The outcome of this is the periodic table of elements. This chapter covers how elements are arranged, the information that can be determined from that arrangement and the properties of particular groups of elements in the periodic table. You will learn about the father of modern chemistry, Dmitri Mendeleev, and his contribution to the modern day periodic table.

Curriculum

The atomic structure and properties of elements are used to organise them in the periodic table (VCSSU123)	
• describing the structure of atoms in terms of electron shells	4.2, 4.3
• explaining how the electronic structure of an atom determines its position in the periodic table and its properties	4.2, 4.3, 4.4
• investigating the chemical activity of metals	4.4, 4.5

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Glossary terms

activity series
alkali metals
alkaline earth metals
anion
cation
covalent bond
displacement reaction
electron
electron shell
electronic configuration
element
ground state
group
halogens
inert
ion
ionic bond
metalloids
native metals
noble gases
period
transition metals
valence electrons

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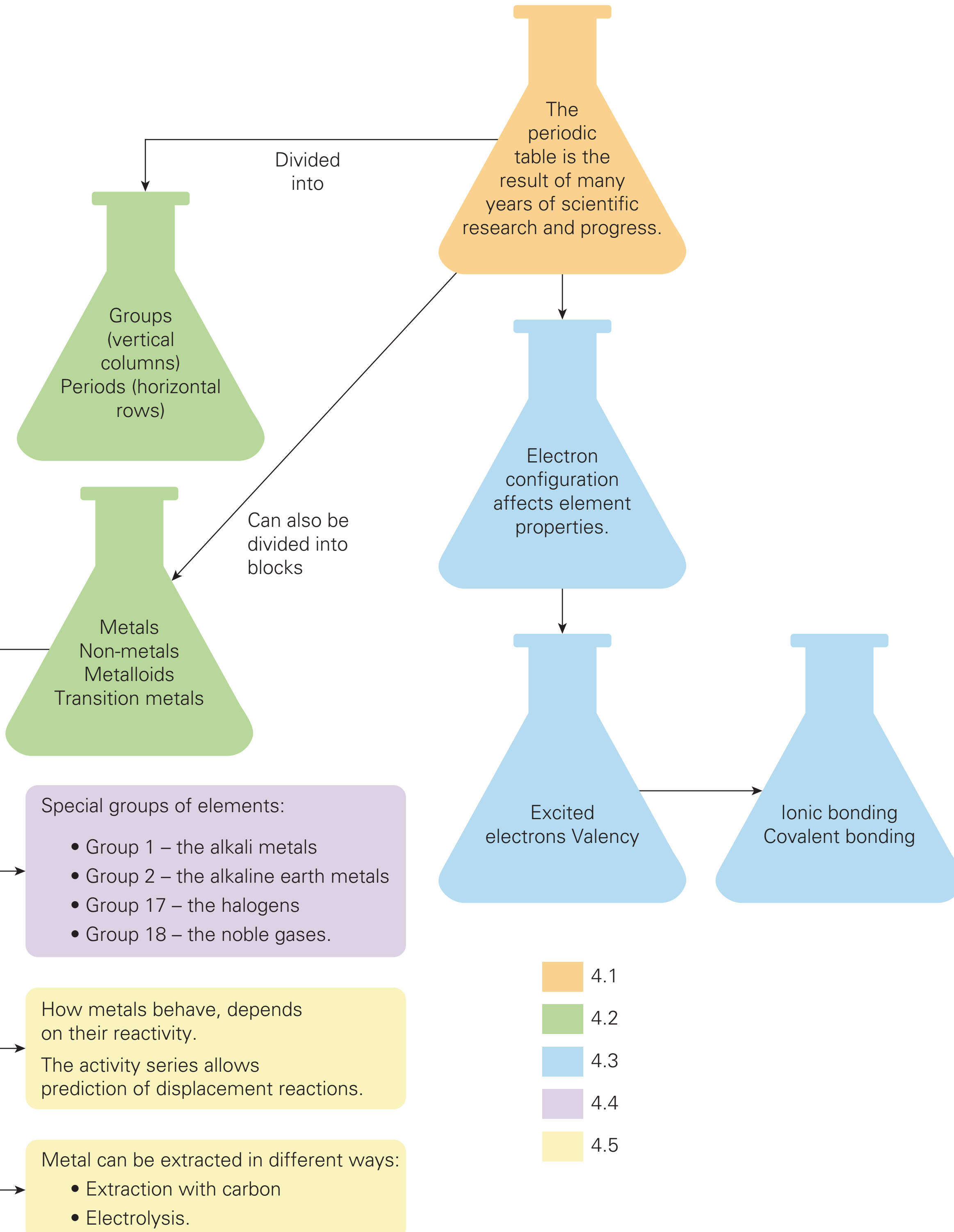
Concept map



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4.1 Development of the periodic table

Throughout history the question of how best to organise chemical **elements** has intrigued scientists. In this section, we will summarise the attempts of six scientists, and see the progress made over time in understanding the nature of elements.

element
a species of atoms that have the same number of protons

WORKSHEET

VIDEO
Do we know the properties of all elements?

Timeline of the periodic table

1789

Antoine Lavoisier

- Lavoisier discovered and named oxygen and hydrogen.
- In 1789 there were thought to be 33 elements (including light!). Lavoisier sorted these elements into gases, metals, non-metals and earths, constructing the first list of the known elements.
- His table of elements quickly became outdated as new elements were discovered.

1808

John Dalton

- Dalton was a chemist, physicist and meteorologist, and was responsible for developing early atomic theory and publishing a table of relative atomic weights.
- Dalton allocated symbols to the 36 known elements, which were later replaced by the symbols devised by Jöns Jacob Berzelius that are still used today.

Figure 4.1 Dalton's element symbols

1817

Johann Wolfgang Döbereiner

- Döbereiner noticed that known elements could be arranged into groups of three by their similarities in appearance and reactions. He called these groups triads (for example, lithium, sodium, potassium). He found that, when the elements in a triad were placed in order of their atomic weight, the middle element had a mass which was the average of the other two.
- Döbereiner's work encouraged others to look for patterns in chemical properties and atomic weights.

Alkali formers	
Li	7
Na	23
K	39

((39 + 7) ÷ 2 = 23)

Salt formers	
Cl	35.5
Br	80
I	127

((127 + 35.5) ÷ 2 = 81)

Figure 4.2 Two Döbereiner triads

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1863

Alexandre-Émile Béguyer de Chancourtois

- De Chancourtois arranged known elements by increasing atomic weight.
- The atomic weight of oxygen was set at 16 and used as a standard for all the other elements.

He wrapped his list around a cylinder which allowed sets of similar elements to line up. As tellurium was situated in the middle of the cylinder he named his system the telluric screw.

- The first geometric representation of periodic law was created, meaning that de Chancourtois' system showed repetition in the properties of elements at certain, regular intervals.

1864

John Newlands

- Newlands listed the known elements in order of their atomic weights into horizontal rows, seven elements long.
- He stated that the eighth element would have similar properties to the first element in the series.
- Some colleagues mocked his proposal, saying he should have just organised the elements alphabetically and saved himself some time! Despite this, his work was the first time anyone had used the sequence of atomic weights to organise the elements.

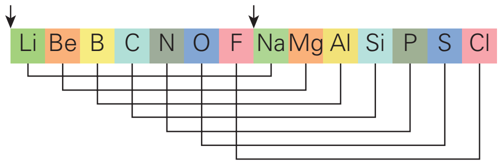

Figure 4.3 Newland's law of octaves. Every eighth element in the row has similar properties. Track the lines and investigate what is similar about each element.

1869

Dmitri Mendeleev

- By 1869 there were 56 known elements, with a new element being discovered approximately once every year.
- Mendeleev organised the elements into a table with rows and columns, grouping elements by properties and in order of their atomic mass.
- Mendeleev left space in his table for elements he thought would be discovered.

Tabelle II.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

der chemischen Elemente.

Figure 4.4 Mendeleev's early attempt at arranging the known elements into a table

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Quick check 4.1

1 Work out the atomic mass of element Y using Döbereiner's method.

Element	Atomic mass
X	24
Y	
Z	58

2 How was Mendeleev's attempt similar to those made by other scientists?

3 How did Mendeleev's attempt differ from attempts made by other scientists?

Predicting future elements

Although Mendeleev's approach was similar to that of other scientists, his arrangement did one thing that the others had missed. Mendeleev realised that new elements were consistently being discovered, and concluded that he must allow for this when grouping the elements together. He therefore left gaps in his table for elements that had yet to be discovered. You can see in Figure 4.4 that he drew lines to show where he thought a discovery would be made. This was all well and good, and worthy of fame, but what makes people think of him as the father of modern chemistry was that he predicted the properties of these unknown elements years before they were even discovered.

To explain how Mendeleev made his predictions we will look at an example: he left a gap between silicon (Si) and tin (Sn).

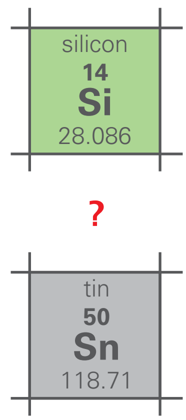

Figure 4.5 Mendeleev predicted that there would be an element between silicon and tin.

He named this element eka-silicon and made the predictions shown in Table 4.1 based on the known properties of the elements above and below it in the periodic table.

Element	Mass	Density (g/cm³)	Density of its chloride (g/cm³)	Boiling point of its chloride (°C)
Eka-silicon	72	5.5	1.9	100

Table 4.1 Mendeleev's predictions for the chemical properties of eka-silicon

How close was he?

In 1886, the element germanium (Ge) was discovered which had the properties shown in Table 4.2.

Element	Mass	Density (g/cm³)	Density of its chloride (g/cm³)	Boiling point of its chloride (°C)
Germanium	73	5.3	1.88	86

Table 4.2 The chemical properties of germanium

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Compare these properties of germanium with Mendeleev's predictions for eka-silicon. He was incredibly close! Luckily, the discovery of germanium occurred within Mendeleev's lifetime and confirmed his arrangement.

Unbelievably, Mendeleev did not receive a Nobel Prize for his efforts, but he does have a chemical element named after him: element 101, mendelevium (Md).

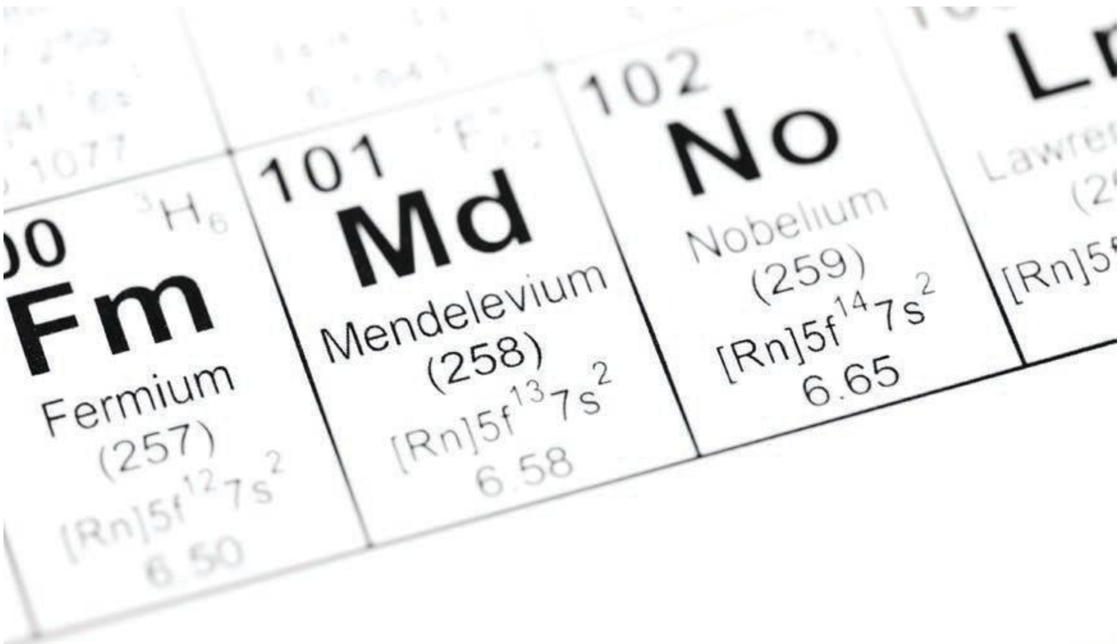

Figure 4.6 Mendelevium has the atomic number 101.

Quick check 4.2

1. How did Mendeleev make his predictions?
2. Copy and complete the sentence:
   The discovery of the element __________ proved that Mendeleev's predictions were correct.

Explore! 4.1

Breaking his own rule

We have already discussed that Mendeleev arranged the elements in order of their atomic mass, which meant that elements with similar properties were placed in the same groups. However, this did not work in all cases.

Take the elements tellurium (Te) and iodine (I) which, when arranged in order of mass, are in group 17 and group 16 respectively.

53 I 126.9 Iodine	52 Te 127.6 Tellurium

Figure 4.7 Iodine and tellurium when arranged by atomic mass

1. On the modern-day periodic table, which groups do iodine and tellurium belong to?
2. Mendeleev broke his rule of ordering by atomic mass in the case of iodine and tellurium. Why do you think this was the case?
3. How is the periodic table arranged now to account for these exceptions?
4. Why didn't Mendeleev order his periodic table in the way it is arranged now?

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Practical 4.1

Predicting properties of elements

Aim
To predict properties of elements.

Materials
- balance
- ruler
- carbon rod
- silicon
- tin
- 50 mL measuring cylinder
- graph paper
- weigh boats

Method
1 Copy the results table below.

Measure the masses

2 Place a weigh boat onto the balance and tare the weight.

3 Place a sample of carbon rod onto the weigh boat and record the mass of the carbon rod.

4 Re-tare the balance.

5 Repeat steps **2–3** with samples of silicon and tin, and record the masses in the results table.

Measure the volumes

6 Half-fill the 50 mL measuring cylinder with water and record the initial volume (1 mL = 1 cm^3).

7 Place the sample of carbon rod into the measuring cylinder gently and record the new volume.

8 Subtract the initial volume from the new volume to find the volume of the carbon rod sample.

9 Repeat steps **6–8** with samples of silicon and tin, and record the volumes in the results table.

Calculate and graph the densities

10 Calculate the density of the carbon rod, silicon and tin using the formula below, and record it in the results table.
density (g/cm^3) = mass (g) ÷ volume (cm^3)

11 Using the calculated densities in the *y*-axis, draw a scatterplot with the *x*-axis being the period (row) of the element in the periodic table.

12 After plotting the densities, draw a line of best fit for the three points.

13 Using this graph, estimate the density of germanium; this element is in the fourth period/row.

Results

Element	Row	Mass	Volume	Density
Rod				
Silicon				
Tin				

Evaluation
Explain how this experiment relates to the method that Mendeleev used when predicting the properties for the gaps he left in his periodic table.

Conclusion
1 Make a claim about the properties of elements and their positions on the periodic table based on this experiment.

2 Support your statement by using the data you gathered and include potential measurement uncertanties.

3 Explain how the data supports your statement.

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QUIZ

Section 4.1 questions

Remembering

1 Give the names of three scientists who attempted to organise elements.
2 Who created the first version of the modern periodic table?
3 What method did most scientists use to arrange chemical elements?
4 Döbereiner's triads were the forerunner for what similar modern day arrangement of the elements?
5 Which group of elements is missing from Mendeleev's periodic table?

Understanding

6 Compare and contrast Newlands' and Mendeleev's arrangements.
7 Explain why de Chancourtois' arrangement was superior to Döbereiner's.
8 Summarise how Mendeleev made his predictions surrounding the properties of elements which had yet to be discovered.

Applying

9 Using Döbereiner's law of triads, calculate the mass of the middle element.

Element	Mass
A	12
B	
C	34

Analysing

10 Analyse the reasons why Mendeleev's periodic table was accepted.

Evaluating

11 Assess the reasons why there were multiple ways proposed throughout history to arrange chemical elements.
12 Deduce the properties of the middle element in the tables below.

a

	Lithium	Sodium	Potassium
Mass	7		39
Melting point (°C)	180		63

b

	Silicon	Germanium	Tin
Mass	28		119
Melting point (°C)	1414		232

c

	Chlorine	Bromine	Iodine
Mass	35.5		127
Melting point (°C)	−101		114

13 Criticise the earlier arrangements of the chemical elements.
14 Determine why the modern periodic table has remained relatively unchanged since it was reordered by atomic number instead of atomic mass.

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4.2 Structure of the periodic table

The modern periodic table is a list of all the known elements in order of their atomic number. Remember, the atomic number of an element is the number of protons an element has. This makes hydrogen (H) the first element in the periodic table as it has one proton and therefore an atomic number of 1. Oganesson (Og), a synthetic element discovered by Russian scientists in 2002 and officially named in 2016, is currently the last element, with an atomic number of 118.

New elements, heavier than oganesson, may yet be discovered – so watch this space! Each box on the periodic table represents an element with a different atomic number and contains the element's one or two letter symbol.

WORKSHEET

WIDGET
Periodic table

Figure 4.8 Oganesson is currently the last element on the periodic table, with an atomic number of 118.

Explore! 4.2

Naming the elements

Many elements on the periodic table have 'weird' symbols that do not match their name. There are also elements named after scientists.

For the following elements, research why they have that name or symbol:

- Sodium (Na)
- Iron (Fe)
- Curium (Cm)
- Mendelevium (Md)
- Rutherfordium (Rf)

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Groups of the periodic table

The periodic table is arranged into vertical columns called **groups**. There are 18 groups in total.

group the vertical columns in the periodic table

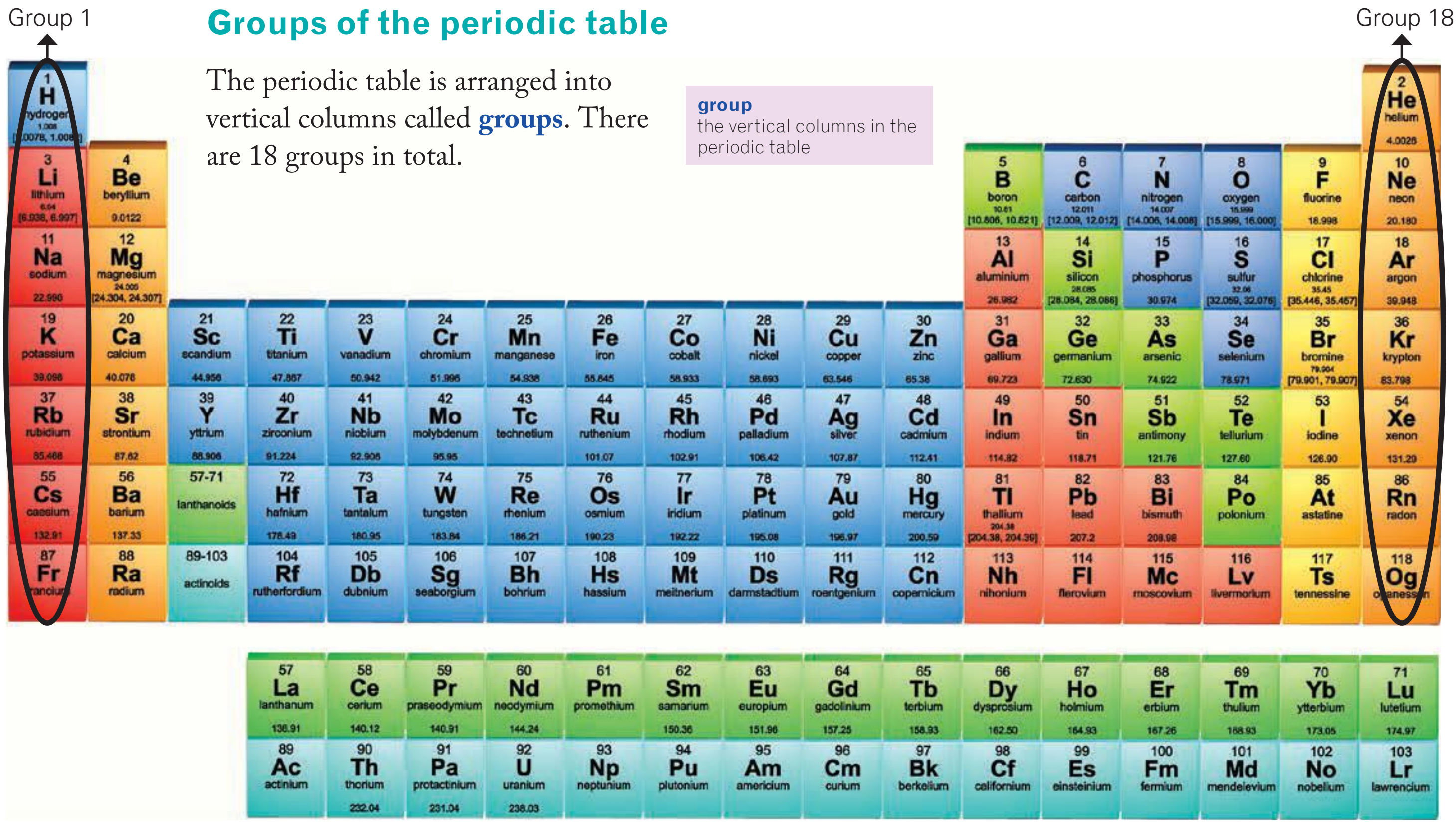

Figure 4.9 Groups are the vertical columns of the periodic table.

Elements in the same group all have similar properties; for example, they react with the same chemicals in similar ways. This lets us predict the properties of elements by looking at others in the same group. For example, sodium, an element in group 1, reacts violently when placed in water. Therefore, we can expect that potassium, also in group 1, will react in a similar way – and it does.

Later on in the chapter, you will be able to explain how and why these elements were grouped together.

Figure 4.10 The group 1 metals all have similar properties so behave in similar ways.

Quick check 4.3

1 Decide whether the following statements are true or false.
 a Groups are the vertical rows in the periodic table.
 b Oxygen (O) is in group 5.
 c As strontium (Sr) is in the same group as silicon (Si), it will have similar properties.

2 Barium (Ba) in group 2 reacts with oxygen (O) to form barium oxide, a metal oxide with the formula BaO. Potassium (K) in group 1 reacts with oxygen (O) to form potassium oxide with the formula K_2O. An unknown element was reacted with oxygen. The product was a metal oxide with the formula XO (X being the unknown element). In which group would you place the unknown element? Explain why.

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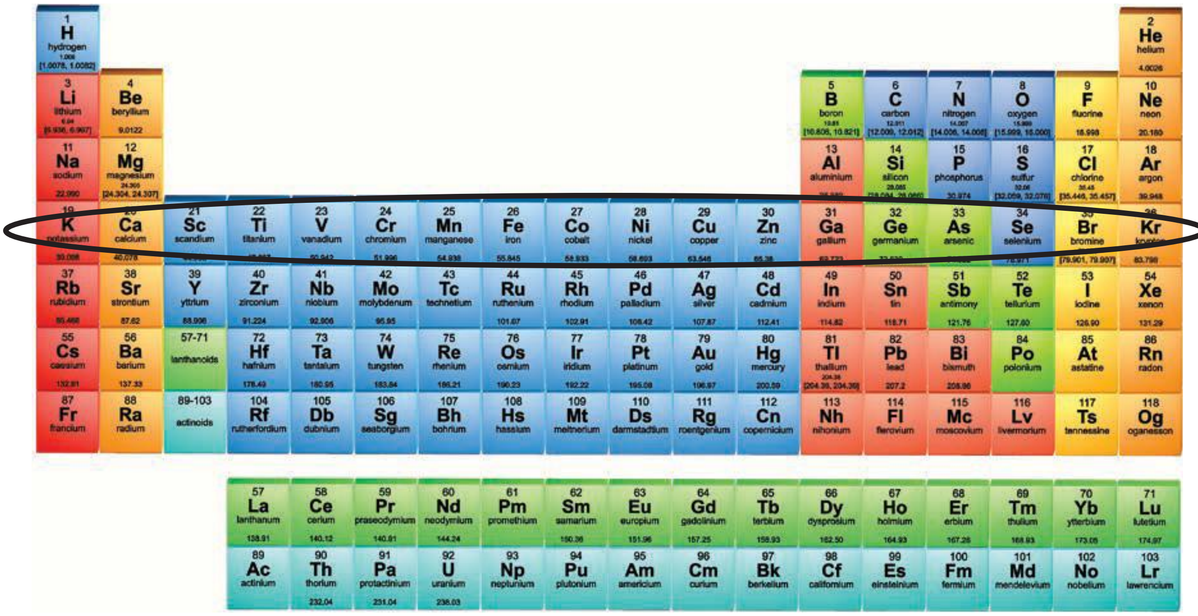

Figure 4.11 Periods are the horizontal rows in the periodic table.

Periods of the periodic table

If groups are the vertical columns, then **periods** are the horizontal rows. There are seven periods in total.

period
the horizontal rows in the periodic table

Make sure that you do not forget about hydrogen (H) and helium (He) – they are the only elements that make up period 1. As you move across a period, the atomic number increases (that is, the number of protons increases), as does the number of **electrons**.

electron
smallest sub-atomic particle in an atom arranged around the nucleus in shells

This arrangement into groups and periods causes elements to have a specific position on the periodic table. For example, carbon (C) is placed in group 14, period 2, and helium (He) is in group 18, period 1. You might wonder why helium is not placed next to hydrogen, in group 2. Helium has a full outer shell of electrons and behaves like all of the other group 18 'noble gases' – it is very unreactive.

Quick check 4.4

1 Decide whether the following statements are true or false:
   a Periods are the horizontal rows in the periodic table.
   b Lithium is in period 1.
2 Give the position of the following elements in the periodic table:
   a copper (Cu)
   b calcium (Ca)
   c neon (Ne)
   d aluminium (Al).

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Blocks of the periodic table

The periodic table can be further split up into different blocks.

Metals, non-metals and metalloids

The elements can be classified as metals, non-metals or metalloids (which share some properties of both metals and non-metals).

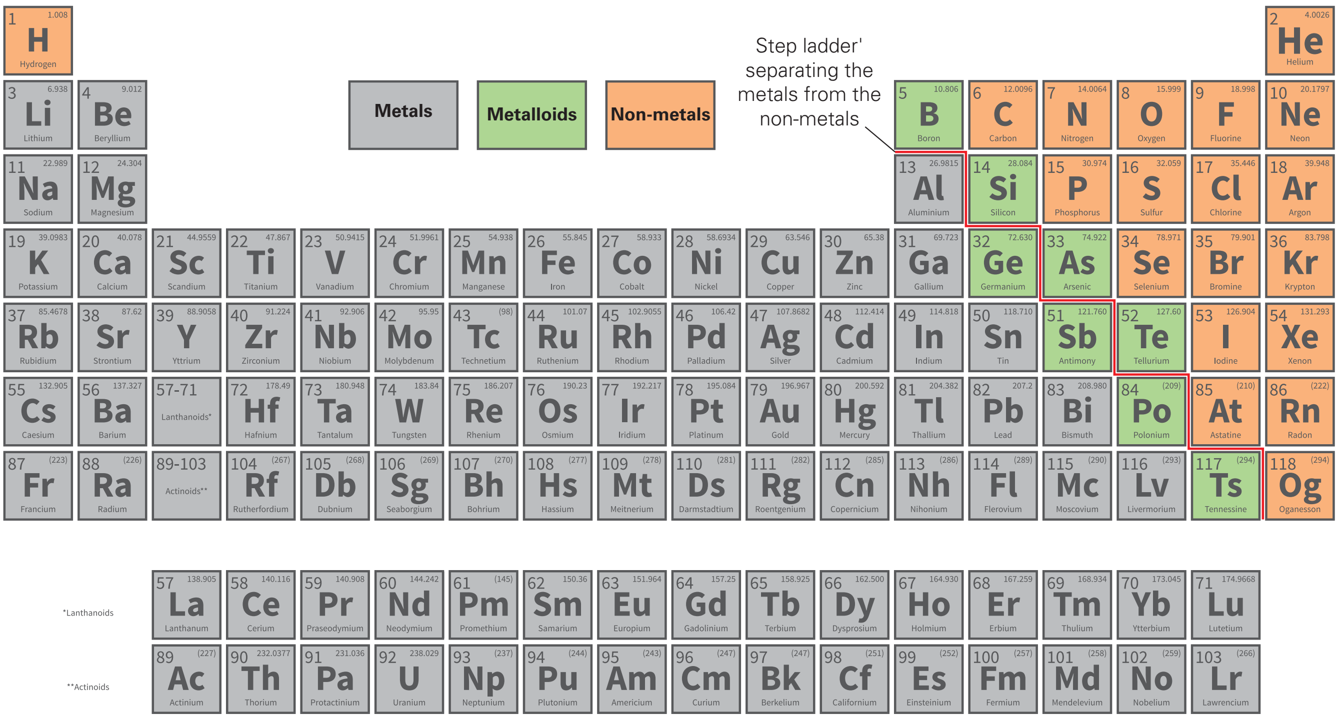

Figure 4.12 Three colours show the elements classified as metals, non-metals and metalloids.

VIDEO
Name a reactive group of metals

Metals

Metals make up the majority of the elements in the periodic table. In fact, 91 of the 118 known elements are metals, and they sit on the left-hand side of the table. Almost all the metals in the periodic table are solids. The exception is mercury (Hg), which is a liquid at room temperature.

Metals have particular properties; they:

- are shiny
- have high melting and boiling points
- are malleable, meaning they can be beaten into shapes
- are ductile, meaning they can be bent into long, thin wires
- are good conductors of heat and electricity.

Figure 4.13 Tiny droplets of liquid mercury, the only liquid metal

Transition metals

The **transition metals** are a large block of metals containing the elements from groups 3 to 12 in periods 4 to 7. They are generally hard and dense. Iron, silver, copper and gold are important transition metals.

transition metals the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

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Science as a human endeavour 4.1

Killer asteroid killing cancer?

How can a metal found in the asteroid that may have killed the dinosaurs help in our fight against cancer? Transition metals have been used in medical treatments for decades now. The transition metal platinum has been used for many years in the chemotherapy drug cisplatin. This has led to scientists researching the potential applications of other transition metals such as iridium for use in the medical industry.

For example, iridium is the world's second densest metal. It is rarely found on Earth, but has been brought to us from space via asteroids, including the giant asteroid whose impact is thought to have led to the extinction of the dinosaurs.

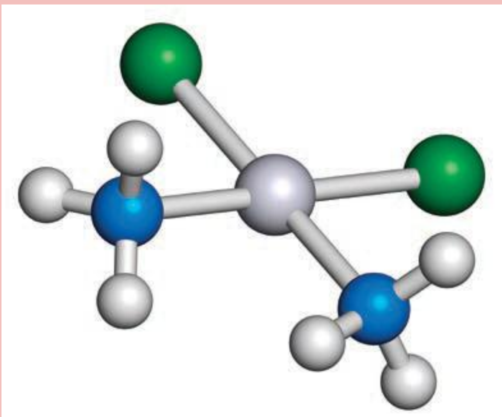

Figure 4.14 Platinum is used in the anti-cancer drug cisplatin, $Pt(NH_3)_2Cl_2$.

Figure 4.15 Asteroids have brought the transition metal iridium to Earth's surface.

Destroying cancer cells using iridium

Iridium can be used to kill cancer cells by filling them with a deadly version of oxygen. Oxygen in the form of O_2 is harmless and, of course, beneficial to cells. But when O_2 is converted into a single oxygen atom (O), it is poisonous and can actually kill cells. This can be done to treat cancer without harming healthy cells. The process works by giving patients a drug which contains the iridium. Trials on a model tumour found that the iridium drug had infused into every layer of the tumour. A visible laser is shone on to the skin where the cancer is located. The laser activates the drug causing it to produce the harmful form of oxygen which can kill cancer cells. This is a very promising breakthrough for cancer patients.

Iridium as an early detection method for some cancers

Dopamine is an important chemical in the body that is involved in transmitting nerve impulses.

Receptors of dopamine have long since been implicated in various cancers, such as lung, breast and colon cancers. Iridium-based probes developed by researchers are able to selectively bind to dopamine receptors, lighting them up and making them visible to the naked eye. This enables constant monitoring and tracking of the receptors' activity. The probes could therefore potentially offer a diagnostic tool for early screening of some cancers.

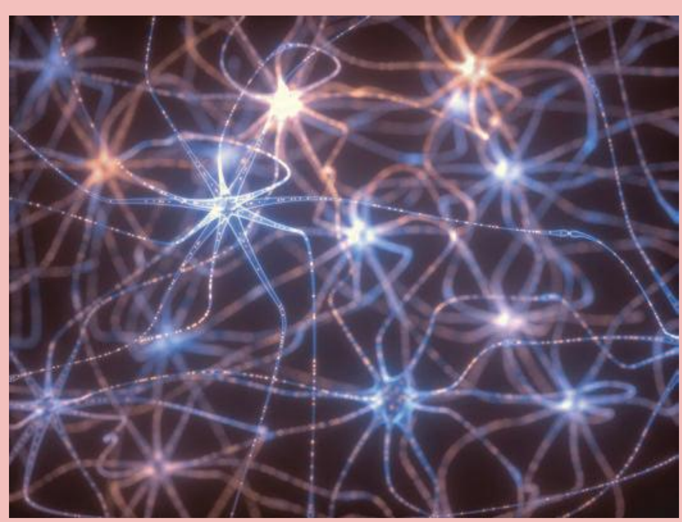

Figure 4.16 Dopamine is a chemical transmitter in the nervous in the system.

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Lanthanides and actinides

The lanthanides and actinides are elements that make up the inner transition metals. They are called such because of their placement on the periodic table between non-metals and metals.

Lanthanides or rare earth metals are all silvery white metals. They include elements with atomic numbers from 58 to 71.

The actinides contain elements with atomic numbers from 89 to 103 and are primarily synthetic elements with a few exceptions, such as uranium. Uranium is a toxic and naturally radioactive metal that is best known for its use in nuclear power plants and nuclear weapons.

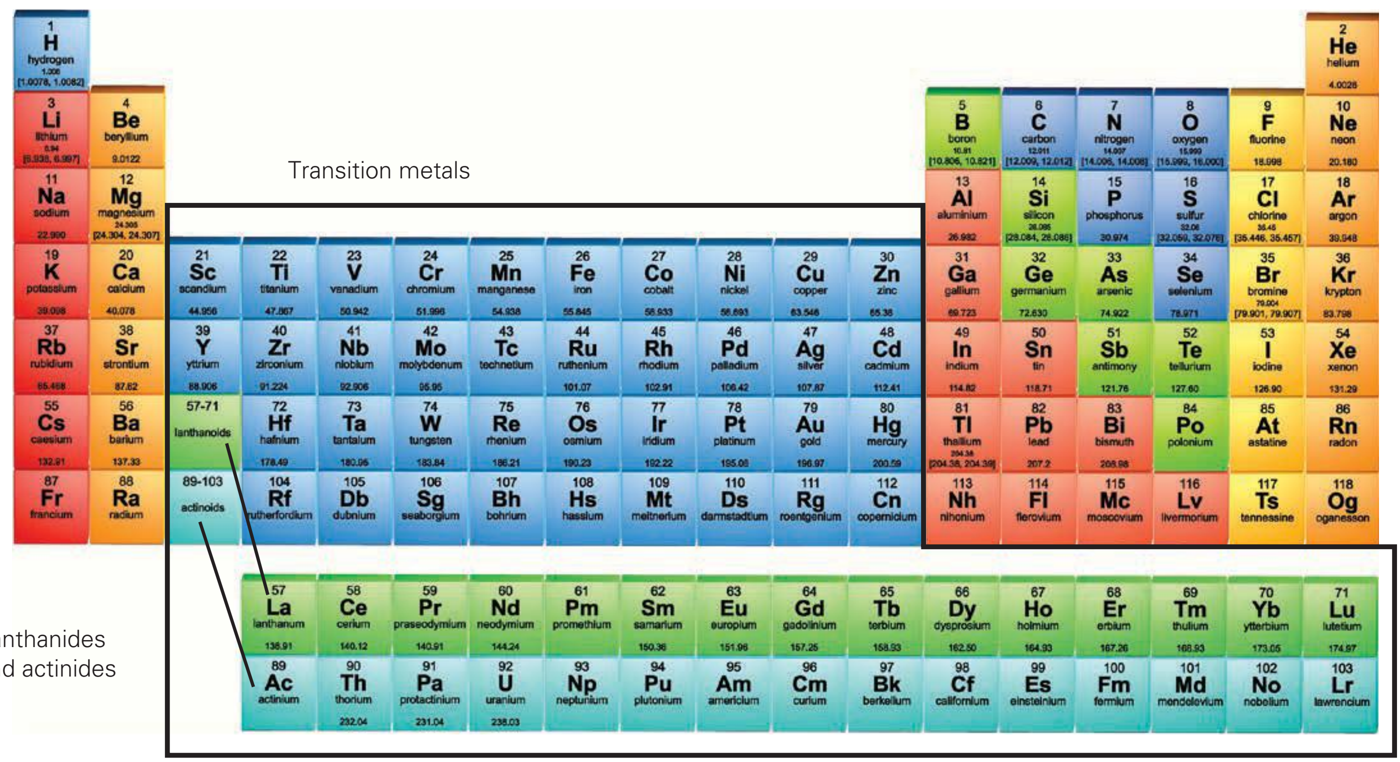

Figure 4.17 Location of the transition metals, lanthanides and actinides

Quick check 4.5

1. The block of elements in the middle of the periodic table, containing groups 3 to 12 is called the:
   - **A** metalloids.
   - **B** lanthanides.
   - **C** transition metals.
   - **D** actinides.
2. Which of the following is a transition metal?
   - **A** sodium (Na)
   - **B** tungsten (W)
   - **C** platinum (Pt)
   - **D** aluminium (Al)
3. True or false? Lanthanides and actinides are inner transition metals.

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Non-metals

Non-metals are located on the right-hand side of the periodic table (except hydrogen). There are fewer non-metals than metals, but their properties are much more varied. They consist of one liquid – bromine (Br) – five solids and 11 gases.

Figure 4.18 A bottle of liquid bromine, the only liquid non-metal

In general, non-metals have particular properties; they:

- are dull
- are brittle, meaning they will shatter when bent
- have low melting and boiling points
- are poor conductors of heat and electricity.

Metalloids

The elements located between the metals and non-metals, are called **metalloids**. There are seven metalloids: boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), tellurium (Te), and polonium (Po). Sometimes astatine (At), carbon (C) and other nearby elements are included as the list of metalloids is not agreed upon. These elements tend to look like metals, but behave more like non-metals. For example, tellurium is shiny and a fair conductor of electricity like a metal, but brittle like a non-metal.

metalloids
elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

Figure 4.19 Arsenic, found in rock, is a metalloid.

Quick check 4.6

1. On which side of the periodic table are metals located?
2. Copy and complete this sentence:
   The name given to elements which behave like metals and non-metals is ___________.
3. Decide whether the following statements are true or false. If false, provide reasons why.
   - a Metals have high melting points.
   - b Almost all non-metals are liquids.
   - c There are more non-metals than metals on the periodic table.
   - d There are only two liquid elements on the periodic table.
   - e Mercury is the only metal that is liquid at room temperature.

Practical 4.2

Comparing the properties of metals and non-metals

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

Aim

To compare the properties of metals and non-metals.

Materials

- samples of various metals and non-metals; for example, zinc, magnesium, iron, carbon, sulfur and silicon (sulfur and silicon to be demonstrated by your teacher only)

continued…

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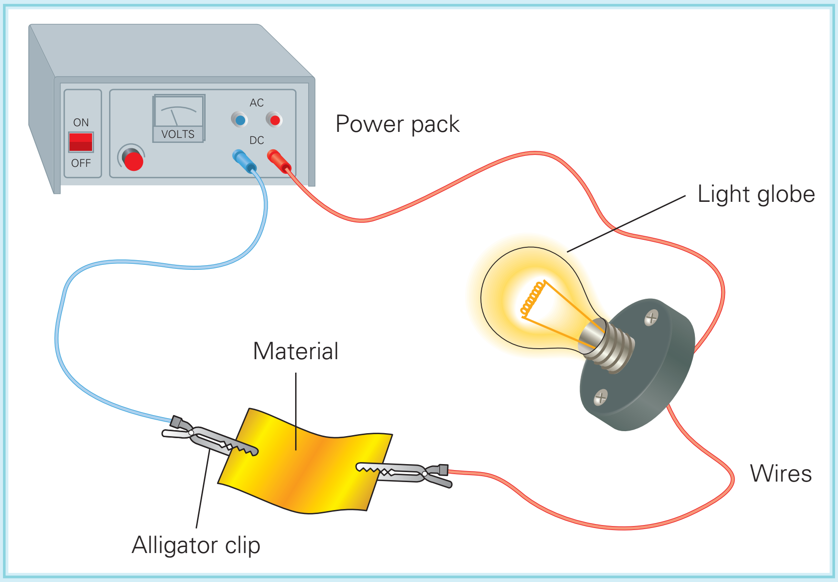
...continued

- 4 × test tubes
- test tube rack
- power pack
- light globe
- 3 × wires
- 2 × alligator clips
- steel wool



Method

1. Copy the results table below.
2. Use the steel wool to rub the surface of each material. After rubbing, decide whether the material is shiny or dull, and record your results.
3. Can you bend each material without it snapping? Record your results whether your material is malleable (bends without snapping) or brittle (snaps when bent).
4. Fill each test tube half full with water and add the materials. Record your observations. Does it react? Does it dissolve?
5. Does your material sink or float in the water? Determine whether you think the material is dense and record your results.
6. Set up a simple circuit as shown in the diagram.
7. Add each material in turn to the circuit using the alligator clips. Determine if the material conducts electricity, and record your results.

Results

Element	Shiny or dull	Malleable or brittle	Reaction with water	Is it dense?	Does it conduct electricity?	Metal or non-metal

Evaluation

1. Using your results from each test, determine whether you think the materials are metals or non-metals and add to the final column in your results table.
2. How easy was it to determine the identity of the elements by using experimental observations rather than just looking at the periodic table?
3. Were there any elements that you found difficult to group? Why do you think this was the case? Use the periodic table to help you.

Conclusion

1. Make a claim about the properties of metals and non-metals based on this experiment.
2. Support your statement by using the data you gathered and include potential experimental faults.
3. Explain how data supports your statement.

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Table 4.3 summarises the properties of metals and non-metals.

Metals	Non-metals
Shiny	Dull
Dense	Less dense
Good conductors of heat and electricity	Poor conductors of heat and electricity
Malleable	Brittle
High melting and boiling points	Low melting and boiling points
Ductile	

Table 4.3 Properties of metallic and non-metallic elements

Section 4.2 questions

QUIZ

Remembering

1 How many groups are there on the periodic table?

2 Name an element in:

- a period 3
- b group 15
- c the transition metals
- d the lanthanides.

3 Hydrogen and helium are in which period?

Understanding

4 Classify the following elements as either metals or non-metals.

Element	Metal or non-metal
Oxygen (O)	
Boron (B)	
Aluminium (Al)	
Iodine (I)	
Nickel (Ni)	

Applying

5 Identify the element that is in:

- a period 4, group 6
- b period 2, group 13
- c period 5, group 18
- d period 7, group 1
- e period 6, group 15.

Analysing

6 Compare and contrast metals and non-metals.

7 Categorise the following elements as transition metals, lanthanides, actinides, metals, metalloids or non-metals.

Element	Category
Promethium (Pm)	
Rubidium (Rb)	
Arsenic (As)	
Thorium (Th)	
Vanadium (V)	

continued…

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...continued

Evaluating

8 Explain why elements close to the 'step ladder' separating metals from non-metals are classified as metalloids.

9 Decide what happens to the number of protons as you move to the right across a period.

10 A new element is discovered that:
- is shiny
- conducts electricity
- is malleable
- sinks when placed in water.

Deduce from these properties whether it will be categorised as a metal or a non-metal.

4.3 Electronic configurations of the elements

WORKSHEET

Where are the electrons?

In Year 9, you learned about the atomic model, so you should be able to recall that electrons are located in shells which 'orbit' the centre of the atom, known as the nucleus. You should also know that the nucleus houses the protons and neutrons of an element. You can work out how many electrons an element has by finding its atomic number or its position on the periodic table. Remember the atomic number is the lowest number given for a particular element.

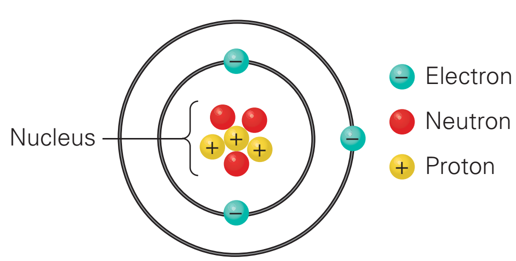

Figure 4.20 The Bohr atomic model

The way electrons arrange themselves around the nucleus of an atom is not random; they arrange themselves in a very organised and important structure that affects the properties of elements. Electrons generally fill the **electron shell** closest to the nucleus first. Electrons, being negatively charged, are strongly attracted to the positively charged nucleus, which is why the closest shell is filled first. As this is a small shell, it can only house two electrons. Being in this inner shell is the lowest energy level for electrons. The second shell away from the nucleus is bigger and can hold a maximum of eight electrons. The third shell is bigger still and can hold a maximum of 18 electrons, and the fourth can hold 32 electrons. Electrons situated in shells furthest away from the nucleus are at higher energy levels than electrons in closer shells.

electron shell houses the electrons which orbit the nucleus of an atom

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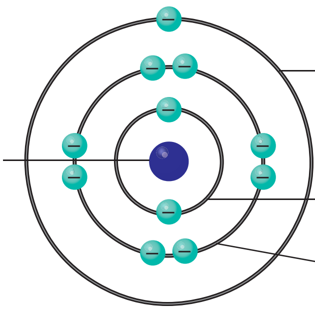

Figure 4.21 Diagram of how electrons arrange themselves in shells around the nucleus

Table 4.4 summarises how many electrons can be housed in each electron shell.

Shell	Maximum number of electrons it can house
1st (lowest energy level)	2
2nd	8
3rd	18
4th (highest energy level)	32

Table 4.4 The number of electrons housed in each shell

Quick check 4.7

1 What is the name of the structure in an atom that houses electrons?
 A Shell **C** Neutron
 B Proton **D** Nucleus

2 Complete the sentence by picking the correct words:
 The electron shell *closest to/furthest from* the nucleus is the *first/last* to be filled.

3 What is the maximum number of electrons which can be housed in the following?
 a First shell **c** Third shell
 b Second shell **d** Fourth shell

Electronic configurations of the elements

The **electronic configuration** shows how the electrons for a particular element are arranged. When electrons fill shells, they always start from the lowest energy level (the electron shell closest to the nucleus). This means that atoms are always at their lowest energy level or **ground state**.

electronic configuration
the arrangement of an atom's electrons in the shells around the nucleus

ground state
the lowest energy level of an atom

Magnesium (Mg) has an atomic number of 12, so it has 12 electrons. It has an electronic configuration of 2.8.2. This shows that there are two electrons in the first shell, eight in the second and two in the third. Figure 4.22 shows the electron arrangement of a magnesium atom. As you can see from the diagram, shell four is empty, as magnesium does not have enough electrons for this shell to be required.

The sum of all the numbers in the electronic configuration should add up to the total number of electrons in that atom.

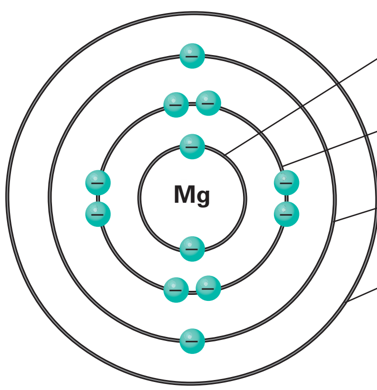

Figure 4.22 The electronic configuration of magnesium

Calcium (Ca) is located directly beneath magnesium in the periodic table, and has a configuration of 2.8.8.2, with a total of 20 electrons. You might expect that, given the third shell has a capacity of 18 electrons, calcium would follow the filling rule and have a configuration of 2.8.10. But elements consider eight electrons in a shell to be stable, so it actually houses the remaining two electrons in the fourth shell. Potassium (K) also does this, and has an electronic configuration of 2.8.8.1.

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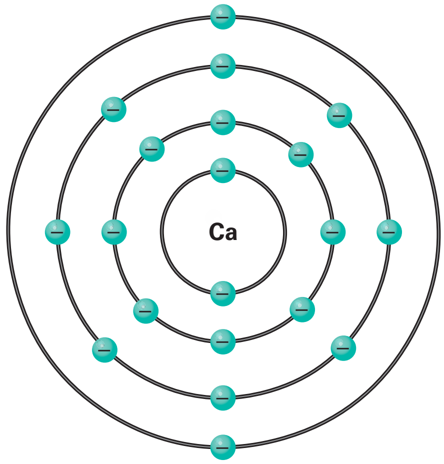

Figure 4.23 The electronic configuration of calcium (2.8.8.2)

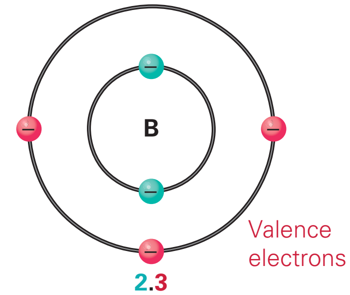

Figure 4.24 Boron (B) has an electronic configuration of 2.3. It therefore has three valence electrons (red).

Quick check 4.8

1. What is the name for atoms when they are at their lowest energy level?
2. How many electrons does an element with an electronic configuration of 2.8.3 have?
3. What is the atomic number of an element which has 18 electrons?
4. What is the electronic configuration of oxygen (8 electrons)?
   - **A** 2.4.2
   - **B** 1.3.4
   - **C** 1.7
   - **D** 2.6

Electronic configuration and element properties

The way atoms react is largely determined by the arrangement of their electrons. Protons and neutrons are situated in the centre of the atom and therefore are not affected when particles bump into one another during chemical reactions. It is the electrons, mainly the outermost electrons, which are the most affected.

The outermost electrons in an atom are called **valence electrons**. It is these electrons in the outer shell that are most affected when atoms bump into one another during chemical reactions.

valence electrons the electrons in the outer shell of an element

The biggest influence on an element's chemical and physical properties is the number of electrons in the outermost shell. This means that elements with the same number of valence electrons are grouped together in the periodic table. For example, all elements in group 1 have one valence electron. Their electronic configurations all end in the number one. The last digit of group 17 tells us that elements in this group have seven valence electrons. This handy trick works for all the elements up to calcium (Ca).

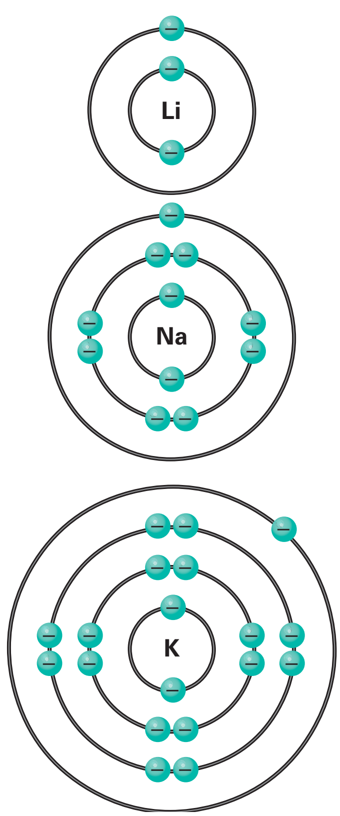

Figure 4.25 These elements in group 1 have one valence electron.

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We can also determine the period an element is in using its electronic configuration. For example, if an electronic configuration contains two numbers (as for lithium), then it is in period 2.

Quick check 4.9

1 What does the term valency relate to?
2 The reactivity of a chemical element is determined by the number of?
 A Electrons
 B Protons
 C Valence electrons
 D Neutrons
3 Which group does the element with the electronic configuration 2.8 belong to, and why?
4 Which period does the element with the electronic configuration 2.8.4 belong to, and why?

Excited electrons

We have already discussed that when electrons fill electron shells they start from the lowest energy level, which is the shell closest to the nucleus. We have referred to atoms arranged in this way as being at their ground state, or lowest energy level. What happens, though, when electrons gain energy?

When electrons gain energy (for example, by a flame or a spark), it can cause electrons to jump to higher energy levels, such as to the next electron shell. When electrons fall back to ground state, this energy is lost as light energy.

The distance between shells affects the amount of energy that is required to excite an electron. This means that the light energy emitted when they fall back to ground state, varies. The colour of light depends on the amount of energy emitted by the electron falling back to ground state.

We can use the colour of light emitted when electrons are excited as a way of identifying some elements.

Figure 4.26 Copper compounds burn with a characteristic green coloured flame.

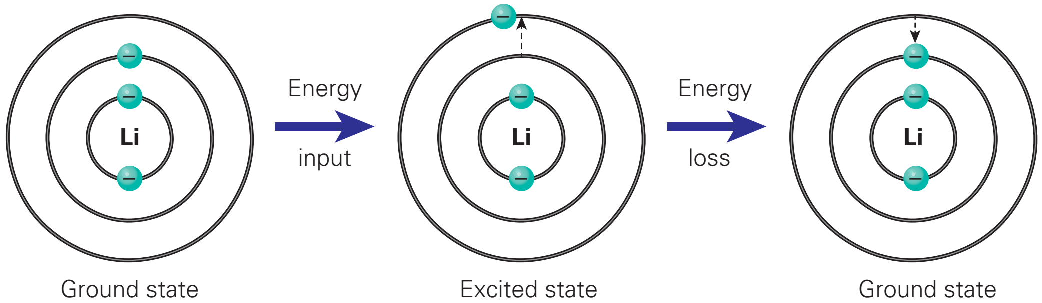

Figure 4.27 What happens to atoms when electrons gain energy?

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Figure 4.28 A gas stove-top burner

Gas stove-top fun

Try this 4.1

If you have a gas burner, with your parent or guardian's permission sprinkle a little bit of table salt onto a lit burner. Notice the colour change.

Table salt is made of a compound containing sodium metal. Excited sodium electrons emit a particular colour of light when they return to ground state.

VIDEO
Name a use of the emission spectrum

Spectroscopes

Explore! 4.3

Spectroscopes separate white light into a very wide spectrum of colours called a continuous spectrum. When spread very wide, black lines can appear in the spectrum showing the specific energies that are being absorbed. The pattern of black lines corresponds to a particular element. This is called an *absorption* spectrum.

In the flame test practical, you will identify elements based on the colour of light emitted from a flame. We can also identify elements by their *emission* spectra.

The pattern of lines on an emission spectrum correspond to a particular element. They are exactly like barcodes!

(Note: you will see this mentioned in relation to stars in Chapter 7.)

1 What are the main differences between an emission spectrum and an absorption spectrum?
2 Find out which colour of light has the highest energy.
3 Deduce what is present in the unknown emission spectrum opposite.
4 Which method (spectroscopes or flame colour) of identifying flame colour do you think is more accurate, and why?

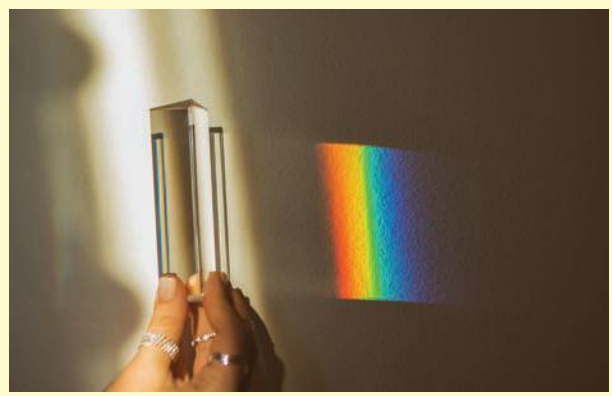

Figure 4.29 White light passes through a prism and is split into a continuous (visible) spectrum.

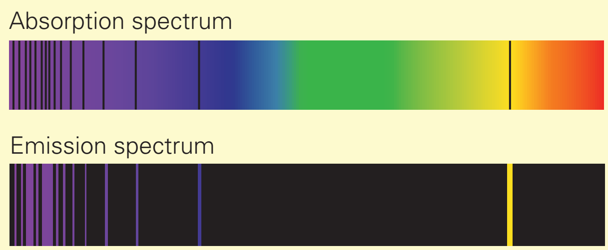

Figure 4.30 The absorption spectrum (top) and emission spectrum (bottom) of a particular element.

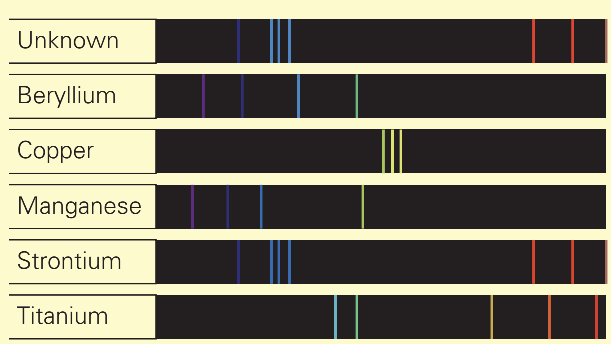

Figure 4.31 We can compare emission spectra to find out the identity of an unknown element.

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Did you know? 4.1

Fireworks

The colours created by fireworks are formed when excited electrons drop back to ground state. The energy they emit corresponds to a particular colour of light. In the fireworks image to the right, the lilac colours you can see come from potassium compounds, the red colours come from strontium compounds and the orange colours come from calcium compounds.

Next time you are at a fireworks display, how about impressing your friends by naming the metal compounds that have been used to create the different colours!

Figure 4.32 Fireworks rely on the energy emitted from excited electrons dropping back to ground state.

Quick check 4.10

1 What causes electrons to become excited and move up energy levels?
2 What type of energy is emitted when electrons return to ground state?
  A Heat B Kinetic C Light D Chemical
3 How can we identify the type of element present when electrons are excited?

Practical 4.3: Self-design

Flame tests

Aim

To identify unknown metals within a compound.

Materials

- solutions of copper chloride, potassium chloride, sodium chloride, lithium chloride and strontium chloride
- unknown solutions labelled A, B and C (A, B and C should each contain one of the known solutions above)
- wooden splints
- Bunsen burner
- bench mat
- matches
- emission spectrometer

Method

1 Copy the results tables below.
2 Design an experiment to test the flame colours of the known solutions.
3 Use these results to determine the metal present in the unknown solutions, labelled A, B and C.

Results

Metal compound	Colour in flame
Copper chloride	
Lithium chloride	
Strontium chloride	
Sodium chloride	
Potassium chloride	

continued…

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...continued

Solution	Colour in flame	Identity of metal
A		
B		
C		

Evaluation

1 What provides the energy in this experiment for electrons to be excited to the next energy level?
2 Why is it better to use a blue, roaring flame than a yellow, safety flame to observe the colour of light emitted?
3 Discuss the results that you would obtain if the same experiment was done with water. What could you conclude about the elements in water?
4 Describe why different colours of light were observed for compounds containing different metallic elements.
5 Describe the appearance of the spectra of different metals.

Conclusion

1 Make a claim about the identities of the unknown substances based on this experiment.
2 Support your statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports the statement, with reference to electronic configurations and light emission.

Valency and bonding

The number of valence (outer shell) electrons an atom possesses determines how it will bond with other atoms. Metals, located on the left side of the periodic table, have fewer than four electrons in their outer shell. Metals tend to want to lose electrons and obtain a full, outer shell – this makes them stable. When they lose electrons, they form positively charged **ions** (known as **cations**) represented like this:

ion
a charged version of an atom, formed from the loss or gain of electrons

cation
a positively charged ion formed from the loss of electrons

Na^+ or Mg^{2+}

A single + sign indicates the atom has lost one electron, while a number before the + sign indicates how many electrons were lost.

Non-metals, located on the right-hand side of the periodic table, have outer shells that are almost full. To achieve stability, they tend to gain electrons – forming negatively charged ions (known as **anions**) represented like this:

anion
a negatively charged ion formed from the gain of electrons

S^{2-} and F^-

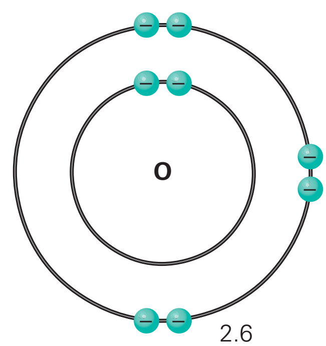

Figure 4.33 An oxygen atom has an electronic configuration of 2.6. It tends to gain two electrons to achieve a stable outer shell, giving it an electronic configuration of 2.8. It now has a net negative charge and is represented as O^{2-}.

A single – sign indicates the atom has gained one electron, while a number before the – sign indicates how many electrons were gained.

Cations and anions are collectively known as ions; that is, a charged version of an atom.

An atom's willingness to lose or gain electrons is known as its reactivity. This concept will be further explored in Section 4.5.

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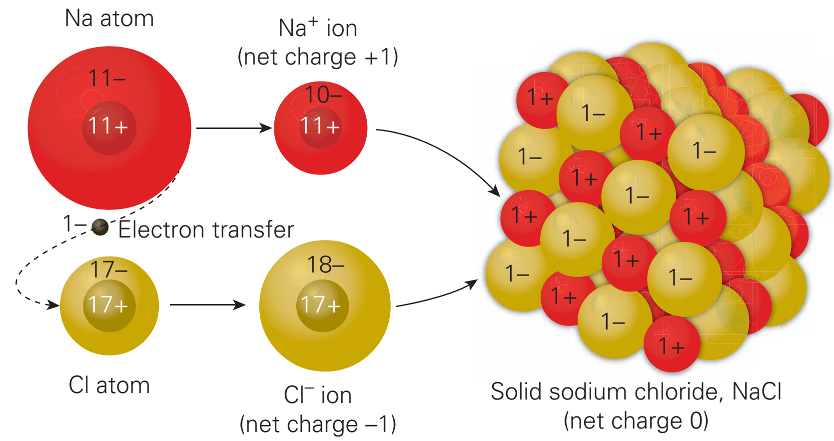

Figure 4.34 A sodium atom donates an electron to a chlorine atom. The sodium atom now forms a positively charged cation and the chlorine atom forms a negatively charged anion. These ions are attracted and bond into an ionic compound. A crystal lattice configuration is a common way to organise an ionic compound.

Ionic bonding

Positively charged cations are attracted to negatively charged anions, and this attraction is known as an **ionic bond**. Strong electrostatic forces bond the molecules together into an ionic compound, which tend to take on a lattice structure. Because the bond is strong, ionic compounds tend to have high melting temperatures. For example, table salt (NaCl) has a melting point of 801°C.

ionic bond
a strong bond between an anion and a cation, formed via electron donation

Covalent bonding

When two non-metals bond together, they both require some electrons to complete their outer shell but neither is prepared to lose theirs! Instead, these two atoms can share electrons, forming a molecule which is held together by a strong **covalent bond**.

covalent bond
a strong bond almost always between two non-metals who share electrons, forming a molecule

An oxygen (O) atom has an electronic configuration of 2.6. As we have seen previously, it requires two electrons to complete its outer shell. Instead of receiving electrons from a metal atom and forming an ionic bond, it can instead share electrons with another non-metal, such as hydrogen, and form a covalent bond. It will need to do this with two hydrogen molecules in order to have a stable outer shell. Refer to the molecule in Figure 4.35: each hydrogen atom has a full outer shell (two electrons) and the oxygen atom has a full outer shell (eight electrons). Each bond in a covalent molecule is actually a shared pair of electrons.

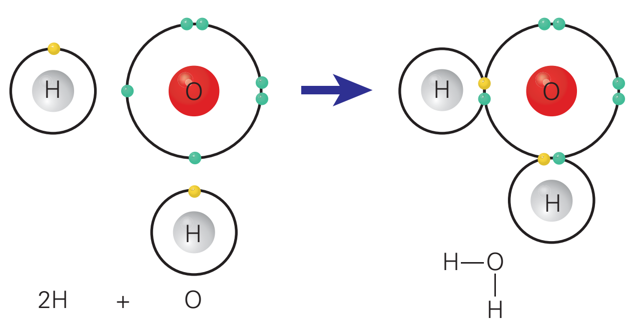

Figure 4.35 Two hydrogen atoms and an oxygen molecule covalently bond to form a water molecule.

Quick check 4.11

1. Define these terms:
   a. ion
   b. cation
   c. anion.
2. Explain why certain elements are likely to form cations while other tend to form anions.
3. Does covalent bonding involve donation or sharing of electrons?

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QUIZ

Section 4.3 questions

Remembering

1 Copy and complete the following table:

Electron shell	Maximum number of electrons housed
1st	
	32
3rd	
	8

2 Why is the shell closest to the nucleus filled with electrons first?

3 Give the elements which have the following electronic configurations:
- a 2.8.1
- b 1
- c 2.7
- d 2.8.8.

4 For the electronic configurations listed previously, give:
- a the number of valence electrons
- b the period they are in
- c the group they are in.

5 What are the electronic configurations for the following elements?
- a Helium (He)
- b Beryllium (Be)
- c Phosphorous (P)
- d Potassium (K)

Understanding

6 The electronic configuration of carbon is 2.4. List all the information you can determine from this.

7 Describe and explain the order in which electrons fill shells around the nucleus.

8 Compare the number of protons and electrons in an uncharged atom with those in an ion.

Applying

9 Apply your knowledge of electron arrangement to explain what is significant about the electronic configurations of group 18 elements.

10 Chlorine has the electronic configuration 2.8.7. Construct a diagram showing the arrangement of the electrons within a chlorine atom.

11 Construct a diagram which shows an example of happens when electrons are excited from ground state.

Analysing

12 A student was instructed to conduct a flame test using copper chloride and strontium chloride. Discuss the results they would obtain.

13 Distinguish between valence electrons and other electrons of an atom.

14 Compare how an oxygen atom would participate in an ionic bond versus a covalent bond.

Evaluating

15 Helium, a group 18 element, has the electronic configuration 2, meaning that it has two valence electrons. Why is helium not located next to hydrogen with the other group 2 elements, which also have two valence electrons?

16 Explain why atoms in the same group have similar properties.

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4.4 Special groups of elements

When scientists were trying to organise the elements, their aim was to group together elements that had similar properties. In the modern day periodic table, elements with similar properties are grouped together in columns, which are known as groups. Although elements in the same group have similar properties, they are not identical to one another. Take group 14 as an example. It contains a non-metal (carbon, C), two metalloids (silicon, Si, and germanium, Ge) and two metals (tin, Sn, and lead, Pb).

WORKSHEET

You have already read about the differing behaviours of metals and non-metals, so you may be wondering why they are put in the same group as they seem to be so different. They are grouped this way because they all have the same number of valence electrons, so they bond with other substances in the same way. You can also see in Figure 4.36 that the elements in group 14 look similar.

The following section will look at four special groups in the periodic table and explain why they are similar to one another.

The alkali metals (group 1)

The **alkali metals** (group 1) make up the first group of the periodic table. The elements lithium (Li), sodium (Na),

alkali metals
group 1 metals that form an alkaline solution when they react with water


Carbon (C)


Silicon (Si)


Tin (Sn)


Germanium (Ge)


Lead (Pb)

Figure 4.36 Group 14 elements

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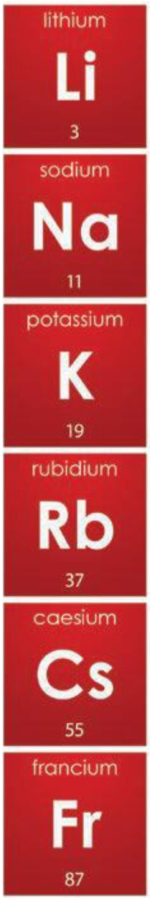

Figure 4.37 The elements in group 1 are also known as the alkali metals.

potassium (K), rubidium (Rb), caesium (Cs) and francium (Fr) all belong to the alkali metals. We will focus on the first three elements of this group as these are the elements that you will have access to in the classroom; you will find out why later on in the section.

Physical properties

Unlike most metals you will have come across, lithium (Li), sodium (Na) and potassium (K) are soft and can be cut with a knife. When they are cut open, they have a shiny appearance on the inside compared to their dull outer surface. This is because their outer surfaces readily react with oxygen in the air, forming dull metal oxides.

This reaction can be written as the following word and balanced formula equations.

$$\text{sodium} + \text{oxygen} \rightarrow \text{sodium oxide}$$

$$4Na + O_2 \rightarrow 2Na_2O$$

Figure 4.38 A piece of sodium metal which has been cut by a knife. It is shiny on the inside and dull on the outside.

When placed in water, lithium, sodium and potassium will float as they are less dense than water. Again, this is unlike most other metals you may have encountered.

Reactivity

All group 1 metals are highly reactive due to their one valence electron. Elements are stable when they have a full outer shell of electrons, so group 1 metals are more than happy to react with other substances and give up their one valence electron. When they do this they all form ions with a +1 charge.

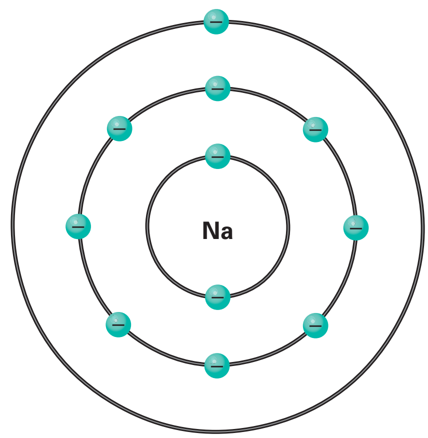

Figure 4.39 The one valence electron makes group 1 elements highly reactive.

The reactivity of group 1 metals actually increases down the group. This is because it becomes easier to remove the outer electron as the atom gets bigger and the outer shell gets further away from the nucleus.

Group 1 elements readily react with group 17 elements forming white salts – one of these salts being table salt that you put on your chips!

Figure 4.40 Table salt is formed when sodium reacts with chlorine to form sodium chloride.

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The following word and balanced formula equations show how sodium (Na) reacts with chlorine (Cl) to form table salt (sodium chloride, NaCl).

$$\text{sodium} + \text{chlorine} \rightarrow \text{sodium chloride}$$

$$2Na + Cl_2 \rightarrow 2NaCl$$

To show how other alkali metals and group 17 elements react with each other, all you need to do is substitute their chemical names and symbols into the two previous equations.

Alkali metals are most famous for their reaction with water and this is where they get their name. All group 1 metals react violently with water, producing hydrogen gas and an alkaline solution.

Did you know? 4.2

Do not touch group 1!

At school, all the group 1 metals will be stored in bottles of oil and your teacher will never touch them with their hands. They are so reactive that even coming into contact with water vapour in the air and sweat on your hands, can cause them to react violently!

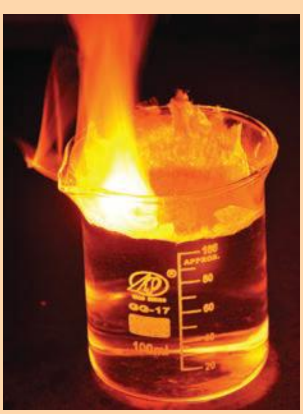

Figure 4.41 What happens when sodium reacts with water? Here the hydrogen gas produced has ignited.

The word and balanced formula equations show what happens when sodium reacts with water.

$$\text{sodium} + \text{water} \rightarrow \text{sodium hydroxide} + \text{hydrogen}$$

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

You can use these equations to predict what will happen when other alkali metals react with water.

Quick check 4.12

1 Why are group 1 metals also known as alkali metals?
2 Why do alkali metals form 1+ ions when they react with other substances?
3 Write a word equation for lithium reacting with fluorine.
4 Why are alkali metals shiny on the inside and dull on the outside?
5 True or false?
   a Alkali metals are denser than water so they float.
   b Alkali metals react with oxygen to form metal oxides.
   c Alkali metals are hard.
6 Other than an alkali, what other product is formed when alkali metals react with water?
7 Which metal is the most reactive in group 1?

Practical 4.4: Teacher demonstration

Investigating the reactivity of group 1 metals

Aim

To determine the order of reactivity of group 1 metals.

Materials

- safety screen
- disposable gloves
- large, thick-walled glass bowl
- lithium and sodium metals
- scalpel
- white tile
- blotting paper
- universal indicator
- tweezers

Method

1 Students write a prediction in their books stating which they think will be the most reactive metal out of lithium, sodium and potassium.
2 Students copy the results table on the next page.
3 Fill the large glass bowl half full with water and add a few drops of universal indicator until the colour can be seen throughout the liquid.

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4 Using the tweezers, take a piece of lithium from its bottle and place it on the white tile.
5 Use the scalpel to cut off a small piece of the metal and observe the appearance of the metal on the inner and outer surfaces.
6 Making sure that all students are behind the safety screen, add the small piece of metal to the water and record your observations.
7 Repeat for sodium.
8 Now students predict what the outcome would have been if we had reacted potassium with water, and record their prediction in the results table.

Results

	Hard or soft	Appearance when cut	More or less dense than water	Observations during reaction
Lithium				
Sodium				
Potassium				

Evaluation

1 Describe the purpose of the universal indicator.
2 Explain the decision to use tweezers rather than hands to pick up the metals.
3 Give three ways in which you can determine the reactivity of each of the metals investigated.
4 Why was a safety screen necessary when conducting this experiment?
5 How did you determine whether the metals were more or less dense than water?
6 Explain why the metals get more reactive as you go down group 1.

Conclusion

1 Make a claim regarding the varying levels of reactivity of the group 1 metals based on this experiment.
2 Support your statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports your statement.

The alkaline earth metals (group 2)

Group 2 metals are also known as the **alkaline earth metals**. This group contains the elements beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba) and radium (Ra).

alkaline earth metals group 2 metals that form an alkaline solution when they react with water

Physical properties

The naturally occurring alkaline earth metals tend to be shiny and silvery white, and they have low melting and boiling points. Magnesium and calcium are abundant in Earth's crust and are considered essential to all living organisms.

Reactivity

All group 2 elements are reactive, but not as reactive as group 1 elements. This is because they have two valence electrons compared to one in group 1 elements. Group 2 elements therefore form ions with a charge of +2 as they lose two electrons when they react.

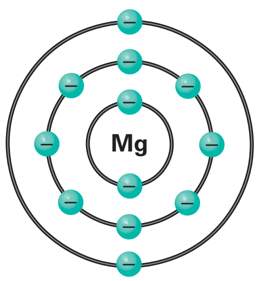

Figure 4.42 Group 2 elements have two valence electrons.

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Just like group 1 metals, alkaline earth metals also react with oxygen to form metal oxides and with group 17 elements to form metal salts. Table 4.5 shows the names and formulas of the products formed.

Element	Product formed when reacting with oxygen	Product formed from reacting with chlorine
Beryllium (Be)	Beryllium oxide BeO	Beryllium chloride $BeCl_2$
Magnesium (Mg)	Magnesium oxide MgO	Magnesium chloride $MgCl_2$
Calcium (Ca)	Calcium oxide CaO	Calcium chloride $CaCl_2$

Table 4.5 The products formed when group 2 metals react with oxygen and chlorine

Quick check 4.13

1 List four of the alkaline earth metals.
2 What charge do alkaline earth metals tend to form when they react?

Practical 4.5

Investigating the reactivity of group 2 metals

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To determine the order of reactivity of group 2 metals by reacting them with acid.

Materials

- small samples of calcium and magnesium
- 2 boiling tubes
- 1 delivery tube
- 100 mL measuring cylinder
- 1 large bowl
- hydrochloric acid (1 M)
- retort stand, boss head and clamp
- stopwatch
- tweezers

Method

1 Write a prediction for your investigation. Which metal do you think will be the most reactive: magnesium or calcium?
2 Copy the results table on the next page.
3 Fill the large bowl and the 100 mL measuring cylinder with water.
4 Without losing any water from the measuring cylinder, invert this in the large bowl (your teacher will show you how to do this if you are not sure) and clamp it in place.
5 Fill a boiling tube to a depth of 5 cm with hydrochloric acid.
6 Using tweezers, add a piece of calcium to the acid in the boiling tube.

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7 At the same time, attach the bung of the delivery tube to the boiling tube and place the other end underneath the measuring cylinder so the gas can be collected (see Figure 4.43 below).
8 Start the stopwatch.
9 After five minutes, record the volume of gas produced (that is, the amount of water that has left the measuring cylinder) and any other observations that you made about the reaction in the results table.
10 Repeat the procedure, but this time add magnesium metal.

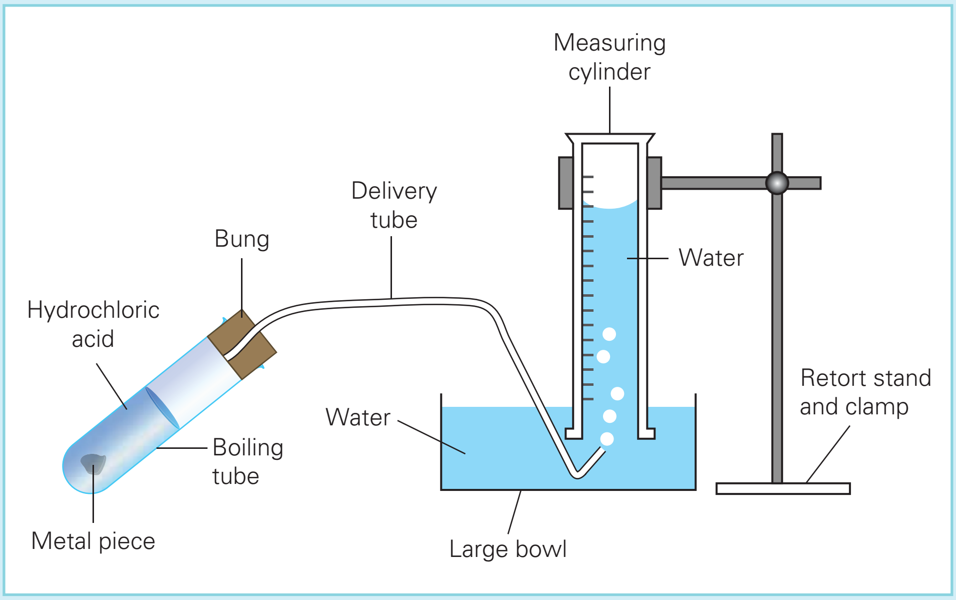

Figure 4.43

Results

	Reaction observations	Volume of gas produced (mL)
Magnesium		
Calcium		

Evaluation

1 From your observations, state whether magnesium or calcium is more reactive.
2 Justify your response.
3 How does the reactivity of group 2 compare to group 1?
4 Why do you think that the reactivity of group 1 metals in this chapter was a teacher demonstration and not a student practical like this one?
5 In Year 9, you learned that when metals react with acids they form a salt and hydrogen. Copy and complete the word equations for the reactions you investigated:
  a ____________ + hydrochloric acid → magnesium chloride + ____________
  b ____________ + hydrochloric acid → calcium chloride + ____________

Conclusion

1 Make a claim about the varying levels of reactivity of the group 2 metals based on this experiment.
2 Support your statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports your statement.

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The halogens (group 17)

halogens
group 17 elements (for example, chlorine and iodine)

Group 17 elements are also known as the **halogens**. This group contains the elements fluorine (F), chlorine (Cl), bromine (Br), and iodine (I).

Physical properties

At room temperature, fluorine and chlorine are gases, bromine is a liquid and iodine is a solid. The halogens are used as bleaching agents and can kill bacteria. This is why chlorine is added to the water in public pools!

Reactivity

All group 17 elements have seven valence electrons. When they react with other substances, they gain an electron to make a full outer shell of eight electrons. This means that they form ions with a charge of -1.

As shown in Table 4.6, the reactivity of group 17 elements decreases as you move down the group. This is because as the size of the atom increases down the group it is harder for it to gain an electron. This is the opposite of group 1.

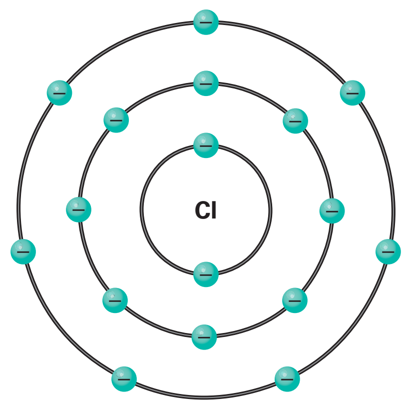

Figure 4.44 Group 17 elements have seven valence electrons.

Halogen	Formula	State	Colour	Melting point (°C)	Boiling point (°C)	Reactivity
Fluorine	F_2	Gas	Pale yellow	−220	−188	Reactivity increases up the group
Chlorine	Cl_2	Gas	Pale green	−101	−35	
Bromine	Br_2	Liquid	Brown	−7.2	58.8	
Iodine	I_2	Solid	Purple	114	184	

Table 4.6 Some properties of the halogens

Going down group 17, the elements become more solid and darker, and the melting and boiling points increase. They all also form molecules that are made up of two atoms – so we call them diatomic, for example, Br_2.

Quick check 4.14

1. Name three elements in group 17.
2. Give the charge of a group 17 ion.
3. State one trend that can be observed going down group 17.

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The noble gases (group 18)

Group 18 elements are also known as the **noble gases**. This group contains the elements helium (He), neon (Ne), argon (Ar), krypton (Kr), and xenon (Xe).

noble gases group 18 elements (for example, neon and krypton)

Physical properties

The noble gases tend to be colourless, odourless and non-flammable. Their applications include neon signs, medical imaging and radiotherapy to treat cancer.

Figure 4.45 Neon is used in fluorescent signs.

Reactivity

Unlike the other groups we have discussed, noble gases are extremely unreactive. They are also called **inert** gases. This is because they all have a full outer shell of electrons; and therefore, do not need to gain or lose electrons to become stable. This also means that they do not form ions.

inert unreactive

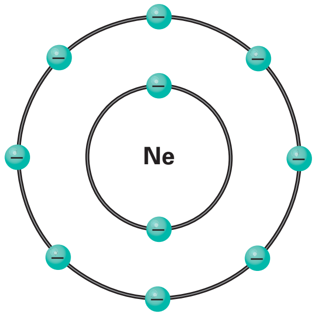

Figure 4.46 Group 18 elements all have eight valence electrons and therefore a full outer shell.

Quick check 4.15

1. Name three elements in group 18
2. Why don't noble gases form ions?
3. What other name is given to noble gases?

Explore! 4.4

The Hindenburg disaster

Figure 4.47 The Hindenburg airship was a revolution in travel.

The Hindenburg airship could travel from Europe to North and South America in half the time of the fastest ocean liner. The airship was filled with hydrogen rather than helium due to export restrictions that the USA imposed against Nazi Germany.

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In 1937, while trying to land in New Jersey, United States, the Hindenburg caught fire and burst into flames. It was completely destroyed. Out of 97 people on board, 35 were killed.

Figure 4.48 The Hindenburg bursting into flames on arrival in New Jersey, United States

1 What was the problem with using hydrogen gas in the Hindenburg airship?
2 Why would helium have been a safer alternative?
3 Why is helium able to be used to fill airships?
4 Helium is heavier than hydrogen and therefore provides less lift. Why is this a problem for airship designers?

Section 4.4 questions

QUIZ

Remembering

1 Give the group number of the following:
   a alkaline earth metals
   b halogens
   c noble gases
   d alkali metals.
2 Recall what happens to the reactivity as you move down group 1.
3 True or false?
   a All halogens are gases.
   b All alkali metals form hydrogen when they react with water.
   c Noble gases do not form ions.
   d Alkaline earth metals form ions with a +2 charge.
   e The general formula of a halogen molecule is X_2.
4 State how many valence electrons each of the following groups has:
   a alkali metals
   b alkaline earth metals
   c halogens
   d noble gases.

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...continued

5 A new element is discovered. It is shown to form an ion with a charge of +2. Which group should it belong to?

Understanding

6 Explain why group 2 elements are less reactive than group 1.
7 Helium does not have eight valence electrons. Explain why it is still classified as a noble gas.
8 Explain why alkali metals are stored in oil or even sealed in inert gases.

Applying

9 Predict the products of the following reactions:
 a potassium and water
 b magnesium and chlorine
 c calcium and oxygen
 d sodium and fluorine.
10 Using the examples already in the text, construct a balanced formula equation for the reaction between:
 a rubidium and water
 b lithium and oxygen.

Analysing

11 Analyse the properties of the halogens in Table 4.6. Astatine (At) is also a group 17 element placed below iodine. Use Table 4.6 to predict some properties of astatine.
12 Classify the following elements as alkali metals, alkaline earth metals, halogens or noble gases:
 a magnesium
 b argon
 c sodium
 d potassium
 e iodine.
13 Compare and contrast the properties and reactions of group 1 and 2 elements.

Evaluating

14 Deduce why group 18 was not present in Mendeleev's periodic table.
15 Would you expect strontium to be, chemically, more similar to calcium or rubidium? Justify your choice.

4.5 The reactivity of metallic elements

WORKSHEET

You have already read about the properties of a few significant groups of metals in the periodic table, the main ones being the alkali metals (group 1), the alkaline earth metals (group 2) and the transition metals. The way these metals behave, depends on their reactivity. Alkali metals are very reactive, more reactive than group 2 and the transition metals. The more reactive a metal, the easier it is for it to lose an electron from its outer shell (the valence electrons). This is known as the activity of a metal.

The activity series

To find out how easy it is for metals to lose electrons compared to one another you can look at the **activity series**. Figure 4.49 shows the order of activity of some common metals in the periodic table.

activity series
a series of metals ordered by their reactivity, from highest to lowest

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Metal	Easier to lose an electron	More reactive
Potassium (K)	↑	↑
Sodium (Na)		
Calcium (Ca)		
Magnesium (Mg)		
Aluminium (Al)		
Zinc (Zn)		
Iron (Fe)		
Nickel (Ni)		
Tin (Sn)		
Lead (Pb)		
Copper (Cu)		
Silver (Ag)	↓	↓
Gold (Au)	Harder to lose an electron	Less reactive

Figure 4.49 The activity series

The activity series shows that tin is more reactive than lead and that zinc is more reactive than gold, for example. Potassium is the most reactive metal listed, gold is the least reactive metal.

Quick check 4.16

1 Pick the correct statement to complete the sentence:
The *more/less* reactive a metal, the *easier/harder* it is to lose an electron.

2 Decide whether the following statements are true or false:
  a Potassium is the most reactive metal in the activity series shown in Figure 4.49.
  b Silver is more reactive than gold.
  c Group 1 metals are the most reactive in the activity series.
  d Zinc finds it easier to lose an electron than calcium does.

3 Name the only group 3 element in the activity series.

Displacement reactions

Using the activity series, you can predict the outcome of a particular type of reaction involving these metals, called a **displacement reaction**. In a displacement reaction, a more reactive metal will displace (remove) a less reactive metal from its compound. The following is an example:

displacement reaction when a more reactive metal removes a less reactive metal from its compound

copper sulfate + iron → sulfate + copper

$$CuSO_4 + Fe \rightarrow FeSO_4 + Cu$$

In this reaction, the iron has displaced (or removed) the copper from its compound. Iron has joined with the sulfate and copper has been left on its own. This reaction occurred because iron is higher up in the activity series and therefore more reactive than copper. So what happens when the metal on its own is less reactive than the metal in the compound?

zinc sulfate + tin → X

$$ZnSO_4 + Sn \rightarrow X$$

In this case there is no reaction. Tin is not reactive enough because it is lower in the activity series, so it cannot remove the zinc from its compound.

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Practical 4.6

Displacement reactions

Aim

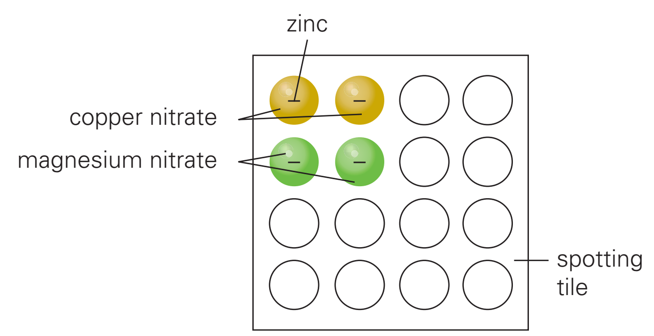
To determine the order of reactivity of metals by the outcome of displacement reactions.

Materials

- dimple tile or spotting tile
- 2 pieces of each metal (zinc, magnesium, copper)
- 1 dropper bottle of zinc nitrate
- 1 dropper bottle of magnesium nitrate
- 1 dropper bottle of copper nitrate

Method

1. Make a prediction using the activity series about the outcomes of the reactions studied.
2. Copy the results table below.
3. Add 3 drops of copper nitrate to 2 dimples in a row.
4. Add 3 drops of magnesium nitrate to 2 dimples in a row
5. Add a piece of zinc metal to each dimple and record your observations in the results table.
6. Repeat twice more for the other two sets of reactions, changing the metal added each time.



Results

	Zinc (Zn)	Magnesium (Mg)	Copper (Cu)
Copper nitrate ($Cu(NO_3)_2$)			
Magnesium nitrate ($Mg(NO_3)_2$)			
Zinc nitrate ($Zn(NO_3)_2$)			

Evaluation

1. List the reactions which showed displacement.
2. What observations did you use to determine that a displacement reaction had taken place?
3. Write word equations for each of the successful displacement reactions.
4. List the reactions which did not show displacement.
5. How did you know that no reaction had occurred?
6. Why were some of the boxes shaded out on the results table?

Conclusion

1. Make a claim about the reactivity of the metals investigated based on this experiment.
2. Support your statement by using the data you gathered and include potential experimental faults.
3. Explain how the data supports your statement.

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Quick check 4.17

1 For the following mixtures of metals and metal compounds, state whether a reaction will occur or not:
  a iron chloride + nickel
  b copper sulfate + zinc
  c iron sulfate + sodium
  d sodium sulfate + gold.
2 Describe the meaning of the term displacement.

Explore! 4.5

Galvanising

Iron and steel in the presence of water and oxygen form rust. This means that they react with oxygen forming iron oxide, which is characteristically red in colour.

Figure 4.50 Rust coating nuts and bolts

But what about this plant pot?

Figure 4.51 Plant pot made of steel

This plant pot is made of steel and will be left outside in constant contact with water and oxygen. You do not want it to rust days after it has been bought, so how can you protect the steel from rusting?

1 Research the meaning of the term ‘galvanised’.
2 What are steel and iron galvanised with?
3 Why is this material suitable for galvanising iron and steel? Relate your answer back to the activity series.
4 If iron and steel rust so easily, why do we even bother using them as materials?
5 Research the term ‘sacrificial protection’. How does this relate to the galvanising of iron and steel?
6 Tin is used to coat steel cans. Explain why this is not an example of galvanising.

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Extracting metals

As most metals in their pure states are reactive, many of them are found naturally as compounds, known as ores. Ores are impure forms of metals, often because the metals have reacted with oxygen. It is harder to extract the most reactive metals from their ores than it is to extract less reactive metals. The easier it is for metals to lose electrons, the harder it is for them to take them back!

Native metals

Metals at the bottom of the activity series, for example gold and silver, are known as **native metals**. As these metals are unreactive they do not form ores and they can be extracted in their pure form.

native metals elements that are found in their pure states in the environment

Extraction with carbon

Metals in the middle of the activity series can be extracted by reacting them with carbon. The carbon removes the oxygen from the metal ore, forming carbon dioxide and the pure form of the metal. The reaction below is an example of this form of extraction:

iron oxide + carbon monoxide → iron + carbon dioxide

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

Figure 4.52 Gold is a less reactive metal, which is why it can be found in its pure form in nature, i.e. it is a native metal.

Figure 4.53 Molten iron spews out of a blast furnace where iron ores are reacted with carbon to form pure iron metal.

Figure 4.54 An open cut gold mine in Cobar, NSW

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Practical 4.7

Extracting iron from a matchstick

Aim

To extract iron from a matchstick by reacting with carbon.

Be careful

Ensure appropriate personal protective equipment is worn

Materials

- 1 safety match
- crucible tongs
- weighing boat
- spatula
- Bunsen burner
- bench mat
- magnet
- iron (III) oxide powder
- sodium carbonate powder
- 100 mL beaker filled with water

Method

1. Copy the results table below.
2. Run the magnet over the iron (III) oxide powder, sodium carbonate powder and match head. Record whether they were magnetic.
3. Moisten the head of the match by dipping it into a beaker of water.
4. Roll the head of the the match in the sodium carbonate powder and then in the iron (III) oxide powder.
5. Using the pair of tongs, hold the match into a blue Bunsen burner flame – only let it burn half way down the match.
6. Allow the match to cool.
7. Use the spatula to crush the charred head of the match into the weighing boat.
8. Run the magnet underneath the weighing boat and record what you see.

Results

Substance	Magnetic?
iron (III) oxide powder	
Sodium carbonate powder	
Match head (before heating)	
Charred remains (after heating)	

Evaluation

1. In this experiment, you reacted iron (III) oxide powder with carbon to try to extract the metal. Which chemical did the carbon come from?
2. How did you know that iron metal was the product formed?
3. Write a word equation for the reaction studied.
4. Why can iron be extracted in this way?

Conclusion

1. Give a statement regarding your success in extracting iron.
2. Support your statement by using the data you gathered and include potential experimental faults.
3. Explain how the data supports your statement.

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Electrolysis

For metals at the top of the activity series, reacting with carbon is not suitable because carbon is not reactive enough. To extract these metals, an electrical current is passed through a molten form of the impure metal, resulting in the extraction of the pure form of the metal. As this process is expensive, it is only used to extract reactive metals like sodium and potassium.

Figure 4.55 Industrial electrolysis pools in a factory

Quick check 4.18

1. Define native metals.
2. Define a metal ore.
3. Name a metal that can be extracted by:
   a. reacting with carbon
   b. electrolysis.

A summary of extracting metals

Table 4.7 summarises the extraction methods used to obtain pure forms of each metal.

Metal	Method of extraction
Potassium (K)	Electrolysis
Sodium (Na)	
Calcium (Ca)	
Magnesium (Mg)	
Aluminium (Al)	
Zinc (Zn)	Reaction with carbon
Iron (Fe)	
Nickel (Ni)	
Tin (Sn)	
Lead (Pb)	
Copper (Cu)	
Silver (Ag)	Native metals
Gold (Au)	

Table 4.7 Extraction methods for metals in the activity series

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Section 4.5 questions

QUIZ

Remembering

1 Which metals are found as native metals?
- a less reactive metals
- b most reactive metals
- c metals that can be extracted by reacting with carbon
- d all metals

2 Recall how aluminium is usually extracted from its ore.

3 State why electrolysis is not used to extract all metals in the activity series.

4 Recall what form most metals are found in.

Understanding

5 Classify the following as more or less reactive metals than iron:
- a potassium
- b gold
- c copper
- d zinc.

6 Explain why sodium cannot be extracted by reacting with carbon.

7 Explain why native metals require no form of extraction.

Applying

8 Select a metal from the activity series in Figure 4.49 that:
- a can be extracted by electrolysis
- b can displace a solution of nickel nitrate
- c finds it the easiest to lose electrons
- d is a native metal.

9 Train track welding is often known as thermite welding. In this reaction, aluminium metal is reacted with iron oxide in a displacement reaction.
- a Construct a word equation to show the reaction and the products formed.
- b Explain why this process allows train tracks to be bonded together.

Analysing

10 Analyse the reasons why jewellery is often made from gold and silver.

11 Distinguish between the extraction methods of electrolysis and the reaction with carbon.

Evaluating

12 Explain why it is harder to extract more reactive metals from their ores.

13 Predict the outcome of the following displacement reactions:
- a iron oxide + carbon
- b copper nitrate + potassium
- c magnesium sulfate + zinc
- d gold + zinc nitrate.

14 Explain the advantages of some metals being extracted by both electrolysis and reaction with carbon before they are used.

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Review questions

SCORCHER

Remembering

1 Give the group and period of the following elements:
- **a** boron (B)
- **b** titanium (Ti)
- **c** platinum (Pt)
- **d** strontium (Sr).

2 Give the group number of the following:
- **a** an element with the electronic configuration 2.8.1
- **b** an element with 18 electrons
- **c** the halogens
- **d** a noble gas.

3 Recall the name of Johann Döbereiner's groupings in his attempt at organising the elements.

4 Magnesium and beryllium are in group 2. What other name is given to elements in group 2?

5 List the metals in the activity series in Figure 4.49 that are native metals.

6 Name a metal that will displace magnesium.

Understanding

7 Describe the position of metals and non-metals on the periodic table.

8 Explain why elements in the same group have similar properties.

9 Explain why Mendeleev left gaps in his periodic table.

10 Describe the change in properties of the halogens as you move down group 17.

11 Summarise the extraction methods for non-native metals.

Applying

12 Identify the names and positions of three elements in the transition metals.

13 A new element has been discovered that:
- reacts violently with water
- is soft
- has an electron configuration of 2.8.8.1.

Given those properties, identify the group with which it belongs. Justify your choice.

14 Construct a diagram to show the electron arrangement of an atom of carbon.

15 Select the best statement that describes why elements are placed together in the same group.
- **A** They are placed in the same group so they are in alphabetical order.
- **B** They are in placed in the same group as they have the similar chemical and physical properties. This is because they have the same number of electrons in the outer shell.
- **C** They are in placed in the same group because they behave the same.
- **D** They are placed in the same group because they are metals or non-metals.

16 Construct a word equation to show the displacement reaction of iron sulfate with zinc.

Analysing

17 Compare ionic and covalent bonding by completing this table:

	Ionic bonding	Covalent bonding
Strength of bond		
Bond is between …		
How is the bond formed?		

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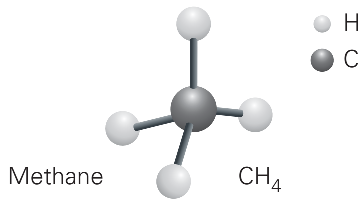
18 Compare and contrast the properties of iron and chlorine.

19 Observe the methane molecule shown below. It is a gas at room temperature and has a chemical formula of CH_4. Infer what sort of bond exists between the carbon and hydrogen atoms.



20 Distinguish between elements in group 1 and elements in group 2.

Evaluating

21 Determine the relationship of an element's atomic number, number of electrons and its position in the periodic table.

22 Compare and contrast an absorption spectrum and an emission spectrum.

23 Criticise Mendeleev's method of predicting the properties of unknown elements.

24 Defend the inclusion of helium in the noble gases, even though it does not have eight electrons in the outer shell.

Figure 4.56 Balloons filled with helium

25 Use the melting point data below to predict the physical states (solid, liquid or gas) of the unknown elements at room temperature. Note that room temperature is around 20°C.

Element	Melting point (°C)	Physical state
X	−240	
Y	17	
Z	57	

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STEM activity: Creating composite materials

VCSSU123 VCDSTC056 VCDSTC059 VCSSU115 VCSIS135 VCSIS140

Background information

In this chapter you learned that the electronic structure of an atom determines its properties and where it sits on the periodic table. Sometimes, there is no single element that has suitable properties for a particular purpose, so elements are combined chemically and physically to create materials.

Materials engineers develop and test materials at the atomic level and apply their understanding to develop materials that meet certain requirements. The substances they study include metals, ceramics, nanomaterials (extremely small substances) and other substances. They may also combine different materials that have different properties so the materials work together to produce new properties. These are called 'composite materials'. Fibreglass is an example of a composite material. It is made of plastic or carbon fibres and glass.

Composite materials are made by combining two or more materials. Usually the individual materials differ in their properties. The materials do not bond or blend with one another, so it is easy to tell the different materials apart. Mud bricks are an example of a composite material. Mud bricks are made of straw and mud. Mud is strong if you press down on it, but breaks when you bend it. Straw is strong if you pull on it, but it easily crumples. Mixing straw and mud together creates bricks that hold shape when squeezed or bent. Mud bricks are great as building blocks, whereas neither mud nor straw individually is good.

Figure 4.57 Mud bricks (left) are a composite of mud and straw. Concrete (right) is a composite of cement and sand; adding metal rods or wires to concrete increases its strength when bent or placed under tension.

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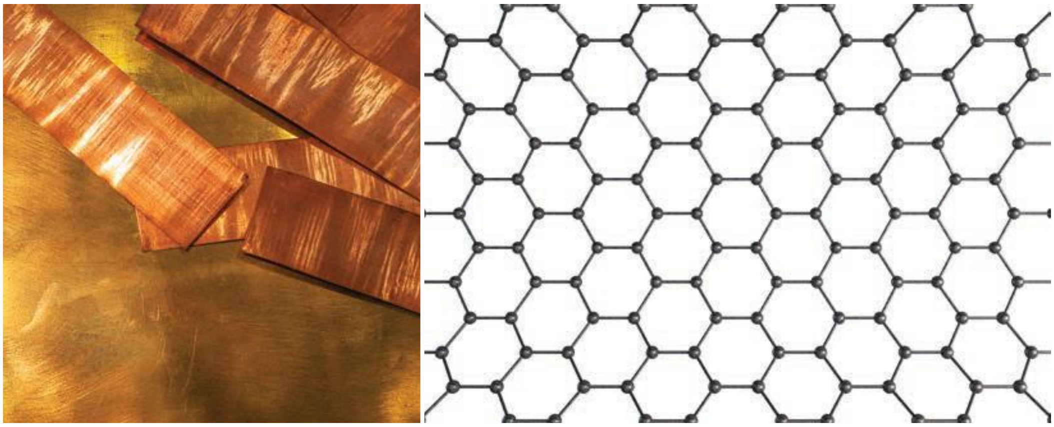

Figure 4.58 Researchers have found that combining copper (left) and graphene (carbon atoms in a hexagonal lattice; right) makes the copper 500 times stronger than it is on its own.

Design brief: Create a composite material for the purpose of building a specific product.

Activity instructions

In groups of three or four, decide what kind of structure you would like to build. For example, you could build a beam bridge, an aeroplane, a building or a chair. Then conduct some research and brainstorm what kind of properties you need in the material used to build the product. Think about what kinds of tests would be useful to determine if the material is suitable or not.

Next design a prototype of the composite material and test it against these properties. Build and test the prototype. Then think of some ways it could be improved and test it again.

Suggested materials

- web browser
- scissors
- ruler
- coins
- paper towels
- tape
- PVA glue
- popsicle sticks
- paper
- cardboard
- elastic bands
- string or yarn
- other materials where possible

Evaluate and modify

1 Research and decide the important properties your materials need to have for the purpose of your chosen product.

2 Discuss some methods you could use to test your material.

   a Apply forces to your material. Record the type of force (such as gravity) and evaluate the original material capabilities compared to the new material. What changed?

   b What are the maximum forces that could be applied to each iteration? Why is this? Compare your data.

3 Suggest some ways to improve the composite material. Should another material be added? Should the ratios of the component materials be altered?

4 Predict how the composite material might behave differently if it was constructed differently but with the exact same materials.

5 Test your second prototype and compare it to the first prototype you built. Are there any improvements? What changed?

6 Research the two composite materials: glass fibre-reinforced concrete (GFRC) and steel-reinforced concrete.

   a What are their differences, and what are the benefits of one material over the other? Use a Venn diagram to present your ideas.

   b How would the discovery of each material change the way we use concrete?

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Chapter 5 **Chemical reactions**

Chapter introduction

The chemical industry produces a large number of useful substances in vast quantities, many of which you could not do without. Understanding how to monitor chemical reactions is a crucial part of determining the optimum reaction conditions to produce these substances quickly and efficiently. In this chapter, you will learn how to represent chemical reactions as word, molecular and balanced formula equations. You will investigate factors that can affect the rates of chemical reactions and how these rates can be monitored.

Curriculum

Different types of chemical reactions are used to produce a range of products and can occur at different rates; chemical reactions may be represented by balanced chemical equations (VCSSU125)	
• investigating how chemical reactions result in the production of a range of useful substances, for example, fuels, metals and pharmaceuticals	5.2
• using word or symbol equations to represent chemical reactions	5.1
• investigating the effect of a range of factors, for example, temperature and catalysts, on the rate of chemical reactions	5.3, 5.4
• investigating how social actions have led to changed government policies and social behavioural change in relation to the use of chlorofluorocarbons (CFCs) in aerosol spray cans	5.2

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Glossary terms

activation energy
agitating
aqueous
biofuel
catalyst
chlorofluorocarbons
coefficients
collisions
concentrated solution
concentration
diatomic
dilute solution
formula equation
galvanising
molecular equation
monatomic
monomers
polymer
products
reactants
reaction rate
surface area
word equation

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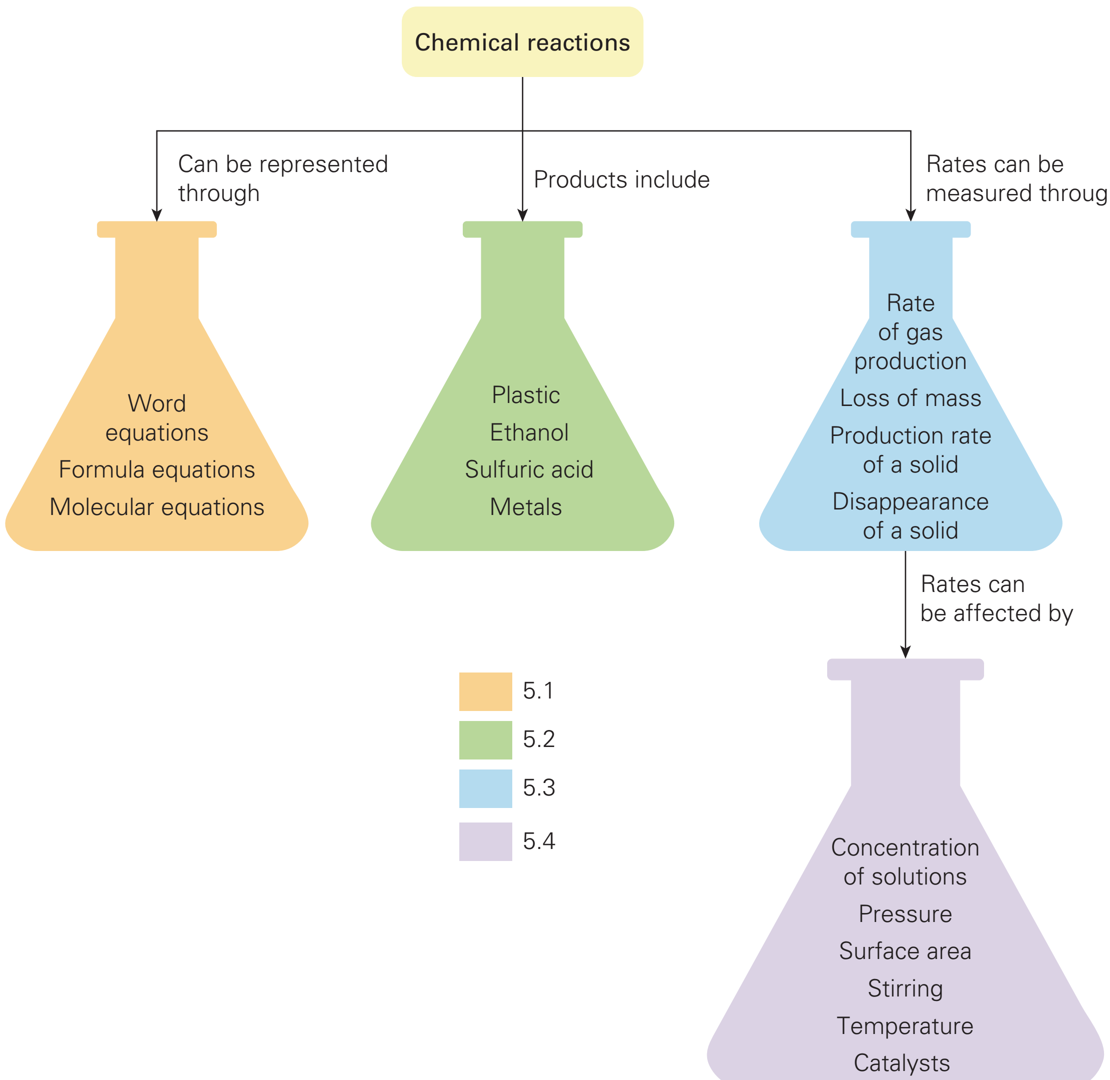
Concept map



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5.1 Representing chemical reactions

reactants
the chemicals which react together in a reaction

products
the chemicals produced in a reaction

In Year 9 you learned that, in a chemical reaction, bonds are broken in **reactants** and new bonds are formed to make the **products**. You should remember that reactants are those chemicals that are being reacted together and products are the chemicals that are made in a reaction. In this section you will learn how to represent chemical reactions as word equations, balanced formula equations and molecular equations.

Word equations

word equation
a chemical reaction written using the names of the reactants and products involved

One way to represent a chemical reaction is with a **word equation**. Word equations are written with just the names of the reactants and products in the chemical equation. Below is the word equation for the reaction of two common chemicals you will have already used in your science lessons, an acid and an alkali. You should already be able to identify the reactants and products yourself.

sodium hydroxide + hydrochloric acid → sodium chloride + water

✓

Notice that all the reactants are on the left-hand side of the arrow and the products are on the right-hand side. It is very tempting, if you run out of paper, to write the same chemical reaction like the example below.

sodium hydroxide + hydrochloric acid → sodium
chloride + water

✗

However, you must make sure that the reactants are always on the left and the products are always on the right of the arrow.

If you run out of paper, set your word equation out like the one below, and you will not go wrong!

WORKSHEET

sodium hydroxide	+	hydrochloric acid	→	sodium chloride	+	water

Quick check 5.1

1. What is wrong with the following word equation?
   CO_2 + water → glucose + oxygen
2. What should you do if you are running out of paper and still have to finish writing a word equation? (HINT: there could be more than one correct answer.)
   - **A** Just carry on to the next line, it does not matter where you write the reactants and products.
   - **B** Rewrite the equation so it fits onto the piece of paper.
   - **C** Split some of the reactants or products over two lines, to ensure that all reactants are on the left of the arrow, and all products are on the right.
   - **D** If it is too long do not bother writing the word equation at all.

Formula equations

formula equation
a chemical reaction written using the formulas of the reactants and products involved

A second way of representing a chemical reaction is by using a **formula equation**. They are structured the same way as word equations but use chemical symbols instead of words to represent the substances in the reaction.

You know from the previous chapter that the symbols for chemical elements are listed on the periodic table. Remember that some elements have two letters in their chemical symbol. If this is the case, the first letter is upper case (capital) and the second letter is lower case. Get into the habit of writing elemental symbols correctly.

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Figure 5.1 Iron is one of those elements with two letters in its chemical symbol. One is upper case (capital) the other is lower case.

monatomic
one atom, sometimes spelled 'monoatomic'

diatomic
two atoms bonded together

All the metallic elements on the periodic table exist on their own and are described as being **monatomic**, meaning one atom. However, many non-metallic elements do not exist on their own. They tend to exist naturally as a gas or liquid with two atoms bonded together. These elements are known as **diatomic**, meaning two atoms. Table 5.1 lists the seven diatomic elements on the periodic table. You will see that it does not include all of the gaseous or liquid elements - some, such as helium and neon, are monatomic.

Element	Formula
Hydrogen	H_2
Nitrogen	N_2
Oxygen	O_2
Fluorine	F_2
Chlorine	Cl_2
Bromine	Br_2
Iodine	I_2

Table 5.1 The seven diatomic elements on the periodic table

The subscript (small and low) '2' shows that there are two atoms of these elements bonded together. You know already that these substances are called molecules. Substances with no subscript number after the chemical symbol have only one atom of that element present; for example, Ca represents just one atom of calcium.

Working out the formulas of compounds, such as sodium carbonate, is more complicated than elements. So for now you will need to look them up when formulating a symbol equation.

Let's take a look at the word equation from before and see if we can turn it into a symbol equation.

sodium hydroxide + hydrochloric acid → sodium chloride + water

The word equation shows us that sodium hydroxide (NaOH) is reacting with hydrochloric acid (HCl) to form sodium chloride (NaCl) and water (H_2O). Using the symbols for these compounds, you can create a formula equation like the one below.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

This formula equation shows you what is happening to one molecule of sodium hydroxide in this reaction. It may seem unusual to focus on only one molecule, but it gives us an idea of how the atoms are rearranged. Remember, though, what is going on with one molecule is also happening to every other molecule in the reaction.

Quick check 5.2

1 What does the formula $C_6H_{12}O_6$ tell you about one molecule of glucose?
2 Chlorine is a diatomic molecule. What does this mean?
3 Write a formula equation for the reaction between iron (Fe) and chlorine (Cl_2) to make iron chloride ($FeCl_2$).

State symbols

Formula equations give you more information than word equations regarding the rearrangement of atoms within compounds. You can add more information to formula equations by using state symbols. State symbols show the physical states of the substances in a chemical equation. Table 5.2 summarises the symbols used for each of the four physical states.

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State	Symbol	Example
Solid	(s)	iron
Liquid	(l)	water
Gas	(g)	oxygen
Aqueous	(aq)	salt water

Table 5.2 State symbols are used to represent the physical states of the substances in a chemical equation.

You may be familiar with at least three of these states; however, you may not be familiar with the term **aqueous**. Aqueous is a term used to describe solutions; that is, a solid dissolved in a liquid. An example is salt water.

aqueous
a physical state of matter which means dissolved in water (for example, salt water)

You can now make the formula equation even better by adding in state symbols for the four substances in the equation.

$$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Most acids and alkalis you will come across in this chapter are aqueous. In this example, sodium hydroxide (NaOH) is aqueous as it has been made by dissolving solid sodium hydroxide in water. Likewise, hydrochloric acid is also aqueous as it is made by dissolving the acidic gas hydrogen chloride in water.

Figure 5.2 Seawater is an aqueous solution because salt (sodium chloride) is dissolved in the water.

Quick check 5.3

1. Why is salt water described as an aqueous solution?
2. Which of the following compounds would be given the state symbol (s):
   a. hydrogen
   b. copper
   c. sugar (glucose)
   d. hydrochloric acid?

Molecular equations

molecular equation
a chemical reaction written using the bonding structure of the reactants and products involved

Finally, you can also use **molecular equations** to represent chemical reactions. Here, molecular diagrams (pictures showing the arrangement of the atoms) are used. You can convert the formula equation used previously to a molecular equation.

One of the advantages of using a molecular equation to represent a chemical reaction is that you can see how the atoms are bonded. The formula of water for example is H_2O. This, however, only shows that water contains two hydrogen atoms and one oxygen atom. The molecular equation tells you this as well, but it also shows that each of the hydrogen atoms is bonded to the oxygen atom. Another advantage is that you can see how the atoms have rearranged in the reaction. In the molecular equation shown in Figure 5.3, the bond between the

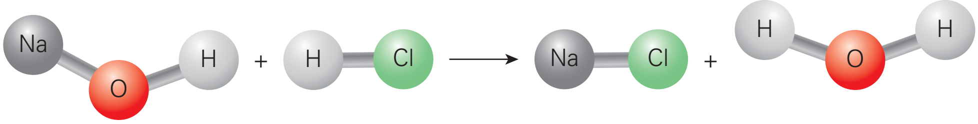

Figure 5.3 The molecular equation for the reaction between sodium hydroxide and hydrochloric acid

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sodium and oxygen in sodium hydroxide and the bond between hydrogen and chlorine in hydrochloric acid have broken, and these atoms have rebonded with other atoms to make different products.

Quick check 5.4

1 What are molecular diagrams?
2 What is the main advantage of a molecular equation?

WIDGET
Balancing formula equations

VIDEO
Indicators of chemical reactions

Balancing formula equations

You have learned in Year 9 that chemical reactions must observe the law of conservation of mass, which states that mass is neither gained or lost, but always conserved. Therefore, the mass of reactants must equal the mass of the products. Atoms from the products cannot disappear, and similarly, atoms cannot just appear in the products.

A balanced formula equation has the same number and types of atoms on the left-hand side (reactants) as it does on the right-hand side (products). Looking at the diagram of the molecular equation can make it easier to pinpoint when equations are not balanced.

Look at the example equation used throughout this section:

$$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Figure 5.4 Equations with the same number of reactant atoms as product atoms are said to be balanced.

To determine whether this equation is balanced or not, you need to count the number of each atom on both sides of the equation. It helps to do this in a table and it can also be easier to use the molecular equation, shown again in Figure 5.5.

As there are the same number and types of atoms in both the reactants and products, you can determine that this is a balanced formula equation. Therefore, you do not need to modify it in any way.

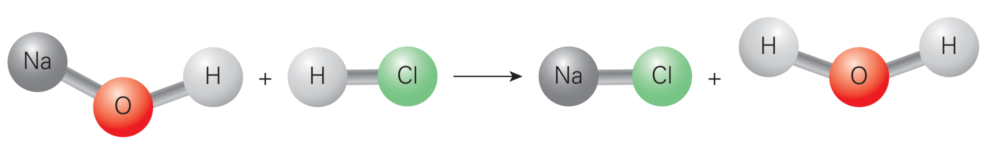

Figure 5.5 Molecular equation

	Number of atoms in reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	1	1
Oxygen (O)	1	1
Hydrogen (H)	2	2
Chlorine (Cl)	1	1

Table 5.3 It helps to use a table to determine whether an equation is balanced or not.

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In the following example, solid sodium metal (Na) is reacting with chlorine gas (Cl_2) to make solid sodium chloride (NaCl).

$$Na_{(s)} + Cl_{2(g)} \rightarrow NaCl_{(s)}$$

Record the number of each atom on both sides of the equation using the method you used in the previous example, as in Table 5.4.

	Number of atoms in reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	1	1
Chlorine (Cl)	2	1

Table 5.4 When recording the number of atoms in this equation, you can determine that the equation is unbalanced.

You should notice that there is one more chlorine atom in the reactants than there is in the products. This equation is not balanced.

So how do you fix chemical equations that are unbalanced? One thing that you cannot change is the formula of any of the substances in the equation. For example, you cannot just simply remove one of the chlorine atoms in a Cl_2 molecule, as this is not how chlorine exists in the real world (it is a diatomic molecule). The subscript numbers that appear after a chemical symbol tell you how many atoms of that element are present in the compound. These cannot be altered.

What you have to do is add more molecules of each substance to both sides of the equation until the number of atoms balances out. Putting numbers in front of the chemical symbol or chemical formula changes the amount of that molecule, for example:

Changing $O_{2(g)}$ to $2O_{2(g)}$ means there are two molecules of oxygen gas instead of one.

The problem identified in the equation was that there were two molecules of chlorine in the reactants, but only one in the products. To even out the number of chlorine molecules you can to add another NaCl molecule to the products, as shown here.

$$Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$$

Use Table 5.5 to see if you have solved the problem.

	Number of atoms in reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	1	2
Chlorine (Cl)	2	2

Table 5.5 Is the equation now balanced?

You have solved the original problem of the unbalanced chlorine atoms, but by adding another molecule of sodium chloride (NaCl), you have also altered the number of sodium atoms. Now these do not balance. To make them balance, you need to add another sodium atom to the reactants. See if this works using Table 5.6.

$$2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$$

	Number of the atoms in reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	2	2
Chlorine (Cl)	2	2

Table 5.6 A balanced equation

As you can see from Table 5.6, by adding another sodium chloride molecule and a sodium atom, the equation is now balanced. All you have to remember is that the big numbers before the chemical symbol (or **coefficients**) indicate the number of molecules and the small subscript numbers indicate the number of atoms within the molecule.

coefficients
the large numbers placed before molecules in a chemical equation to ensure that it is balanced

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Quick check 5.5

1 Determine whether the following chemical reactions are balanced or unbalanced.
   a $Fe + O_2 \rightarrow Fe_2O_3$
   b $H_2 + O_2 \rightarrow H_2O$
   c $Zn + CuSO_4 \rightarrow Cu + ZnSO_4$
   d $Be + Cl_2 \rightarrow BeCl_2$
2 Describe an equation that is unbalanced.
3 Balance these chemical equations. (Draw molecular equations if you need help. To help you, the first two have spaces to show where you should add coefficients.)
   a $\_\_H_2 + O_2 \rightarrow \_\_H_2O$
   b $\_\_Mg + O_2 \rightarrow \_\_MgO$
   c $Fe + O_2 \rightarrow Fe_2O_3$
   d $Ca(OH)_2 + HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$ (Hint: $(OH)_2$ means there are 2 oxygens and 2 hydrogens.)

VIDEO
Haber process

Explore! 5.1

The Haber process

The German scientist Fritz Haber, together with Carl Bosch, a chemist and engineer, developed the Haber process. Haber was awarded a Nobel Prize for his efforts in 1918. The Haber process was able to produce ammonia (NH_3) on a large scale by reacting nitrogen (N_2) gas with hydrogen (H_2) gas under optimum conditions. The largest ammonia plant in Australia is on the Burrup Peninsula in Western Australia; it produces around 330 000 tonnes each year.

1 Write a word equation for the production of ammonia in the Haber process.
2 Write a balanced symbol equation with state symbols.
3 The Haber process is actually a reversible reaction. How is this represented in the word and symbol equations?
4 Why is the large-scale production of ammonia so beneficial?

Figure 5.6 Fritz Haber

Practical 5.1

Burning methane

Aim

To write balanced formula equations for the complete and incomplete combustion of methane.

Materials

- Bunsen burner
- heatproof mat
- matches

Method

1 Copy the results table on the next page.
2 Set the Bunsen burner onto the heatproof mat and light with a match.

continued…

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...continued

3 Observe the colour of the flame with the air hole closed and record in your results table.
4 Observe the colour of the flame with the air hole open and record in your results table.

Results

	Observations	Complete or incomplete combustion
Air hole closed		
Air hole open		

Evaluation

1 In Year 9 you learned that complete combustion meant that a fuel was burned in a plentiful supply of oxygen, and that during incomplete combustion a fuel was burned in a limited supply of oxygen. Using this information, decide which scenario was complete or incomplete combustion.
2 During the complete combustion of methane (CH_4) with a plentiful supply of oxygen (O_2), carbon dioxide (CO_2) and steam (H_2O) are formed.
   a Write a word equation for this reaction.
   b Write a balanced formula equation with state symbols.
3 During the incomplete combustion of methane (CH_4) with a limited supply of oxygen (O_2), carbon monoxide gas (CO) and steam (H_2O) are formed.
   a Write a word equation for this reaction.
   b Write a balanced formula equation with state symbols.
4 During the incomplete combustion of methane (CH_4) with a very limited supply of oxygen (O_2), solid carbon (C) and steam (H_2O) are formed.
   a Write a word equation for this reaction.
   b Write a balanced formula equation with state symbols.
5 Why should water not be in liquid form in the equations above?

Conclusion

1 Give a statement regarding the ease of formulating balanced chemical equations for the reactions you observed. Were some easier than others?
2 Support your statement by using your observations and include potential sources of error.
3 Explain how the observation supports your statement.

Summary of representing reactions

Table 5.7 summarises the three ways in which a chemical reaction can be represented.

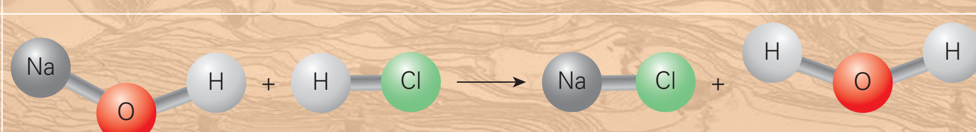
Type	Example
Word equation	sodium hydroxide + hydrochloric acid → sodium chloride + water
Balanced formula equation with state symbols	$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
Molecular equation	

Table 5.7 The three ways you can represent a chemical equation

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QUIZ

Section 5.1 questions

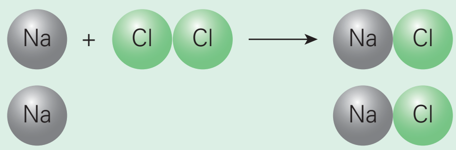
Remembering

1 Give the type of equation shown in the following examples.

a carbon + oxygen → carbon dioxide

b $2Ca_{(s)} + O_{2(g)} \rightarrow 2CaO_{(s)}$

c



2 Give the state symbols that would represent the following substances:

a sodium chloride (salt)

b sulfuric acid

c water

d nitrogen.

3 Which of the following molecules are diatomic?

a H_2O

b CO_2

c N_2

d F_2

4 When sodium is reacted with water containing universal indicator, the water will turn purple as sodium hydroxide (an alkali) is produced. Hydrogen gas is also made.

a Give the reactants in the reaction.

b Give the products in the reaction.

c Write a word equation.

Understanding

5 Describe the composition of copper sulfate ($CuSO_4$) in terms of the number of each type of atom.

6 Explain, using the term 'conservation of mass', why it is important that chemical equations are balanced.

7 Outline each way of representing a chemical reaction by completing the following table for the reaction between solid calcium (Ca) with liquid bromine (Br_2) to form solid calcium bromide ($CaBr_2$)

Type	Example
Word equation	
Balanced formula equation with state symbols	
Molecular equation	

Applying

8 Identify the coefficients in the equations below.

a $2Ca + O_2 \rightarrow 2CaO$

b $2Fe + 3Cl_2 \rightarrow 2FeCl_3$

c $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

9 Construct a balanced symbol equation with state symbols for the reaction of potassium metal with oxygen to form solid potassium oxide (K_2O).

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10 Electricity can be used to break down water into its constituent elements. There is no other reactant.
- **a** Construct a balanced symbol equation with state symbols to show this.
- **b** Identify how much more hydrogen is produced in this reaction compared to oxygen.

Analysing

11 Compare and contrast molecular and formula equations.

12 Analyse the way the following equation has been balanced:

Unbalanced: $H_{2(g)} + O_{2(g)} \rightarrow H_2O_{(l)}$

Balanced: $H_{2(g)} + O_{2(g)} \rightarrow H_2O_{2(l)}$

Evaluating

13 Decide whether the following equations are balanced or unbalanced, and then correct the unbalanced equations.
- **a** $Ca + Br_2 \rightarrow CaBr_2$
- **b** $NaOH + HCl \rightarrow NaCl + H_2O$
- **c** $CuO + C \rightarrow Cu + CO_2$
- **d** $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
- **e** $Ag + H_2S + O_2 \rightarrow Ag_2S + H_2O$

14 Explain why it is important that you only change coefficients of molecules in a chemical equation and not the subscripts.

15 Explain why this chemical equation is unbalanced.

$HNO_3 + Ca \rightarrow Ca(NO_3)_2 + H_2$

	Reactants	Products
H	1	2
N	1	2
O	3	6
Ca	1	1

5.2 Chemical reactions that produce useful products

In this section, we will discuss a number of important chemical reactions that produce useful substances, many of which you cannot do without!

Chemical reactions produce a huge variety of different products. The chemical industry is involved in producing almost all substances that do not occur in vast quantities naturally. For example, chemical reactions in the pharmaceutical industry are used to make medicines that treat many conditions.

WORKSHEET

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Did you know? 5.1

In the limelight

The phrase 'being in the limelight' originated from the use of quicklime (calcium oxide) to produce a strong white light in theatres. The theatre industry likes bright, white lights to illuminate performers, but in the early days it was hard to create this type of light. In 1837, limelight was first used in a public theatre. Oxygen and hydrogen blowpipes were used to inject these gases into a flame, making it exceptionally hot. Introducing a small amount of quicklime to the flame resulted in a blinding white light – the aptly named limelight.

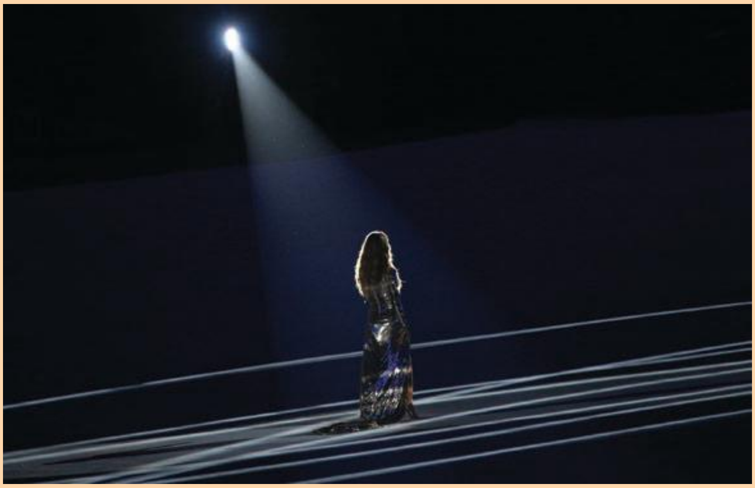

Figure 5.7 The model Gisele Bündchen is 'in the limelight' as she walks across the stage at the opening ceremony of the 2016 Rio de Janeiro Olympic Games.

Explore! 5.2

Taxol: from yew tree to anti-cancer drug

Figure 5.8 Felled logs of Pacific yew trees. The bark is the sole source of the breast cancer drug paclitaxel, commonly sold as Taxol.

In 1962, scientists extracted bark from Pacific yew trees and found that it was toxic to living cells. They purified the active ingredient in the bark, which was found to be paclitaxel, and began to test its biological action. It was not until 15 years later, in 1977, that scientists were able to confirm that paclitaxel had antitumor properties in mice. And it took another 15 years before the drug, Taxol, was approved for use in treating ovarian cancer and advanced breast cancer.

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Figure 5.9 A Taxol drip is set up for this patient who has breast cancer.

To date, Taxol is the bestselling cancer drug ever manufactured.

1 Research why it took so long for Taxol to be approved for clinical trials.
2 Outline the reasons why drugs must go through a clinical trial process before being approved for widespread use on humans.

Plastic from crude oil

Plastics are an integral part of our everyday lives. They form the wrap used on sandwiches and the pen that you use to write in school, to name only two uses. Plastics are incredibly useful, but because they do not biodegrade readily they can be bad for the environment when they are not disposed of correctly.

VIDEO
Fractional distillation – crude oil

Figure 5.10 Plastic packaging in use at a supermarket (left); plastic waste can be bad for the environment (right).

Try this 5.1

Write your routine from when you get up in the morning to when you arrive at school and start your first lesson. Highlight where you have used plastic during this time. You may be surprised how many times you use plastic in your daily life.

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monomers
single units that when joined together repeat to make a polymer

polymer
a long chained molecule made of repeating sub units called monomers

Plastics are made from individual chemical units called **monomers** joined together to make a giant molecule called a **polymer**. The reaction that joins them is known as polymerisation. The polymers are then modified to form plastics with different properties. Polyethene (also known as polyethylene) is used to make plastic shopping bags, and is one of the most common plastics used today. It is made by reacting ethene monomers made from crude oil. Under high temperatures and pressures, and with the help of a catalyst to speed up the reaction, these ethene monomers join together to form polyethene (Figure 5.11). Note how the single ethene molecule (the monomer) has a double bond between the two carbon molecules: this molecule is said to be unsaturated. When the ethene molecules join together, the double bond is broken and the carbon atoms instead share an electron with the ethene molecule to either side, forming the polymer named polyethene.

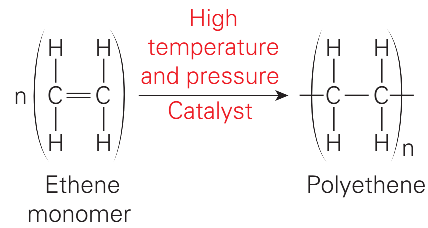

Figure 5.11 Many ethene monomers join together to make a long-chain polymer called polyethene. The 'n' in the diagram relates to any number of ethene monomers joining together to make a polymer of any length.

Many other polymers, such as polyvinylchloride (PVC) and polyester, a synthetic fibre, are formed using similar methods. PVC has many applications, including credit cards, toys, pipes and shower curtains. Polyester is used in car tyres, clothing and pillow stuffing.

Quick check 5.6

1. What is the name of the monomer that is used to make polyethene?
2. Why are plastics called polymers?

Practical 5.2: Teacher demonstration

Making nylon

Aim

To observe a polymerisation reaction in action.

Be careful

Do NOT handle nylon directly.
All materials are to be collected to be disposed of appropriately.
Ensure appropriate personal protective equipment is worn.

Materials

- 1,6-diaminohexane solution (5%)
- adipoyl chloride in cyclohexane (5%)
- 2 × 50 mL beakers
- forceps
- 2 stirring rods
- 2 × 10 mL measuring cylinders

Method

NOTE: the whole reaction, including measuring the volumes of each chemical, should be done under a fume hood.

1. Measure 10 mL of the adipoyl chloride solution using a 10 mL measuring cylinder and pour into one of the 50 mL beakers.
2. Measure 10 mL of the 1,6-diaminohexane solution using the other 10 mL measuring cylinder and pour into one of the 50 mL beakers.
3. Gently pour the adipoyl chloride down one side of the beaker containing the 1,6-diaminohexane solution.
4. Using forceps, lift the skin formed between the two layers of solutions out of the beaker.

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5 Continue to lift the skin out of the beaker using the stirring rods to support the strand. See how long you can make the thread.

Evaluation

1 Give the name for the term used to describe the reactants in the above reaction.
2 Give the name for the term used to describe the product in the above reaction.
3 State a use for nylon. Explain the properties of nylon that make it suitable for that use.

Conclusion

1 Make a claim about polymerisation based on this demonstration.
2 Support your statement by using your observations and include potential experimental faults.
3 Explain how the observation supports your statement.

Fermentation to produce ethanol

Many Australian drivers can now purchase petrol that contains a certain percentage of ethanol. Alcohols such as ethanol contain carbon, hydrogen and oxygen. Ethanol is added to petrol because it produces heat energy when burned, but burns more 'cleanly' than petrol does.

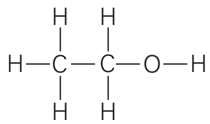

Figure 5.12 The structure of ethanol. The O-H functional group in the molecule makes ethanol an alcOHol.

Recently grown and decayed plant material can be fermented to produce ethanol that can be burned. Here, ethanol is known as a **biofuel**. During fermentation, yeast (a micro-organism) breaks down glucose (sugars) in the absence of oxygen to produce ethanol and carbon dioxide, shown in the following reaction.

biofuel
a fuel that comes from living materials

glucose → ethanol + carbon dioxide

$$C_6H_{12}O_{6(aq)} \rightarrow 2C_2H_5OH_{(l)} + 2CO_{2(g)}$$

This process is not only used to manufacture biofuels, but is also used in the production of beer and wine.

Figure 5.13 A brewer samples beer, which is produced by the fermentation of sugars using yeast.

Quick check 5.7

1 Name the micro-organism needed to break down sugars in fermentation.
2 What is the name of fuels that are made by fermenting sugars?

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Practical 5.3

Investigating the products of fermentation

Aim

To determine the products of fermentation.

Materials

- 100 mL conical flask
- boiling tube
- 50 mL measuring cylinder
- balance
- weighing boat
- cotton wool
- 5 g glucose
- 1 g yeast
- limewater
- test tube rack (can be shared between groups)

Method

1. Copy the results table below.
2. Measure 5 g of glucose using the balance and weighing boat and pour into the conical flask.
3. Measure 50 mL of warm water from a hot tap. Pour into the conical flask containing the glucose and swirl to dissolve.
4. Measure 1 g of yeast using the balance and weighing boat and pour into the conical flask, then loosely plug the top with some cotton wool.
5. Set aside for 15 minutes while fermentation takes place.
6. Meanwhile, pour about 3 cm depth of limewater into the boiling tube and set in a test tube rack (you will need this later).
7. When the mixture has been fermenting for 15 minutes, remove the cotton wool and pour the invisible gas into the boiling tube containing the limewater. Do not pour any of the liquid in. Observe what happens to the limewater.
8. Replace the cotton wool on top of the flask and leave to ferment for 24 hours.
9. After 24 hours, remove the cotton wool again and smell the solution. Cup the air above the flask and bring it to your nose, do not smell it directly from the flask.

Results

Product of fermentation	Test
Carbon dioxide	
Ethanol	

Evaluation

1. Write a word equation for the reaction you investigated.
2. Why did we add warm water to the mixture, not cold or boiling hot?
3. How did you know that carbon dioxide was produced?
4. To determine that ethanol was produced, you smelled the mixture. You could have also separated the ethanol from the mixture by carrying out a distillation. Research how and why distillation would separate the ethanol produced.

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Conclusion

1 Make a claim about the products of fermentation based on this experiment.
2 Support your statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports your statement.

Making sulfuric acid

Sulfuric acid is one of the most important compounds made in the chemical industry. It is used to make hundreds of other useful compounds, such as fertilisers, paints and paper.

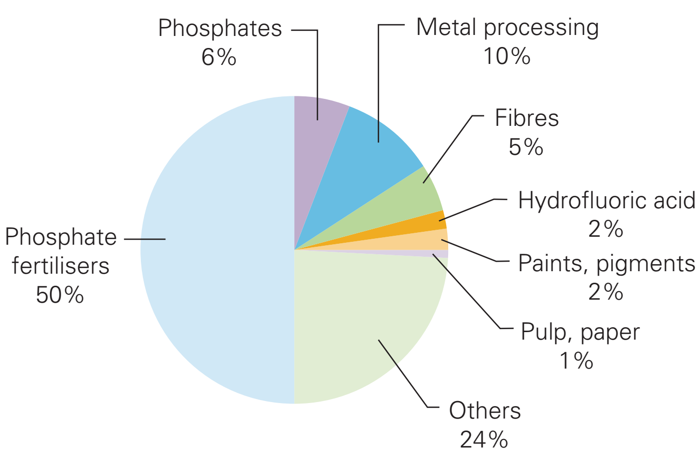

Figure 5.14 Uses of sulfuric acid

To make sulfuric acid, sulfur needs to be extracted and then reacted with oxygen to make sulfur dioxide. The sulfur dioxide is then further reacted with oxygen to make sulfur trioxide. This is converted into sulfuric acid in the equation below.

sulfur trioxide + water → sulfuric acid

$$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$$

Quick check 5.8

1 Give two uses for sulfuric acid.
2 Name the reactants used in the final reaction which produces sulfuric acid.

Making metals

Extraction of iron

Almost all metals are extracted from their ores by a chemical reaction. The best example of this is the extraction of iron in a blast furnace. Here, iron oxide (iron ore) is reacted with carbon to produce iron and carbon dioxide.

iron oxide + carbon → iron + carbon dioxide

$$2Fe_2O_{3(s)} + 3C_{(s)} \rightarrow 4Fe_{(l)} + 3CO_{2(g)}$$

Ninety per cent of the metal that is refined today is iron, with most of it being used to manufacture steel. Steel is less brittle and softer than iron, and therefore has a wider variety of uses. The production of steel also involves a chemical reaction. Oxygen is blown into the molten iron. It reacts with the excess carbon, producing carbon dioxide which can escape from the molten metal.

Figure 5.15 Steel sleeves produced for car suspensions

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Protecting metals

galvanising
coating iron or steel with a protective layer of zinc

Galvanising is a rust-prevention method; that is, galvanising stops iron from reacting with oxygen and water in the air. The iron or steel object is coated in a thin layer of zinc. Because zinc is more reactive than iron, it oxidises instead and forms a protective layer of zinc oxide.

Quick check 5.9

1 Name the method for preventing the formation of rust.
2 Name the products of the reaction in a blast furnace.

Practical 5.4

Galvanising to prevent corrosion

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To determine how galvanising an iron nail with zinc can affect the rate of corrosion.

Materials

Part 1: To make up the agar mixture (can be prepared beforehand by technicians)

- 200 mL water
- 2 g agar
- 2 mL potassium hexacyanoferrate (III) (0.1 M)
- 2 mL 0.1% phenolphthalein indicator
- Bunsen burner
- bench mat
- tripod
- gauze mat
- 500 mL beaker
- 250 mL measuring cylinder
- 10 mL measuring cylinder
- balance
- weighing boat
- stirring rod
- disposable gloves

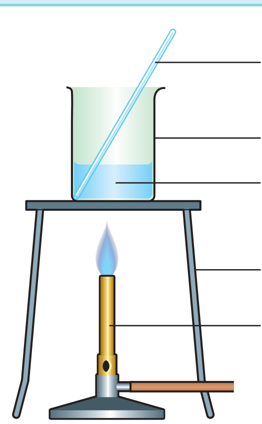
Part 2: To test the iron nail

- 2 clean iron nails
- 6 cm zinc strip
- emery paper
- 2 Petri dishes and lids
- sticky tape
- black marker pen
- disposable gloves

Method

Part 1: To make up the agar mixture

1 Measure 200 mL of water in a 250 mL measuring cylinder and pour into the 500 mL beaker.
2 Heat the water on top of the bench mat, Bunsen burner, tripod and gauze mat as shown below.



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3 Using the balance, weigh out 2 g of agar into the weighing boat.
4 Remove the water from the heat and stir in the agar using the stirring rod.
5 Heat gently while stirring to make sure that the agar is mixed through the water thoroughly.
6 Using the 10 mL measuring cylinder, measure 2 mL of 0.1 M potassium hexacyanoferrate (III) and 2 mL of 0.1% phenolphthalein indicator, and add to the agar mixture, stirring thoroughly.

Part 2: To test the iron nail

1 Write a hypothesis for this investigation, in which you will have two Petri dishes of agar mixture, with a nail in one, and a nail wrapped in zinc in the other. In which Petri dish do you think you will see the most corrosion?
2 Copy the results table below.
3 While the agar is cooling, clean the two iron nails with emery paper and place one of them in one of the Petri dishes.
4 Clean the surface of the zinc strip with the emery paper and wrap it around the other nail tightly so that they are in full contact with one another. Put this nail into the second Petri dish.
5 Pour in the cooled agar mixture over the nails in each Petri dish until the nails are covered to a depth of about 0.5 cm.
6 Cover the Petri dishes with the lids and allow the agar to solidify at room temperature.
7 Seal the Petri dishes with four bits of sticky tape on opposite sides of the plate.
8 Leave the dishes overnight and observe their appearance the next day. Record your observations in the results table.

Results

The blue colour shows areas where iron has corroded or where oxidation has taken place.

Contents of Petri dish	Observations
Iron nail and agar mixture only	
Iron nail wrapped in zinc and agar mixture	

Evaluation

1 Describe the differences in appearance between the two dishes.
2 Describe the location on the iron nail which showed the greatest amount of corrosion.
3 Explain the results you obtained.
4 Outline what you think would have happened if the nail had been coated in a less reactive metal, like copper.

Conclusion

1 Make a claim about the effect of zinc on corrosion rates of an iron nail based on this experiment.
2 Support your statement by using the data you gathered and include potential experimental faults. Refer back to the activity series of metals in Chapter 4 to support your claim.
3 Explain how the data supports your statement.

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Science as a human endeavour 5.1

'Green' steel

To make steel, coke (which is made from coal) is reacted in a blast furnace at very high temperatures with iron ore (an impure form of iron).

Figure 5.16 Burning coke in a blast furnace

The result of the reaction is molten steel, which can be set into moulds and used in many applications, primarily in the construction industry. The problem with this method is that coke is a non-renewable resource so supplies will eventually run out. There are an estimated 1.1 trillion tonnes of proven coal reserves worldwide. This means that there is only enough coal to last us around 150 years at current rates of production and usage.

Figure 5.17 A coal mine in Russia

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Scientists at the University of New South Wales' Centre for Sustainable Materials Research and Technology (SMaRT@UNSW) have developed a solution to this problem. By investigating carbon reactions at high temperatures, researchers found that waste tyres and plastics could partially replace the non-renewable coke.

Figure 5.18 A dump of 30 million waste tyres threatens to pollute the waters of Rhode Island, United States.

Using this technology in Australia has prevented more than two million waste rubber tyres ending up in landfill. Stacked on top of each other, that many tyres would reach the International Space Station.

Green steel is now being produced worldwide. In 2012, the US Society for Manufacturing Engineers included the technology in their list of innovations that could change the way we manufacture.

Manufacturing chlorofluorocarbons

Chlorofluorocarbons (CFCs) were first manufactured in the 1930s and have a wide variety of applications due to their lack of reactivity and heat-absorbing properties. They contain carbon, fluorine and chlorine. They have been used as refrigerants in air conditioners and refrigerators, as blowing agents in foams and insulation, and as propellants in aerosol cans.

chlorofluorocarbons chemicals containing atoms of carbon, chlorine, and fluorine that are nontoxic and non-flammable

Scientists first thought that CFCs would be harmless to Earth's atmosphere because they are very unreactive and insoluble in water, and

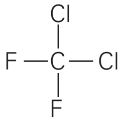

Figure 5.19 A simple CFC named dichlorodifluoromethane. The lines represent covalent bonds between carbon and fluorine, and carbon and chlorine. Refer to Chapter 4 for more information on covalent bonding.

so are very stable. However, in the late 1970s, scientists found out that higher up in Earth's atmosphere, where the Sun's ultraviolet (UV) light waves are more intense, the CFCs break down into highly reactive chlorine radicals, i.e. single chlorine atoms (Cl not Cl_2). These radicals can damage Earth's ozone layer, which protects us from cancer-causing UV radiation.

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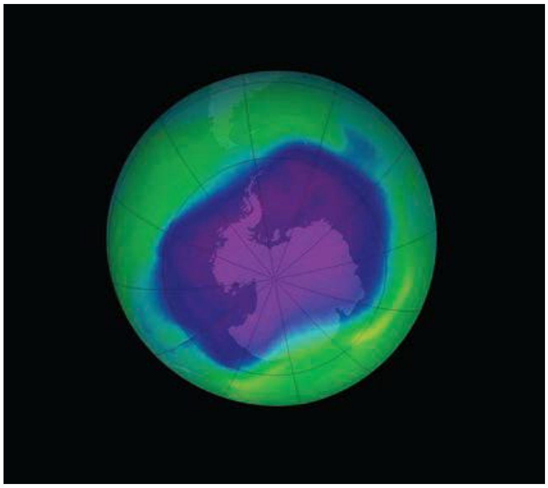

Figure 5.20 The hole in the ozone layer above Antarctica. The blue and purple colours are where there is the least ozone.

As a consequence of these findings, the Montreal Protocol on Substances that Deplete the Ozone Layer was established in 1987. It has since been signed and ratified by all nations in the world, one of the first treaties of any kind in the history of the United Nations system to achieve this.

The damage to the ozone layer, however, was worse than first expected so the protocol was amended and production of CFCs ceased in 1996. Due to the action and agreement of the world's countries, the ozone layer is expected to be fully healed by the middle of the twenty-first century.

Figure 5.21 The 28th Meeting of the Parties to the Montreal Protocol in Kigali, Rwanda, in 2016

Quick check 5.10

1 Give the name of the protocol signed by all countries to combat the depletion of the ozone layer by CFCs.
2 Name two uses of CFCs.

QUIZ

Section 5.2 questions

Remembering

1 Name the industry involved in producing substances in vast quantities that do not occur naturally.
2 State the raw material used to make plastics.
3 Give a reaction condition required to make polyethene.
4 Recall the elements present in all alcohols.
5 Name the layer of Earth's atmosphere that is damaged by CFCs.

Understanding

6 Explain how CFCs damage the ozone layer.
7 Outline what happens when ethene monomers are reacted under high temperatures and pressures with a catalyst.
8 Explain why iron is often coated in a layer of zinc.

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Applying

9 Construct a balanced formula equation to show the reaction of iron oxide with carbon in a blast furnace.

10 Describe how you could model polymerisation using paper clips.

Analysing

11 Compare and contrast iron and steel.

12 Analyse the importance of the chemical industry in producing the substances that have been discussed in this section.

13 Analyse how social actions have led to changed government policies and social behavioural change in relation to the use of chlorofluorocarbons (CFCs) in aerosol spray cans.

Evaluating

14 Evaluate the usefulness of biofuels produced by fermentation.

15 Decide whether making plastics from crude oil is a sustainable process.

5.3 Rates of chemical reactions

reaction rate
the quantity of reactant or product used up or made per unit time; how fast the reaction goes

The **reaction rate** can be found by measuring the quantity of a reactant used or the quantity of product formed over time.

$$\text{reaction rate} = \frac{\text{quantity of reactant used up}}{\text{time}}$$

$$\text{reaction rate} = \frac{\text{quantity of product formed}}{\text{time}}$$

The quantity of a reactant or product can be measured by the mass (in grams) or volume (in millilitres). Therefore, the units for rate of reaction may be given as g/s or mL/s. The quicker a product forms or a reactant is used up, the faster the rate of reaction.

Various methods can be used to monitor the rate of a chemical reaction. It is important for you to be able to determine the method that would be most suitable for certain types of reactions.

Measuring the rate of gas production

WORKSHEET

Upturned measuring cylinder

An upturned measuring cylinder, filled with water and placed in a trough of water, can be used to measure the volume of gas produced in a reaction over a set period of time. In this technique, the volume of displaced water is measured, as this is the same as the volume of gas produced. Figure 5.22 shows the set-up for this method of measuring reaction rates.

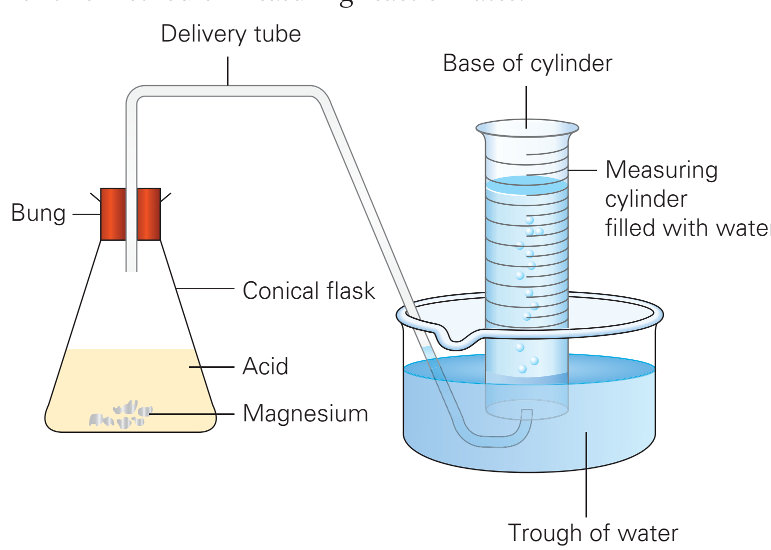

Figure 5.22 Diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

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In this example, the magnesium reacts with the acid to produce hydrogen gas, which travels through the delivery tube and collects in the measuring cylinder, displacing the same volume of water. This lets you measure the total volume of gas produced over a certain time. As volume is the dependent variable, the unit of rate will be mL/s.

Gas syringe

Gas syringes directly collect the volume of gas produced by a reaction. Figure 5.23 shows a gas syringe set-up. The increased pressure inside the syringe causes the plunger to move outwards. The volume of gas produced in a certain time can be recorded using the scale. Again, as volume is the dependent variable the units of rate will be mL/s. Gas syringes are more accurate than measuring cylinders so they are often used as the preferred option to monitor reactions which produces gases.

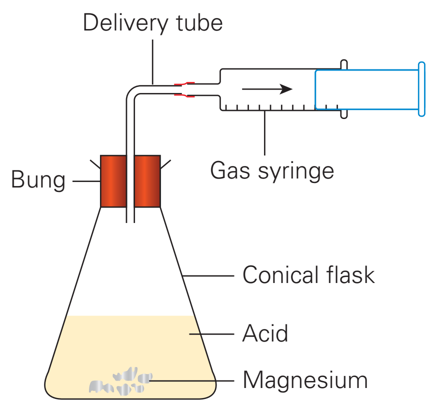

Figure 5.23 Diagram showing how to set up a gas syringe to monitor reaction rate

Quick check 5.11

1. Determine which of the following reactions can have their rate monitored using a gas syringe. Give reasons for your choice.
   a. $Na_2CO_{3(aq)} + 2HNO_{3(aq)} \rightarrow 2NaNO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$
   b. $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
   c. $Zn_{(s)} + CuSO_{4(aq)} \rightarrow Cu_{(s)} + ZnSO_{4(aq)}$
   d. $H_2O_{2(aq)} \rightarrow H_{2(g)} + O_{2(g)}$
2. Why is a gas syringe better than using an upturned measuring cylinder?
3. What are the units of rate when measuring the volume of gas produced?

Measuring the rate of mass loss

In this method, the reaction vessel is placed on top of an electronic balance. As gas is lost into the atmosphere, the mass of the reaction vessel decreases. The mass can be recorded at regular periods of time to determine the reaction rate. As mass is the dependent variable, the unit of rate is g/s. This method relies on gas loss into the atmosphere so it can only be used for reactions which produce a gas.

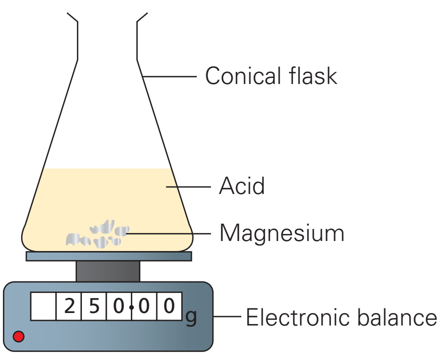

Figure 5.24 A diagram showing how reaction rate can be monitored by measuring loss of mass

Quick check 5.12

1. Determine which of the following reactions can have their rate monitored by measuring the loss of mass. Give reasons for your choice.
   a. $Na_2CO_{3(aq)} + 2HNO_{3(aq)} \rightarrow 2NaNO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$
   b. $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
   c. $Zn_{(s)} + CuSO_{4(aq)} \rightarrow Cu_{(s)} + ZnSO_{4(aq)}$
   d. $H_2O_{2(aq)} \rightarrow H_{2(g)} + O_{2(g)}$
2. Why is using an electronic balance more accurate than using a gas syringe or upturned measuring cylinder?
3. What are the units of rate when measuring the loss of mass in a reaction?

Measuring the rate of solid production

In reactions in which a solid is produced, the rate of production of that solid can be used as a way of monitoring reaction rate. This can be done by collecting the precipitate and

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weighing it, thus producing a reaction rate in grams per second (g/s).

Another way for comparing relative reaction rates can be seen in the set-up in Figure 5.25, as the solid is produced the cross beneath the conical flask will become more difficult to see. The time when the cross can no longer be seen is recorded and can be compared to the same reaction when variables are changed, such as concentration or temperature.

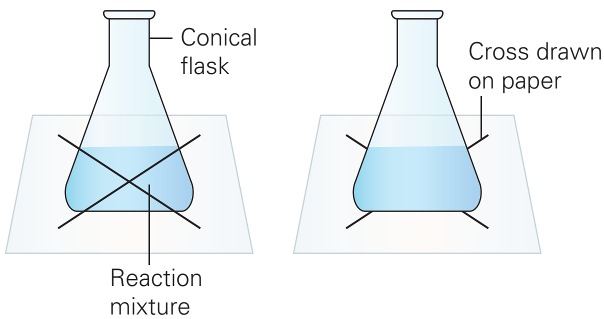

Figure 5.25 A diagram illustrating how to monitor the relative rate of a reaction in which a solid product is formed

Quick check 5.13

1 Determine which of the following reactions can have their relative rate monitored using the time taken for a cross to disappear. Give reasons for your choice.
 a $Na_2CO_{3(aq)} + 2HNO_{3(aq)} \rightarrow 2NaNO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$
 b $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
 c $Zn_{(s)} + CuSO_{4(aq)} \rightarrow Cu_{(s)} + ZnSO_{4(aq)}$
 d $H_2O_{2(aq)} \rightarrow H_{2(g)} + O_{2(g)}$
2 What are the units of relative rate when measuring the production of a solid in a reaction?

Using colorimetry to monitor reaction rates **Explore! 5.3**

Figure 5.26 A scientist placing a sample for testing in a colorimeter

Research the process of using a colorimeter to monitor the rate of a chemical reaction, and answer the following questions.

1 For what type of reactions would colorimetry be a suitable method to monitor the rate?
2 How does a colorimeter allow for reaction rates to be studied?
3 How does the concentration of the solution affect the amount of light absorbed by the sample?
4 In the following reaction, the solution of iodine in propanone starts off brown. As the iodine is used up the solution turns orange, then yellow and eventually colourless.
 propanone + iodine → iodopropanone + hydrogen iodide
 a Describe what you would expect the readings from the colorimeter to look like as the reaction progresses.
 b Sketch a graph of the results you would expect (concentration of iodine on the *x*-axis and absorbance on the *y*-axis).

Measuring rate of solid consumption

It is possible to record the time taken for a solid reactant to react with a liquid. The weight of the solid is recorded at the start. Then the solid is placed into the liquid reactant. If the liquid is clear enough for the solid pieces to be observed, then the time taken for the solid to disappear can be recorded. The unit of rate for the consumption of solid is grams per second (g/s).

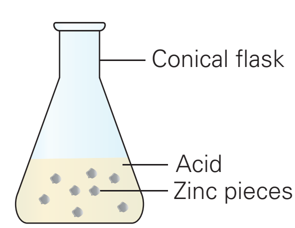

Figure 5.27 A reaction containing a solid and a liquid reactant can be monitored by eye if the solid pieces are large enough to be observed.

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Graphing experimental data

After collecting data, graphs can be plotted to provide more information on the rate of a chemical reaction. The steeper the gradient on a graph, the faster the rate.

The graph shows that the powdered reactant produces a greater rate of reaction as it has a steeper gradient than the reactant in granule form. This means that a greater volume of gas is produced in a shorter amount of time.

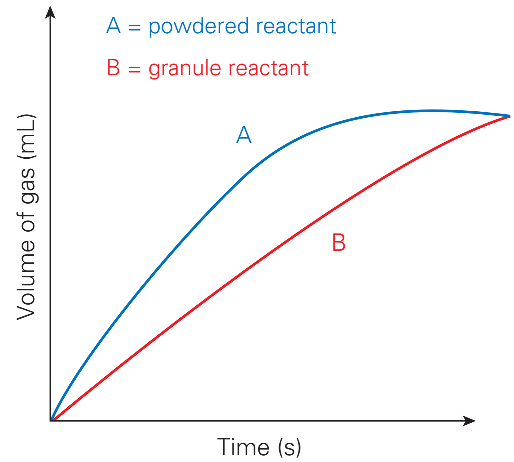

Figure 5.28 A graph showing the effect of surface area on the volume of gas produced over time.

Practical 5.5

Monitoring reaction rates

Aim

To determine how the mass of zinc affects the rate of reaction with nitric acid, by using the upturned measuring cylinder technique.

Materials

- 50 mL measuring cylinder
- 25 mL measuring cylinder
- large bowl
- electronic balance
- 1 bung and delivery tube
- 250 mL conical flask
- zinc powder
- weighing boat
- nitric acid (2 M)
- boss head and clamp
- stopwatch

Be careful

Ensure appropriate personal protective equipment is worn.

Method

1. Write a hypothesis for your investigation regarding the effect that the mass of zinc will have on the rate of the reaction.
2. Copy the results table on the next page.
3. Half-fill the large bowl with water.
4. Fill a 50 mL measuring cylinder with water and carefully invert in the large bowl of water. Do not lose any water out of the measuring cylinder.
5. Clamp the measuring cylinder in place using a boss head and clamp.
6. Using the 25 mL measuring cylinder, measure 20 mL of 2 M hydrochloric acid and pour the acid into the conical flask.

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...continued

7 Using the electronic balance, measure 0.5 g of zinc powder into a weighing boat.
8 Set up the delivery tube so the end without the bung runs underneath and into the upturned measuring cylinder (see Figure 5.22 to help you).
9 Pour the zinc powder into the conical flask containing the acid. At the same time, put the bung on top of the flask and start the stopwatch.
10 After one minute, record the volume of water displaced from the measuring cylinder. This is the same as the volume of gas produced.
11 Repeat once more with the same mass of zinc.
12 Repeat the steps for the other masses of zinc powder.

Results

Mass of zinc (g)	Volume of gas (mL)		
	1	2	Average
0.5			
1.0			
1.5			
2.0			

Evaluation

1 Calculate the average volume of gas released for each mass of zinc.
2 List the independent and dependent variables in this investigation
3 Give three controlled variables.
4 Plot a graph with mass on the *x*-axis and volume of gas on the *y*-axis
5 What does your graph tell you about the relationship between the mass of zinc and reaction rate?
6 Write a balanced formula equation with state symbols for the reaction between zinc metal (Zn) and nitric acid (HNO_3) to form zinc nitrate ($Zn(NO_3)_2$) and hydrogen (H_2).
7 List other methods you could have used to monitor the rate of this reaction.

Conclusion

1 Make a claim about the effect of the mass of zinc on the rate of the reaction in this experiment.
2 Support your statement by using the data you gathered and include potential sources of measurement uncertainties or experimental faults.
3 Explain how the data supports your statement.

Section 5.3 questions

QUIZ

Remembering

1 Give two ways of monitoring the production of a gas from a chemical reaction.
2 Give the units of rate for the following methods of measuring reaction rates:
  a loss of mass
  b production of a solid
  c gas syringe.

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...continued

3 Complete the following sentences:

a The greater the rate of reaction, the _______________ the reactants are used up.

b The steeper the gradient on a volume versus time graph, the _______________ the rate of reaction.

Understanding

4 Describe what is meant by the term 'rate of reaction'.

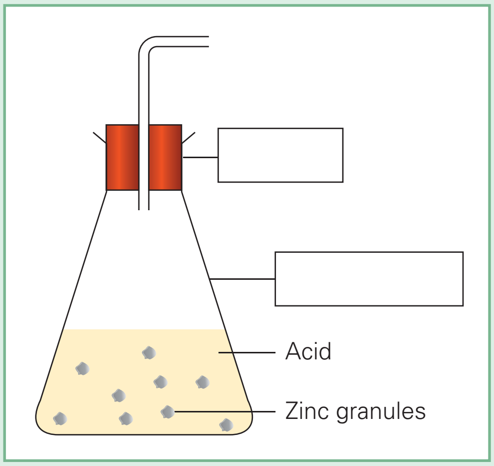
5 Explain why the rate of reaction is greatest at the beginning.

Applying

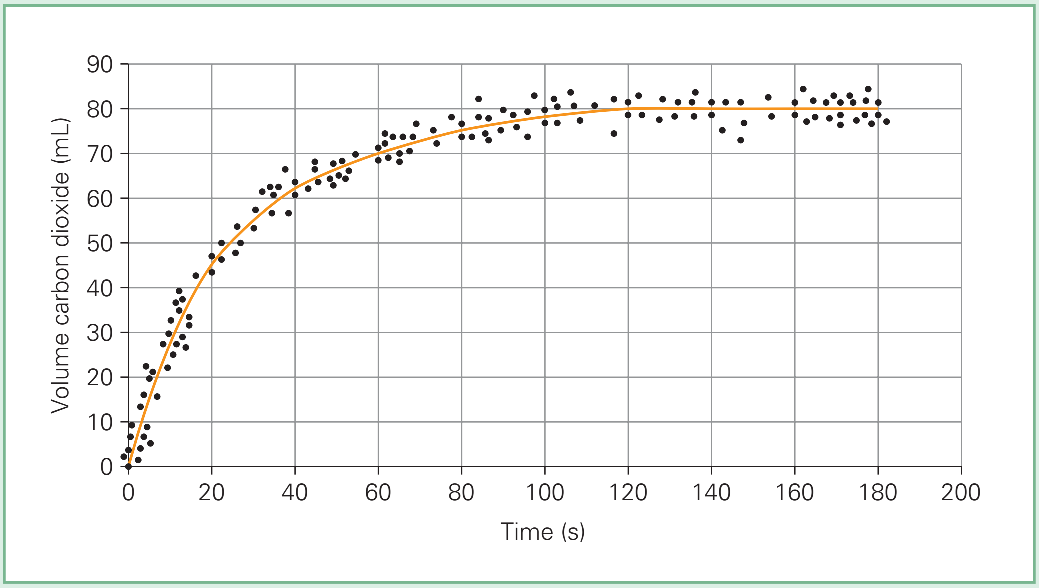
6 Select the most accurate technique to monitor the rate of this chemical reaction. Justify your choice.

$Zn_{(s)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(aq)} + H_{2(g)}$

7 Complete the diagram to show how a gas can be collected, and therefore, the rate of reaction measured. Label the equipment in the diagram.



8 Identify the time period during this experiment which showed the fastest rate of reaction. Justify your choice.



9 During an experiment, 45 mL of carbon dioxide was collected in 90 seconds. Calculate the rate of reaction and give appropriate units. Show your working.

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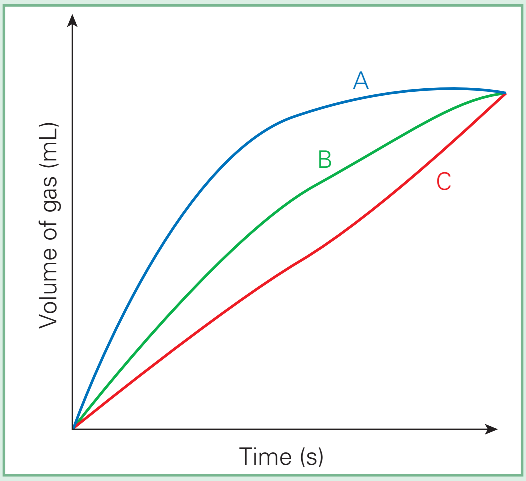
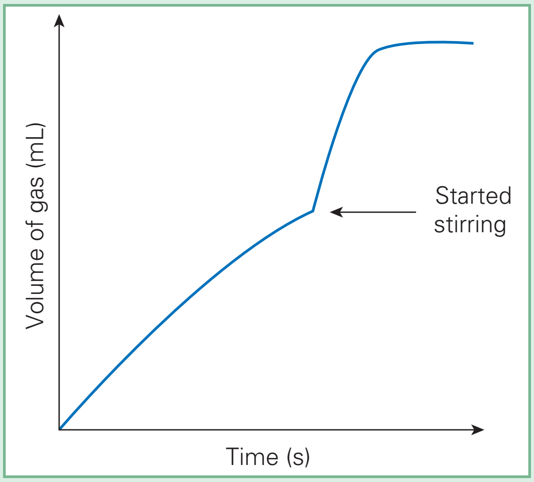
Analysing

10 Contrast the rates of reaction for the three experiments shown in the following graph.

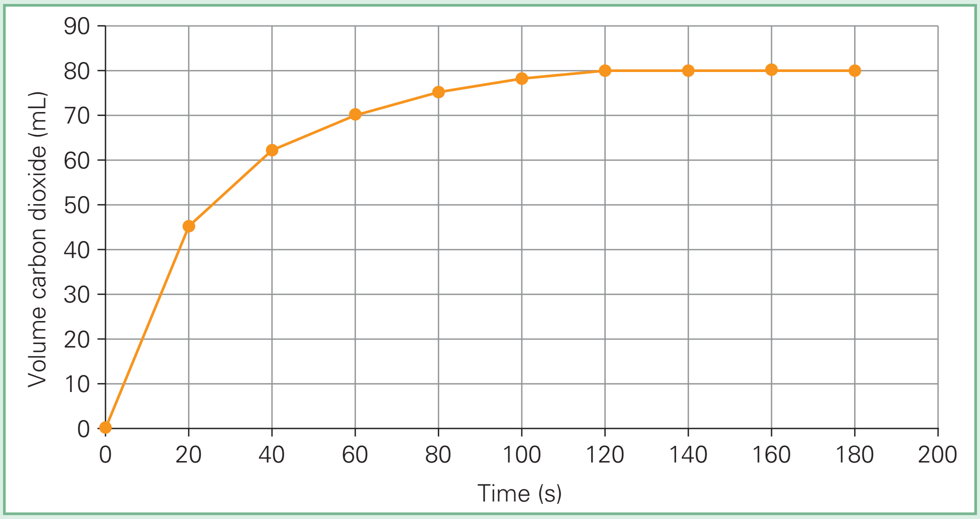


11 Analyse how stirring the reaction mixture affected the rate of this chemical reaction.



Evaluating

12 a Explain, using your knowledge of chemical reactions, why between 120 and 180 seconds the volume of carbon dioxide stays the same in this experiment.



b Deduce the value for the rate of the reaction during this time period.

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5.4 Factors affecting reaction rates

WORKSHEET

It is important to know how the rate of a chemical reaction can be increased, particularly in industry, where producing the maximum amount of product with the greatest efficiency is crucial.

For a chemical reaction to occur, reactant particles must collide with one another to form the products. However, not all **collisions** are successful ones. This is because reactant particles must also collide with at least a certain level of energy, unique to each chemical reaction, called the **activation energy**. The activation energy is the minimum energy required to break bonds in the reactants so they are able to form new bonds and make the products. If you can increase the frequency (number) of collisions and/or reduce the energy required for a successful collision (activation energy), you can increase the rate of reaction.

collisions particles must collide for a chemical reaction to occur

activation energy the minimum energy required for a successful collision and therefore to start a reaction

Quick check 5.14

1 Give two requirements for a successful chemical reaction.
2 Give the definition of the term 'activation energy'.

Figure 5.29 Industrial chemical plants rely on knowledge of reaction rates to produce maximum amounts of product in minimal amounts of time.

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Concentration

The **concentration** of a solution is a measure of the number of particles per unit volume.

concentration
the amount of substance in a given space

concentrated solution
a solution which contains a large amount of solute compared to solvent

dilute solution
a solution which contains a small amount of solute compared to solvent

A solution which contains a large number of particles within a given volume is called a **concentrated solution**. Likewise, a solution which contains a small number of particles within a given volume is called a **dilute solution**. Increasing the concentration of a solution means that you are putting more particles into the same volume.

If the concentration of a solution is increased, the particles are more likely to collide; and therefore, the reaction rate will increase. It is a bit like cramming lots of people onto a bus – it gets a bit tricky to avoid bumping into each other!

Although increasing the concentration increases the frequency of collisions, it does not affect the activation energy. Particles still need to collide with the same activation energy for collisions to be successful.

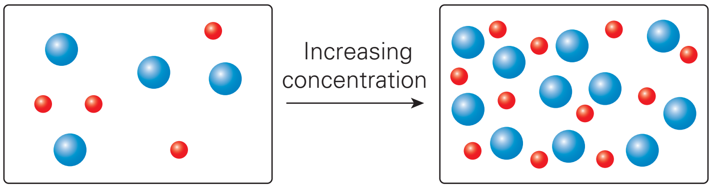

Figure 5.30 Increasing the concentration of solution increases the number of particles within the same volume.

Quick check 5.15

1 Decide whether the following statements are true or false.
  a A dilute solution contains a large number of reactant particles in a given volume.
  b Increasing the concentration of a reactant only affects the frequency of collisions.

Practical 5.6

Concentration and reaction rate

Aim

To determine how changing the concentration of hydrochloric acid affects the rate of reaction with sodium thiosulfate.

Materials

- 250 mL conical flask
- 1 piece of white paper
- black marker pen
- 50 mL measuring cylinder
- 10 mL measuring cylinder
- hydrochloric acid (2 M)
- sodium thiosulfate solution (0.15 M)
- stopwatch
- stirring rod

Be careful
Ensure appropriate personal protective equipment is worn.

Method

1 Construct a hypothesis for your investigation regarding how the hydrochloric acid concentration will affect the reaction rate.
2 Copy the results table on the next page.

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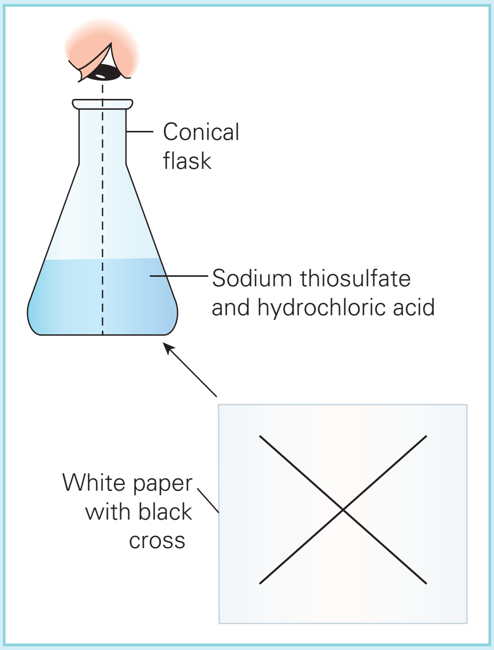
3 Using the black marker draw a large 'X' on to the paper.
4 Using a 50 mL measuring cylinder, measure 50 mL of sodium thiosulfate and pour it into the 250 mL conical flask. Place the conical flask onto the black cross.
5 Using the 10 mL measuring cylinder, measure 5 mL of hydrochloric acid.
6 Pour the acid into the conical flask, stir with a stirring rod and start the stopwatch.
7 Stop timing when the cross is no longer visible and record the time in your results table.
8 If available, dispose of the reaction mixture in a fume cupboard, otherwise pour down the sink rinsing with lots of cold water.
9 Repeat the steps for each concentration of sodium thiosulfate in the results table. The concentration of the sodium thiosulfate you add does not change (it is 0.15 M); however, adding water dilutes the solution.
10 Work out the relative of the reaction by calculating 1/reaction time.
11 Plot a graph of concentration (*x*-axis) versus rate (*y*-axis).



Results

Concentration of sodium thiosulfate (M)	Volume of sodium thiosulfate (mL)	Volume of water (mL)	Time taken for cross to disappear (s)	Reaction rate (1/time) (s^{-1})
0.15	50	0		
0.12	40	10		
0.09	30	20		
0.06	20	30		
0.03	10	40		

Evaluation

1 Give the independent and dependent variables in this experiment.
2 List three controlled variables and explain why they need to be controlled.
3 Explain why the disappearing cross method was suitable for this reaction, using the equation below.
$Na_2S_2O_{3(aq)} + 2HCl_{(aq)} \rightarrow S_{(s)} + SO_{2(g)} + 2NaCl_{(aq)}$
4 Using your graph, describe how increasing the concentration of sodium thiosulfate affects the rate of this chemical reaction.
5 Explain why increasing the concentration of a reactant normally increases the rate of reaction.

Conclusion

1 Make a claim about the concentration of sodium thiosulfate and the effect this has on the rate of reaction.
2 Support your statement by using the data you gathered and include potential measurement uncertainties.
3 Explain how the data supports your statement.

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Pressure

To increase the pressure of gaseous molecules, you can increase the number of particles and/or decrease the volume of the container.

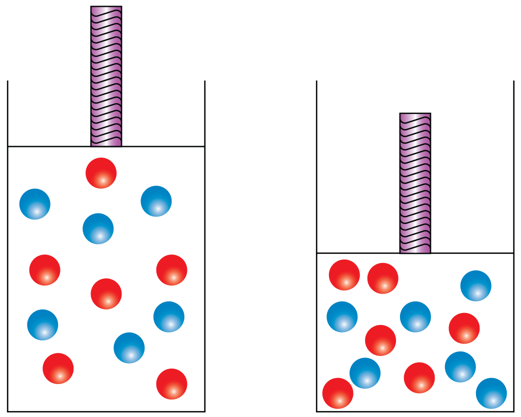

Figure 5.31 Reducing the volume of the container increases the pressure of gaseous molecules.

Gaseous particles under a high pressure are more likely to collide as there are more molecules within a smaller volume. Therefore, increasing the pressure increases the rate of reaction. This can only happen if one of the reactants is a gas because solid and liquid particles are nearly impossible to compress. It is a bit like the comparison between a class of 30 students running around a sports hall with the same class running around in an English classroom. The smaller space increases the pressure, meaning you are more likely to collide. The energy with which you collide, however, is not affected.

Quick check 5.16

1. Why does increasing the pressure of solid and liquid reactants not affect reaction rate?
2. How can the pressure of a gas be increased?

Surface area

When solids react, it is only the particles on the surface, which are in contact with the other reactant, that react. If you can make the solid reactant smaller, by cutting into pieces or grinding it into a powder, then the **surface area** is increased and more particles are exposed. Imagine a cake: when its surface area is increased by cutting into smaller pieces there is greater area of the cake exposed to the air; and therefore, it will dry out more quickly.

surface area the area of the outer part or surface of an object

Figure 5.32 Cutting a cake into pieces increases its surface area.

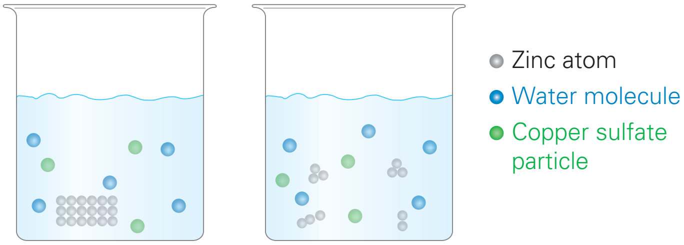

Figure 5.33 To increase the surface area of a solid reactant, cut it into smaller pieces or grind it into a powder.

Increasing the surface area of a solid will cause the reaction rate to increase. This is because there are more particles exposed to the reaction, increasing the frequency of collisions. However, just like increasing the concentration, the energy with which the particles collide is not be affected.

Quick check 5.17

1. Give two ways that the surface area of a solid can be increased.
2. A chemical reaction contains a liquid and a gas reactant. Can increasing their surface area increase reaction rate? Justify your answer.
3. Why does increasing the surface area of a reactant increase reaction rate?

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Figure 5.34 Apples go brown when cut.

Try this 5.2

Grab three apples. Cut one of them in half, one of them into eight segments and one into small cubes. Time how long it takes for the surfaces to go brown. After reading this section you should be able to make a prediction stating which apple have the greatest area of discolouration.

Practical 5.7: Self-design

Surface area and reaction rate

Be careful

Ensure appropriate personal protective equipment is worn.

Aim

To investigate how changing the surface area of calcium carbonate affects the rate of reaction with hydrochloric acid.

Materials

- small calcium carbonate chips
- large calcium carbonate chips
- calcium carbonate powder
- hydrochloric acid (1 M)
- 50 mL measuring cylinder
- any other common laboratory equipment that you may request after discussion with your teacher

Method

1 Using the materials listed and the techniques you have read about already in this chapter, plan an investigation to determine how the surface area of calcium carbonate chips affects the rate of reaction with hydrochloric acid. It may be useful for you to research the products of the reaction before you start planning!
2 Write a hypothesis for your investigation.
3 List the dependent and independent variables.
4 Give at least three controlled variables and why you need to control them.
5 Complete a risk assessment to show your teacher that you have taken into account all the risks associated with the experiment.
6 Write a step-by-step method, ensuring that you have accounted for any repeats.
7 Draw a suitable results table for your experiment.
8 Show your plan to your teacher. If your teacher is happy, carry out your experiment and collect the results.

Evaluation

1 Evaluate how successful your method was in monitoring the rate of a chemical reaction.
2 How did your plan ensure that your results were reliable?
3 Write a balanced formula equation with state symbols for the reaction of calcium carbonate ($CaCO_3$) with hydrochloric acid (HCl) to form calcium chloride ($CaCl_2$), carbon dioxide (CO_2) and water (H_2O).
4 How did changing the surface area of the calcium carbonate affect the rate of the reaction?

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Conclusion

1 Make a claim about the effect of surface area on the rate of a reaction.
2 Support your statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports your statement.

Stirring (agitation)

Stirring or **agitating** a chemical reaction increases the reaction rate as it allows more of the reactant particles to collide with one another. When a chemical reaction is left undisturbed (like the one in Figure 5.35), the product forms on the surface of the solid reactant, creating a barrier for any further reaction. Like increasing concentration and surface area, stirring a chemical reaction only increases the frequency of collisions, not the activation energy.

agitating stirring or shaking a mixture

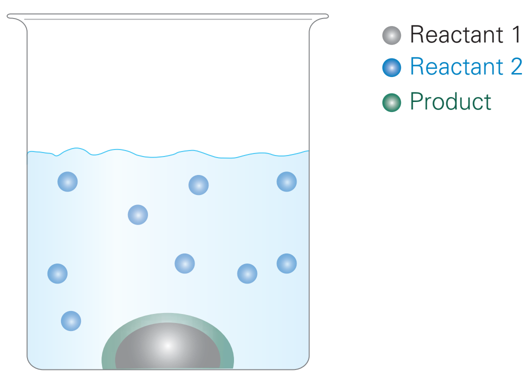

Figure 5.35 Stirring this reaction mixture would allow all of reactant 1 to come into contact with reactant 2.

Quick check 5.18

1 Why does stirring increase reaction rate?

Temperature

When you increase the temperature of a reaction the rate of reaction also increases. The thermal energy added to the reaction is converted into kinetic (movement) energy, so the particles move at greater speeds. Particles are more likely to collide, and because they move at faster speeds, they are also more likely to collide at the reaction's activation energy.

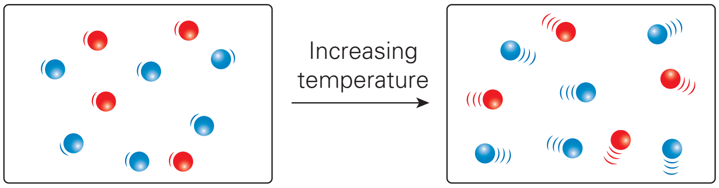

Figure 5.36 Increasing the temperature of a reaction increases kinetic (movement) energy of the reactant particles, increasing the number of successful collisions.

Therefore, increasing the temperature of a reaction also increases the number of successful collisions. It is a bit like running in a corridor: if you are moving fast you are more likely to bump into someone *and* it is more likely to hurt!

Quick check 5.19

1 When heat is applied to a chemical reaction, the particles convert this energy into:
   A Chemical energy.
   B Gravitational potential energy.
   C Kinetic energy.
   D Light energy.
2 Why does increasing the temperature of a chemical reaction increase the frequency of successful collisions?

Try this 5.3

Get three glasses and fill one with ice cold water, one with room temperature water and one with hot water. Crack three glow sticks and add one to each glass. Observe which one glows the brightest.

Figure 5.37 A chemical reaction causes glow sticks to release light.

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Practical 5.8

Temperature and reaction rate

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To determine the effect of temperature on reaction rate.

Materials
- electronic balance
- 250 mL conical flask
- 3 pieces of magnesium ribbon (3 cm in length)
- hydrochloric acid (2 M), initially at room temperature
- 50 mL measuring cylinder
- 2 water baths (one set at 40°C and one ice cold)
- stopwatch

Method
1. Write a hypothesis for your investigation regarding the effect of temperature on reaction rates.
2. Copy the results table below.
3. Using the 50 mL measuring cylinder, measure 50 mL of the room temperature 2 M hydrochloric acid and pour it into the conical flask.
4. Place the flask on top of the electronic balance.
5. Add one piece of magnesium ribbon to the conical flask. At the same time, note the starting mass and start the stopwatch.
6. Measure the mass of the conical flask and its contents every 30 seconds for three minutes.
7. After the three minutes, dispose of the reaction mixture down the sink and rinse out the conical flask.
8. Repeat the steps above for the other acid temperatures, now using the water baths to alter the temperatures of the hydrochloric acid once it is in the conical flask.

Results

Time (s)	Mass (g)		
	Room temperature	Warm	Cold
0			
30			
60			
90			
120			
150			
180			

Evaluation
1. Identify the independent and dependent variables in this investigation.
2. Give two controlled variables and why they needed to be controlled.
3. Plot a graph of your results. You will need to put time on the *x*-axis and mass on the *y*-axis. Think about how you will represent each of the three data sets on the same graph.
4. Write a word and balanced formula equation with state symbols for the reaction of magnesium (Mg) with hydrochloric acid (HCl) to form magnesium chloride ($MgCl_2$) and hydrogen gas (H_2).
5. Describe and explain how and why you were able to monitor the rate of reaction using the method in the experiment.

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...continued

Conclusion

1 Make a claim about the effect of temperature on reaction rate based on this experiment.
2 Support your statement by using the data you gathered and include potential experimental faults or uncertainties.
3 Explain how the data supports your statement.

Catalysts

A **catalyst** is a substance that can be added to a chemical reaction to increase the reaction rate. During the reaction, though, the catalyst is not used up and is not part of the reaction product. That is why the catalyst is not included in the chemical reaction, but it is often written above the reaction arrow between the reactants and products.

catalyst
speeds up a chemical reaction by lowering the activation energy, and does not get used up in the process

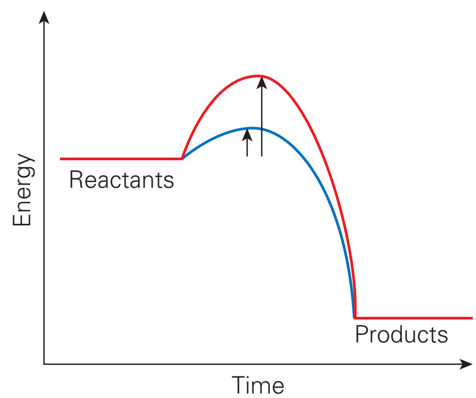

Figure 5.38 Adding a catalyst to a chemical reaction decreases the activation energy and therefore increases the number of successful collisions and therefore reaction rate.

When you eat carbohydrate-rich foods, the starch molecules are reacted with water and broken down into glucose. The enzyme amylase, which is found in your saliva, acts to catalyse (speed up) this reaction. Catalysts increase the reaction rate by providing an alternative route, which has a lower activation energy, for the reaction.

It is a bit like sheep jumping over a fence. The sheep are the reactant particles and the fence is the activation energy. If the fence (activation energy) is high, fewer sheep (particles) will reach the other side (fewer collisions will produce a successful reaction). On the other hand, if the fence is lowered by adding a catalyst, more sheep will be able to jump the fence (there will be a greater number of successful collisions).

Quick check 5.20

1 What is a catalyst?
2 How does a catalyst speed up a chemical reaction?

Practical 5.9: Teacher demonstration

Catalysts and reaction rate

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To determine the most effective catalyst to decompose hydrogen peroxide.

Materials

- 4 × 250 mL measuring cylinders
- 1 cm^3 piece of potato
- 1 cm^3 piece of liver
- 0.5 g manganese (IV) oxide

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...continued

- 0.5 g iron (III) oxide
- 50 vol hydrogen peroxide solution
- washing up liquid
- plastic tray
- stopwatch

Method

1 Copy the results table below.
2 Line up the four measuring cylinders into the tray and add about 1 mL of washing up liquid to each measuring cylinder.
3 Add 25 mL of the 50 vol hydrogen peroxide to each measuring cylinder.
4 Add the manganese oxide to one of the measuring cylinders and start the stopwatch.
5 Stop the stopwatch when the foam has risen to the top of the measuring cylinder.
6 Repeat for each of the catalysts.

Results

Catalyst	Time (s)
Manganese oxide	
Iron oxide	
Potato	
Liver	

Evaluation

1 Which catalyst was the most effective at decomposing the hydrogen peroxide? How did you know?
2 Which catalyst was the least effective at decomposing the hydrogen peroxide? How did you know?
3 Write a balanced formula equation including state symbols for the decomposition of hydrogen peroxide (H_2O_2) into water (H_2O) and oxygen (O_2)
4 One of the products produced relights a glowing splint. Identify this product.
5 How could you improve the reliability of your results?

Conclusion

1 Make a claim about the effect that catalysts have on the rate of reactions.
2 Support your statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports your statement.

Catalytic convertors

Explore! 5.4

Catalytic converters have been a key component of car exhaust systems in Australia since 1986. Their outer body is made of stainless steel and their inside comprises a honeycombed ceramic block containing transition metals such as platinum and palladium. The role of a catalytic convertor is to speed up a chemical reaction which converts harmful emissions produced by burning petrol and diesel into less harmful emissions. Catalytic convertors play such an important part in reducing harmful exhaust emissions that you can be given a heavy fine if your car does not have one.

1 Give the name of some harmful gases produced by burning petrol and diesel and describe how they could affect the environment.
2 Give the name of the gases produced by the catalytic convertor and describe how they affect the environment.

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3 Give the balanced formula equation for the reduction of nitrogen monoxide (NO) into nitrogen (N_2) and oxygen (O_2) which occurs in a catalytic converter. Include state symbols.

4 Give the balanced formula equation for the oxidation of carbon monoxide (CO) into carbon dioxide (CO_2) by reacting it with oxygen (O_2) that occurs in a catalytic converter. Include state symbols.

5 Explain the advantage of a catalytic converter having a honeycomb structure.

6 Explain why catalytic converters are less efficient when you start your car cold than when it has warmed up.

Figure 5.39 A catalytic converter used in a car's exhaust system.

A summary of changing reaction rates

Table 5.8 summarises how each factor discussed in this section influences the rate of a chemical reaction.

<table>
<tr><th>Factor increasing</th><th>Effect on the frequency of collisions</th><th>Effect on number of successful collisions</th><th>Effect on rate</th></tr>
<tr><td>Concentration of reactants</td><td rowspan="5">Increases</td><td rowspan="4">Not affected</td><td rowspan="6">Increased</td></tr>
<tr><td>Pressure of gaseous reactants</td></tr>
<tr><td>Agitation (stirring)</td></tr>
<tr><td>Surface area of solid reactants</td></tr>
<tr><td>Temperature</td><td rowspan="2">Increased</td></tr>
<tr><td>Adding a catalyst</td><td>Not affected</td></tr>
</table>

Table 5.8 A summary of how each factor discussed affects reaction rate

Section 5.4 questions

QUIZ

Remembering

1 Give three factors that can affect the rate of a chemical reaction.

2 Decide whether the following statements are true or false:

  a Increasing the rate of stirring has no effect on the rate of reaction.

  b Changing the surface area of liquid reactants will increase the reaction rate.

  c Changing the pressure of a reaction mixture will only affect reactions containing gaseous reactants.

  d Increasing the temperature of a reaction increases the frequency and energy of collisions.

3 Define the term 'activation energy'.

4 Give the name of chemicals that are added to a chemical reaction to reduce the activation energy.

Understanding

5 Outline the requirements for a chemical reaction.

6 Summarise the relationship between temperature and reaction rate.

7 Custard powder can explode when launched into the air, but not when it is tightly packed in a container. Explain why.

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...continued

Applying

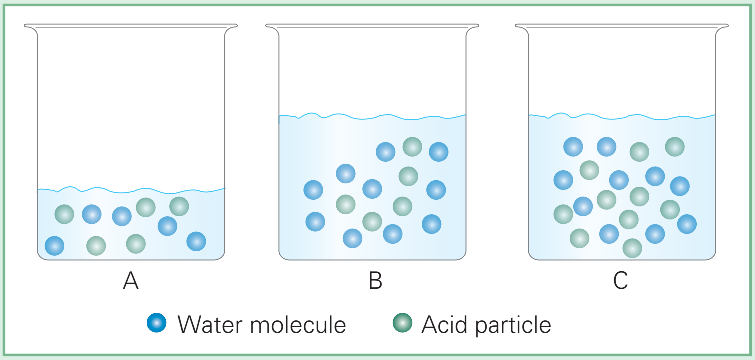
8 Children are advised to take fewer tablets than adults. Identify the factor affecting reaction rate that is influencing this advice.

9 Your fire is not hot enough, so you add more fuel. Identify which factor you have changed to increase the reaction rate.

10 The chemical reaction that occurs when you bake cake mixture requires a large amount of heat for it to be successful. What can you deduce about the activation energy of this reaction?

11 a Which solutions in the figure below have the same concentration?

b Is the solution in the other beaker more concentrated or more dilute? Justify your choice.



Analysing

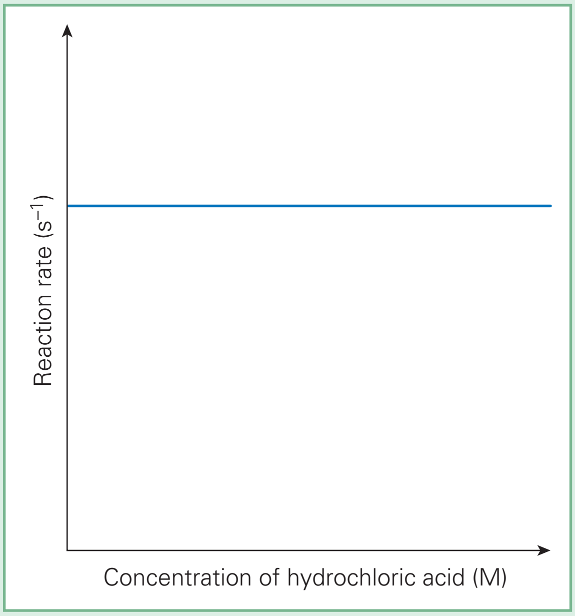
12 Contrast a dilute and concentrated solution.

13 What is the relationship between surface area and reaction rate?

Evaluating

14 Scientists often use magnetic stirrers to stir chemical reactions. Explain why this continuous stirring increases the rate of reaction.

15 A student conducted an experiment to determine how changing the concentration of hydrochloric acid affected the rate of reaction with sodium thiosulfate. They plotted a graph of their results, which can be seen below. What can you conclude about the effect of increasing the concentration of acid in this reaction? Deduce why this may be the case and provide reasoning.



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...continued

16 Your sugar cube is dissolving too slowly in your tea. Propose how you could make it dissolve faster and why.

17 You have two beakers of the same solution. They are both of the same concentration. To increase the concentration of the solution, you pour them into the same beaker. Decide whether you have changed the concentration or not. Justify your choice.

Review questions

Remembering

SCORCHER

1 Name three diatomic elements on the periodic table.

2 State the meaning of the term ‘monomer’.

3 Give one method of monitoring reaction rates.

4 Recall one factor which speeds up the rate of a chemical reaction solely by affecting the number of collisions.

Understanding

5 Explain why it is important that chemical equations are balanced.

6 Explain why alcohol is added to petrol.

7 Demonstrate by way of a labelled diagram how you could monitor the rate of a gas producing chemical reaction using an upturned measuring cylinder.

8 Describe what is meant by the term ‘successful collision’.

Applying

9 When hydrogen and oxygen react together at high temperatures, water is made. Construct a word equation and a balanced formula equation with state symbols to represent this reaction.

10 Identify why sulfuric acid is such an important chemical to the chemical industry.

11 Construct a word equation for a reaction that can be monitored by timing the disappearance of a solid.

12 Construct a graph to show how surface area could affect reaction rate.

Analysing

13 Analyse the mistakes made in the following balanced formula equation.

$HNO_{3(aq)} + 2Cu_{(g)} \rightarrow 2Cu(NO_3)_{2(aq)}$ + hydrogen

14 Analyse the use of a less reactive metal, like copper, in preventing the corrosion of iron.

15 On a rate graph, how could the start and end of a reaction be distinguished?

16 How does reaction rate affect the time a reaction takes?

Evaluating

17 Discuss the importance of balancing equations in the chemical industry.

18 Evaluate the advantages of the whole world coming together to sign the Montreal Protocol.

19 Decide what the equations below are telling you about the nature of the Mn^{4+} ion.

$2Fe^{2+} + Mn^{4+} \rightarrow 2Fe^{3+} + Mn^{2+}$

$Mn^{2+} + 2Ce^{4+} \rightarrow Mn^{4+} + 2Ce^{3+}$

20 Discuss the importance of our understanding of reaction rates on the chemical industry.

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STEM activity: Making leather out of apples

Background information

VCDSTC048 VCDSCD049 VCDSCD051 VCSIS113

Sustainable use of materials is a hugely important consideration in most industries. As a result, there is an emerging branch of chemical engineering that looks at developing new sustainable materials and chemical processes.

Two major factors contribute to the sustainability of materials. Materials need to be sustainable over their entire lifetime, which includes the production as well as the disposal and degradation of the material. Sustainable materials have a low carbon footprint, which means that processes used to make them do not use a lot of energy (particularly from fossil fuels). At the end of their useful lifetime, sustainable materials should be able to biodegrade or be easily recycled. This cycle is referred to as cradle-to-grave, or cradle-to-cradle, which is the product's lifecycle.

The fashion industry uses many different types of materials, some more sustainable than others. For example, using leather for clothing and accessories is energy intensive, as well as being an issue of animal cruelty. While the fashion industry has moved towards more sustainable leather, fashion industry pioneers in recent years have been developing a vegan leather material out of food waste to help solve some of these problems.

As well as being a kinder and greener option than animal leather, fruit leather can also solve the problem of food waste. It is estimated that as much as 20–40% of the fruit that is grown in Australia never reaches supermarket shelves because it does not pass quality standards. Rather than going to waste, it could be used to produce leather.

Figure 5.40 Leather is traditionally made from cow skins that are a by-product of meat production.

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Figure 5.41 Waste from apples has been used to create a leather-like material.

Design brief: Design a fashion industry product and construct it out of fruit leather.

Activity instructions

In small groups, brainstorm a number of products that are made out of leather. Choose one of these products and sketch a picture of the it. Annotate the sketch with all the features of the design, identifying joining and construction methods used.

Research and decide on a suitable method of making fruit leather. The methods you will find on the internet will most likely be for making fruit leather for eating (like roll-ups), so you will need to think about which techniques are appropriate (or not appropriate) for the desired product. Write down the materials and the method you will use, and have it approved by your teacher.

Suggested materials/presentation formats

- apples (or other fruit like apricots)
- water
- saucepan
- hotplate
- spatula
- wire mesh strainer
- large tray
- convection oven or dehydrator (optional)

Evaluate and modify

1 During the traditional process of tanning animal leather, the skin is made more stable by replacing some collagen with chromium. This changes the property of the leather: it becomes more flexible and able to withstand 100°C boiling water. Deduce whether this is a chemical or physical reaction and state your reasoning. Can the same be said of fruit leather?
2 Describe any difficulties you came across when creating your product from fruit leather.
3 Evaluate whether fruit leather is a viable alternative for making your product. Explain why or why not.
4 Suggest some changes you could make to your method or construction process that would improve the viability of fruit leather for making your product. How could you make it more durable, increase its strength and increase its resistance to water?
5 Discuss environmental implications of making fruit leathers, and how this might change the way we make products.

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Chapter 6 **Global systems**

Chapter introduction

The first time people had a glimpse of Earth from space was in December 1968. Apollo 8 astronauts took pictures of our planet on their way to the Moon. This allowed us to understand Earth from a different perspective: as a global system. Earth is a dynamic and ever-changing planet consisting of interconnecting spheres. In this chapter, you will learn about Earth's chemical spheres and how they interact. You will understand how humans are disrupting the balance and how scientists can make predictions about our future. It is the interactions between Earth's systems, both natural and enhanced, that have shaped its history and will continue to shape its unpredictable future.

Curriculum

Global systems, including the carbon cycle, rely on interactions involving the atmosphere, biosphere, hydrosphere and lithosphere (VCSSU128)	
• modelling a nutrient cycle within the biosphere, for example, the carbon, nitrogen or phosphorus cycle	6.1, 6.2
• investigating how human activity affects global systems	6.1, 6.4
• distinguishing between 'natural' and 'enhanced' greenhouse effects	6.3
• investigating the effect of climate change on sea levels and biodiversity	6.4

Victorian Curriculum F–10 © VCAA (2016)

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Glossary terms

ammonification
atmosphere
biodiversity
biosphere
carbon sinks
carbon sources
climate
decomposers
denitrification
enhanced greenhouse effect
geosphere
glacial periods
greenhouse effect
greenhouse gases
hydrosphere
interglacial periods
keystone species
lithosphere
nitrification
nitrogen fixation
stratosphere
sustainable ecosystem
troposphere
weather

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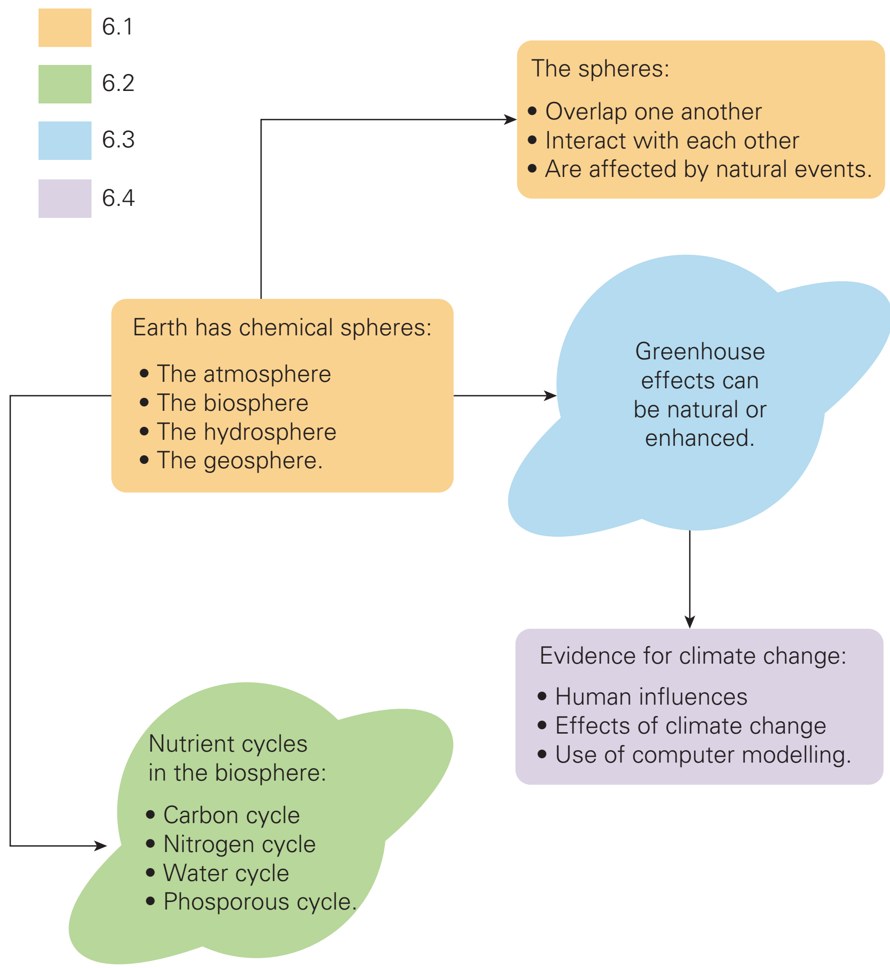
Concept map



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6.1 Earth's interacting spheres

In your Science studies so far, you have learned about two of Earth's cycles: the rock cycle and the water cycle. You should therefore have an appreciation for the fact that matter on Earth is constantly moving. That is why we say that Earth is dynamic – meaning constantly changing – unlike the Moon, which remains relatively unchanged.

Atmospheric gas	Percentage composition (%)
Nitrogen	78
Oxygen	21
Argon	1
Trace gases (for example, carbon dioxide, neon, methane, water vapour)	<1

Table 6.1 The composition of gases in Earth's atmosphere

WORKSHEET

VIDEO
Name and briefly explain Earth's spheres

Chemical spheres

To make it easier to describe the movement of matter around Earth, scientists have split the planet into four major systems called spheres. Despite their name, they are not spherical in shape. These spheres are the atmosphere, biosphere, geosphere and hydrosphere.

The atmosphere

The **atmosphere** consists of all the gases above Earth's surface – without it there would be no life on Earth. Two main gases make up our atmosphere: nitrogen and oxygen. There are also smaller proportions of other gases.

atmosphere
the mixture of gases above the surface of Earth

Our atmosphere in total is about 500 km thick and contains five layers: the **troposphere**, **stratosphere**, mesosphere, thermosphere and exosphere. These layers allow us and other living things to breathe, protect us from the Sun's harmful ultraviolet (UV) radiation and keep the surface temperature constant. The layers of most importance to us and life on Earth are the troposphere and the stratosphere.

troposphere
a layer of Earth's atmosphere which is closest to Earth's surface and where most of the weather occurs

stratosphere
a layer of Earth's atmosphere above the troposphere containing the ozone layer

Figure 6.1 The Moon is not dynamic, unlike matter on Earth which is constantly on the move.

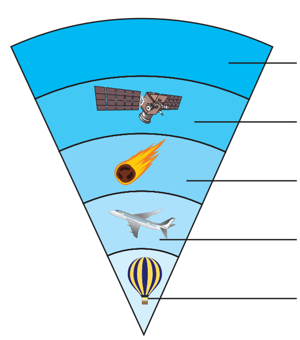

Figure 6.2 The five layers of Earth's atmosphere

Quick check 6.1

1 Name the gas which is the most abundant in Earth's atmosphere.
2 Recall the functions of Earth's atmosphere.

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The troposphere

The troposphere is the layer closest to the surface of Earth and is between 10 km and 15 km thick. It contains about 75% of the mass of the entire atmosphere. It is in the troposphere that most of the weather occurs – resulting from hot air rising and cold air sinking within this layer. Greenhouse gases, carbon dioxide, methane and water vapour are also found in the troposphere; more on this later on in the chapter.

The stratosphere

The stratosphere lies directly above the troposphere and is about 35 km deep. Within the stratosphere is the ozone layer, a thin layer of ozone molecules (O_3). The ozone layer protects Earth from high-energy UV radiation released from the Sun. Jet aircraft fly in the lower part of the stratosphere.

Figure 6.3 Most of Earth's weather is found in the troposphere.

Figure 6.4 Jet aircraft fly in the lower stratosphere to avoid turbulence.

Quick check 6.2

1 List some features of the troposphere.
2 Give the function of the ozone layer in the stratosphere.

Explore! 6.1

The Antarctic hole in the ozone layer

In 1985 scientists found that parts of the ozone layer above the continent of Antarctica had broken down. They also noticed that similar thinning of the ozone layer was happening over parts of Australia, and that this was correlated with an increase in cases of skin cancer. They needed to find out why this had happened and if it could be reversed. Do some research and answer the following.

1 State the similarities and differences between the atomic structures of oxygen gas (O_2) and ozone gas (O_3).

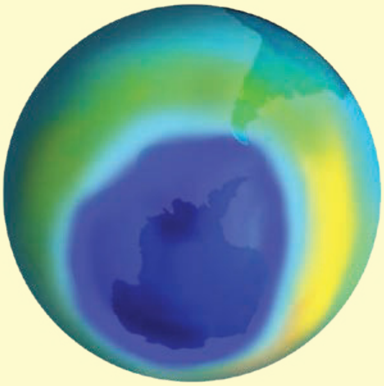

Figure 6.5 The hole in the ozone layer above Antarctica. The purple areas show the least amount of ozone.

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2 Identify the main function of the ozone layer in more detail to explain the impact of ozone thinning.
3 Research the causes of ozone thinning.
4 Describe the purpose of the Montreal Protocol.
5 Discuss whether the process of ozone thinning can be reversed. Collect some evidence to support your discussion.

Science as a human endeavour 6.1

Felix Baumgartner: the fastest man on Earth

On 14 October 2012, Austria's Felix Baumgartner climbed nearly 39 km to the stratosphere in a helium-filled balloon. He then jumped into thin air, free falling for four minutes and 22 seconds before opening his parachute. The entire journey back to the ground lasted just over nine minutes. Baumgartner reached an estimated speed of 1342 km/h which makes him the first man to break the speed of sound in free fall, and he broke the record for the world's highest ever free fall.

The jump nearly did not happen because a fault in the heater of Baumgartner's visor was making it fog up when he breathed out. During the dive, there was concern early on as he could not get in to the correct position for freefall (head down, arms swept back). Instead, he found himself tumbling over and over. However, due to his extensive freefall experience, Baumgartner was able to correct his fall and get into a stable position.

Figure 6.6 Felix Baumgartner

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The biosphere

biosphere
all the areas on Earth and in its atmosphere that contain life

The **biosphere** consists of all areas of Earth and its atmosphere that contain life. It comprises all the living organisms on the planet – including plants, animals (including humans), fungi and microscopic organisms like bacteria and viruses.

Quick check 6.3

1 What is the biosphere?
2 Flying birds are part of the atmosphere, true or false? Justify your choice.

The hydrosphere

hydrosphere
all of the water found on Earth (for example, lakes and rivers)

The **hydrosphere** is made up of all the water on Earth. This includes the oceans, rivers, lakes, glaciers, rain, underwater basins and even puddles!

Quick check 6.4

1 What is the hydrosphere?
2 Give an example of something that is part of the hydrosphere.

Figure 6.7 Elephants, as living organisms, are part of the biosphere. The Fox glacier in New Zealand is part of the hydrosphere.

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The geosphere

The **geosphere** includes all the natural and lifeless parts of Earth's surface, crust and core. For example, all the rocks and sand from dry land to the bottom of the ocean, minerals, lava and magma below Earth's crust.

geosphere
all the lifeless parts of Earth's surface, crust and core

Figure 6.8 Uluru is part of the geosphere.

The geosphere is in a constant cycle, with matter constantly moving in the processes involved in the rock cycle. Magma erupts from volcanoes as lava, which solidifies forming rocks. This rock is eroded into sediment, which builds up over time and sinks further into the crust until it is spewed out onto Earth's surface again as lava.

You may also hear the **lithosphere** mentioned as part of Earth's global systems.

lithosphere
the lifeless parts of Earth's crust and upper mantle only

The lithosphere relates to Earth's crust and the upper part of the mantle only, whereas the geosphere includes all Earth's minerals and rock from the crust to the inner core. The lithosphere is broken up into tectonic plates which float on top of the mantle – most earthquakes and volcanoes occur at boundaries between tectonic plates.

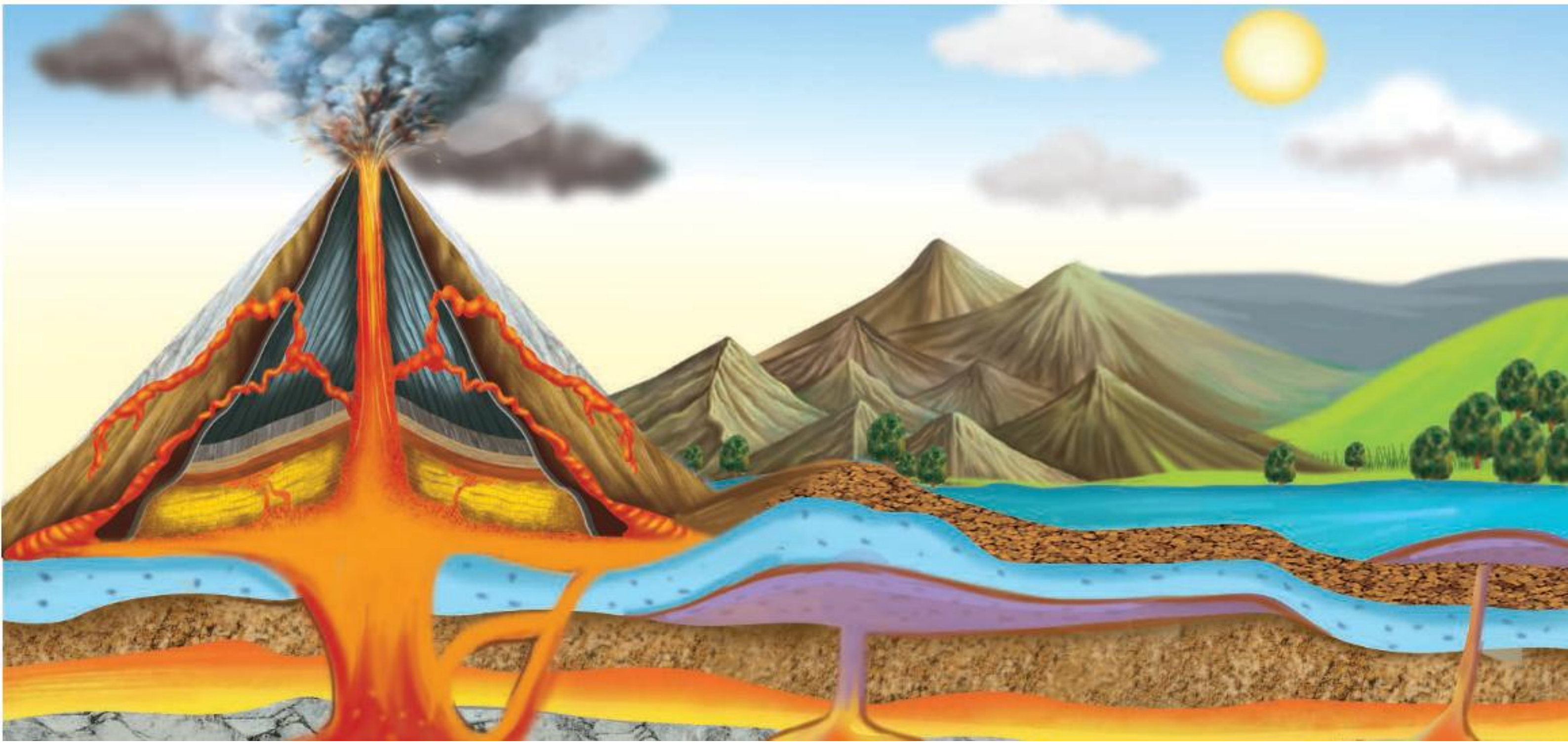

Figure 6.9 The geosphere is constantly in motion due to the many processes involved in the rock cycle.

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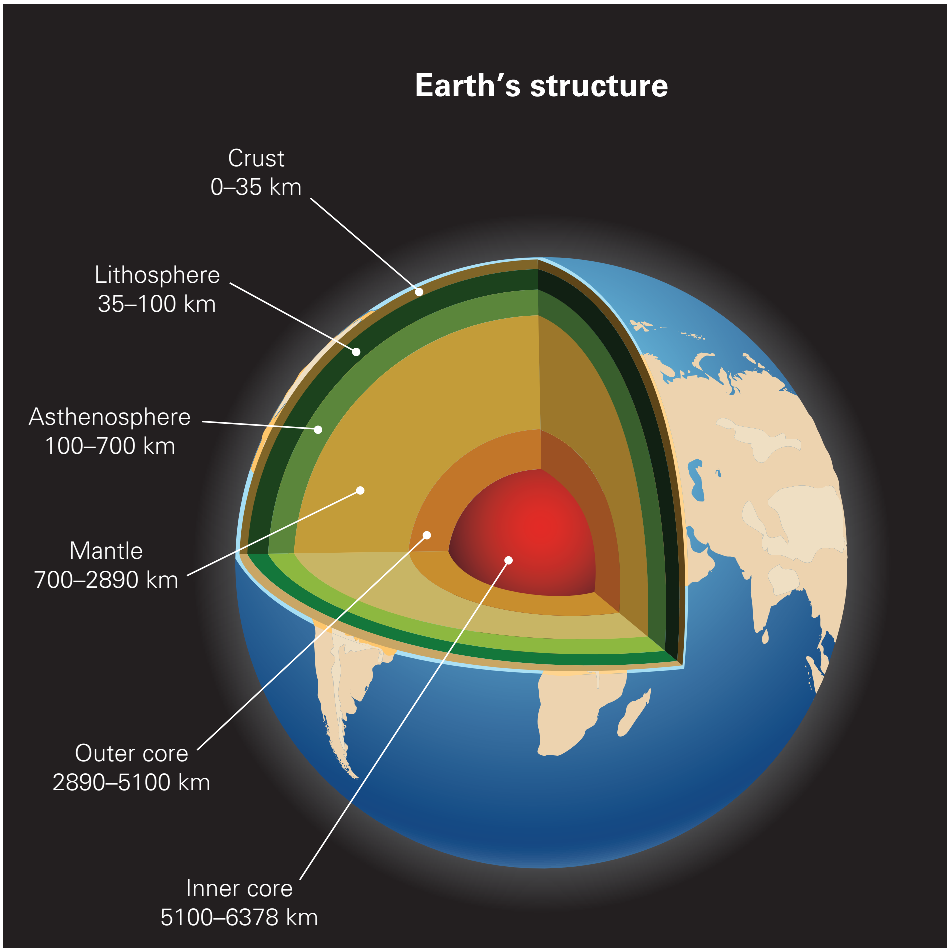

Figure 6.10 The structure of Earth's geosphere, measured from Earth's surface

Quick check 6.5

1. What is the geosphere?
2. Give an example of something that is part of the geosphere.
3. Name the cycle that results in constant movement of the geosphere.

Overlapping spheres

Sometimes it is not easy to classify substances as being exclusively part of one sphere. This is because, if you look closely, some matter belongs to two or more spheres at the same time. A healthy soil is described as one that contains plenty of water, air, minerals and bacteria, as well as other organic matter. If we were to assign soil to a chemical sphere, you could argue that it belongs to them all: water from the hydrosphere, air from the atmosphere, minerals from the lithosphere and bacteria from the biosphere.

Figure 6.11 Healthy soil belongs to all four chemical spheres.

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Practical 6.1

The components of healthy soil

A healthy soil is made up of a mixture of minerals such as sand, silt and clay, water and rotted plant (organic) material.

Be careful

Ensure appropriate personal protective equipment is worn.

Aim

To determine the composition of different soils.

Materials

- straight-sided jam jar
- 250 mL beaker
- stirring rod
- soil sample (three different soil samples will be provided; you just need to do one)
- measuring tape

Method

1. Copy the results table below.
2. Fill up the straight-sided jam jar about a third of the way with the soil that you are testing.
3. Now add water to the jar of soil until it is almost full.
4. Using the stirring rod, mix the soil and water thoroughly.
5. Leave the jar for one hour or until the contents have settled.
6. Measure the height of the total soil sample and water and record in your notes.
7. Measure the height of each soil layer. Your results table tells you that sand is at the bottom, working upwards towards organic material at the top.
8. Work out the percentage composition of the soil sample by dividing the depth of each soil layer by the total depth of the whole soil sample and multiplying by 100.

Results

Name of layer	Depth of soil layer	Percentage composition
Sand		
Silt		
Clay		
Water		
Organic material		

Evaluation

1. Determine whether your sample was a healthy soil. Justify your choice using data from the table.
2. Compare your results to other groups who did different soil samples.
3. Describe the overlapping spheres in the soil samples.
4. Another factor of a healthy soil is a large proportion of bacteria. Research how you could test if the conditions in the soil were optimum for bacterial growth.

Conclusion

1. Make a claim about the composition of soil based on this experiment.
2. Support the statement by using your observations and include potential experimental faults or sources of measurement uncertainty.
3. Explain how your observations support your claim.

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Sphere interactions

The chemical spheres on Earth interact and affect each other, maintaining a natural balance on Earth. Matter constantly moves between spheres in cycles. The energy driving the movement of matter comes from the Sun and from Earth's core. It is the flow of this energy and the cycling of matter that produces chemical and physical changes in Earth's materials. Earth gains and loses mass and energy in different ways, as summarised in Table 6.2.

	Gain	Loss
Energy	Radiation from the Sun (mostly infrared, visible and UV wavelengths) Gravitational forces from the Sun, Moon and planets	Heat loss into space
Mass	Meteorites and comets	Escape of gases into space

Table 6.2 A summary of Earth's gains and losses of mass and energy

Quick check 6.6

1 Earth can be described as a closed system, meaning that its total mass does not change. Decide whether this statement is true or false.
2 List one way that Earth can gain and lose mass and energy.
3 The rate that matter moves around Earth varies, from very slow to incredibly fast. Decide whether this statement is true or false.

Figure 6.12 Farmland, where multiple sphere interactions take place

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The lithosphere, the rigid crust and upper mantle of our planet, comes into contact with the other spheres. Let's take Figure 6.12 as an example to describe some of the sphere interactions that can take place. Plants in the biosphere obtain water from the hydrosphere and nutrients from the geosphere via soil. Water vapour is released by plants into the atmosphere.

Quick check 6.7

1 Give the name of the sphere where most of the sphere interactions take place.
2 Give an example of a transfer of matter from the biosphere to the atmosphere.

Figure 6.13 Plants interact with multiple chemical spheres.

Practical 6.2

Demonstrating the interaction between chemical spheres.

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To demonstrate the interaction between chemical spheres.

Materials
- celery sticks with leafy tops
- food colouring
- 250 mL measuring cylinder
- paring knife
- cutting board

Method
1 Copy the results table below.
2 Using the 250 mL measuring cylinder, measure 25 mL of water and add to it several drops of food colouring.
3 Using the paring knife and cutting board, cut along the base of the celery stick to expose a fresh section.
4 Place the stalk into the measuring cylinder, with the cut end in the liquid.
5 Leave it in bright sunlight.
6 Every five minutes for 30 minutes, record the height that the water has travelled up the celery stick.

Results

Time (mins)	Distance liquid has moved (cm)
5	
10	
15	
20	
25	
30	

continued…

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...continued

Evaluation

1 Identify the sphere interactions that were demonstrated in this investigation.
2 If this experiment had been conducted using the water content of soil, what other substances would have been taken up with the water? Would this have demonstrated any other sphere interactions?
3 Plants also interact with the atmosphere. Give one way plants do this.

Conclusion

1 Make a claim about the interaction of chemical spheres based on this experiment.
2 Support the statement by using your observations and include potential experimental faults.
3 Explain how your observations support your claim.

Natural events affecting chemical spheres

Natural events such as earthquakes and volcanoes influence the interactions between the chemical spheres. Table 6.3 summarises how natural events cause sphere interactions.

Natural event	Impact on the lithosphere	Impact on the biosphere	Impact on the atmosphere	Impact on the hydrosphere
Earthquake	Fault lines move apart or together. Land rises or subducts (sinks). Landslides Mudslides 	Damage to lithosphere destroys ecosystems.	Gas emissions from the ground release toxic gases.	Tsunamis Change the course of rivers Destroy dams 
Volcano	Volcanic lava can create islands. 	Lava burns plants and animals. New islands are habitats for ecosystems.	Large ash clouds release many gases, including greenhouse gases and toxic gases. 	Toxic gases dissolve in water and fall as acid rain.
Cyclone	Intense rainfall causes erosion of the land.	Uproot trees and plants destroying ecosystems 	High wind speeds	Produce very heavy rain causing floods Storm surges 

Table 6.3 How natural events influence the interaction between spheres

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Section 6.1 questions

QUIZ

Remembering

1 Match the chemical sphere to its definition.

Atmosphere	Water in all of its forms
Biosphere	Earth's crust and upper part of the mantle
Lithosphere	Living things
Hydrosphere	Mixture of gases surrounding the planet

2 Choose the correct sphere for the following examples:
  a glacier
  b tectonic plates
  c earthworms
  d ozone.
3 Recall the layer of the atmosphere where most of the weather occurs.
4 Give the name of the second most abundant gas in Earth's atmosphere.
5 Recall the two sources of energy that drive the movement of matter on Earth.

Understanding

6 Explain why you cannot describe Earth as a closed system (one where the total mass does not change).
7 Compare the geosphere with the lithosphere.
8 Show examples of the chemical spheres present in Figure 6.14.

Figure 6.14

9 Explain the problems associated with a hole in the ozone layer.

continued...

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...continued

Applying

10 Identify which of Earth's spheres would contain matter that has arrived from space.

11 Identify the sphere interactions taking place in Figure 6.15.

Figure 6.15

12 Identify the role of Earth's atmosphere as it relates to sustaining life on Earth.

Analysing

13 Analyse why a healthy river containing dissolved nitrogen, oxygen and carbon dioxide, algae and other organisms, and mineral and rock fragments, contains components from all the chemical spheres.

14 Contrast the movement of matter on Earth and the Moon.

Evaluating

15 Decide which sphere clouds belong to, and justify your choice.

16 Discuss how a natural disaster, such as an earthquake, can affect chemical spheres. Try to include all the spheres in your answer.

6.2 Nutrient cycles in the biosphere

WORKSHEET

The cycling and recycling of nutrients such as nitrogen, carbon and water in the chemical spheres is important for sustaining life and ecosystems.

A **sustainable ecosystem** is a biological environment that is able to support itself without outside assistance.

sustainable ecosystem a biological environment that is able to support itself without outside assistance

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The carbon cycle

The carbon cycle describes the movement of carbon through all four spheres. Carbon is one of the most important chemicals for life on Earth – an essential building block for cells. The carbon cycle occurs in many steps, but it is important to note that carbon can stay at one particular stage for thousands of years before moving on to the next step.

Table 6.4 summarises the forms of carbon in each of the chemical spheres.

VIDEO
Why is carbon important?

Chemical sphere	Carbon content
Atmosphere	Carbon dioxide (CO_2) gas, methane (CH_4)
Biosphere	Carbohydrates (such as glucose $C_6H_{12}O_6$), fats, proteins, vitamins and the DNA of all living things
Hydrosphere	CO_2 dissolved in rivers, lakes and the ocean, forming carbonic acid (H_2CO_3)
Lithosphere	Decomposed organic matter in soils Fossil fuels (coal, oil and gas) Limestone (calcium carbonate $CaCO_3$)

Table 6.4 A summary of the carbon content in each chemical sphere

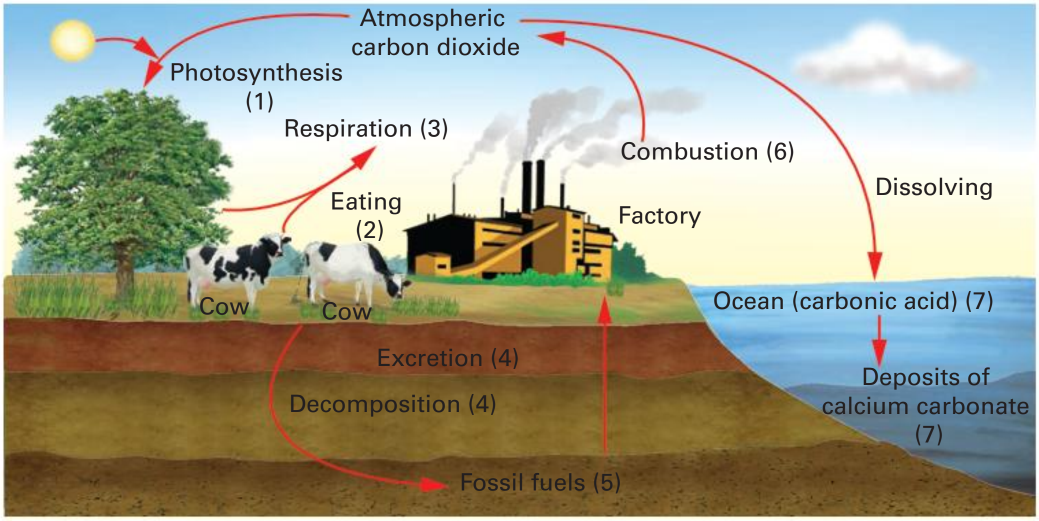

Figure 6.16 The main stages and processes in the carbon cycle

The carbon cycle can be summarised in seven processes, which either increase or decrease carbon dioxide in the atmosphere.

1. Photosynthesis

Carbon dioxide in Earth's atmosphere is absorbed by plants during photosynthesis. The carbon dioxide reacts with water taken in from the soil to make glucose, a carbon-containing compound.

The following equations summarise the process of photosynthesis:

carbon dioxide + water → glucose + oxygen

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

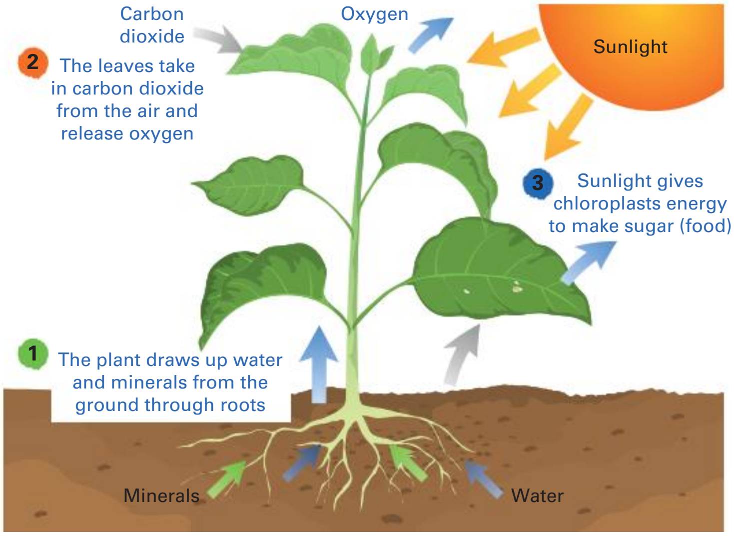

Figure 6.17 Plants remove atmospheric carbon dioxide during photosynthesis.

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Quick check 6.8

1. What is a sustainable ecosystem?
2. Why is the recycling of carbon so important?
3. Give the name of the form of carbon in the hydrosphere.
4. Carbon dioxide is converted into what form of carbon in photosynthesis?

2. Transfer of carbon through the food chain

Animals obtain their carbon by eating plants and other animals. When animals and plants are eaten, their carbon content is transferred through the food chain.

Figure 6.18 The carbon content of the cricket is now being consumed by the leopard gecko!

3. Respiration

Plants and animals break down glucose using oxygen to form carbon dioxide and water. This process is called respiration. The carbon dioxide is added to the atmosphere when organisms breathe out.

The following equation summarises respiration:

glucose + oxygen → carbon dioxide + water

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

Figure 6.19 During respiration, organisms release carbon dioxide gas into the atmosphere.

4. Excretion, death and decomposition

Some of the carbon content of animals and plants enters the soil as waste, such as urine, faeces and fallen leaves.

Figure 6.20 Excretion increases the carbon content of the soil, like this wombat faeces.

Dead animals and plants (organic matter) also contribute to the carbon content of the soil. Dead organic matter is broken down by **decomposers**, which respire, releasing carbon dioxide back into the atmosphere.

decomposers living organisms that break down dead organic matter

Quick check 6.9

1. How do animals obtain their carbon in the carbon cycle?
2. Apart from carbon dioxide, what other product is released during the break down of glucose in respiration?
3. Name ways that animals can increase the carbon content of soil.

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5. Formation of fossil fuels

Fossil fuels like coal, oil and gas are composed of the carbon from plants and animals that died millions of years ago. Carbon is stored as fossil fuels for millions of years before re-entering the carbon cycle.

Figure 6.21 Coal is a fossil fuel formed from the carbon content of dead plants that have been buried and compressed for millions of years

6. Combustion

When fossil fuels are burned in oxygen (combustion), carbon dioxide and water are formed. Carbon dioxide is therefore released back into the atmosphere. Later in this chapter we will look in more detail at how humans are affecting the balance of carbon in the carbon cycle.

Figure 6.22 The combustion of coal in an incinerator produces large amounts of carbon dioxide gas.

The following equation shows the combustion of octane, a component of oil:

octane + oxygen → carbon dioxide + water

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

7. Formation of limestone

Carbon dioxide gas in the atmosphere can dissolve in the oceans, forming carbonic acid. This carbonic acid is used, along with calcium ion mineral deposits, to make calcium carbonate ($CaCO_3$) – the major component of shells. Shells from dead animals sink to the bottom of the ocean. Over millions of years, compaction of these shells results in the formation of limestone. Limestone is a sedimentary rock and an important building material. The carbon stored in limestone can remain there for millions of years before it re-enters the carbon cycle.

Figure 6.23 Fossilised shells in limestone

Quick check 6.10

1. Give an example of a fossil fuel.
2. Give the name of the processes where fossil fuels are burned releasing carbon dioxide back into the atmosphere.
3. What is the scientific name and formula for limestone?

The following table summarises the gains and losses of atmospheric carbon in the carbon cycle.

Atmospheric carbon gains	Atmospheric carbon losses
Respiration	Photosynthesis
Combustion	Formation of fossil fuels
Excretion, death and decomposition	Dissolving in the oceans and forming limestone

Table 6.5 A summary of the gains and losses of atmospheric carbon within the carbon cycle

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Practical 6.3

The oceans and carbon dioxide

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To determine what happens when carbon dioxide dissolves in water.

Materials
- test tube
- bottle of universal indicator and pH scale
- straw
- test tube rack

Method
1 Copy the results table below.
2 Fill the test tube with water to a depth of about 5 cm.
3 Add three drops of universal indicator and note the colour and pH in the results table.
4 Place the straw into the test tube and blow gently into it for 10 seconds. Be careful to only blow into the straw, you might want to practise before actually doing it.
5 Note the colour and pH of the solution after you have blown into it.

Results

	Colour	pH
Before blowing		
After blowing		

Evaluation
1 Identify what is indicated by the colour and pH of the water before blowing.
2 Identify what is indicated by the colour and pH of the water after blowing.
3 Give the name and formula of the solution formed after blowing.
4 Which stage of the carbon cycle does this experiment represent? Justify your choice.
5 Discuss what happens to the carbon dioxide in the water after it has dissolved.

Conclusion
1 Make a claim about the ability of carbon dioxide to dissolve in water based on this experiment.
2 Support the statement by using your observations and include potential sources of error.
3 Explain how your observations support your claim.

Practical 6.4

Limestone and carbon dioxide

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To determine whether limestone contains carbon dioxide.

Materials
- calcium carbonate chips
- hydrochloric acid (1 M)

continued…

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...continued

- 2 test tubes
- delivery tube
- limewater
- 2 × 10 mL measuring cylinders
- test tube rack

Method

1. Using a 10 mL measuring cylinder, measure 5 mL of hydrochloric acid and pour it into one of the test tubes.
2. Using another 10 mL measuring cylinder, measure 5 mL of limewater and pour it into the other test tube.
3. Add three calcium carbonate chips to the acid, and at the same time attach the bung of the delivery tube to this test tube with the other end in the limewater solution.
4. Observe what happens to the limewater.

Results

Record your observations from the experiment in your notes.

Evaluation

1. Describe what happened to the limewater solution.
2. Explain what these observations tell you about the composition of limestone.
3. In this reaction, calcium carbonate was reacted with hydrochloric acid. Three products were formed. Two of those products were calcium chloride and water. Write a word equation for the reaction which includes the third product.
4. Identify the part of the carbon cycle represented by this investigation.

Conclusion

1. Make a claim about the carbon dioxide content of limestone based on this experiment.
2. Support the statement by using your observations and include potential sources of error.
3. Explain how your observations support your claim.

Practical 6.5

Combustion and carbon dioxide

Be careful

Ensure all hot equipment is allowed to cool and hot glassware is handled with a hot beaker glove.

Aim

To determine whether carbon dioxide is a product of combustion.

Materials

- tea light
- 250 mL beaker
- box of matches
- heatproof mat
- hot beaker glove

Method

1. Light the tea light using a match and place on the heatproof mat.
2. Place the empty 250 mL beaker upside down over the tea light.
3. Observe what happens to the candle.

continued...

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Results

Record your observations from the experiment in your notes.

Evaluation

1 Explain your observations from the experiment.
2 Identify the stage of the carbon cycle that is represented in this investigation. Justify your choice.
3 Write a word equation to show the burning of wax in oxygen to form carbon dioxide and water.

Conclusion

1 Make a claim about carbon dioxide as a product of combustion based on this experiment.
2 Support the statement by using your observations and include potential sources of experimental faults.
3 Explain how your observations support your claim.

The nitrogen cycle

Nitrogen in its elemental form has the formula N_2. Nitrogen is important for all living things as it is the basis of DNA and the subunits of proteins called amino acids. The majority (78%) of nitrogen in the form of N_2 is found in the atmosphere. However, a large proportion of organisms cannot access this form of nitrogen.

Table 6.6 summarises the forms of nitrogen in each of the chemical spheres.

The nitrogen cycle can be summarised in six processes which can result in either the gain or loss of nitrogen in the form of nitrates from the soil.

Chemical sphere	Nitrogen content
Atmosphere	Nitrogen (N_2) gas
Biosphere	Amino acids (the building blocks of proteins) and the DNA of all living things
Hydrosphere	Nitrates (NO_3), leached into the water from the soil
Lithosphere	Nitrates (NO_3) from the decomposition of organic matter and nitrification

Table 6.6 A summary of the nitrogen content in each chemical sphere

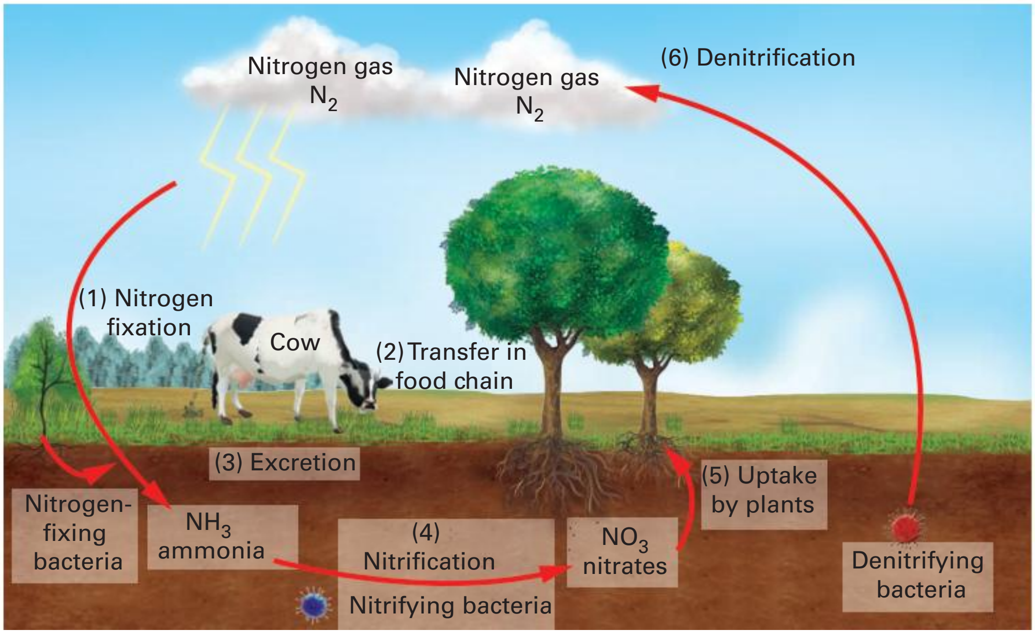

Figure 6.24 The main stages and processes in the nitrogen cycle

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1. Nitrogen fixation

Nitrogen fixation makes nitrogen in the atmosphere accessible to the majority of organisms. Nitrogen-fixing bacteria can take the nitrogen gas (N_2) that is in the atmosphere and convert it into a nitrogen-containing compound called ammonia (NH_3), which can be used by plants. Another process that makes the atmospheric nitrogen available for use is lightning strikes – the energy in a lightning strike is enough to convert nitrogen into ammonia.

nitrogen fixation the conversion of atmospheric nitrogen into ammonia by nitrogen-fixing bacteria or lightning

Figure 6.25 Lightning converts nitrogen gas in the atmosphere into ammonia (NH_3).

Quick check 6.11

1 Identify where the majority of nitrogen is found in the nitrogen cycle.
2 Name the process and bacteria involved in converting nitrogen gas into useful nitrogen-containing compounds.

2. Transfer through the food chain

Animals obtain their nitrogen through eating plants and other animals. The nitrogen-containing compounds are therefore transferred through the food chain.

Figure 6.26 Animals obtain their nitrogen by eating other animals or plants.

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3. Excretion, death and decomposition

When plants and other organisms that have gained nitrogen during their lifetime die, they are broken down by decomposers, forming ammonia. These decomposers convert the nitrogen in the organic matter into ammonia, in a process called **ammonification**.

ammonification
the process in which bacteria in the soil converts dead plant and animal material into ammonia

4. Nitrification

Plants can take up the ammonia formed during the decomposition of nitrogen in organic matter and through nitrogen fixation. However, nitrogen is of more use to plants in the form of nitrates (NO_3). Converting ammonia to nitrates is called **nitrification**, and is carried out by nitrifying bacteria.

nitrification
the conversion of ammonia into useful nitrates by nitrifying bacteria

Figure 6.27 Decomposing organic matter and animal excretions are part of both the ammonification and nitrification processes.

5. Uptake by plants

The nitrates formed during nitrification are taken up by plants and used to make DNA and amino acids, the building blocks of proteins.

Quick check 6.12

1. Identify where in the nitrogen cycle animals obtain their nitrogen.
2. Name the organisms that are responsible for breaking down dead organic matter into ammonia.
3. Name the process and bacteria involved in converting ammonia into nitrates.

Figure 6.28 Plants take up nitrogen-containing compounds from the soil.

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6. Denitrification

denitrification the process of converting nitrates into nitrogen gas to be released back into the atmosphere

The process of **denitrification** also involves bacteria, in this case denitrifying bacteria. Denitrification is the conversion of nitrates back into nitrogen gas, which is released back into the atmosphere.

Table 6.7 summarises the gains and losses from the soil of nitrogen in the form of nitrates in the nitrogen cycle.

Nitrate gains	Nitrate losses
Excretion, death and decomposition	Denitrification
Nitrogen fixation	Uptake by plants
Nitrification	

Table 6.7 A summary of the gains and losses of nitrates in the soil in the nitrogen cycle

Quick check 6.13

1 Name the process and bacteria involved in converting nitrates back into nitrogen gas.
2 State the importance of nitrogen for living organisms.

Explore! 6.2

The phosphorus cycle

Phosphorus in its elemental form is highly reactive; however, animals and plants rely on more stable forms of phosphorus to survive. Like carbon and nitrogen, different forms of phosphorus are recycled through the phosphorus cycle.

Figure 6.29 A phosphate mine on Christmas Island, Western Australia. Phosphates (and nitrates) are important chemicals in the manufacture of fertilisers.

Use your knowledge of other nutrient cycles as well as other resources such as books and the internet to answer the following questions.

1 Where is the element phosphorus found in humans?
2 In which chemical sphere would you find no phosphorus present and why?
3 Describe some of the major steps that lead to the cycling of phosphorus.
4 Describe how humans have influenced the phosphorus cycle, and explain the impacts this has caused.
5 Compare the phosphorus cycle to the other nutrient cycles discussed in this section.

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The water cycle

The water cycle is responsible for the recycling of water around the chemical spheres. Precipitation falls from clouds in the atmosphere. This water either joins the oceans or rivers in the hydrosphere or reaches the soil in the lithosphere. Plants take in water from the soil and then lose this water through transpiration. Thermal energy from the Sun returns water back to the atmosphere as water vapour through the process of evaporation.

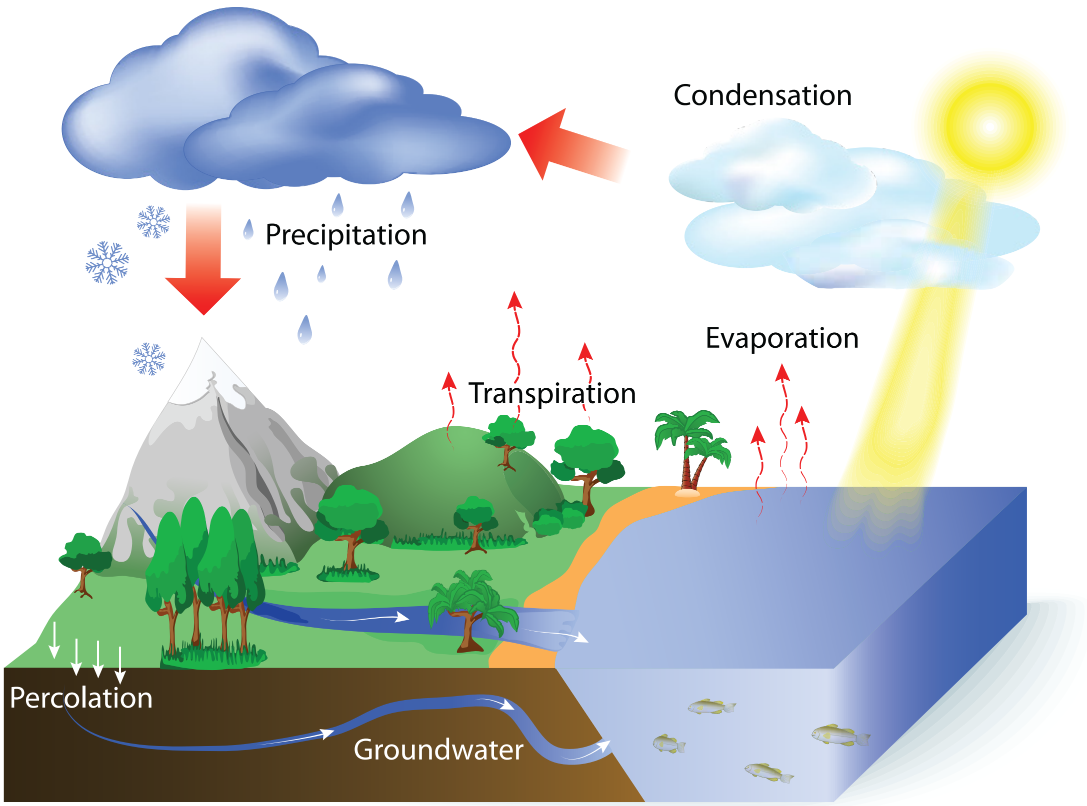

Figure 6.30 The main stages in the water cycle

QUIZ

Section 6.2 questions

Remembering

1 Give the name of the cycle (carbon, nitrogen or water) which includes the following processes:
   a denitrification
   b respiration
   c decomposition
   d transpiration
   e combustion.

2 State the name and formula of the compound in which carbon is found in the atmosphere.

3 Recall the name of the process that takes nitrogen gas out of the atmosphere and adds it into the soil as ammonia.

4 Give the reason why animals and plants require nitrogen.

5 Bacteria can take nitrogen from the atmosphere and convert it into nitrogen compounds in the soil. State another component of the nitrogen cycle that is able to do this.

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...continued

Understanding

6 Describe the process of photosynthesis to show how carbon dioxide from the atmosphere is transferred into plants and animals.

7 Demonstrate, with the use of a word equation, why respiration is part of the carbon cycle.
8 Explain why the water cycle involves all four chemical spheres.
9 Outline the role of decomposers in both the carbon and nitrogen cycles.
10 Explain where the carbon in coal, oil and gas originally came from.

Applying

11 Identify which of the following processes involve bacteria and explain how bacteria are involved:
- a nitrification
- b decomposition
- c photosynthesis
- d evaporation
- e percolation.

12 Select the best definition for a sustainable ecosystem, and justify your choice.
- A An environment that requires intervention to continue.
- B A biological environment which is self-sustaining; that is, does not require any outside assistance.
- C A system that is a mixture of biotic and abiotic factors.

Analysing

13 Compare and contrast the processes of nitrogen fixation and denitrification in the nitrogen cycle.
14 Examine both the carbon and nitrogen cycles. What processes are similar?

Evaluating

15 Evan says that humans are affecting both the carbon and the nitrogen cycles in a negative way. Trent however, disagrees with this statement and thinks that humans do not affect these cycles at all. Discuss who you think is correct.
16 Explain why carbon stored in fossil fuels remains in this form for a long period of time.
17 Explain why plants can suffer from a lack of nitrogen when they are surrounded by a plentiful supply of nitrogen in the atmosphere.
18 Deduce what would happen if the nitrogen cycle stopped.

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6.3 The greenhouse effect in the atmosphere

WORKSHEET

Some parts of the world are too cold to grow certain fruits and vegetables, so growers have to grow these crops in greenhouses. Greenhouses are used to grow weather- or temperature-sensitive plants, or those that are out of season. The advantage of using a greenhouse is that growers have more control over the conditions in which the plants grow.

Figure 6.31 Greenhouses protect plants from cold and adverse weather conditions.

Greenhouses are made from glass and plastic. When the Sun's radiation passes through these materials, it heats the ground and air of the greenhouse. As the ground heats up, it emits infrared radiation which is reflected back into the greenhouse by the glass or the plastic. As the air heats up, it starts to rise, but it cannot exit the greenhouse as it is stopped by the roof and walls. All of this results in the greenhouse heating up, keeping the plants at an optimum temperature for growth.

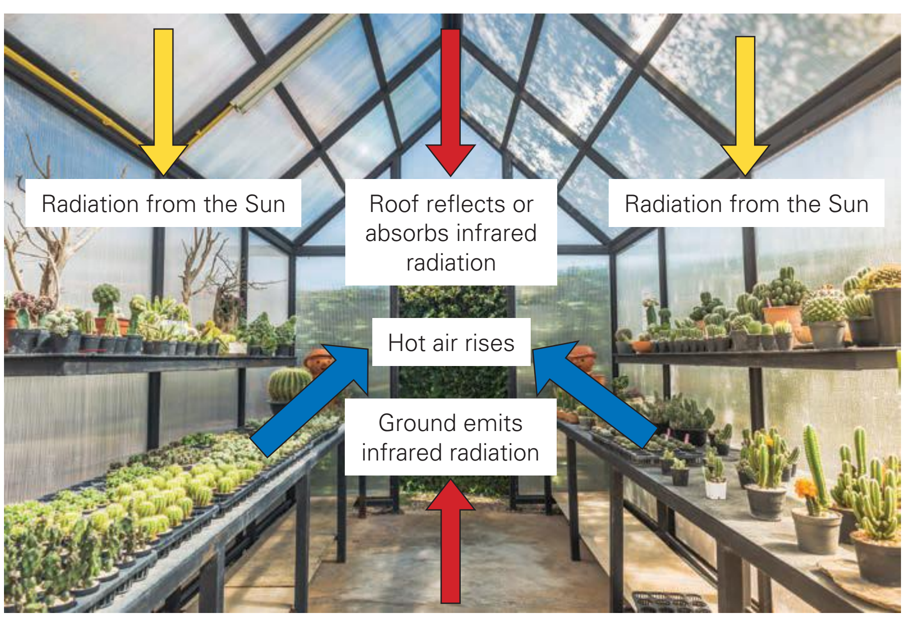

Figure 6.32 How greenhouses keep in the thermal energy

Quick check 6.14

1 Name the type of radiation emitted from the ground and air.
2 Explain why greenhouses are made of glass or plastic.

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The natural greenhouse effect

Earth has its own way of keeping the heat in, similar to a greenhouse but on a much larger scale. Most of the Sun's radiation passes through Earth's atmosphere where the majority heats the ground and the oceans. The remainder is reflected back into space by ice, clouds and water. The ground and oceans emit radiant energy back towards the atmosphere as infrared radiation. However, instead of leaving Earth's atmosphere, some of this radiation is absorbed and reflected back towards the surface by a layer of gases called **greenhouse gases**. Water vapour (H_2O) is the most abundant (95%) greenhouse gas. Methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) are three of the most common greenhouse gases.

greenhouse gases
gases that contribute to the greenhouse effect

The following table compares the effectiveness in retaining heat of the three most common greenhouse gases.

Figure 6.33 The Sun emits radiation which passes through our atmosphere.

Quick check 6.15

1 Give the name and formula of one common greenhouse gas.
2 Most of the radiation emitted from the Sun heats the ground and the oceans. What happens to the rest of this radiation?

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)
% of the total number of greenhouse gases	84	9	5
Persistence in the atmosphere	100 years	10 years	100 years
Effectiveness of trapping heat compared to carbon dioxide		30 times more effective	300 times more effective

Table 6.8 A summary of the three most common greenhouse gases, excluding water vapour

Practical 6.6

Does land or water warm faster?

Aim
To determine whether land or water heats up faster.

Materials
- 2 thermometers
- 2 plastic containers (they should be the same size and shape)
- sand
- water
- lamp

continued...

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...continued

Method

1. Predict whether the land or water will heat up or cool down the quickest.
2. Copy the results table below.
3. Pour sand into one of the plastic containers to a depth of about 5 cm. This container will represent the land.
4. Pour water into the other plastic container to the same depth of 5 cm. This container will represent the water.
5. Measure the starting temperature using the thermometer of each material and record it in the results table at time = 0.
6. Place the two containers 10 cm either side of the lamp and switch it on.
7. Start the stopwatch and record the temperature of each container every two minutes for 10 minutes.
8. After 10 minutes, turn off the lamp.
9. Record the temperature of each container every two minutes, until a total time of 20 minutes.

Results

Time (mins)	Temperature (°C)	
	Sand	Water
0		
2		
4		
6		
8		
10 (turn off the lamp)		
12		
14		
16		
18		
20		

Evaluation

1. Plot a graph of time on the *x*-axis and temperature on the *y*-axis. You will need two lines on the same graph: one for the sand data and one for the water data.
2. Which substance heated up the fastest? Did this match your prediction?
3. Which substance cooled down the fastest? Did this match your prediction?
4. Using your results, explain why a pool can still feel warm hours after the Sun has gone down.
5. Explain how this experiment links to your understanding of the greenhouse effect.

Conclusion

1. Make a claim about whether land or water heats up faster based on this experiment.
2. Support the statement by using your observations and include potential experimental faults or sources of measurement uncertainty.
3. Explain how your observations support your claim.

greenhouse effect the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

The process of trapping the Sun's solar energy in Earth's atmosphere is called the **greenhouse effect**. The radiation from the Sun is described as short-wave radiation (being mostly in the visible light wavelength; UV is also short-wave). This type of radiation is able to pass directly through the atmosphere. The infrared radiation emitted from the ground and the oceans is described as long-wave radiation. This type of radiation is absorbed by greenhouse gases, keeping

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Earth warm. If the Sun's radiation was not converted into infrared, we would lose all of the thermal energy back into space, and Earth would be a lot less habitable. Plants, animals and humans would struggle to survive on Earth without the greenhouse effect's role in maintaining a cozy, consistent average temperature.

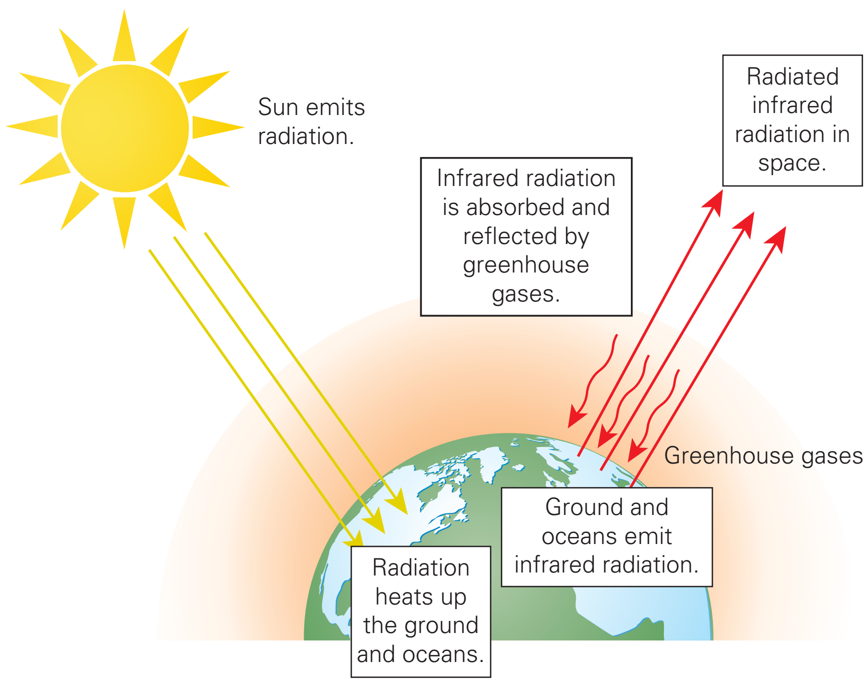

Figure 6.34 A summary of the greenhouse effect

Did you know? 6.1

We need the natural greenhouse effect

Earth's average temperature is 14°C. Without the natural greenhouse effect, this temperature would decrease to −18°C.

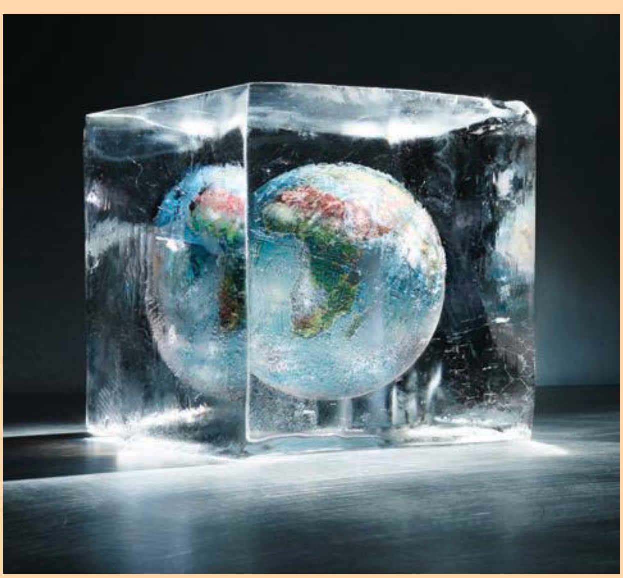

Figure 6.35 Earth would freeze without the greenhouse effect.

Explore! 6.3

The greenhouse effect on Venus

Mercury is the closest planet to the Sun and therefore should be the hottest planet in our solar system. However, this award goes to Venus which has surface temperatures around 460°C –hot enough to melt lead. If you stood on Venus, you would be exposed to an atmospheric pressure 92 times that of Earth. Scientists think that Venus used to be similar to Earth with lower temperatures and even liquid water.

Figure 6.36 Venus is over 400 times hotter than Earth.

1 Research what the atmosphere of Venus is made of.
2 What happened to change Venus's atmosphere, increasing the surface temperature and evaporating any liquid water?
3 Why was the evaporation of water on Venus such a problem in maintaining a cooler temperature?
4 In your opinion, could the same thing that happened on Venus happen on Earth?

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Practical 6.7: Self-design

Which materials are the best emitters of infrared radiation?

Be careful
Ensure all hot glassware is handled with a hot beaker glove

Aim
To determine which material emits the most infrared radiation.

Materials
- kettle
- 25 mL measuring cylinder
- 3 boiling tubes
- test tube rack
- small pieces of aluminium foil and different colours of card
- stopwatch
- 3 thermometers
- hot beaker glove

Method
1. Design a valid experiment using the equipment above to determine which material emits the most infrared radiation.
2. Write a hypothesis for your investigation.
3. Submit a risk assessment to be approved by your teacher before you start collecting data.

Results
Draw a suitable results table for your investigation.

Evaluation
1. State the dependent and independent variables in your investigation.
2. Give two controlled variables and explain why they needed to be controlled.
3. State the experimental control that could have been used in this investigation and explain why it is a control.
4. Recall one way in which this experiment could have been made more accurate.
5. Recall one way in which this experiment could have been made more repeatable or reproducible.
6. Which material was the best emitter of infrared radiation? How did you know?
7. Explain how this experiment links to your understanding of the greenhouse effect.

Conclusion
1. Make a claim about the emission of infrared radiation from different materials based on this experiment.
2. Support the statement by using your observations and include potential experimental faults or sources of measurement uncertainties.
3. Explain how your observations support your claim.

Table 6.9 summarises the features of solar and infrared radiation.

Solar radiation	Infrared radiation
Emitted by the Sun	Emitted by the Sun, the ground and oceans
Short-wave	Long-wave
Not trapped by the atmosphere	Trapped by greenhouse gases in the atmosphere

Table 6.9 Features of solar and infrared radiation

Quick check 6.16

1. Name a source of short-wave radiation.
2. Name the radiation that is absorbed by greenhouse gases in the atmosphere.

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Greenhouse gases can absorb a certain amount of infrared radiation; the rest is radiated back into space. The more greenhouse gases there are in our atmosphere, the more infrared radiation is trapped and the hotter Earth becomes.

The enhanced greenhouse effect

The natural greenhouse effect keeps our planet at a comfortable temperature; however, human activity has caused this natural process to intensify. This is called the **enhanced greenhouse effect**.

enhanced greenhouse effect the intensifying of the natural greenhouse effect due to human activity

Causes

The major cause of the enhanced greenhouse effect is an increase in the concentration of greenhouse gases: carbon dioxide, methane, nitrous oxide and water vapour in the atmosphere. Table 6.10 summarises how humans have contributed to the increased levels of these greenhouse gases.

Greenhouse gas	How humans have increased its concentration in the atmosphere
Carbon dioxide	Burning fossils fuels such as coal, oil and gas Currently, 70% of Australia's electricity is produced by burning coal. 
Methane	Farming cattle (which produce methane when they digest grass) and growing rice in paddies Increasing temperatures which is leading to melting of permafrost in the Arctic. Permafrost is frozen soil which contains trapped methane produced from the decomposition of plants and animals. 
Nitrous oxide	Using fertilisers, which increases the amount of nitrogen in the nitrogen cycle therefore increasing the production of nitrous oxide 
Water vapour	While water vapour is already the most abundant greenhouse gas naturally, as the concentrations of carbon dioxide, methane and nitrous oxide in the atmosphere increases due to human activity, more heat is trapped which contributes to increasing water vapour concentrations (increased humidity). This has a positive feedback effect on increasing temperatures, enhancing the greenhouse effect.

Table 6.10 How humans have increased the concentration of greenhouse gases in the atmosphere

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Quick check 6.17

1 State one way in which we have increased the concentration of carbon dioxide in the atmosphere.
2 Give one way we have increased the concentration of nitrous oxide in the atmosphere.
3 State the composition of permafrost.

Practical 6.8

Comparing the natural and enhanced greenhouse effects

Aim

To compare the impacts of the natural and enhanced greenhouse effects.

Materials

- high-intensity lamp
- 2 thermometers
- 2 × 500 mL beakers
- cling wrap
- 2 elastic bands
- baking soda
- 2 weighing boats
- balance
- water
- vinegar
- marker pen
- sticky tape
- 100 mL measuring cylinder
- stopwatch

Method

1 Copy the results table on the next page.
2 With the marker pen, label one of the 500 mL beakers 'control'.
3 Using the sticky tape, tape one of the thermometers to the inside of this beaker. It must be about 5 cm above the bottom of the beaker.
4 With the marker pen, label the second beaker 'CO_2'.
5 Tape the thermometer to the inside of this beaker, again making sure it is 5 cm from the bottom.
6 Using the balance, weigh out 35 g of baking soda into each weighing boat and pour into each beaker.
7 Prepare the cling wrap and elastic bands for sealing; you will cover each beaker immediately after you have poured in the liquid.
8 Using the 100 mL measuring cylinder, measure 65 mL of water and pour into the control beaker. Immediately cover it with the cling wrap and elastic band.
9 Using the same 100 mL measuring cylinder, measure 65 mL of vinegar and pour into the CO_2 beaker. Immediately cover it with the cling wrap and elastic band.
10 Swirl the contents of each beaker to make sure that the baking soda has fully dissolved.
11 Place both beakers underneath the lamp.
12 Record the starting temperature of each atmosphere before the lamp is turned on.
13 Make a prediction as to which atmosphere you think will heat up and cool down the quickest.
14 Turn on the lamp and start the stopwatch.
15 Measure the temperature in each beaker every two minutes for eight minutes, recording the temperature in your results table.
16 At eight minutes, turn off the light and record the final temperature two minutes later.

continued...

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...continued

Results

Atmosphere	Temperature (°C)					
	0 mins	2 mins	4 mins	6 mins	8 mins (turn off light)	10 mins
Control						
CO_2						

Evaluation

1. Calculate the increase in temperature in each container by the difference between the temperature at six minutes and the starting temperature.
2. Calculate the thermal energy retention by the difference in the temperature at eight minutes to the temperature at 10 minutes.
3. State the container that gave the greatest increase in temperature. Did this match your prediction?
4. State the container that retained the most thermal energy in the final two minutes. Did this match your prediction?
5. Predict what would happen to the temperature in a container that produced more CO_2.

Conclusion

1. Make a claim about the enhanced greenhouse effect based on this experiment.
2. Support the statement by using your observations and include potential experimental faults or sources of measurement uncertainties.
3. Explain how your observations support your claim.

Out of balance

Carbon dioxide emissions from human activity are our most significant contributor to the enhanced greenhouse effect. Since the Industrial Revolution in the 1800s, we have been burning fossil fuels for energy. This means we have been moving stored carbon from the lithosphere into the atmosphere, directly affecting the balance of the carbon cycle.

carbon sources
areas where carbon can be retrieved (for example, the atmosphere)

carbon sinks
areas where carbon is stored (for example, fossil fuels)

As part of the carbon cycle, Earth has **carbon sources**, areas where carbon can be easily retrieved (such as the atmosphere) and **carbon sinks**, areas where carbon is stored (such as the oceans or fossil fuels).

VIDEO
Name some effects of climate change

Figure 6.37 The atmosphere is an example of a carbon source.

Figure 6.38 The ocean is an example of a carbon sink.

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The problem with burning fossils fuels and releasing the carbon stored in them is that the carbon cycle does not have enough carbon sinks to remove the excess carbon from the atmosphere. Fossil fuels take millions of years to form, and Earth's carbon sinks cannot remove enough carbon dioxide to prevent it from building up in the atmosphere. The accumulation of carbon dioxide in the atmosphere is increasing Earth's greenhouse effect.

WIDGET
Greenhouse effect

Quick check 6.18

1 State the definition of carbon sources and give an example.
2 State the definition of carbon sinks and give an example.

QUIZ

Section 6.3 questions

Remembering

1 Name three gases in the atmosphere that are responsible for the greenhouse effect.
2 Define the enhanced greenhouse effect.
3 State the name of the radiations emitted from:
   a the Sun
   b the ground and oceans.

Understanding

4 Explain the differences between the natural and enhanced greenhouse effects.
5 Compare and contrast short-wave and long-wave radiation.
6 Explain why the following statement is incorrect:
   The greenhouse effect is caused by humans.
7 Explain how a greenhouse mimics the greenhouse effect.

Applying

8 Identify why your feet burn on the sand on the beach on a sunny day, but are freezing cold in the water.
9 Draw a diagram to show how the greenhouse effect keeps Earth warm.
10 Predict what the conditions on Earth would be like without greenhouse gases and the greenhouse effect.

Analysing

11 Distinguish between greenhouse gases and other gases in the atmosphere, such as nitrogen and oxygen.
12 Compare and contrast carbon sinks and carbon sources by giving examples.
13 List the sources of methane in the atmosphere.

Evaluating

14 Evaluate why our focus related to the enhanced greenhouse effect is on carbon dioxide and not on other greenhouse gases.
15 Propose reasons why, even though we have known about the damaging effects of carbon emissions for a long time, Australia still produces 70% of its electricity from coal.
16 Assess the reasons why the carbon cycle is altered by the release of carbon emissions from burning fossil fuels.

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6.4 Changing climates

Climate versus weather

WORKSHEET

The difference between **weather** and **climate** is merely a measure of time. Weather describes the conditions of the atmosphere in terms of temperature, cloud, rain and wind over a short period of time (minutes to months). The climate of an area is how the area behaves over a much longer period of time, usually over a period of 30 or more years. Different areas can have different climates; for example, the climate in Central Australia is very different to the climate in Siberia.

weather
the conditions in the air above Earth such as temperature, cloud, rain or wind, especially at a particular time over a particular area

climate
the average or prevailing weather conditions of an area over long periods of time

Figure 6.39 Frozen shipwrecks on Lake Baikal in Siberia, Russia. The climate here is described as subarctic with annual average temperatures of about -5°C.

Areas of the world have differing climates due to the:

- uneven distribution of the Sun's rays because of the shape of Earth
- land (or sea) surface; compared to water, land temperatures can increase more with the same amount of thermal energy transfered to it compared to water, so land temperatures rise more in the daytime and fall more during the night compared to water
- tilt of Earth's axis, which causes seasons
- features of the land, such as mountains
- type of soil or plant life.

Quick check 6.19

1 Define the term weather.
2 Give one reason why climates on Earth differ.

Did you know? 6.2

How China used rockets to control the weather

China used rockets before and during the 2008 Beijing Olympics opening ceremony to control the weather. They fired 1100 rockets at a rain belt that could have disrupted the ceremony. The rockets contained silver iodide which caused the rain clouds to disperse. As a result, a city south-west of Beijing recorded 100 mm of rainfall on the evening of the opening ceremony, whereas the capital stayed dry!

Figure 6.40 The opening ceremony of the Beijing Olympics in 2008

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Climate change

Climate change has occurred when there has been a significant change to normal weather patterns that has been sustained for a long time – between tens and millions of years.

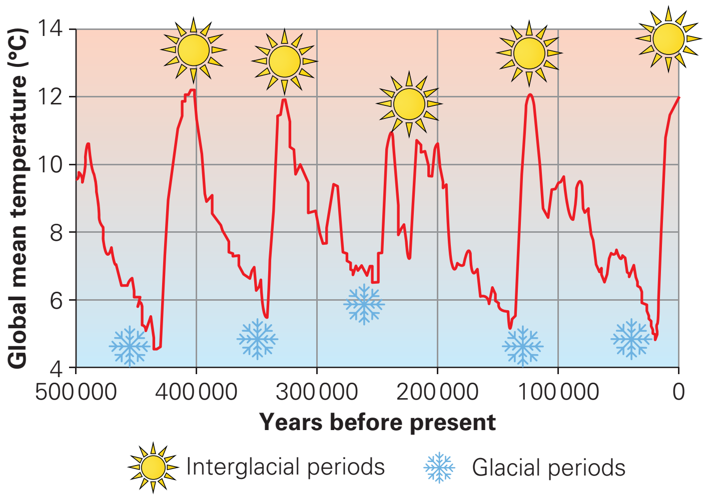

Figure 6.41 Earth has undergone natural cycles of warming and cooling.

Earth has undergone natural cycles of warming and cooling throughout its history.

A **glacial period** is when a reduction in global temperatures is sustained for a long period of time. The last glacial period started around 115 000 years ago and ended around 11 700 years ago. During the latter part of this period, Kangaroo Island off the South Australian coast was connected to the mainland and parts of Tasmania were covered by glaciers.

glacial periods
periods in Earth's history when a reduction in global temperatures is sustained for a long period of time

An interglacial period is when an increase in global temperatures is sustained for a long period of time. We are currently experiencing an **interglacial period**. However, scientists are concerned about the current unusually rapid rises in temperature, and the evidence suggests that human activities have something to do with it.

interglacial periods
periods in Earth's history when a warming in global temperatures is sustained for a long period of time

Figure 6.42 Kangaroo Island is located south-west of Adelaide about 14.5 km off the coast. The star on the picture shows the location of mainland Australia. The island was connected to the mainland at the end of the last glacial period.

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Quick check 6.20

1 Define climate change.
2 State the name of the term for when Earth is undergoing a period of cooling.
3 State the name of the term for when Earth is undergoing a period of warming.

Evidence for climate change

In order to determine what the climate was like in the past, scientists study various evidence.

Glaciers

Glaciers advance during periods of cooling and retreat during periods of warming.

Figure 6.43 The Franz Josef glacier on the South Island of New Zealand

Ice cores

Scientists take cores deep down into the ice. These cores show the layers of snow that fell and were compacted thousands of years ago.

Scientists analyse the chemical composition of the snow, which gives them information on the temperature and carbon dioxide levels in that time period.

Figure 6.44 An ice core taken from the Antarctic

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Pollen

Pollen which has been fossilised in rock gives an indication of the number and species of plants living in that time period. We can work out when the plants were growing by dating the rock in which the pollen is fossilised.

Sea levels

The location of sedimentary rocks and fossil distribution can give an indication of past sea level heights. Fossilised sea creatures have even been found in the centre of Australia!

Figure 6.45 Fossilised pollen can indicate the number and species of plants around in a particular time period.

Figure 6.46 Fossilised remains of sea creatures

Quick check 6.21

1 Give one piece of evidence scientists can use to monitor climate conditions.
2 Identify what a glacier in retreat will tell us about the climate conditions.

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Human influences on climate change

It is clear that humans are influencing climate change. The concentration of carbon dioxide in the atmosphere has increased from 280 parts per million (ppm) before 1800 to well over 400 ppm in 2018. Table 6.11 summarises the influences that humans are having on the climate and how climate change is affecting global systems.

Human influence	Global system affected	How the climate is affected
Deforestation	Carbon cycle and water cycle	Fewer trees results in less carbon dioxide being taken in from the atmosphere through photosynthesis. If the wood is burned this contributes further to the greenhouse effect. 
		Trees release large amounts of water vapour during transpiration. Fewer trees means less water vapour in the atmosphere and less rain. In 2017–18, parts of western Victoria experienced the lowest ever rainfall on record. 
Agriculture	Carbon cycle	Cows and sheep produce carbon-containing methane when digesting grass. More cattle mean more emissions. Agriculture accounts for 11% of Australia's greenhouse gas emissions, and 70% of that comes directly from livestock. 
Burning fossil fuels	Carbon and nitrogen cycle	Burning fossil fuels produces carbon emissions, which alters the carbon cycle. Nitrogen oxides (NOx) are also produced when fossil fuels burn, causing smog and acid rain. 
Fertilisers	Nitrogen cycle	Adding fertilisers containing nitrates to the soil speeds up their conversion into nitrous oxide, another greenhouse gas. 

Table 6.11 A summary of some human influences on climate change

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Quick check 6.22

1 State one way humans have affected the nitrogen cycle.
2 Explain how deforestation affects the water cycle.

Explore! 6.4

Diesel: the dream or nightmare fuel?

A decade ago, many governments and the car industry were promoting diesel as a dream fuel and a cheaper way to the save the planet. But in 2012, mayors of major cities like Paris, Madrid and Athens agreed that their cities would be diesel free by 2025. What had caused this dramatic turnaround in opinion in only two years? Do some research to answer the following.

Figure 6.47 Diesel is an alternative fuel to petrol.

1 Contrast diesel and petrol.
2 Give reasons why diesel fuel became so popular.
3 Research conducted in 2012 found that diesel cars released nitrogen oxides (NOx) and carbon particulates, pollutants which were given the name 'silent killers'. Find out the negative effects of these pollutants.
4 Phasing out diesel cars would be difficult. However, a recent poll in London suggested that 52% of Londoners would support a ban on diesel cars in the city centre despite its inconvenience. Discuss what this suggests about the changing views of the general public.

Effects of climate change

As carbon dioxide concentrations rise, Earth continues to warm up.

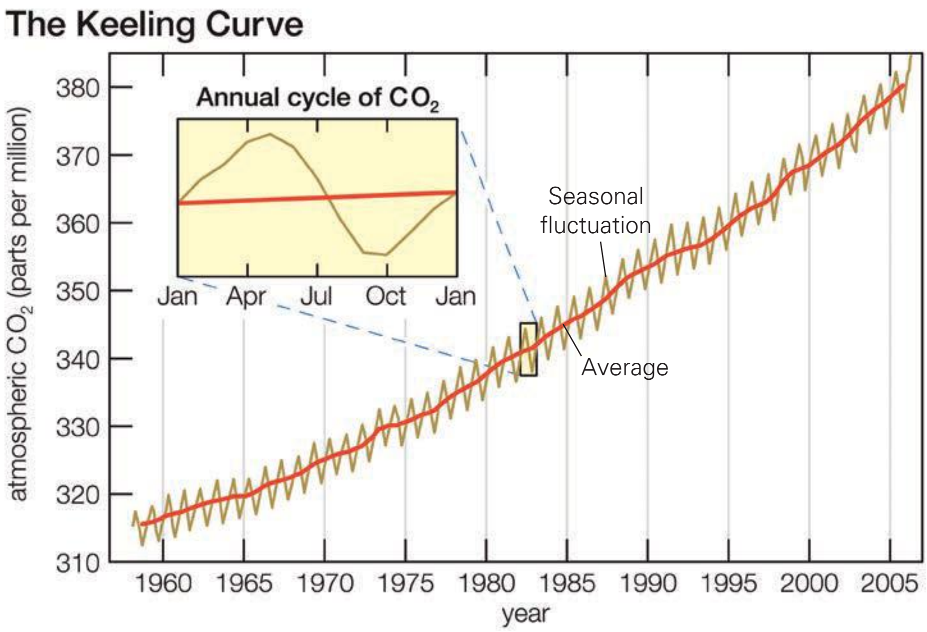

Figure 6.48 The Keeling curve shows the concentration of carbon dioxide in parts per million from 1960 to 2005. This positive gradient shows that carbon dioxide levels are continuing to increase.

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Over the past 100 years, Earth's average temperature has risen between 0.4 and 0.8°C, and 2016 was the hottest year since records began. While people have varying opinions on the possible consequences of climate change, the effects of rising temperatures could have dramatic repercussions.

Figure 6.49 Melting ice from the Eqi glacier in Greenland

Polar ice

Melting polar ice caps

As temperatures on Earth rise, polar ice caps melt, which raises sea levels. Low-lying areas of land, such as Osaka in Japan which is already being battered by coastal typhoons, are most at risk. Ice also acts as barrier that prevents sunlight from reaching the oceans. With less ice cover, more of the ocean is able to absorb sunlight, increasing its temperature. Water expands when it gets warmer. This is an ongoing cycle, ultimately leading to increased ice melting and sea level rise.

Practical 6.9

Melting ice and sea level rise

Be careful

Ensure appropriate personal protective equipment is worn.

Aim

To determine how melting glaciers and icebergs affect sea levels.

Materials

- plastic container
- half a potato
- 6 ice cubes
- ruler

Method

1. Copy the results table on the next page.
2. Write a hypothesis for your investigation. What do you think will happen to the sea levels when icebergs and glaciers melt?
3. Create a model island from the potato, make sure that the top is flat so your 'glaciers' can sit on top of it.
4. Place the island in the plastic container.
5. Add water to the container, making sure the island is not fully submerged.
6. Record the sea level using a ruler.
7. Add three ice cubes (icebergs) to the water.
8. When the icebergs have melted record the sea level using the ruler.
9. Add three ice cubes to the top of your island, these will represent glaciers.
10. When they have melted, record the sea level using the ruler.
11. Calculate the change in sea level and record in your results table.

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Results

	Sea level before adding ice cubes (cm)	Sea level after ice cubes have melted (cm)	Change in sea level (cm)
Icebergs			
Glaciers			

Evaluation

1 Which experiment gave the greatest change in sea level? Is this what you thought might happen?
2 Discuss whether your hypotheses are supported by your results.
3 Assess how this experiment simulated the melting of polar ice caps in the real world.
4 Examine how rising sea levels may affect the area in which you live.

Conclusion

1 Make a claim about how melting glaciers and icebergs affect sea levels based on this experiment.
2 Support the statement by using your observations and include potential experimental faults or sources of measurement uncertainties.
3 Explain how your observations support your claim.

Reflecting ice

Meltwater contributing to a greater volume of seawater is not the only risk caused by melting polar ice. Ice reflects the Sun's radiation back into space, which has a cooling effect on the planet. Less ice means less radiation is reflected and an increase in global temperatures.

Ocean density driving currents

When seawater freezes in winter, only the water freezes – the salt is left behind in the unfrozen seawater below. Waters with higher concentrations of salt are denser and are the main cause of ocean currents, circulating seawater around the globe, along with thermal energy and nutrients. With rising temperatures, less seawater is freezing which is reducing the density of the oceans. These global ocean currents could eventually cease all together.

Quick check 6.23

1 Identify the main problem of melting polar ice caps.
2 Identify the problem with a decreased ocean density resulting from reduced freezing of ice in the winter.

Figure 6.50 Ice reflecting the midnight Sun in the Arctic Ocean

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Practical 6.10

Salinity and density

Aim
To determine how the concentration of salt in water (salinity) affects its density.

Materials
- balance
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- 5 × 100 mL beakers
- weighing boats
- 5 pipettes
- salt
- food colouring (blue, green, yellow and red)
- water

Method
1. Copy the results table below.
2. Using a 100 mL measuring cylinder, measure 60 mL of water and pour it into one of the 100 mL beakers. Repeat four more times.

Solution	Mass of salt (g)	Volume of water (mL)	Amount of food colouring (drops)
1	5	60	2 of blue
2	10	60	2 of green
3	15	60	2 of yellow
4	20	60	1 of yellow 1 of red
5	25	60	2 of red

3. Add the required drops of food colouring from the table above to each beaker.
4. Using the weighing boat and balance, measure the five different masses of salt. Pour the salt into the correct coloured beaker.
5. Stir the solutions to make sure all the salt has dissolved.
6. Using a pipette, draw up 2 mL of solution 1 and add to the 10 mL measuring cylinder.
7. Using a pipette, draw up 2 mL of solution 2. Place the pipette along the inside of the measuring cylinder, near the solution added previously. Drop solution 2 drop by drop, allowing it to roll down the side of the measuring cylinder.
8. Repeat Step **7** for solutions 3, 4 and 5, adding each in turn to the 10 mL measuring cylinder.

Results
1. Complete the results table.

Solution	Mass of salt (g)	Mass of water (g)	Mass of the solution (g) (mass of salt + mass of water)	Volume of solution (mL)	Density of the solution (g/mL) (mass of solution ÷ volume)
1	5	60		60	
2	10	60		60	
3	15	60		60	
4	20	60		60	
5	25	60		60	

continued…

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...continued

2 Plot a graph of mass of salt on the *x*-axis and density on the *y*-axis.

Evaluation

1 Use your graph to describe the link between amount of salt and the density of a solution.
2 Discuss how rising global temperatures affects the concentration of salt in the oceans and how this relates to climate change.

Conclusion

1 Make a claim about the relationship between amount of salt and density of water based on this experiment.
2 Support the statement by using your observations and include potential experimental faults or sources of measurement uncertainties.
3 Explain how your observations support your claim.

Biodiversity

Biodiversity is a measure of the variety of species, environments and genes in an area. There are three types of biodiversity which are summarised in Table 6.12.

biodiversity
the variety of species, ecosystems and genes that exist in a particular area

Type of biodiversity	Description
Ecosystem	The environments in which organisms live; for example, jungle, rainforest and tundra
Species	The number of different species of organism in an ecosystem
Genetic	A range of genes within a species

Table 6.12 The three types of biodiversity

The more biodiverse an environment, the more resistant that environment is to change (it is more stable). An environment which is not biodiverse may be at risk of complete collapse. Any changes to an environment, like the ones previously discussed can affect the balance within an ecosystem.

So, what happens when an ecosystem is affected by climate change? In a coral reef ecosystem, the coral is defined as a **keystone species**. These are species which are relied upon by numerous other species for food and shelter.

keystone species
a species that has a dramatically large impact on a particular ecosystem relative to its population

Figure 6.51 The Amazon rainforest is one of the most biodiverse ecosystems in the world.

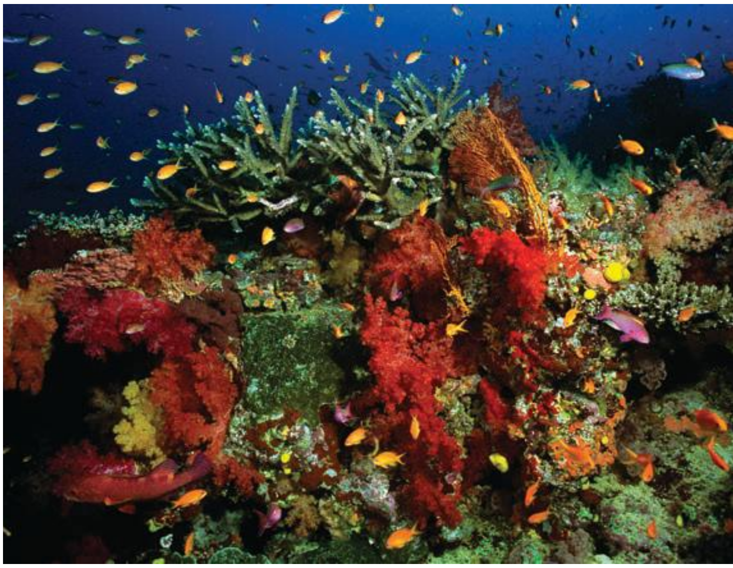

Figure 6.52 Corals are keystone species in the Great Barrier Reef.

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Corals in coral reefs rely on single celled organisms called protists to provide their nutrition. When the ocean temperatures rise even by one degree, the corals will release these protists and eventually die. Scientists are able to observe this happening as the corals lose their colour. This process is called coral bleaching. When corals are eliminated from this ecosystem, many of the other organisms that relied on the coral also die out – a whole ecosystem can be destroyed.

Figure 6.53 Bleached branching coral

Quick check 6.24

1. Define the term biodiversity.
2. State the name of the term given to coral in a coral reef ecosystem.
3. Describe the cause of coral bleaching in oceans.

Computer modelling and its applications

Without computers, it is almost impossible to make predictions about Earth's climate thousands and millions of years into the future. Computer modelling is the use of computer simulations to make accurate predictions. With their high processing power, computers are able to run numerous simulations over and over again in a short period time, something that could take a human over a lifetime to complete. By running numerous simulations, predictions made by computer modelling are much more accurate than those made manually by humans.

Figure 6.54 A super computer at the German Climate Computing Centre crunches data about Earth's climate to predict the future effects of climate change.

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Table 6.13 summarises the applications of computer modelling.

Application of computer modelling	Description
Predicting the weather 	You will see this use every day if you watch the news! Multiple simulations are run by computers. Meteorologists (scientists who study the weather) use these simulations to make an average prediction of the weather conditions that week.
Predicting climate change 	Models predicting climate change are based on observational data and fundamental numerical laws founded on theory, such as Newton's laws. Perhaps the most complex climate models are the general circulation models (GCMs). Data on climate change reported in the media is generated from numerous simulations of the GCMs.
Monitoring pollution levels 	Atmospheric dispersion modelling predicts the behaviour of pollutants in the air over a specific period of time. It is used by governments to monitor air quality as well as to make predictions of the effects of chemical spills.

Table 6.13 A summary of some of the applications of computer modelling

Quick check 6.25

1 Why do scientists use computer modelling to predict phenomena?
2 Give one application of computer modelling.

Although there are obvious advantages to using computer models to predict future phenomena, there are some disadvantages. Computer models rely on accurate data being fed into the simulation. If scientists do not provide correct data, then the results from these models can be inaccurate. Also, major geological events on Earth, such as earthquakes and volcanoes, can be unpredictable.

If a major volcanic eruption occurred on Earth that was not accounted for, this could result in a wildly inaccurate forecast of climate change.

Figure 6.55 Volcanic eruptions can drastically affect predictions made from computer simulations.

Despite these limitations, computer modelling remains the most accurate way of predicting what Earth will be like in years to come.

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Section 6.4 questions

QUIZ

Remembering

1 Name the models used to make predictions about climate change.
2 Define the term 'climate'.
3 Complete the sentence: Earth is currently experiencing *an interglacial/a glacial* period.
4 State one way that humans have influenced the climate on Earth.
5 Give a property of ice that allows it to have a cooling effect on Earth.

Understanding

6 Classify the following as either an effect or a cause of climate change:
   a melting polar ice
   b reduced ocean currents
   c increased use of fertilisers
   d reduced biodiversity.
7 Explain why computer models are useful in predicting future events.
8 Describe some differences in climate between Central Australia and Siberia.
9 Explain why it is important to maintain the biodiversity of an environment.

Applying

10 Identify the reasons why coral bleaching is so disastrous for an environment.
11 Identify the uses of atmospheric dispersion modelling.

Analysing

12 Compare global warming and climate change.
13 Describe the relationship between global temperatures and the terms glacial and interglacial periods.

Evaluating

14 Explain how global warming could cause sea levels to rise.
15 Explain why less seawater freezing in winter affects ocean currents.
16 Evaluate the effect of an unexpected volcanic eruption on climate change predictions.

Figure 6.56 The ice on Lake Baikal in Siberia, Russia.

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Review questions

SCORCHER

Remembering

1 State two natural cycles which transfer matter or energy around Earth.
2 Give the name and formula of the form of nitrogen in the atmosphere.
3 The majority of the Sun's radiation that reaches Earth is absorbed by the ground and oceans. Recall what happens to the rest of the Sun's radiation.
4 Give one reason why different areas on Earth have different climates.

Understanding

5 Describe the effects of cyclones on each of Earth's chemical spheres.
6 Describe and explain the role of nitrifying bacteria in the nitrogen cycle.
7 Outline the journey of UV solar radiation emitted from the Sun.
8 Explain why you could once walk from Kangaroo Island to Adelaide.

Applying

9 Copy and complete the following table to contrast the ozone layer and greenhouse gases.

	Ozone layer	Greenhouse gases
Composition		
Function		
Location		

10 Construct a word equation to show how process of respiration leads to an increase in atmospheric carbon dioxide.
11 Using the summary of greenhouse gases in Table 6.8 on page 263, calculate the percentage of greenhouse gases that have not been mentioned in this chapter.
12 Construct a graph to show how carbon dioxide concentrations have changed over the last two decades.

Analysing

13 Analyse the sphere interactions that are taking place in the Figure 6.57.

Figure 6.57

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14 List the main processes involved in the water cycle.
15 Analyse the changes in carbon dioxide concentration in the atmosphere since the Industrial Revolution.
16 Examine the reasons why low-lying areas are most at risk from climate change.

Evaluating

17 Evaluate why most sphere interactions take place in the lithosphere.
18 Explain how excretion, death and decomposition influence both the carbon and nitrogen cycles.
19 Using the summary of greenhouse gases in Table 6.8 on page 263, explain why we should focus on nitrous oxide emissions as well as those from carbon dioxide.
20 There is debate as to whether climate change is a significant risk to life on Earth. Give your opinion based on what you have learned in this chapter. Justify your opinion with facts and evidence.

Figure 6.58

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STEM activity: Using aerial imagery to track environmental change

VCSSU128 VCDSTS054 VCDTDI048 VCSIS107 VCSIS111 VCSIS140

Background information

Aerial photographs were pioneered by the French photographer and balloonist Gaspard-Félix Tournachon in 1958, four decades after the invention of the camera. Soon, governments over the world realised the potential of aerial imagery in gathering information for military use and monitoring territories. Early military aerial photographers even fixed small adjustable cameras on the chest of mail pigeons and flew them over enemy positions. Aerial imagery techniques developed rapidly, from using balloons to using aeroplanes with coupled cameras, high-resolution satellite imagery and, most recently, highly sophisticated drones.

Today, we can also use high-tech satellites to gather high-quality data (not only images) from our ever-changing world. For example, you probably use a mobile device with an in-built GPS module, capable of giving you directions to pretty much all corners of the globe. Importantly, we can now use this amazing technology to help us monitor our impact in our environment.

This was shown on 5 November 2015, the day the world heard about the municipality of Mariana, in the state of Minas Gerais, Brazil. This once paradisiacal location was the location of Brazil's biggest environmental disaster – the collapse of a dam wall on the Gualaxo do Norte river. The resulting flow killed eighteen people and covered an entire sub-district with toxic mud from an upstream mine. Studies to recover the area and the affected rivers have already begun. Satellite imagery will play a pivotal role in the recovery for years to come.

There is very little doubt that satellite and aerial imagery will play many important roles in our future. In these exciting times, we can ask: How can we use aerial imagery to monitor deforestation in Australia? How can we use drones to protect endangered rhinos and elephants in Africa? How can aerial imagery help us develop more sustainable cities? The sky is the limit when we use technology and human creativity!

Figure 6.59 A modern airport, a river meandering through the landscape, rice terraces in Bali and a quarry viewed from above.

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Design brief: Using aerial imagery to track environmental change

Activity instructions

You are an environmental researcher working for your local council along with a team of other professionals, including engineers, policymakers and designers. The Land Management Team asked you to design an interactive tool capable of tracking environmental change over time in specific areas within the council boundaries. They want to demolish a number of buildings in the area for development, and requested your opinion about possible implications for nearby rivers and creeks. You understand the potential for satellite imagery use (available free on Google Earth) in this situation, and you decide to give your advice after creating a time-lapse video (or series of images) that shows changes in landscape use over time. (Teachers, please check the Online Teaching Suite for a detailed guide and example for this activity.)

Suggested materials

- Google Earth Pro (free to download) web browser (any)
- iMovie, Movie Maker or GIFMaker.org (recommended)

Evaluate and modify

1. Outline the advantages and disadvantages of using satellite imagery to assess environmental change within your region. Describe the expertise (skills) needed to gather and decode these images and the potential benefits to the local economy (for example, possible jobs created or improvement to traffic conditions) of using them.
2. Analyse your time-lapse sequence and list at least 10 noticeable changes to the landscape within your chosen area. What benefits or disadvantages have these changes brought to the local community?
3. In your own words, explain how you could use the skills gained in this activity to enhance environmental conservation in your region.
4. As a class, evaluate the time-lapse sequences created by your peers and reflect on the challenges associated with anonymous aerial image gathering. In your opinion, are there any privacy concerns or implications associated with this technology? What measures are taken to improve privacy for people in relation to aerial image gathering?

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Chapter 7 The universe

Chapter introduction

Humans have always been inspired by the universe. The movement of the Sun, stars, Moon and planets has been studied for centuries, and there is still so much unknown. Advances in technology have let us see further and further into space to hypothesise about how the universe began and what it is made of. There is a certain feeling of insignificance that people experience when they think about the enormous size of our expanding universe. In this chapter, you will learn about what can be observed in the night sky and what information can be gathered from stars and galaxies to find out about how it all began.

Curriculum

The Universe contains features including galaxies, stars and solar systems; the Big Bang theory can be used to explain the origin of the Universe (VCSSU129)	
• identifying the evidence supporting the Big Bang theory, for example, Edwin Hubble's observations and the detection of microwave radiation	7.1, 7.4
• recognising that the age of the Universe can be derived by applying knowledge of the Big Bang theory	7.4
• describing how the evolution of the Universe, including the formation of galaxies and stars, has continued since the Big Bang	7.2, 7.3
• Science as a Human Endeavour • recognising the contribution of Australian scientists, for example, Brian Schmidt and Penny Sackett, in the exploration and study of the Universe	7.3, 7.4
• Science as a Human Endeavour • considering how information technology can be applied to different areas of science, for example, the Square Kilometre Array, and the analysis of radio astronomy signals	7.1

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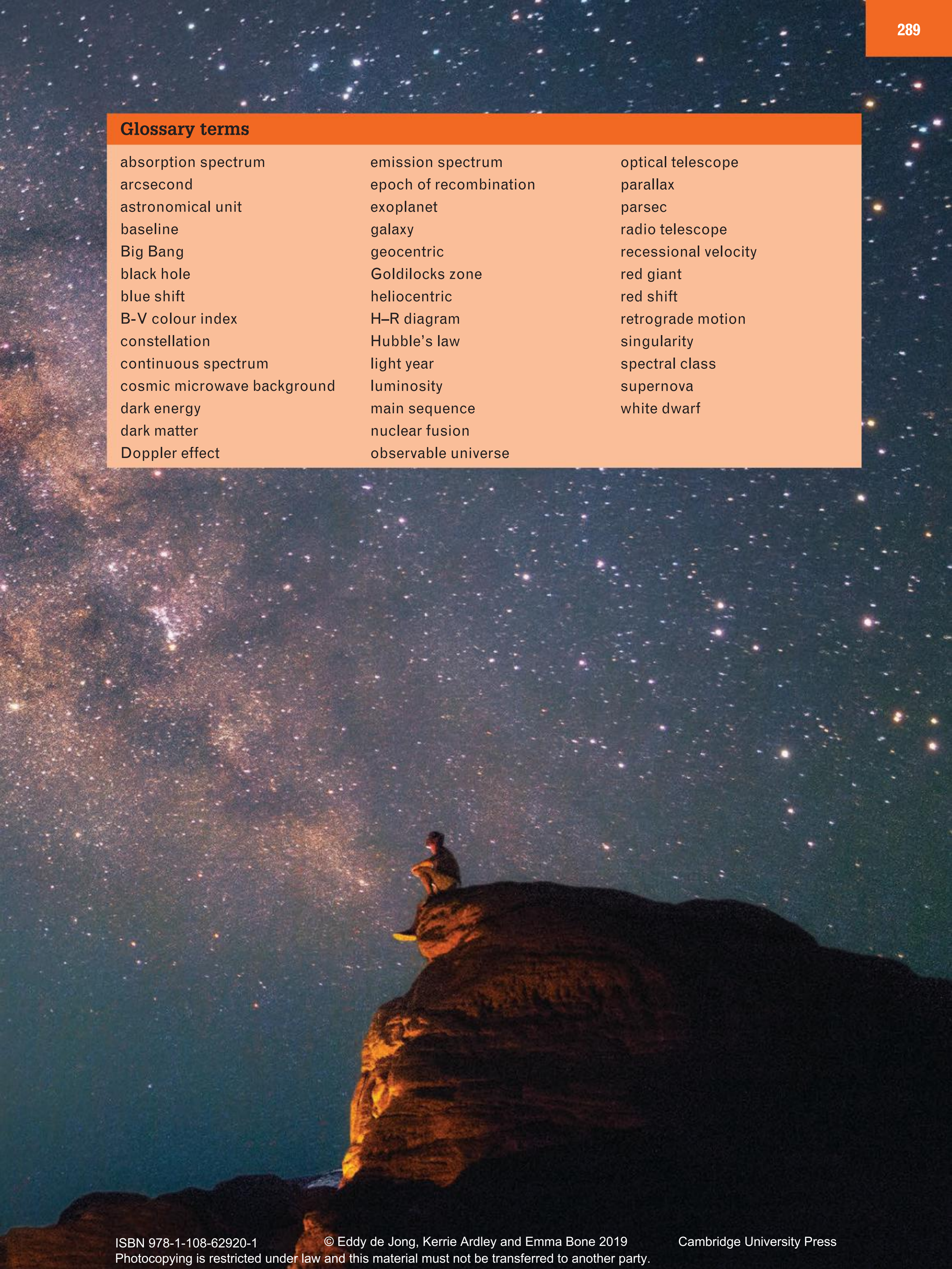
Glossary terms

absorption spectrum
arcsecond
astronomical unit
baseline
Big Bang
black hole
blue shift
B-V colour index
constellation
continuous spectrum
cosmic microwave background
dark energy
dark matter
Doppler effect
emission spectrum
epoch of recombination
exoplanet
galaxy
geocentric
Goldilocks zone
heliocentric
H–R diagram
Hubble's law
light year
luminosity
main sequence
nuclear fusion
observable universe
optical telescope
parallax
parsec
radio telescope
recessional velocity
red giant
red shift
retrograde motion
singularity
spectral class
supernova
white dwarf



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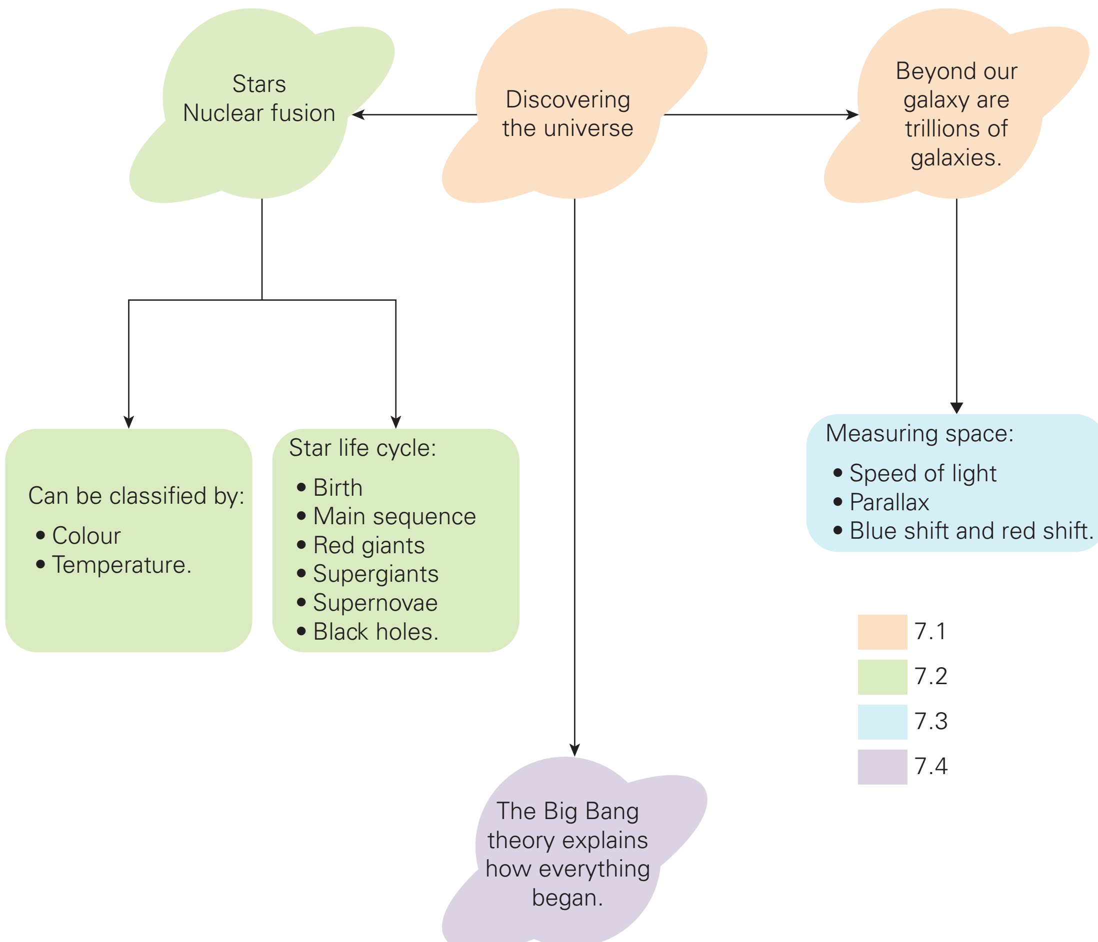
Concept map



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7.1 Discovering the universe

Look up at the sky tonight. Take note of what you can see. Congratulations, you are now an astronomer! The earliest western astronomers to record what they could see in the night sky were ancient Greek philosophers. They grouped stars into formations that looked like pictures, or **constellations**. Constellations were important in early human migration and thereby shaped the modern world. Today, astronomers and astrophysicists use advanced technology to make their observations. Astronomy is, however, a field of science where you do not have to be a professional to take part. An Australian amateur astronomer, Thiam-Guan Tan, a retired engineer with a fascination for the stars, discovered a distant planet orbiting a star 40 light years away from Earth from his backyard. The planet is thought to be one of billions of other planets that are 'habitable zones', in other words, able to support life.

constellation
a group of stars as seen from Earth that appear to form a familiar shape

WORKSHEET

WIDGET
Timeline of the universe

VIDEO
The Big Bang

Figure 7.1 Amateur astronomers can make significant astronomical discoveries.

Try this 7.1

Observing the night sky

Download an app or program for observing the night sky. Stellarium for PC or SkyView for Apple and Android devices may be good ones to use. Use it outside at night to identify all of the stars and planets that you can see in the sky. Some may already be familiar to you. If you live close to a city or in a built-up area, you may only be able to see a few stars or planets. If you live in a rural area with no light pollution, you may be able to see thousands of stars! See if you can also identify some constellations. Most night sky viewers have a function to show constellation pictures.

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Early astronomers

The early astronomers relied on the naked eye to make observations about the positions of celestial objects and how they moved over time.

Claudius Ptolemy was an astronomer from the second century who suggested that Earth was at the centre of the universe. He proposed a **geocentric** model in which all celestial objects orbited around Earth. It is easy to see why he suggested this model, given that the Sun, stars and Moon all appear to rise in the east, follow a circular pattern while they are up, and then set in the west.

geocentric
a model of the solar system with Earth at the centre

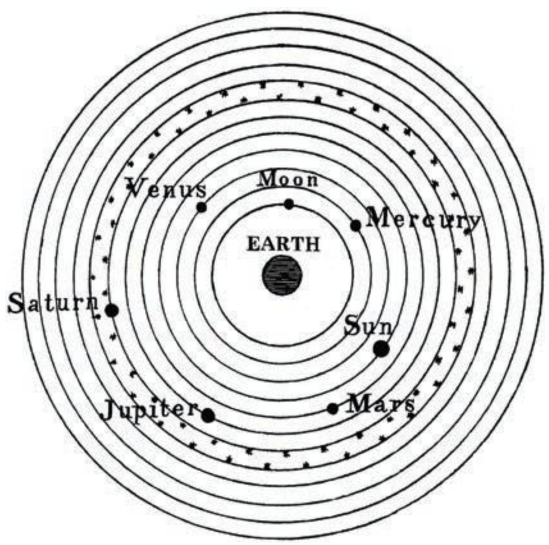

Figure 7.2 The geocentric model proposed that Earth was the centre of the universe, with the planets and stars orbiting around it.

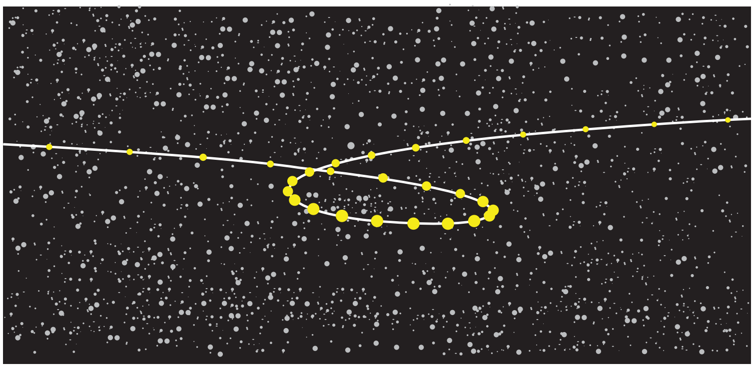

Figure 7.3 Retrograde motion of Mars across the the sky as seen from Earth

There was one main problem with Ptolemy's geocentric model. At different points in the year, the motion of the planets across the sky appear to go backwards for a few days. It is called **retrograde motion** and could not happen if the planets orbited Earth.

retrograde motion
apparent backwards motion of a planet as seen from Earth

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

In the early 1500s, Nicolaus Copernicus proposed a **heliocentric** model of the solar system, in which the planets revolved around the Sun. This could explain the retrograde motion of the planets.

With the invention of the telescope in the 1600s, Galileo Galilei was able to observe the four largest moons of Jupiter and could confirm that they were orbiting Jupiter.

Telescopes changed the world of astronomy in a huge way. They have allowed us to see the outer planets of the solar system, the moons of other planets, millions more stars and distant galaxies.

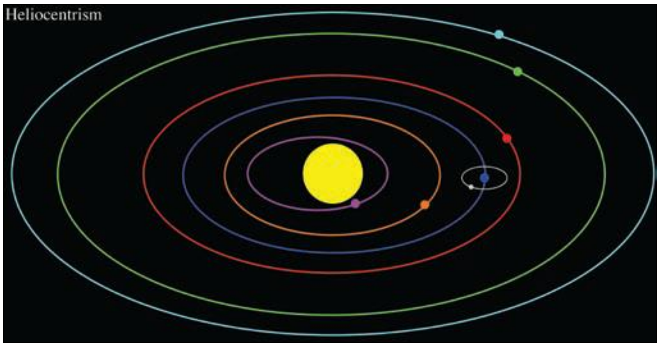

Figure 7.4 The heliocentric model proposes that planets revolve around the Sun, rather than Earth.

Quick check 7.1

1. What celestial object is at the centre of a geocentric model?
2. What celestial object is at the centre of a heliocentric model?
3. How can the circular path of the Sun and stars across our sky each day be explained?

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Did you know? 7.1

Emu in the sky

Rather than imagining shapes from the bright spots (stars) in the night sky, Australian Aboriginal and Torres Strait Islander astronomy visualises shapes made from the dark areas between bright spots. The 'emu in the sky' constellation can be seen by looking at the dark sections within the Milky Way smear that we see across the southern part of the sky.

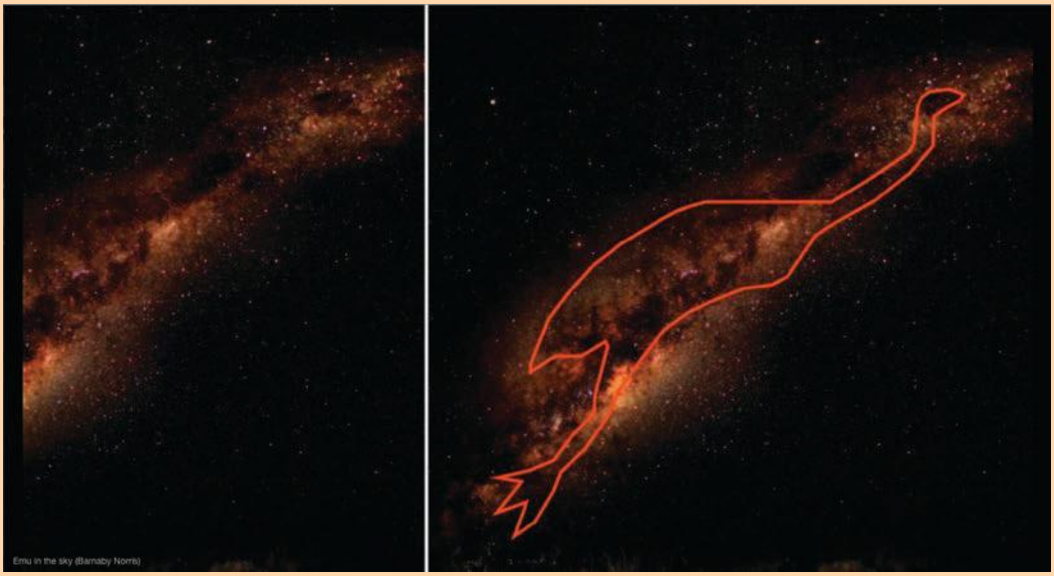

Figure 7.5 The emu in the sky

Modern day astronomy

Modern day astronomers have amazing technology to work with. Modern telescopes have become larger and larger to allow us to see further into space. In 1995, the Hubble Space Telescope was pointed towards a region of space previously thought to be empty. The photo produced after two days showed multitudes of galaxies that had never been observed before. It further demonstrated the enormous size of the universe.

Figure 7.6 The Hubble Deep Field image showed hundreds of galaxies in a region of space previously thought to be empty.

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Telescopes and technology

The first telescopes were **optical telescopes**, which use lenses to collect light and focus it for the eye to see. The larger the diameter of the lens, the more light that can be collected and the further you can see. But, as telescopes got larger, the size of the glass lenses required reached the point where they would be too big to support their own weight, so polished mirrors were used instead to collect and focus light. The Very Large Telescope (VLT) array in Chile has mirrors 8.2 metres in diameter, and the Extremely Large Telescope (ELT) now under construction in Chile will have a mirror 39.3 metres in diameter. Optical telescopes must be positioned far away from light pollution and at a high altitude to minimise the effects of the atmosphere, so the best optical telescopes have been built on tall mountains in Chile and Hawaii.

optical telescope
a device that collects and focuses light from the visible spectrum to form an image

Figure 7.7 The Very Large Telescope in Chile has four main mirrors, each with a diameter of 8.2 metres.

To minimise the effects of light pollution and the distorting effects of the atmosphere completely, the Hubble Space Telescope was launched into Earth's orbit and is controlled remotely from Earth. It has been instrumental in developing our understanding of the universe and the Big Bang.

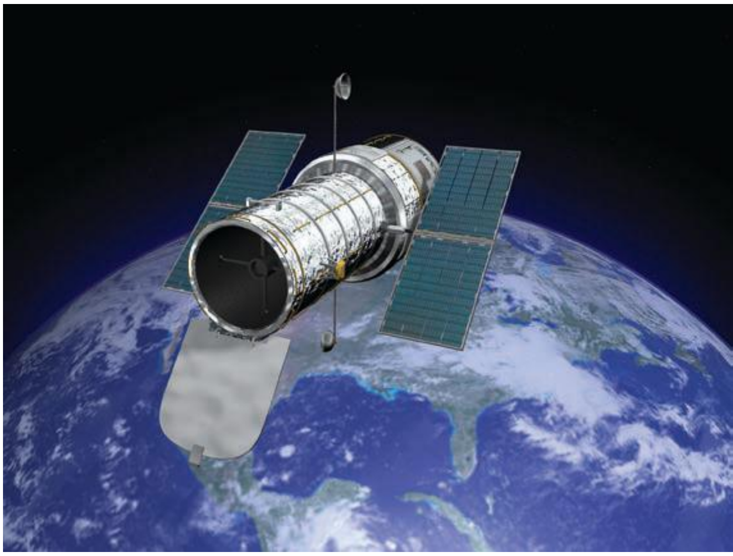

Figure 7.8 The Hubble Space Telescope can observe the light from distant galaxies without the dimming and distorting effects of Earth's atmosphere.

Radio telescopes gather information in the form of radio waves. Radio telescopes follow the same principle as optical telescopes, in that they collect signals and reflect them inwards to focus them, but the reflective surfaces do not need to be polished mirrors. This means that radio telescopes can be made much larger than optical telescopes. Multiple radio telescopes can also be linked together to look even further into space. The Square Kilometre Array radio telescope, which will begin construction in Western Australia in 2019, will be made up of thousands of dishes whose total collection area will be bigger than one square kilometre (or one million square metres). An artist's impression of what it might look like is shown in Figure 7.9.

radio telescope
a device that receives radio waves emitted by stars and other celestial objects

Quick check 7.2

1. List the two main types of telescopes and recall which part of the electromagnetic spectrum they detect.
2. Where are the best telescopes located?

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Figure 7.9 The Square Kilometre Array will have the potential to look further into space than what has ever been possible before.

Did you know? 7.2

The Parkes radio telescope

The Parkes radio telescope in New South Wales was instrumental in the 1969 Moon landing mission. It was used to relay footage back to Earth for the live television broadcast. NASA had intended to swap between the signals relayed from three different radio telescopes in order to sustain the best quality signal available, but when they changed over to the Parkes signal they found it to be so superior to the other signals that it was used for the entire 2.5-hour live broadcast.

Figure 7.10 The Parkes radio telescope in New South Wales

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QUIZ

Section 7.1 questions

Remembering

1 Recall the reason that most observatories are located remotely and at high altitudes.

Understanding

2 Contrast the geocentric and heliocentric models, and explain why the motion of the planets as observed on Earth supports the heliocentric model.

Applying

3 What is the purpose of the large dish on the Parkes radio telescope? You may like to draw a diagram in your answer.

Analysing

4 Explain the advantages and disadvantages of having a telescope in space.

Evaluating

5 Summarise the improvements in technology since early astronomers that have allowed us to look further and further into space.

7.2 Stars

WORKSHEET

VIDEO
Do small stars or large stars last longer?

It is amazing to think that all of the atoms that make up all of the molecules that make up all of the cells in your body were formed in distant stars well before Earth and the Sun and our solar system even existed. Carl Sagan once said, 'We're made of star stuff', and he was right!

Nuclear fusion

Many people will describe the Sun and other stars as a big ball of burning gas. That is a rather oversimplified explanation of how they produce their energy. In reality, their energy comes from a process called **nuclear fusion**.

nuclear fusion the process of joining two nuclei to produce energy

Nuclear fusion occurs when two atoms combine (or fuse) to create a new element. Because it is so hot inside the cores of stars, hydrogen nuclei have enough energy to overcome the electrostatic repulsion between their protons. They fuse together to form helium and an enormous amount of energy is released in the process.

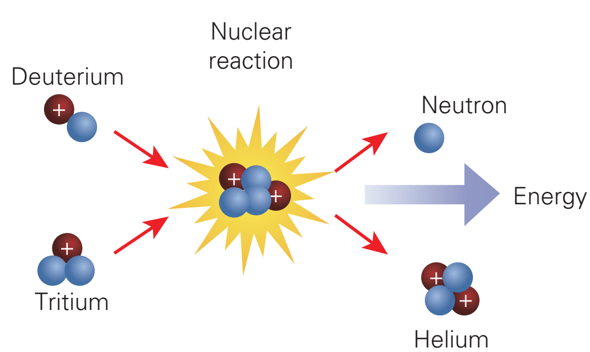

Figure 7.11 One step in the fusion of hydrogen happens when the isotopes deuterium (one proton and one neutron) and tritium (one proton and two neutrons) fuse together. A neutron is released and a helium nucleus is formed (two protons and two neutrons).

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Star colour and temperature

When you look at stars in the night sky, you will notice that they vary in colour. The colour of a star is related to its temperature: blue stars are the hottest and red stars are the coolest. Stars are given a **spectral class** letter based on their temperature and colour. They were originally classified alphabetically starting at A, but some letters were skipped, and others reordered as more was discovered about star surface temperatures. Our Sun is a relatively small yellow star with a surface temperature of around 6000 K, so a G-type star.

spectral class
a group into which stars are classified based on their spectra/colour

Colour	Star temperature (Kelvin)	Spectral class
Blue	>30 000	O
Blue white	10 000 to 30 000	B
White	7500 to 10 000	A
Yellow white	6000 to 7500	F
Yellow	5200 to 6000	G
Orange	3700 to 5200	K
Red	2400 to 3700	M

Table 7.1 Temperatures and spectral classes of the star colours

B-V colour index

Most stars look white but a few stars, such as Betelgeuse, seem to have a very slight reddish tinge. So how do we know what the colours of stars actually are? Astronomers measure the brightness of stars through different coloured filters. They subtract the amount of light that comes through a green filter (called the visual filter) from the amount of light that comes through a blue filter. This is called the **B-V colour index**. The lower (or more negative) the number, the bluer the star, and the higher (or more positive) the number, the redder the star. Rigel, a large blue star, has a B-V colour index of -0.03, for example. Betelgeuse, a large red star, has a B-V colour index of 1.85.

B-V colour index
the difference in brightness measured through blue and green filters, indicating the colour of a star

Quick check 7.3

1 What is the name of the process that occurs inside stars?
2 Recall what the colour of a star tells us.

Explore! 7.1

Aldebaran is the brightest star in the Taurus constellation. It is classified as an orange K-type star and has a surface temperature of around 4000 Kelvin. Research examples of stars that belong to each spectral class (O, B, A, F, G, K and M).

Practical 7.1

Colour and temperature

Aim

To determine the relationship between colour and temperature.

Be careful
Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit. Care to be taken when handling the light globe, as it can become hot with prolonged use.

Materials

- light globe
- power pack
- switch
- wires

Method

1 Copy the results table below, allowing room for descriptions.
2 Connect a globe and switch to a power pack.
3 Set the voltage to 2 V and close the switch to light the globe. You may need to wait a minute after each time you change the voltage so that the globe has time to warm up.
4 Describe the colour of the globe in the results table.
5 Carefully feel the temperature of the globe with your hand and record it in the results table.
6 Repeat the observations for 4 V, 8 V and 12 V, and record your results.

Results

Voltage (V)	Colour (describe in detail)	Temperature (describe in detail)
2		
4		
8		
12		

continued...

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...continued

Evaluation

1 Describe the relationship between colour and temperature from your results.
2 Relate this relationship to what you know about the colours of stars.
3 Identify the limitations of using a light globe as a model for star colour and temperature.

Conclusion

1 Make a claim about the relationship of colour and temperature based on this experiment.
2 Support the statement by using your observations and include potential sources experimental faults.
3 Explain how the observations support the statement.

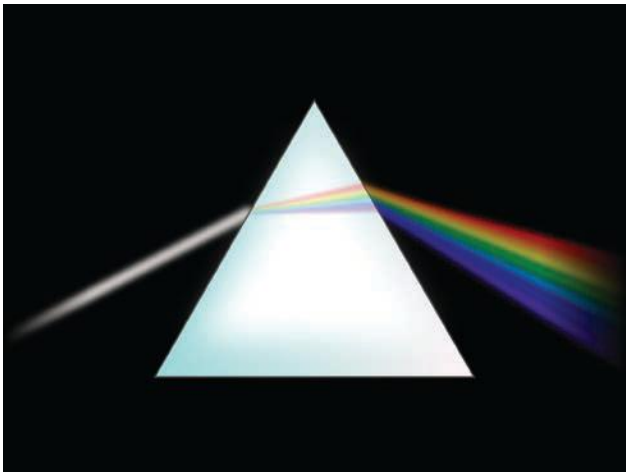

Figure 7.12 White light consists of the full range of wavelengths (colours) from the visible spectrum.

Light from stars

All stars emit a full range of wavelengths from the visible spectrum (colours). This means you would observe a complete rainbow if you were to split the star's light into different colours using a prism. However, a star's spectrum peaks at a certain colour, and this is the colour that we observe the star to be. You will notice that there are no green stars listed in the spectral class system. There actually are stars whose spectrum peaks are in the green part of the spectrum, but their total combination of colours emitted appears white to our eyes.

A **continuous spectrum** contains all the wavelengths and colours possible from the visible spectrum. When light passes through gas (like through an atmosphere), some of the wavelengths (colours) of light are absorbed and black lines will appear in the spectrum. This is called an **absorption spectrum**. We can compare that to light produced by the gas itself that only produces light of a single wavelength in the same position. This produces an **emission spectrum**. Figure 7.13 shows the differences between each of these spectra.

continuous spectrum continuous range of colours/wavelengths

absorption spectrum a spectrum showing dark lines due to specific wavelengths that have been absorbed by a substance

emission spectrum a spectrum showing bright lines at wavelengths specific to emission from a substance

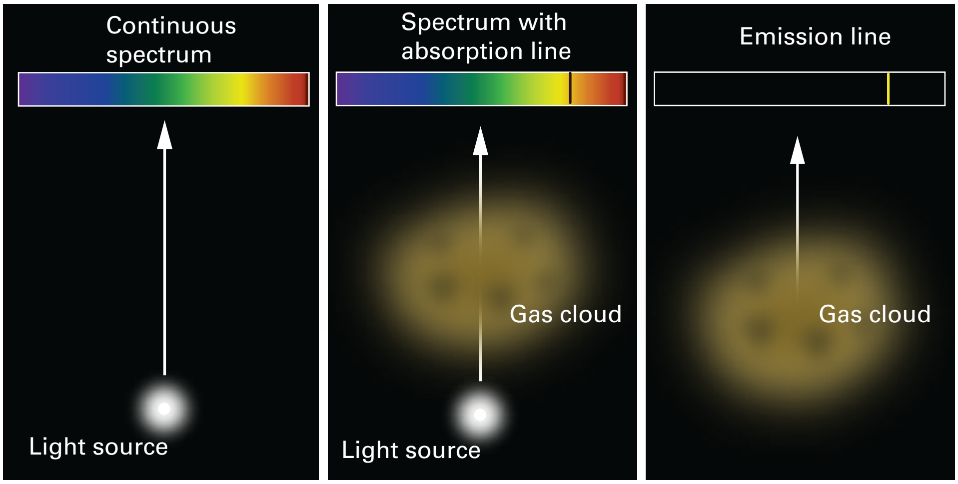

Figure 7.13 A demonstration of how the three types of spectra are produced

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Practical 7.2: Teacher demonstration

Observing emission spectra

Be careful

Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit. Care to be taken when handling the light globe, as it can become hot with prolonged use.

Aim

To observe and classify different types of spectra.

Materials

- spectroscope
- sodium lamp and/or other gas discharge lamps if available
- incandescent globe

Method

1. Copy the results table below.
2. Point the slit of the spectroscope towards a patch of sky (never look directly at the Sun).
3. Name the type of spectrum (continuous, absorption or emission) and draw the spectrum that you can see. Take particular note of the very faint dark lines, the most notable being at a wavelength of 4.9 and 5.2 (in hundreds of nanometres).
4. Repeat for the sodium lamp, incandescent globe and classroom lights (generally fluorescent).

Results

Light source	Type of spectrum	Colours (wavelength in hundreds of nm) 4 4.5 5 5.5 6 6.5 7
Sun		
Sodium lamp		
Incandescent globe		
Room lights (fluorescent)		

Evaluation

1. At which wavelengths did you observe dark lines in the Sun's spectrum? Research which elements are found in the Sun's atmosphere that coincide with spectral lines at those wavelengths.
2. Use your results to explain how a continuous spectrum, emission spectrum and absorption spectrum are produced.
3. Suggest why spectra are referred to as 'fingerprints' for different elements.

Conclusion

1. Make a claim about the different types of spectra based on this experiment.
2. Support the statement by using your observations and include potential experimental faults.
3. Explain how the observations support the statement.

Luminosity

When you look at stars in the night sky, you will notice that they also vary in brightness. Astronomers call this **luminosity** and define it as the rate at which a star produces energy. The scale of luminosity is based around our Sun, which is given a luminosity of 1. Stars that are brighter than the Sun have a luminosity of greater than 1 and stars that are less bright than the Sun are given a luminosity of less than 1. For example, a star with a luminosity of 100 is 100 times brighter than the Sun.

luminosity the intrinsic brightness of a celestial object

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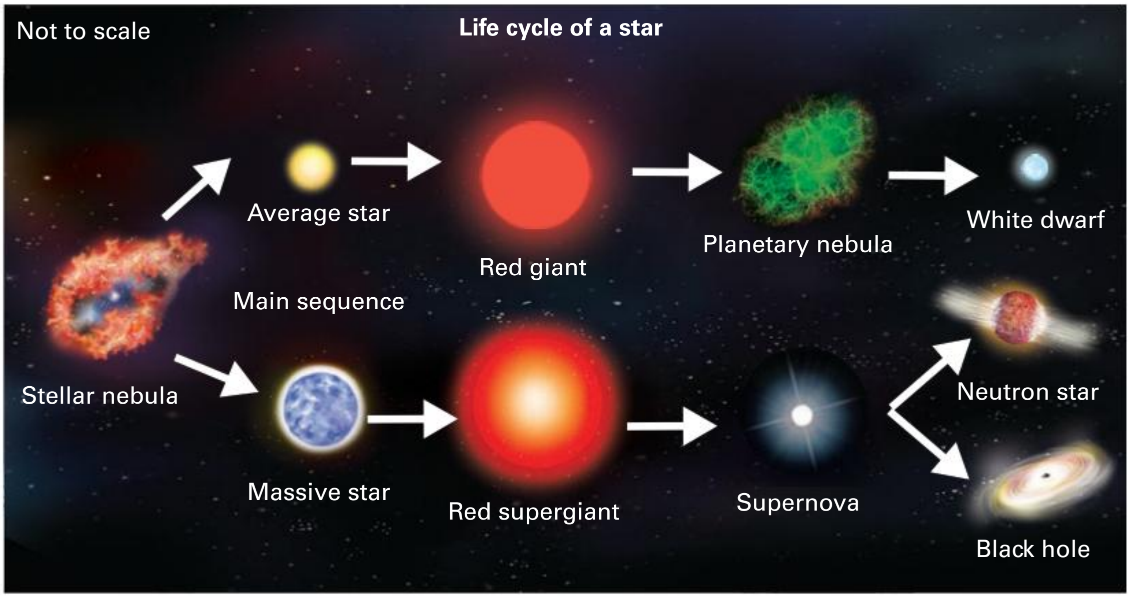

Figure 7.14 How stars change over time depends on their size.

Star life cycle

Stars do not have a limitless fuel source. At some point, each star will run out of material to burn and will come to the end of its lifetime. The changes that stars go through in their life time is predictable and depends on their size.

Birth of stars

Stars form out of clouds of dust and gas called molecular clouds. The dust and gas collapses under its own gravity and becomes a protostar. Over millions of years, a protostar stabilises and begins nuclear fusion.

Main sequence stars

Stars spend the majority of their life in the **main sequence**. This is the phase in which they convert hydrogen into helium via nuclear fusion. Roughly 90% of known stars are in the main sequence. Our Sun is 4.6 billion years old and will spend another 5 billion years in the main sequence before it moves to its next stage.

main sequence
stars that convert hydrogen into helium at their cores

Red giants

As an average-sized star's hydrogen is converted into helium, the helium builds up in the core of the star. The region where hydrogen is still undergoing fusion becomes a shell around the core, and the star will gradually increase in size to become a **red giant**. For our Sun, this size increase will happen in roughly five billion years, and the red giant will envelop the first four planets in our solar system (including Earth). Nuclear fusion in the core of a red giant then begins to fuse helium into heavier elements.

red giant
a very large, bright, cool star that has run out of hydrogen at its core

When a red giant runs out of fuel, its outer layers drift off in a planetary nebula and it collapses into a **white dwarf**. The white dwarf will slowly cool over time and eventually be no longer visible. A star at this stage is given the name black dwarf, but it is only theoretical because a black dwarf is expected to take longer to form than the current age of the universe!

white dwarf
a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

Supergiants

Stars that are more than 10 times the mass of our Sun take a different path. Massive stars have a much shorter life time than smaller stars like our Sun. They may be anywhere

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up to 50 times as massive as our Sun but can be more than a million times brighter. This means that they burn much hotter and faster than smaller stars. Massive O-type stars may only live for a few million years because they burn through their fuel so quickly, whereas the smaller K-type and M-type stars live for many billions of years.

Supernovae

When a supergiant runs out of fuel, it collapses under its own gravity and produces an enormous explosion called a **supernova**. All of the elements heavier than iron, such as uranium and gold, are theorised to have been created during these spectacular explosions. If a supernova is less than 40 times the mass of our Sun, it collapses into a neutron star, while a supernova that has a mass greater than 40 times the mass of our Sun it will become a black hole.

supernova
the explosion of a massive star

Black holes

If the mass of a supernova is great enough, the amount of gravity can be so enormous that it pulls all of the remaining matter of the exploded star into a tiny amount of space. This is called a **black hole**. We cannot see black holes because they do not emit light, but we can observe them indirectly by the effects that they have on objects around them. Some black holes have a diameter of only a few kilometres but the mass of 10 000 Suns! There is a supermassive black hole at the centre of the Milky Way **Galaxy**, and astronomers predict that most spiral galaxies have a black hole at their centre.

black hole
the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing, not even light, can escape

galaxy
an independent groups of stars that are held together by gravity

Quick check 7.4

1 Recall which factor determines the path that a star takes through its lifetime.
2 List the order of phases that a Sun-like star will go through in its lifetime.

Explore! 7.2

Spaghettification and worm holes

Black holes have captured the imagination of astronomy enthusiasts, science fiction writers and astrophysicists alike since their discovery in the early 1900s. There are many theories surrounding black holes and how light and matter can interact with them.

1 Research the ideas behind spaghettification and worm holes, and summarise the main concepts in a few paragraphs.
2 Propose what it might look like to watch something travel into a black hole.

Science as a human endeavour 7.1

The first image of a black hole

Figure 7.15 is the first 'image' of a black hole, released on April 10, 2019. The image is not a photograph, but an image created by the Event Horizon Telescope (EHT) project. A network of eight radio observatories on four continents observed a black hole in a supergiant elliptical galaxy for 10 days in order to capture the image.

The black hole itself is unseeable, as it's impossible for light to escape from it; what we can see is its event horizon, or the golden ring in the image. The event horizon is the boundary around a black hole beyond which no light or other radiation can escape the massive gravitational pull of the black hole. Objects that pass into the event horizon go through spaghettification (refer back to your research in Explore! 7.2).

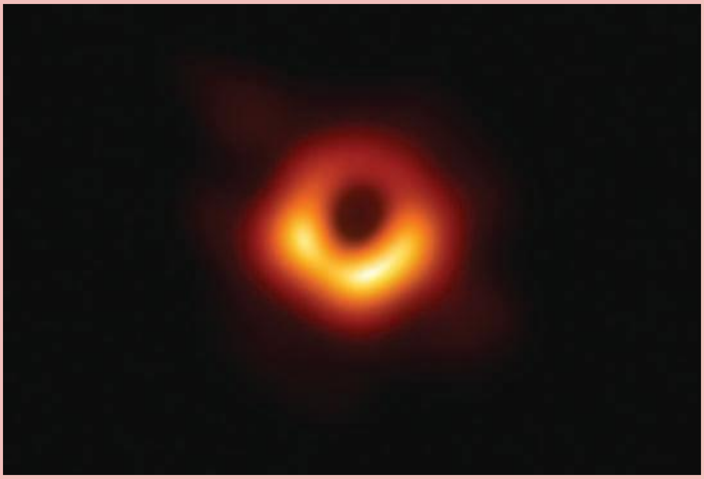

Figure 7.15 The black hole at the centre of galaxy Messier 87

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Hertzsprung–Russell diagrams

H–R diagram
a graph where the star luminosity is plotted against spectral type/temperature (Hertzsprung–Russell diagram)

A Hertzsprung–Russell or **H–R diagram** is a plot of star brightness (measured as luminosity) against star temperature/colour. In Figure 7.16, you can see a diagonal band of stars that represent stars in the main sequence. Red giants, supergiants and white dwarfs make up their own section of the graph.

Remember, the luminosity scale gives us an idea of how bright a star is compared to our Sun. Stars with a luminosity of 1 are as bright as our Sun.

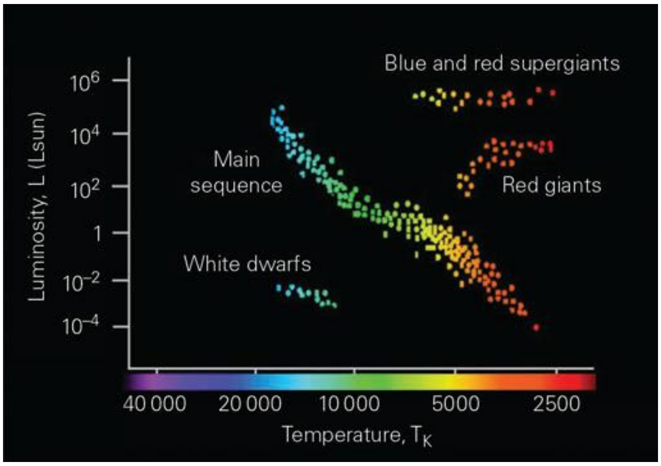

Figure 7.16 A Hertzsprung–Russell diagram plots star brightness (luminosity) against surface temperature.


QUIZ

Section 7.2 questions

Remembering

1 Recall the temperature and luminosity of our Sun.

Understanding

2 Describe the process by which a star forms.
3 Explain the two factors that determine how bright a star appears from Earth.

Applying

4 Obtain a copy of an H–R diagram and plot the following stars on it:

Star	Temperature (K)	Luminosity (Sun = 1)
Sirius	9940	25.4
Canopus	7350	10 700
Arcturus	4290	170
Alpha Centauri	5790	1.5
Vega	9602	40
Rigel	11 000	120 000
Betelgeuse	3500	140 000

a Which of the stars you have plotted is a red supergiant?
b Which of the stars you have plotted is most like our Sun?
c What colour is Canopus? How do you know?
d How many times brighter than the Sun is Sirius?
e Will Rigel's lifetime be longer or shorter than the Sun's? Explain your answer.

Analysing

5 Propose a reason why nobody has ever seen a black hole. How do we know that they are there?

Evaluating

6 Create a summary of the observable features of stars and how they relate to each other.

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7.3 Beyond the Milky Way

All the stars that you can see in the night sky are within the Milky Way. It is mind-boggling to imagine the immense distances in space unless some things are put in perspective. Our closest star is the Sun and it takes 500 seconds (about eight minutes) for light to travel from the Sun to Earth (a distance of 150 000 000 km). The closest star to our solar system is Alpha Centauri. Light takes 4.4 years to travel from Alpha Centauri to Earth. Our solar system is positioned on an outer arm of the Milky Way Galaxy and it takes light 106 000 years to travel across the Milky Way. Our closest galaxy is the Andromeda galaxy, and it takes light 2.5 million years to travel to Earth from Andromeda. There are over 30 galaxies in our Local Group and over two trillion galaxies in the observable universe (that is just the part of the universe we can actually see)!

WORKSHEET

VIDEO
What are some shapes of galaxies?

Galaxies

Galaxies are classified by their shape, according to the Hubble galaxy classification scheme. Galaxies can be classified as elliptical, lenticular, spiral or irregular.

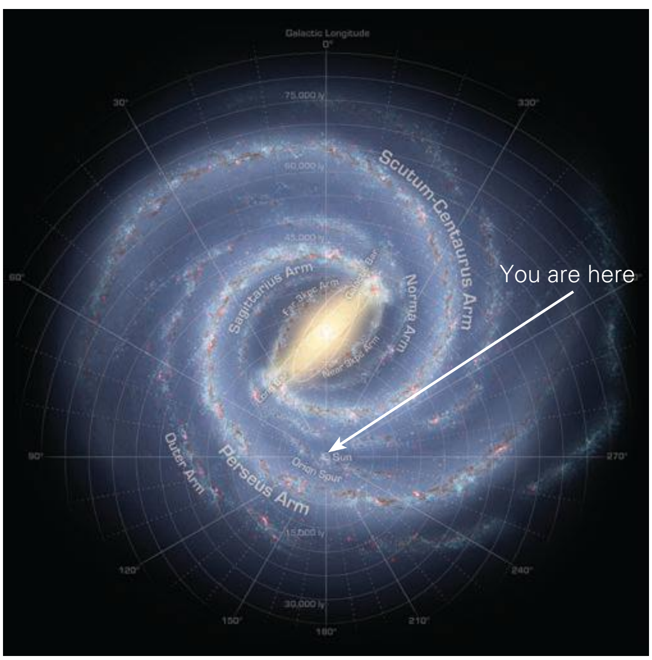


Figure 7.17 Our solar system sits on the Orion arm of the Milky Way.

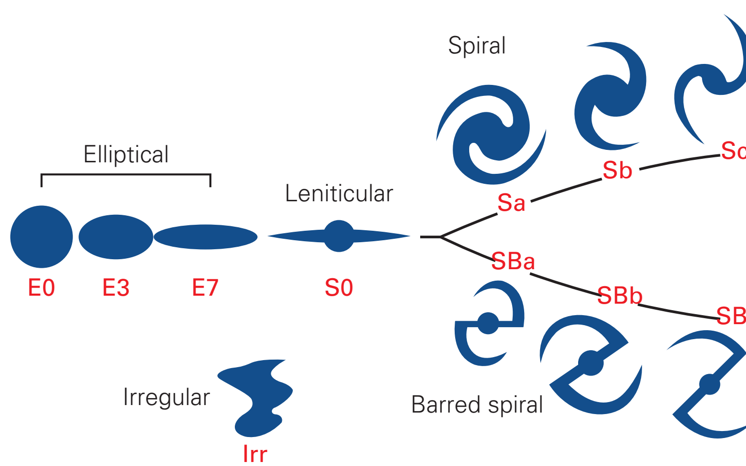
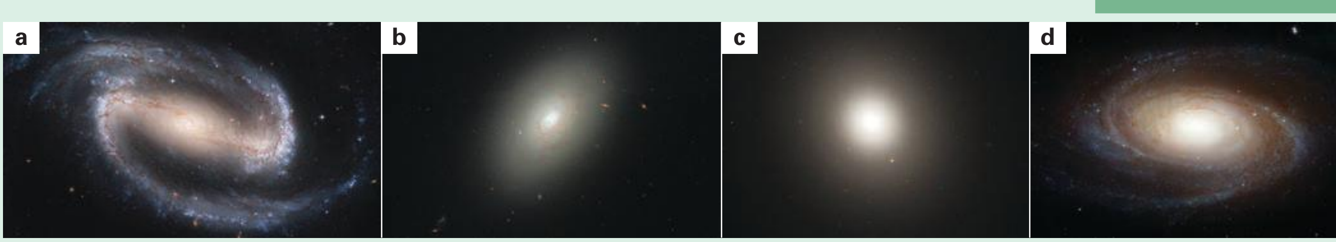


Figure 7.18 Hubble's galaxy classification scheme

Quick check 7.5

1 Classify the following galaxies using Hubble's classification scheme:



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Try this 7.2

Classifying galaxies

Astronomers now have so many photos of galaxies that they simply do not have the time to classify them all. A group of astronomers has set up a crowdsourced astronomy project call Galaxy Zoo that allows anyone to take part in some real science. You can try this too.

Search for Zooniverse Galaxy Zoo on the internet and you can have a go at classifying galaxies for yourself. You will be shown a galaxy and asked a series of questions about what you can see and the shape of the galaxy. Do not be afraid that you will get it wrong – the galaxies are shown about 30 different times to make sure that the responses are consistent.

Astronomical distances and the speed of light

Light travels at a speed of 300 million metres every second, or 3×10^8 m/s. A **light year** is a unit of distance equivalent to how far light travels in a year, which is equal to 9.46 trillion kilometres.

light year the distance that light travels in one year (about 10 trillion km)

Try this 7.3

Cheese and light

Use your microwave to calculate the speed of light!

Be careful

Handle with care as cheese may be extremely hot.

1. Take the plate out of your microwave and remove the rotating platform.
2. Line a dinner plate with cheese singles and place it in the microwave.
3. Turn on the microwave for about 10 seconds or until small hotspots start to form on the layer of cheese.
4. Take the plate out of the microwave and measure the distance between two of the hotspots. This value will be half of the wavelength of the microwave radiation.
5. Locate the frequency of your microwave, in hertz (Hz), which should be listed inside the door.
6. Use the formula $v = f\lambda$, where v is the speed in m/s, f is the frequency in Hz and λ is the wavelength in m, to calculate the speed of light (remember to multiply your hotspot measurement by two to get the wavelength). Compare it to the actual value.

Figure 7.19 A microwave heating up a slice of cheese

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The kilogram

Explore! 7.3

On 16 November 2018, scientists from all around the world gathered to vote on changing the definition of a kilogram. The kilogram was originally based on the mass of a metal cylinder, a single physical piece of metal nicknamed Big K, that is locked away in a vault in Paris. It was the last of the base SI units (Standard International units) still based on a physical artefact rather than a fundamental natural constant. One important reason for the change is that Big K is not constant. It has lost around 50 micrograms (about the mass of an eyelash) since it was created in 1899. Interestingly, when Big K lost mass, it was still exactly one kilogram, by definition! That was not suitable, so a new definition of the kilogram based on fundamental constants was created.

Figure 7.20 A replica of Big K, the global standard for a kilogram

Planck's constant (h) is a fundamental natural constant that gives the relationship between energy (E) and the frequency of electromagnetic radiation (f), given by the formula $E = hf$. We also know that energy is related to mass (m) and the speed of light (c), given by the formula $E = mc^2$. By equating these two formulas, we can see that Plank's constant is also related to mass: $hf = mc^2$.

Planck's constant is equal to $6.626070040 \times 10^{-34}$. Therefore a kilogram measure based on Planck's constant will always be certain.

1 Research the seven base SI units and list the physical quantities that they measure.
2 There are three other base SI units that needed their definitions changed because of the new definition of the kilogram. Find out what they were and explain how they are related to mass.

Parallax

Have you ever wondered how we measure distances in space? One method is by using **parallax**. If you hold your index finger in front of you at arm's length and close one eye, then swap eyes and close the other one, your finger will appear to move because you are essentially observing your finger from a different location. The same thing happens when we look at the stars in the night sky from a different position in space. As Earth travels around the Sun, our position in space changes and we see the stars arranged slightly differently. We can measure the angle between the apparent location of a nearby star and a 'fixed' distant star. This is called the parallax angle. Using the distance between Earth and the Sun (the **astronomical unit** or AU) as the **baseline** and some trigonometry, we can work out how far the star is from Earth.

parallax
the effect by which the position of an object seems to change when it is observed from different locations

astronomical unit
the distance between Earth and the Sun

baseline
a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

This technique enables us to measure distant stars in **parsecs** (pc): one parsec is equal to 3.26 light years or 30 trillion kilometres. A star that is one parsec

parsec
the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

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arcsecond
1/3600th of a degree

away will have a parallax angle of one **arcsecond**, which is one 3600th of a degree (there are 60 arcminutes in one degree and 60 arcseconds in one arcminute).

Using parsecs to measure distance makes it easier to calculate distances with the following formula:

$$\text{Distance to star (in pc)} = \frac{1}{\text{parallax angle in arcseconds}}$$

The further away a star is, the less it appears to move due to parallax, and the smaller the parallax angle becomes. This gives a limit to the distance that we can measure using the parallax method, because when stars are too far away, their parallax angle is too small to measure. The limit to which we can use parallax is around 100 light years.

Parallax

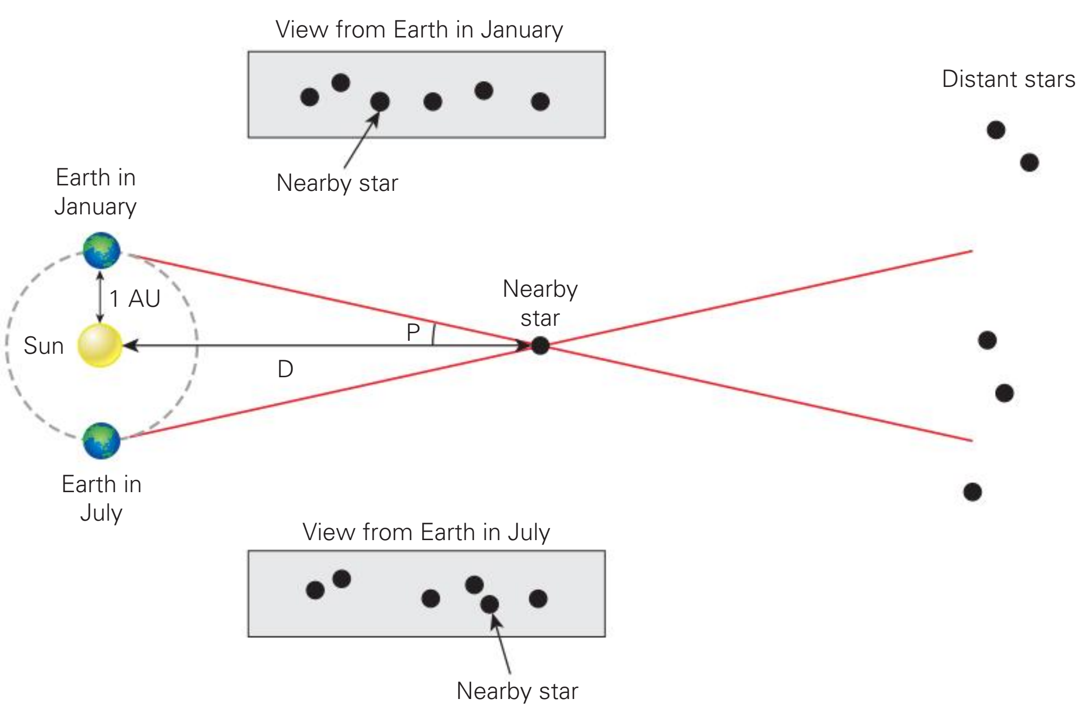

Figure 7.21 Astronomers can work out the distance to nearby stars by comparing their apparent location relative to the background of distant stars (which are unaffected by parallax).

Quick check 7.6

1 Does a light year measure time or distance?
2 What is the limit out to which star distance can be measured using the parallax method?
3 Will a closer star have a larger or smaller parallax angle?

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Practical 7.3

Parallax

Aim

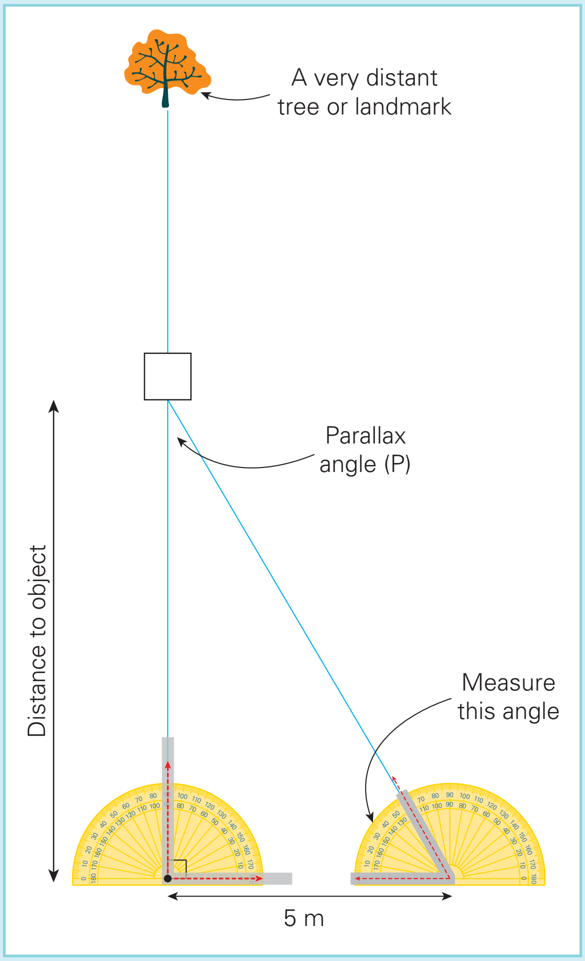
To use parallax to calculate distance.

Materials

- an 'object' (something that can be placed in the middle of the school oval and be visible from the perimeter)
- 2 rulers
- large protractor
- trundle wheel

Method

1. Your teacher will place an object in the middle of the school oval (the whole class will determine the distance to this one object).
2. Find a location near the perimeter of the oval where the object lines up with a distant landmark; for example, a tree, the edge of a fence, a gate, the edge of a building or a flagpole.
3. At this location, use the two rulers and protractor to make a right angle perpendicular to the line going through the object and the landmark.
4. Measure out a 5 m line along this perpendicular direction (this will be your baseline).
5. At the end of the 5 m line, use the two rulers and protractor to measure the angle between the base line and the ruler directed towards the object. (You may have to lie on your stomach to line up the objects by sight.)
6. Calculate the parallax angle (P) by subtracting the measured angle from 90.
7. Use trigonometry ($D = tanP \times 5$) to calculate the distance (D) to the object.
8. Use the trundle wheel to measure the distance and compare it to your calculated distance.



Results

Set up a table of class results to compare distance to the object and parallax angle. Plot a graph of distance to the object against parallax angle.

Evaluation

1. Evaluate the method for this experiment by listing any sources of measurement uncertainty and suggesting improvements to the method for higher accuracy.

Conclusion

1. Make a claim about calculating distances from parallax based on this experiment.
2. Support the statement by using the data you gathered and include potential experimental faults.
3. Explain how the data supports the statement.

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The Doppler effect

When you hear an ambulance travelling past you, the pitch of the siren changes as it passes. When the ambulance is travelling towards you, the sound wave is a little more squashed than usual and results in a higher frequency wave. You hear it as a higher pitch. When the ambulance is travelling away from you, the sound wave is a little more stretched than usual and results in a lower frequency wave. You hear it as a lower pitch. This phenomenon is called the **Doppler effect**.

Doppler effect
a change in the frequency of sound or light waves emitted from an object when its moves towards or away from an observer

The same phenomenon happens with light waves if an object is travelling fast enough. When the object is travelling towards you, the light it emits is of a higher frequency, which translates to the light appearing more blue. This is called **blue shift**. When the object is travelling away from you, the light it emits is of a lower frequency, which translates to the light appearing more red. This is called **red shift**.

blue shift
a spectrum shifted towards shorter wavelengths

red shift
a spectrum shifted towards longer wavelengths

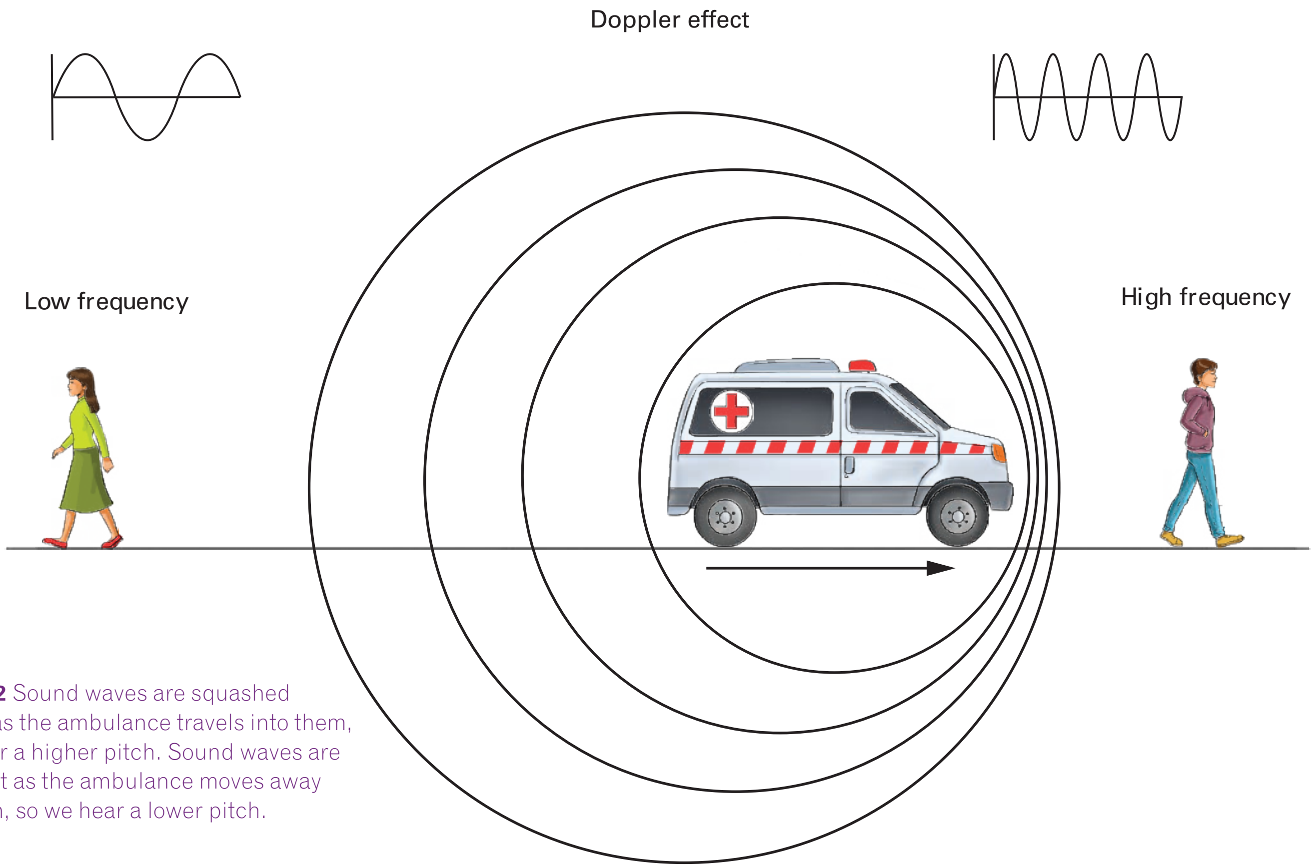

Figure 7.22 Sound waves are squashed together as the ambulance travels into them, so we hear a higher pitch. Sound waves are spread out as the ambulance moves away from them, so we hear a lower pitch.

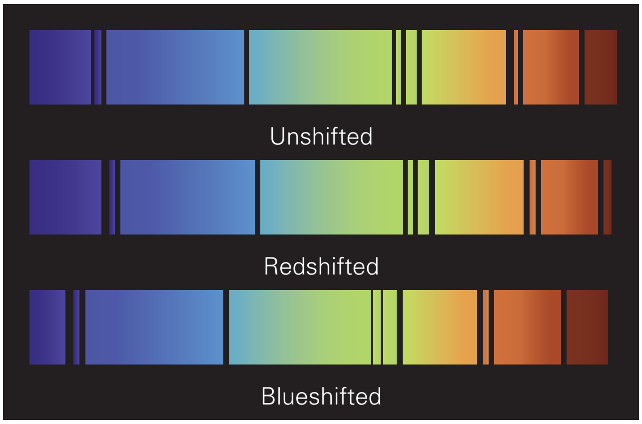

Figure 7.23 The black lines from a galaxy's absorption spectrum are shifted towards red if the galaxy is moving away from us and towards blue if it is moving towards us.

When astronomers look at spectra from distant galaxies, they find that the emission lines are almost always shifted towards the red part of the spectrum. This tells us that the vast majority of galaxies in the universe are moving away from us.

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Travelling large distances

Earth is not going to be around for ever, whether it becomes uninhabitable because humans have destroyed it, it gets enveloped by our Sun expanding into a red giant in five billion years, or it is wiped out by some other catastrophic event. If humanity gets the chance to leave Earth before it is likely to become uninhabitable, we will need to find a way to travel large distances and leave our solar system.

Interstellar travel (that is, travelling outside our solar system) throws up quite a few problems. These problems relate to the vast distances that we would need to travel in order to find and inhabit a new planet. Light takes just over four years to reach the closest star to our solar system, Alpha Centauri. We cannot travel even remotely near the speed of light with current technology. Even if we develop such technology in the future, travelling close to the speed of light has its own problems: it would not only require an enormous amount of energy to accelerate a conventional space ship leaving the earth to 99% of the speed of light, but an equally enormous amount of energy to decelerate at journey's end.

exoplanet
a planet orbiting a star that is outside the solar system

Finding **exoplanets**, planets that orbit other stars, is a lot harder than you might imagine. We can easily observe stars because they emit their own light. Planets only reflect light from the star that they orbit, so are many orders of magnitude dimmer than a star. We cannot see the light from most planets outside our solar system because we are just too far away from them, so the only way we can tell that they are there is when they pass in front of their own star and block out a tiny portion of its light (like a mini eclipse).

Despite this difficulty, astronomers have found over 3000 exoplanets! The problem we then encounter, is finding out whether humans could actually live on these planets. A liveable planet would need to be made of rock, so that we can land on it, and have an atmosphere with enough oxygen in it, so we do not die from the radiation in space (but not so thick that the greenhouse effect makes it unbearably hot). The planet would need to be in what is called the **Goldilocks zone**: not too hot and not too cold. Out of all the exoplanets that have been discovered, only a small number could potentially be habitable. However, astronomers have predicted that there might be more than 10 billion exoplanets orbiting Sun-like stars just in our Milky Way Galaxy.

Goldilocks zone
the habitable zone around a star where the temperature is not too hot and not too cold

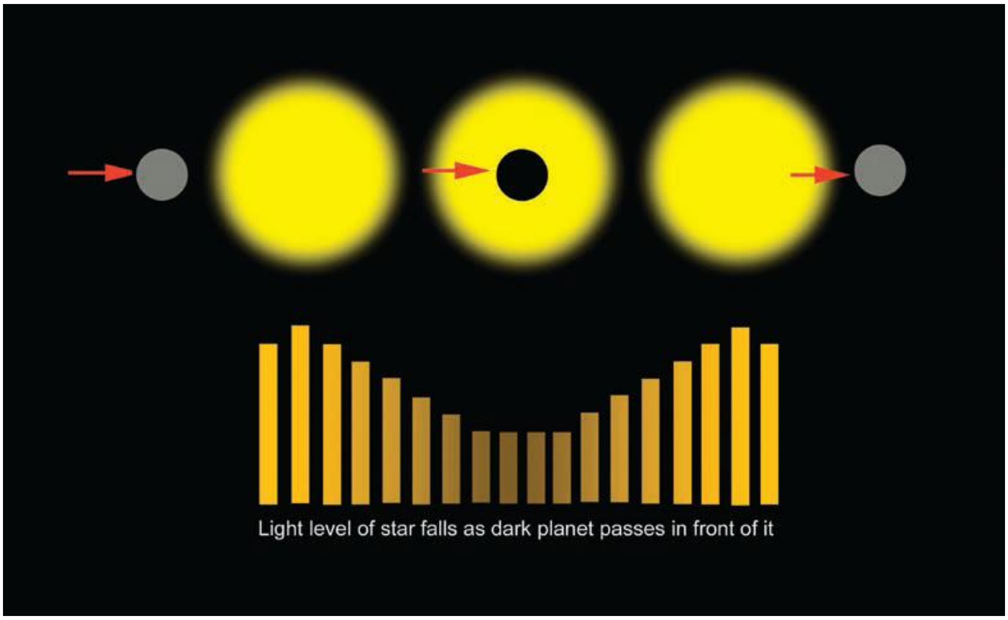

Figure 7.24 Astronomers use transit photometry to detect exoplanets.

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Given the immensely large distances to these potentially habitable planets, the only way to explore them may be to send out one-way space missions. With current technology, spacecraft need fuel to travel. To be able to accelerate very quickly, you need to take more fuel, but extra fuel makes the spacecraft heavier, decreasing the acceleration. Even if in the future we discover a way to travel large distances without carrying fuel, the journey to other star systems will still probably be much longer than a human lifetime. There are a few solutions to this problem.

One might be to send a population of humans that would have multiple generations out on huge spacecraft to explore the stars. These explorers would have to deal with things like a changed physiology due to living in space. Another solution might be to send people away in suspended animation and wake them up when they get to their destination. A third solution might be to not send humans at all and instead send advanced robots or androids. It is not just a world of opportunities, but a universe of possibilities that awaits us!

Science as a human endeavour 7.2

Professor Penny Sackett

Professor Penny Sackett is an American-born Australian astrophysicist and was the Chief Scientist of Australia from 2008 to 2011. She is most well known for her work on detecting exoplanets through a technique called gravitational microlensing. Typically, astronomers can only detect objects that emit light, but gravitational microlensing is an effect where light from a star is bent (like a lens bends light) by the gravity of a nearby dark object (like a planet).

QUIZ

Section 7.3 questions

Remembering

1 Define a light year.

2 Recall the units used to measure parallax angle and star distance (for stars less than 100 light years away).

Understanding

3 Explain why an ambulance siren changes to a slightly lower pitch as it drives past you.

Applying

4 An astronomer collects data from a star in January and then again in July and finds that its parallax angle is 0.8 arcseconds. Calculate the distance to the star. Express your answer in parsecs and light years.

5 What is meant by the term 'Goldilocks zone'? How does it apply to humans being able to live outside our solar system?

Analysing

6 Explain how astronomers determined that the vast majority of galaxies we can observe are travelling away from us.

Evaluating

7 Evaluate the potential of humans finding a way to leave our solar system.

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7.4 The Big Bang

Big Bang
the large explosion that scientists believe created the universe

The **Big Bang** is a theory that most people have probably heard of and accept as the explanation of how the universe began. But how do we actually know what happened such a long time back, and what evidence have astronomers discovered to support it?

Evidence for the Big Bang

singularity
a point at which an infinitely dense matter occupies an infinitely small space

The Big Bang theory suggests that the universe was created 13.7 billion years ago from a very small, yet very dense **singularity**. Three main pieces of evidence support the Big Bang theory:

- The fact that almost all galaxies are red shifted means that almost all galaxies are travelling away from each other. This suggests that the universe is expanding and that, if you extrapolate backwards, the universe had a beginning.
- The abundance of smaller elements in the universe is consistent with them being created in a Big Bang and not inside stars through nuclear fusion.
- Radiation left over from the Big Bang, called **cosmic microwave background**, is consistent with the rate of cooling calculated from such an explosion.

WORKSHEET

cosmic microwave background
electromagnetic radiation left over from the early stages of the universe

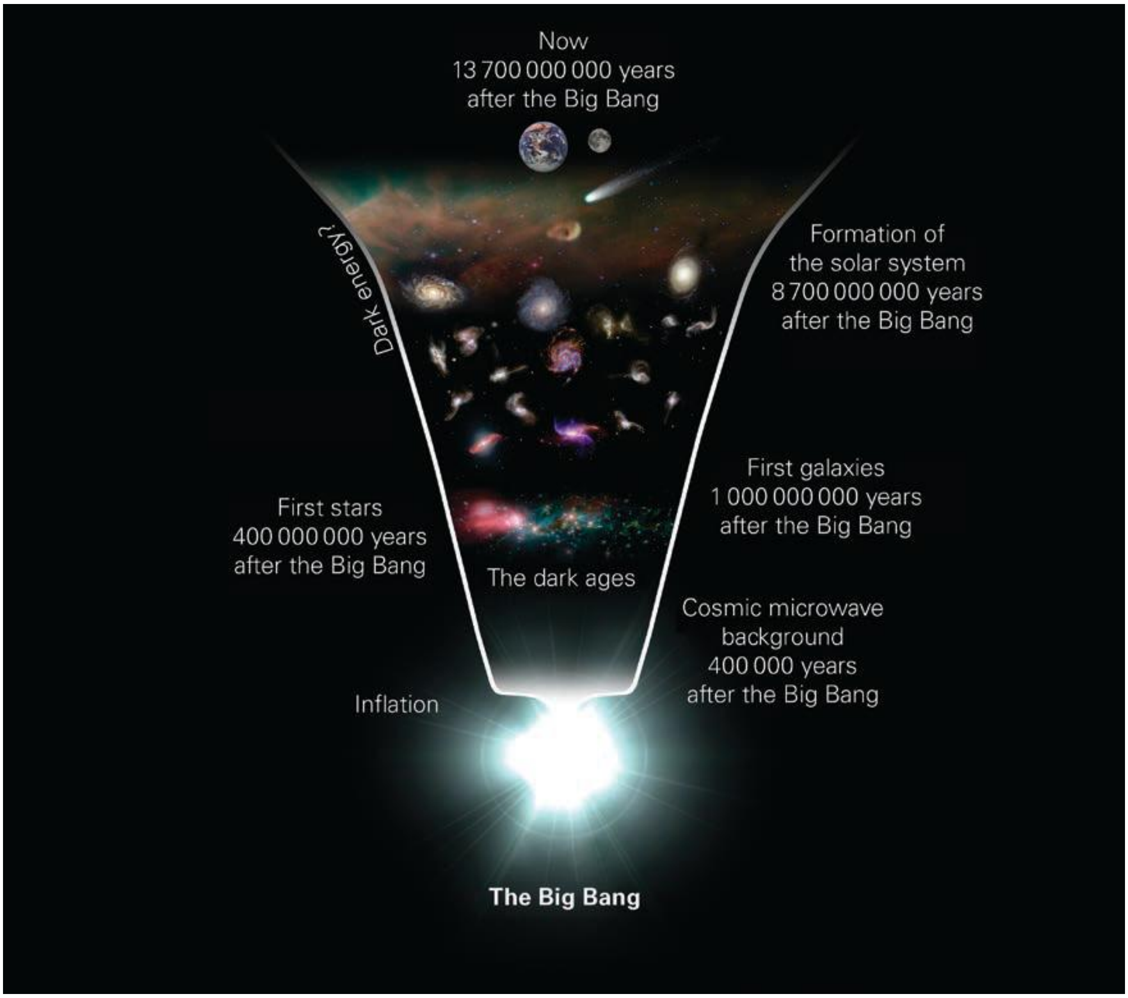

Figure 7.25 The history of the universe

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In the beginning

The Big Bang theory suggests that before the universe was created 13.7 billion years ago it existed in a singularity. Then rapid expansion started, and space and time came into existence. In the first stage of the universe's existence, the first 300 000 or so years, atoms could not yet exist because of the extreme density and temperature of the young universe. Matter existed as plasma, the ionised fourth state of matter, in which ions and electrons are separated. During this phase, all the photons emitted were scattered by the plasma and so we cannot observe photons before this point in time. This early period is referred to as the 'dark ages' of the universe. The point in time where ions and electrons could bond together is called the **epoch of recombination**. The term 'recombination' can be misleading as it does not mean that protons and electrons were combined before, but rather it is a historical convention as the term came about before the Big Bang model became the primary theory for the origins of the universe.

epoch of recombination the point in time where electrons and ions could combine to form atoms

Cosmic microwave background

Radiation is the name that we give to all frequencies of the electromagnetic spectrum, including gamma rays, X-rays, microwaves, ultraviolet waves, visible spectrum light, infrared waves and radio waves. Radiation was emitted from the Big Bang, and we can still observe that radiation today. It exists in the form of very low-frequency waves, even lower frequency than radio waves, and was discovered in the 1960s almost by accident. Two radio astronomers noticed a subtle continuous buzzing that came from the skies and initially thought that it was some type of interference coming from their antenna. They soon realised they were detecting the cosmic microwave background.

When photons are emitted in space, they continue to radiate outwards forever. This is just like if you threw a tennis ball in space – it would continue its motion forever according to Newton's first law. When we look at the light from Alpha Centauri, for example, it has taken 4.4 years to reach Earth, so we are actually looking 4.4 years back in time. So, when we observe cosmic microwave background radiation, we are looking back in time to the earliest observable light in the universe. These photons were emitted just under 13.7 billion years ago!

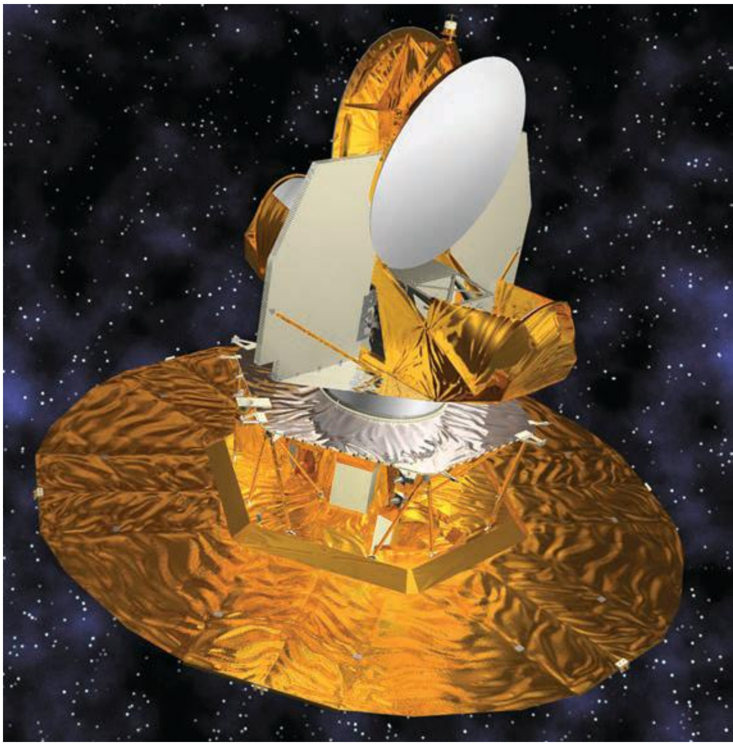

Figure 7.26 The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft operated in the early 2000s to collect temperature data from the cosmic microwave background.

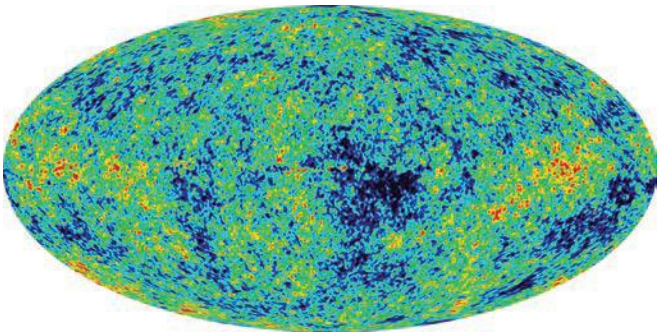

Figure 7.27 Data collected from WMAP was used to give a temperature map of what the universe looked like shortly after the big bang.

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Quick check 7.7

1 Explain why we cannot see photons emitted in the early stages of the universe.

Expansion

What we can observe of the universe from our location on Earth has a limit. The limit is not because of the constraints of our current technology, it is a physical limitation due to the speed of light. We can observe things in the universe when light from an object has travelled to Earth. But for very distant objects, their light has simply not had enough time to travel here in the 13.7 billion years that the universe has existed. The distance out to which we can observe is actually well beyond 13.7 billion light years. This is because of the expansion of the universe. In the last 13.7 billion years, the most distant objects that emitted the light that we are now observing have moved so far away from us that the actual distance to the edge of the **observable universe** is roughly 45 billion light years.

observable universe the spherical region of the universe that can be observed from Earth because light has had time to reach Earth

One of the great mysteries that astronomers are currently working on is finding out about dark matter and dark energy.

Gravity is a property of mass, or matter. All objects have gravity and the more mass, the more gravity. Astronomers have measured the amount of gravity in the universe indirectly; that is, they can measure it by observing the effects that it has on things around it. They have found that there is more gravity in the universe than the amount that can be attributed to matter. So, there is extra gravity and we do not know what is causing it. Astronomers have theorised that there must be some other type of matter causing this extra gravity and have called it **dark matter**.

dark matter matter that does not emit light and is responsible for unidentified gravity in the universe

We know that the universe is expanding because of the fact that light from other galaxies is red shifted. What is really interesting is that galaxies are not just moving away from all other galaxies, but they are doing so at an accelerating rate. It seems that there is some sort of unobservable pressure that is making the universe expansion rate accelerate. This unknown pressure has been termed **dark energy**. It is amazing to think that in the future the universe may have expanded so vastly that all other galaxies will be outside our observable universe, so we will not actually be able to see anything beyond our own galaxy!

dark energy a theoretical force responsible for accelerating the expansion of the universe

Science as a human endeavour 7.3

Professor Brian Schmidt

Professor Brian Schmidt, Australian National University, was one of the scientists who discovered that the universe's expansion rate is accelerating rather than decelerating. He received the Nobel Prize in Physics in 2011 for his discovery.

Figure 7.28 Nobel Prize laureate Professor Brian Schmidt

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The search for extraterrestrial intelligence **Explore! 7.4**

Given the immense size of the universe, it seems likely that life has also arisen in other places in the universe. The SETI program (search for extraterrestrial intelligence) was developed to monitor radio waves from space to potentially find other intelligent life in our galaxy.

1 Research SETI and find out and describe the projects currently under way.
2 Describe the type of data that is collected and explain what we can learn from it.
3 If you are interested, join SETI@home and let your computer download and analyse data to contribute to the SETI program.

Age of the universe

Edwin Hubble made his observations about galaxies in the 1920s, and observed that many 'clouds' of dust and gas were actually distant galaxies. He noticed that these distant galaxies were different sizes and concluded that the smaller ones must be further away. While this assumes that all galaxies are the same size, which they are not, it is nevertheless a pretty good approximation at these distances.

Hubble calculated the **recessional velocity** of the galaxies (that is, the speed that they are travelling away from us) by recording the red shift of their spectra. The further the spectral lines are shifted towards red, the faster the galaxy is moving. What Hubble found was that the further a galaxy is from us, the faster it is travelling away from us, so he proposed a relationship between distance and recessional velocity. This relationship is called **Hubble's law** and is given by the formula $v = H_0D$, where v is the recessional velocity, D is the distance from Earth and H_0 is a constant that we call Hubble's constant. Hubble's original measurement of H_0 was 500 km/s/Mpc (Mpc is megaparsec), or 160 km/s/million-light-years. However, over time the constant has been measured more and more accurately, and the current value is 73.8 km/s/Mpc.

recessional velocity the relative rate at which a star is moving away from Earth

Hubble's law the further away a galaxy is, the faster it is moving away from Earth

Hubble's law demonstrates two points:

- That the universe is not just expanding outwards from Earth, but rather it is expanding from everywhere. If it was only expanding away from Earth, then the recessional velocity would be the same for all galaxies.
- That the expansion of the universe given by the Hubble constant can be traced backwards to where $D = 0$ to find the age of the universe.

Misconceptions about the Big Bang

A few misconceptions arise about the Big Bang – partly because of the name 'Big Bang' and partly because it is just a really difficult concept to comprehend.

One slightly misleading concept is the idea of the singularity that existed before the Big Bang. 'Singularity' might sound like it means that the whole universe was located at a single point, In fact, space-time did not yet exist so the singularity was not in a specific spot – it was everywhere. Essentially, the Big Bang did not happen somewhere, it happened everywhere.

The other misleading part is the word 'bang', which implies some sort of explosion. In fact, a more accurate description would be to call it the 'big stretch'.

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Practical 7.4

Modelling the expanding universe

Aim

To model the expanding universe with a balloon and evaluate the limitations of the model.

Materials

- balloon
- small dot stickers
- permanent marker
- piece of string around 40 cm long
- ruler
- paperclip

Method

1. Copy the results table below.
2. Partially blow up the balloon to about 10 cm in diameter and secure the end with a paperclip (do not tie the balloon as you will need to further inflate it later).
3. Stick six dots on the balloon at random points and label them H (for home) and then A, B, C, D and E. The home dot represents the Milky Way and the other dots represent neighbouring galaxies. You may add more than five neighbouring galaxy dots if you like.
4. Use the string and ruler to measure the distances HA, HB, HC, HD and HE, and record them in the results table under D_1.
5. Remove the paperclip, fully inflate the balloon and tie it off.
6. Measure the five distances again and record them in the results table under D_2.
7. Calculate the average speed that each dot was moving away from the home dot in the time (t) it took you to blow up the balloon (you can assume it took something like five seconds), by using $\textit{average speed} = \frac{(D_2 - D_1)}{t}$.
8. Plot a graph of average speed (on the y-axis) and the second distance (on the x-axis) and add a line of best fit.

Results

Galaxy	D_1 (cm)	D_2 (cm)	Average speed (cm/s)
A			
B			
C			
D			
E			

Evaluation

1. Describe the shape of your line of best fit and suggest what it tells you about the movement of galaxies and expansion of the universe.
2. Predict the misconception that might arise if you drew the galaxies on with the marker rather than using stickers.
3. Evaluate the limitations of using a balloon as a model for 3D space and suggest a better model.

continued...

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continued…

Conclusion

1 Make a claim about modelling the expansion of the universe based on this experiment.
2 Support the statement by using the data you gathered and include potential experimental faults.
3 Explain how the data supports the statement.

QUIZ

Section 7.4 questions

Remembering

1 Recall the age of the universe.

Understanding

2 State the assumption that Hubble made about galaxies and what he concluded about galaxies that appeared smaller than others.

Applying

3 An astronomer observed a distant galaxy to be travelling at a recessional velocity of 370 km/s. Use the current value of Hubble's constant (73.8 km/s/Mpc) to calculate its distance from us. Give your answer in both megaparsecs and light years.

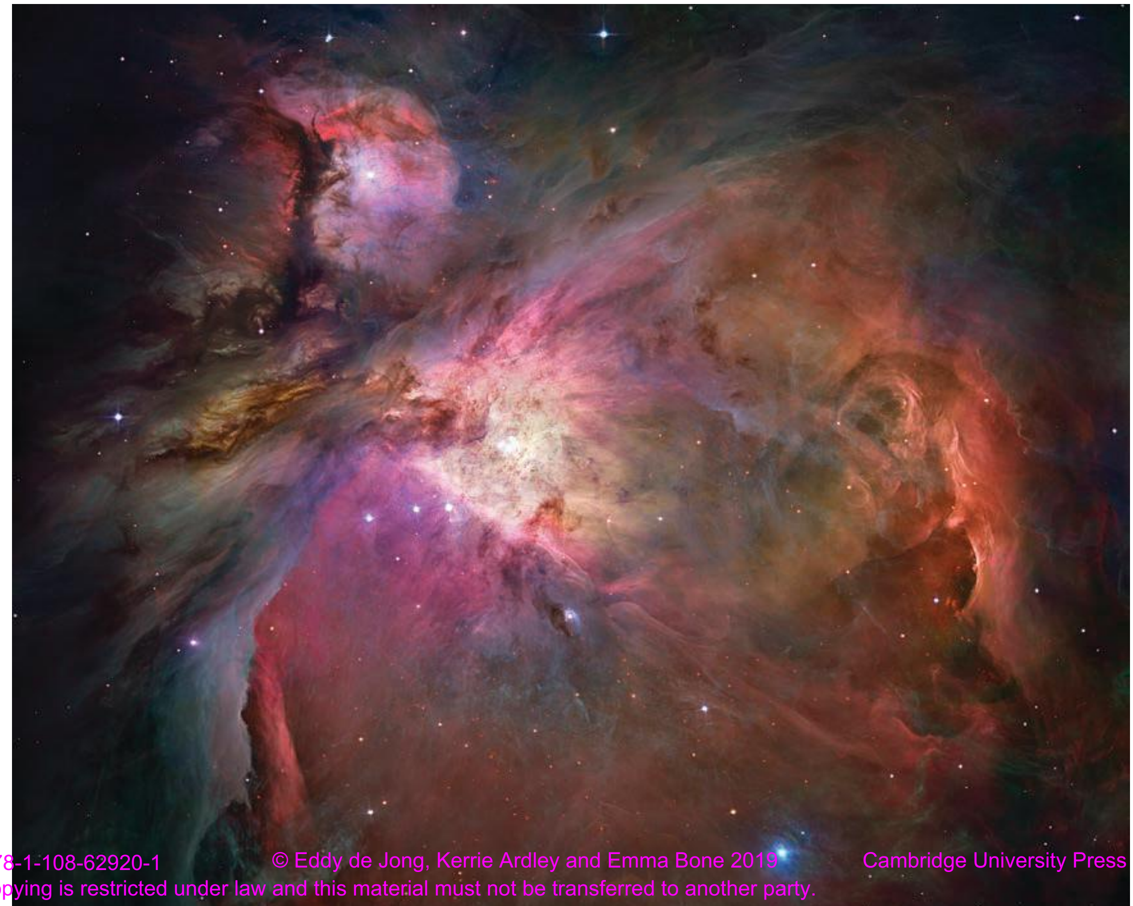
Analysing

4 Explain the concept of the observable universe.

Evaluating

5 Think of a way to demonstrate the enormous size of the universe.

Figure 7.29 The Orion Nebula in a composite image of visible light and infrared, taken by the Hubble Space Telescope.



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Review questions

SCORCHER

Remembering

1 Describe the evidence that Ptolemy used to explain his geocentric model.

2 Describe the evidence that Copernicus used to disprove the geocentric model.

3 List the evidence that supports the Big Bang theory.

Understanding

4 Describe the relationship between star brightness, size and length of lifetime. Explain why this is the case.

5 An astronomer finds that the spectral lines from a distant galaxy are shifted towards the red part of the spectrum. What does this tell us about the galaxy and what does this imply about the universe?

Figure 7.30 An artist's engraving of Ptolemy looking to the sky

Applying

6 Compare and contrast optical and radio telescopes.

Figure 7.31 The Milky Way over a radio telescope in New Mexico, USA.

7 Explain why we cannot see photons emitted in the early stages of the universe.

Analysing

8 An astronomer makes two observations of a star six months apart and measures a parallax angle of 0.1 arcseconds. Calculate the distance to the star. Convert your answer into light years and kilometres.

Evaluating

9 Evaluate the chances of finding intelligent life elsewhere in the universe. Use evidence to justify your answer.

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STEM activity: Creating a representation of our solar system to scale

Background information

VCSSU129 VCMNA277 VCSIS138 VCSIS111

How do you create an image that shows, as accurately as possible, the distance between our Sun and Earth (150 million km)? Have you stopped to think about those tremendous distance numbers? Why not represent our solar system to scale?

Humans are used to handling small numbers and units. We talk about centimetres, metres or kilometres; and minutes, hours, days, months or years. However, in astronomy we see tremendously large numbers in space and time, which escape our understanding and are difficult for us to imagine. In this activity you are invited to create a representation of our solar system to scale to gain a better understanding of its size.

Design brief: Create a representation the solar system with distances to scale.

Activity instructions

In this activity, you and your colleagues will work in groups (a maximum of three) to create a representation of our planetary system to scale, including all planets and known dwarf planets. This is an excellent opportunity for you and your peers to get a better idea on the vastness of our solar system. You will do this by analysing the table provided and finding a way (for example, a formula) to convert the distance and diameter values into something that humans can actually comprehend. You might ask: How do we do that?

Here are a couple of suggestions:

- Imagine that we convert the distance from the Sun to our Earth from 150 million km to 2 metres instead. Can you see how much easier it is to visualise and comprehend the 'metre' than the 'millions of kilometres'? Now you can repeat this same conversion for all planets on the solar system using the table provided. That will let you start comparing distances for these celestial bodies in a much more meaningful way. You can finally visualise the scale of the vastness of our solar system.
- Having the correct distances is a good step, but does not give the full picture. Consider converting the diameter of our planet (12 756 km) to a more manageable number. What about 10 cm? Then convert the diameters of the other bodies in our solar system.

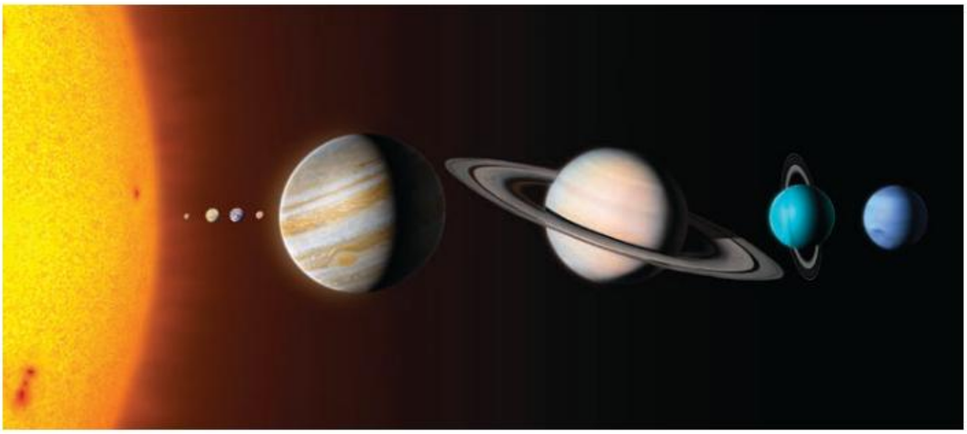

Figure 7.32 A representation of our solar system where the distances are not to scale

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Use your new measurements to create a 2D version of the solar system, showing Earth and all other planets and dwarf planets.

Suggested materials

- a basketball or soccer ball (the Sun)
- large reel measuring tape
- colouring pencils, cardboard and paper to create your planets
- protractor
- scissors

Suggested location

School oval or soccer pitch

Evaluate and modify

1 How could you create a formula to assist you converting all values from millions of kilometres to more manageable units (metres or centimetres)? What skills do you need to perform that task?

2 Analyse Table 7.2 and make a statement about how the orbital period of a celestial body is affected by its distance from the Sun. Explain your reasoning.

3 The dwarf planet Haumea has been described as 'eccentric' by its discoverers. Analyse the table and determine which bit of data shows how this dwarf planet is very different to other dwarf planets.

4 Planets orbit around the Sun on elliptic orbits.

a Compare and contrast the average distance from Sun of planets and dwarf planets.

b How do the orbits of dwarf planets compare (visually) to the orbit of inner planets in our solar system? Feel free to draw or sketch your answer.

5 Research how far humans have ventured into outer space. How far have spacecraft without humans gone? Suggest some reasons for the differences.

Name of planet	Average distance from Sun	Diameter	Time to spin on axis (a day)	Time to orbit Sun (a year)	Distance scale (m)	Diameter scale (cm)
Mercury	57 900 000	4 878 km	59 days	88 days		
Venus	108 160 000	12 104 km	243 days	224 days		
Earth	149 600 000	12 756 km	23 hours, 56 mins	365.25 days	2	10
Mars	227 936 640	6794 km	24 hours, 37 mins	687 days		
Jupiter	778 369 000	142 984 km	9 hours, 55 mins	11.86 years		
Saturn	1 427 034 000	120 536 km	10 hours, 39 mins	29 years		
Uranus	2 870 658 186	51 118 km	17 hours, 14 mins	84 years		
Neptune	4 496 976 000	49 532 km	16 hours, 7 mins	164.8 years		
Dwarf planets						
Ceres	413 900 000	950 km	9 hours, 5 minutes	4 years, 220 days		
Pluto	4 436 820 000 to 7 375 930 000 km	2370 km	6 days, 9 hours	248 years		
Haumea	5 260 000 000 to 7 708 000 000 km	1960 x 1518 x 996 km	4 hours	258 years		
Eris	5 665 500 000 to 14 634 000 000 km	2326 km	7 hours, 46 minutes	557 years		

Table 7.2 Some information about planets and dwarf planets within our solar system

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Chapter 8 **Energy**

Chapter introduction

Energy is all around us – radiating from the Sun, transporting us to where we need to go, powering our many devices, and even stored in the food we eat. Much of our use of energy results in a loss of useful energy, thus there is increasing pressure to be less wasteful and more efficient in our use of energy. This chapter will expand your knowledge on energy and its different forms. We will look at energy transfers and transformations as well as energy efficiency by applying the law of conservation of energy. Through the exploration of energy systems, we will compare the energy changes in physical events and look at everyday examples of energy in action and the physics involved.

Curriculum

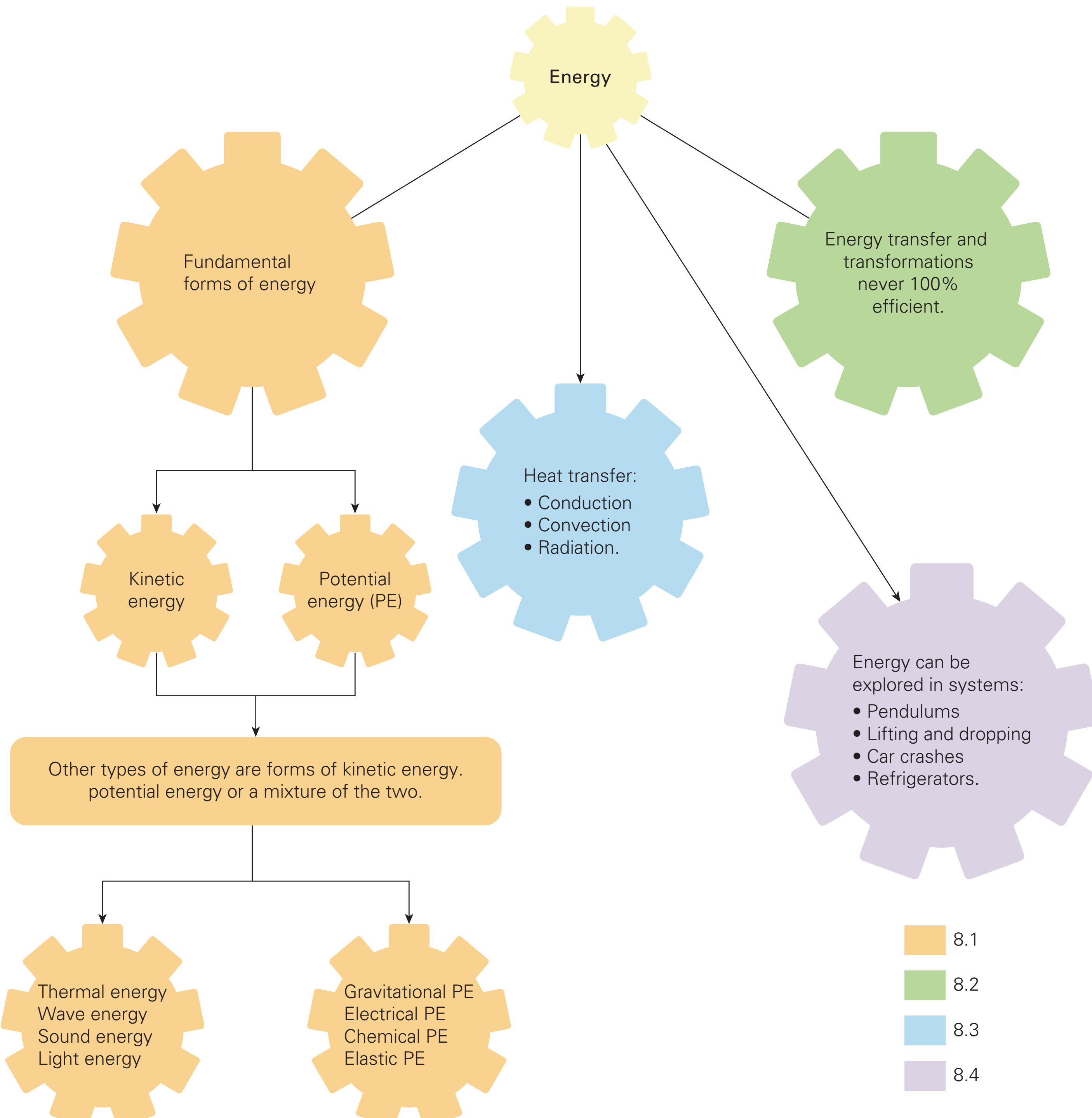
Energy flow in Earth's atmosphere can be explained by the processes of heat transfer (VCSSU132)	
• recognising that the Law of Conservation of Energy explains that total energy is maintained in energy transfers and transformations	8.2, 8.3, 8.4
• recognising that in energy transfers and transformations, a number of steps can occur and the system is not 100% efficient so that usable energy is reduced	8.3
• comparing energy changes in physical events, for example, car crashes, the motion of pendulums, lifting and dropping	8.1, 8.2, 8.3, 8.4

Victorian Curriculum F–10 © VCAA (2016)

Glossary terms

conduction
conductors
convection
efficiency
elastic potential energy
energy
first law of thermodynamics
gravitational potential energy
heat
insulators
kinetic energy
law of conservation of energy
potential energy
radiation
Sankey diagram
system
temperature
thermal energy
thermal equilibrium
thermodynamics
useful energy
work

Concept map



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8.1 Forms of energy

Look at everything happening around you. It does not matter where you are in the world or what you are looking at – everything happening around you, and even within you, is controlled by energy. Often unseen, yet powerful in its nature, what exactly is energy? Let us take a closer look.

What is energy?

Energy is a word that we use every day, usually to describe our ability to move around and be active. Objects can have energy too, and while we cannot always see it, we can easily observe the effects of changes in energy. In physics, **energy** is the capacity to cause change and is defined as the ability to do work. Energy is measured in joules, which has the symbol J, where one joule is the amount of energy transferred when a force of one newton applied to an object causes it to be displaced one metre.

energy
the ability to do work

Work is something that is done on or to an object when an applied force causes the object to move some distance. When you push a box across the floor you are said to have done work on the box.

WORKSHEET

work
the amount of energy transferred when an applied force causes an object to move some distance

Work can be quantified by the equation:

$$W = Fs$$

Where W is work, measured in joules (J); F is the net force acting on the object, measured in newtons (N); and s is the displacement in the direction of the force, measured in metres (m).

For work to be done, the displacement needs to be in the direction of the force. Therefore if a force is applied to an object and it does not move, no work is done.

Figure 8.1 Work is done on a box when a force is applied to it causing it to move some distance in the direction of the force. The larger the applied force or the greater the displacement the more work is done.

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Worked example 8.1

Work

A weightlifter applies a force of 65 N to a barbell and lifts it 1.5 m off the ground. Calculate how much work is done by the weightlifter to lift the barbell.

Figure 8.2 Lifting weights requires work.

Worked solution	
Thinking	**Working**
List the relevant data that has been provided.	$F = 65$ N, $s = 1.5$ m
Recall the definition of work and the equation.	$W = Fs$
Substitute the relevant data into the equation.	$W = 65$ N × 1.5 m
Solve the problem, giving an answer with appropriate units.	$W = 97.5$ J

When a force acts on an object, it causes a change in energy because energy is transferred from other objects or transformed into different forms of energy. For example, the worked example above shows that 97.5 J of work was done, which means that 97.5 J of energy was transferred or transformed. In this example, chemical potential energy in the weightlifter is transformed into the gravitational potential energy stored in the barbell. Chemical potential energy and gravitational potential energy are different forms of energy.

Energy has many different forms. Table 8.1 lists the different forms of energy that you would have learned about in previous years. All of these different forms of energy can be broadly classified as one of either two types of energy: kinetic energy or potential energy.

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Forms of energy	
Potential energy	**Kinetic energy**
Chemical (including food energy and batteries) 	Kinetic (motion) 
Nuclear 	Thermal 
Gravitational 	Radiant (electromagnetic radiation including light) 
Elastic (including springs) 	Electric (current) 
Electric (charge) 	
Mechanical energy	
Mechanical vibrational waves (sound, water waves) 	
Note that mechanical energy is defined as the sum of the Kinetic energy and the Potential energy So sound energy (that is, mechanical vibrational waves passing through an elastic medium) is a combination of kinetic and potential energies.	

Table 8.1 The different forms of energy grouped into the two types of energy – potential and kinetic energy and a mixture of the two.

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WIDGET
Energy conversion flow diagrams

Try this 8.1

Think back to when you ate breakfast this morning and try to identify the forms of energy involved with making and eating your breakfast – you will be surprised at how many there actually are.

Quick check 8.1

1 Explain when work is done on an object.
2 A weightlifter applies an upward force of 100 N to a barbell and in doing so lifts it 1.2 m off the ground, holding it there for 10 seconds before dropping it.
 a Calculate how much work is done by the weightlifter to lift the barbell.
 b Calculate how much work is being done by the weightlifter during the 10 seconds of holding the barbell at 1.2 m above the ground.

Practical 8.1

Jumping paper frogs

Aim

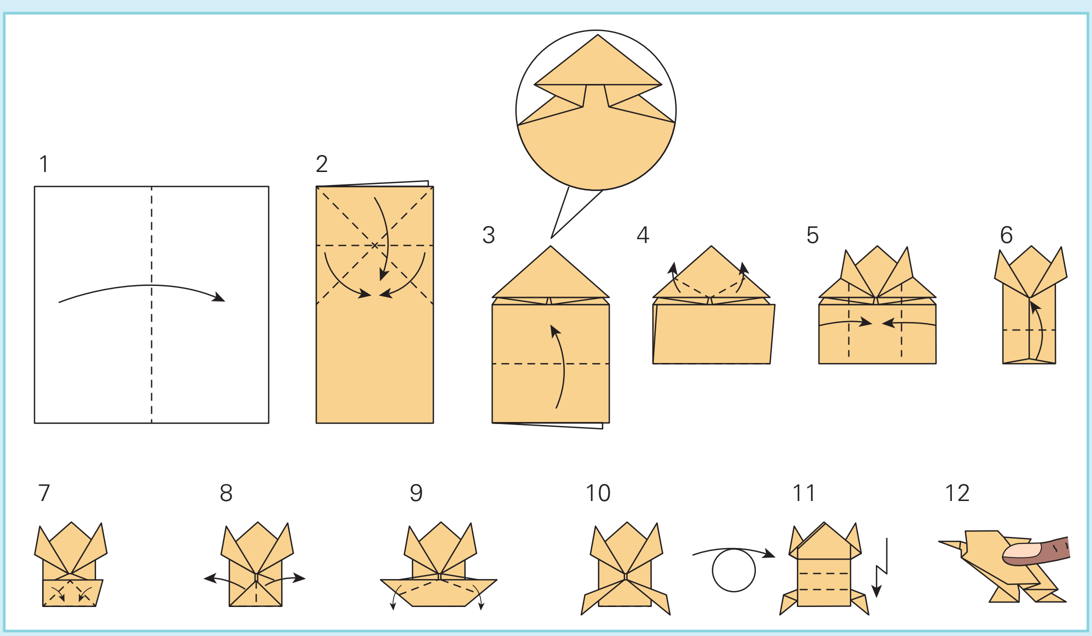
To demonstrate the conversion of elastic potential energy to kinetic energy and gravitational potential energy.

Materials

- cardstock paper squares

Method

1 Copy the results table below.
2 Use the following steps to create your own jumping frog.
3 Press down on your frog to make it jump and record your observations in the table below.



Results

Sense used	Observations
Sight	
Hearing	
Touch	

continued…

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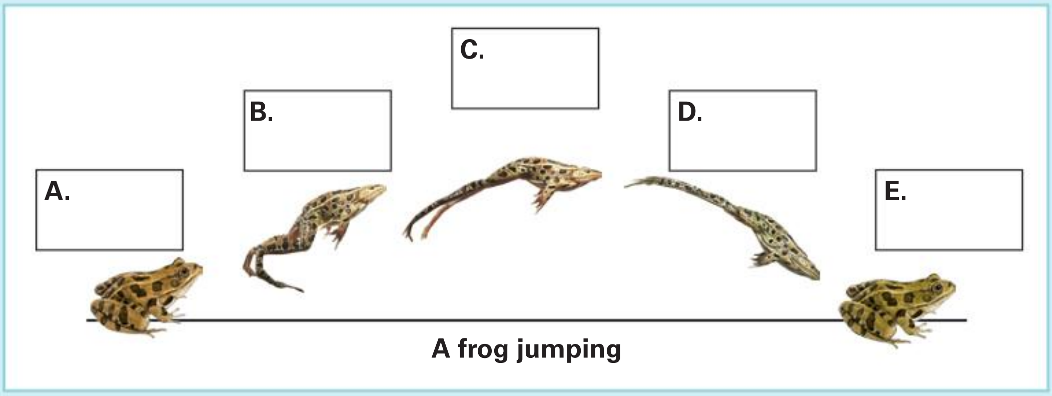
...continued

Evaluation

1 Where does the energy that enables your frog to move come from?
2 Can the amount of energy your frog has be changed to make it jump different heights and distances?
3 Complete the illustration below by indicating the form of energy (kinetic, gravitational potential or elastic potential) possessed by the frog at different stages of its jump.



Conclusion

1 Make a claim about energy conversions based on this activity.
2 Support the statement by using your observations.
3 Explain how your observations support the statement.

Kinetic energy

Kinetic energy is one of the two main types of energy. **Kinetic energy** (K) is the energy an object has due to its motion. When a force is applied to an object that then causes that object to move, work is being done – energy is being transferred. The energy transferred is known as kinetic energy and is possessed by all moving objects. The amount of kinetic energy that an object has depends on its mass and its speed. Thus, the faster an object moves the more kinetic energy it has.

kinetic energy energy possessed by an object due to its motion

Figure 8.3 All objects in motion have kinetic energy. The amount of kinetic energy depends on how fast it is moving as well as its mass.

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To calculate how much kinetic energy an object has, we use the following equation:

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

Here K is kinetic energy, measured in joules (J); m is the mass of the object in motion, measured in kilograms (kg); and v is the speed at which the object is moving, measured in metres per second (m/s or ms^{-1}).

This equation shows that an increase in speed has a more significant effect on the amount of kinetic energy than the same increase in mass. If the mass doubles, kinetic energy doubles as well, but if the speed doubles, the amount of kinetic energy increases by a factor of four. This is because speed is squared in the equation.

Worked example 8.2

Kinetic energy

A motorcycle has a mass of 120 kg and is travelling at 150 km/h. How much kinetic energy does the motorcycle have?

Figure 8.4 A motorcycle in motion possesses kinetic energy.

Worked solution	
Thinking	**Working**
List the relevant data that has been provided.	m = 120 kg, v = 150 km/h
Convert units to the SI base units (Standard International units) used in the equation.	150 km/h ÷ 3.6 v = 41.67 m/s
Recall the definition of kinetic energy and the equation.	$K = \frac{1}{2} m \times v^2$
Substitute the relevant data into the equation.	$K = \frac{1}{2}$ (120 kg) × (41.67 m/s)^2
Solve the problem, giving an answer with appropriate units.	K = 104 183.33 J = 104.18 kJ

Quick check 8.2

1 Identify two factors that affect the amount of kinetic energy an object has and summarise how they affect kinetic energy.

2 A cricket player bowls a 160 g cricket ball at a speed of 150 km/h. Calculate how much kinetic energy is transferred to the ball.

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Figure 8.5 Forms of energy do not exist in isolation: a man moving through the air high above the ground has both kinetic and gravitational potential energy, while a man standing on top of a mountain has more gravitational potential energy and less kinetic energy compared to the other man. Both men still have chemical energy and thermal energy, however they aren't as relevant in this example.

Potential energy

We now know that the man flying through the air in Figure 8.5 has kinetic energy as he is in motion. We even know that the amount of kinetic energy he has depends on his mass and speed. But what do we know about the man standing on top of the mountain?

The observer standing on top of the mountain has stored energy due to his position high above the surface of Earth. This type of energy is called gravitational potential energy. **Potential energy** is energy that is stored in an object or person due to its composition or position.

potential energy
energy that is stored in an object due to its position and other factors, such as its mass, electric charge, and internal stresses

Gravitational potential energy

Gravitational potential energy is an example of stored energy due to an object's position. Specifically, **gravitational potential energy** is the energy stored in an object due to its position above the surface of Earth. Similar to the observer standing on top of the mountain, anything that is positioned above the surface of Earth has the potential to fall due to the effect of gravity. Therefore, the higher an object is above the surface of Earth, the more gravitational potential energy it has.

gravitational potential energy
energy stored in an object due to its position above the surface of Earth

Figure 8.6 As you ride on a rollercoaster the amount of gravitational potential energy that you have is constantly changing, as is your kinetic energy.

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To calculate how much gravitational potential energy an object has, we use the following equation:

$$U_g = m \times g \times h$$

Where U_g is the gravitational potential energy (also represented as *GPE*), measured in joules (J); *m* is the mass of the object, measured in kilograms (kg); *g* is the gravitational acceleration experienced by the object due to the strength of the Earth's gravitational field, measured in metres per second per second (m/s^2 or ms^{-2}) and on Earth has a value of 9.8 m/s^2; *h* is the height of the object above the surface of Earth, measured in metres (m).

From this equation, we can see that the amount of gravitational potential energy an object has depends on its mass and height above the ground. This makes sense because work must be done on an object for it to have this stored energy, and that work requires a force (as you will remember, force (*F*) equals mass (*m*) × acceleration, so in this case $F = mg$) to move the object some distance (height). As a force has moved an object some distance, work has been done, and we can see that the amount of work is equal to the potential energy of the object, where $W = \Delta U_g$. Note that Δ means the change, so ΔU_g means the change in gravitational potential energy.

Worked example 8.3

Gravitational potential energy

A diver on the diving board has a mass of 60 kg.

a If the diving board is 10 m above the ground, what is the diver's gravitational potential energy?

b When the diver is 0 m above the ground, what is his gravitational potential energy?

c What does this mean in terms of work done $W = \Delta U_g$ if the diver wants to go from 0 m back to 10 m above the ground?

Figure 8.7 A diver waiting to dive has gravitational potential energy due to his position relative to Earth's surface.

a

Worked solution	
Thinking	**Working**
List the relevant data that has been provided.	m = 60 kg, h = 10 m, g = 9.8 m/s^2
Recall the definition of gravitational potential energy and the equation.	$U_g = m \times g \times h$
Substitute the relevant data into the equation.	U_g = 60 kg × 9.8 m/s^2 × 10 m
Solve the problem, giving an answer with appropriate units.	U_g = 5880 J = 5.88 kJ

b At h = 0 m, the gravitational potential energy is 0 J.

c This means that if he wants to climb back up from the ground to a height of 10 m, there will have to be work done of 5.88 kJ as that is the difference in gravitational potential energy, ΔU_g.

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Engine-less planes?!

Explore! 8.1

Figure 8.8 A glider is an aircraft that does not have an engine yet can stay airborne for hours at a time.

In a powered aircraft, the energy required to give sufficient lift to oppose the weight of the plane and achieve lift-off is provided by the thrust force produced by the engine. The thrust force also opposes the drag during the flight, so the plane can maintain its altitude for a long time. A glider, on the other hand, is a special kind of aircraft that has no engine. In order for a glider to fly, it must generate enough lift to oppose its weight (force due to gravitational acceleration). As the glider moves through the air, it also generates drag due to air resistance. If a glider has no engine, it cannot produce the thrust required to overcome the effects of air resistance and gravity. How then are gliders able to stay aloft for hours at a time? Research gliders to answer the following questions:

1. How do gliders gain potential energy?
2. How does a glider generate the velocity needed for flight?
3. Explain how some gliders can stay aloft for hours despite their constant descent.

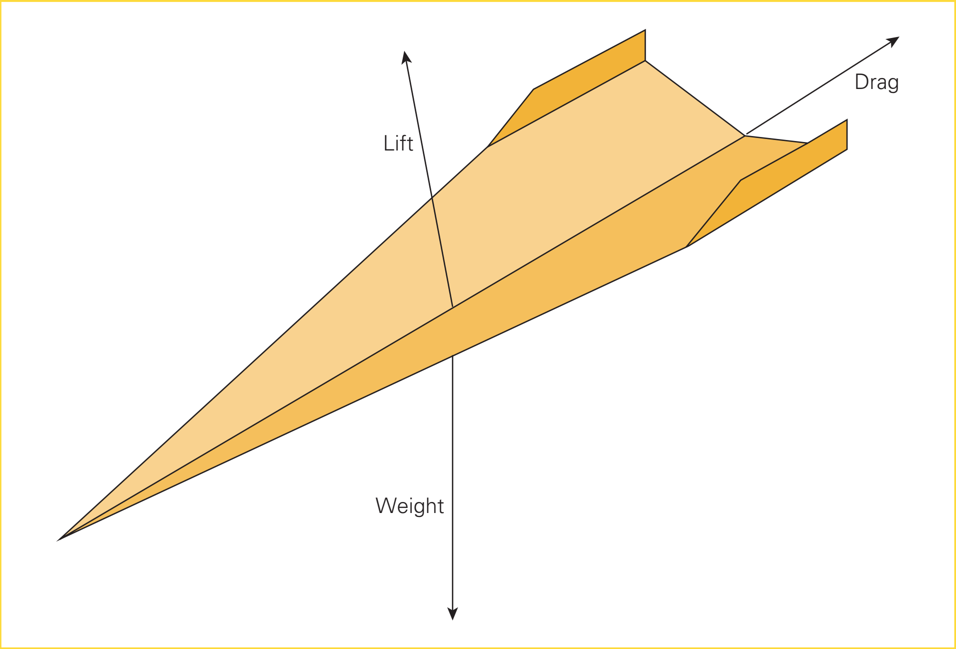

Figure 8.9 The three forces acting on a glider. A glider needs to have enough lift to overcome the weight of the aircraft. As drag is unopposed, the aircraft will eventually slow down if it cannot generate the velocity needed to keep it in motion.

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Practical 8.2

Falling from a height

Be careful
Loose ball bearings can be a slip hazard.

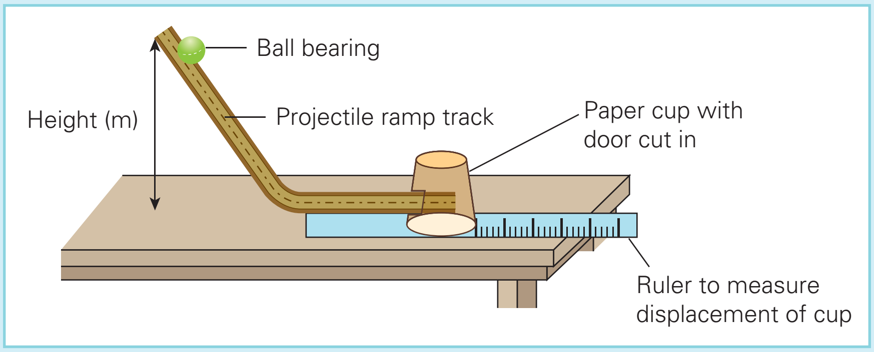
Aim

To investigate the effect that height has on the energy of a falling object.

Materials

- projectile ramp
- ball bearings
- paper cup
- scissors
- ruler
- balance

Method



1. State your hypothesis.
2. Copy the results table below.
3. Cut a square section out from the side of your cup larger than the diameter of your ball bearing.
4. Measure the mass of the paper cup in kilograms using a scale and record in the table below.
5. Set equipment up as shown in the diagram above, ensuring that the cup is placed at the end of the ramp and the ball bearing in the groove of the projectile ramp's track.
6. Select an initial release height, and record it in the results table in metres.
7. Place ball bearing at the selected height and release.
8. Measure the displacement of the cup using a ruler and record in metres in the results table.
9. Repeat steps **7–8** two more times, recording data in the results table.
10. Repeat steps **6–9** for two additional heights.
11. Calculate the average displacements for each release height and record in the results table.
12. Calculate the gravitational potential energy of the ball bearing and record your results in joule in the results table.
13. Calculate the work done on the cup to displace it and record your results in joule in the results table.

Results

Release height (m)	Mass of the paper cup (kg)	Distance the cup was displaced (m)				Gravitational potential energy of ball bearing (J)	Work done to displace cup (J)
		Trial 1	Trial 2	Trial 3	Avg	$GPE = m \times g \times h$	$W = F \times s$

Evaluation

1. What happens to the cup when it is struck by the ball bearing?
2. How does the displacement of the cup change when the release height is increased?
3. Explain why the release height affects the displacement of the cup. Ensure that you use the following terms in your answer: gravitational potential energy, force on cup, work done to displace cup.

Conclusion

1. Make a claim about height and energy based on this experiment.
2. Support the statement by using the data you gathered and include potential sources of error.
3. Explain how your data support the statement.

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Elastic potential energy

Just as an object can have stored energy due to its position, it can also have stored energy due to its shape. **Elastic potential energy** is the energy stored in an object due to its shape, and usually results from the object either being compressed or stretched. When stretched or compressed, some materials store more energy than others.

elastic potential energy
energy stored in an object due to its shape, usually resulting from the object either being compressed or stretched

To calculate the amount of elastic potential energy an object has, we use this formula:

$$U_E = \tfrac{1}{2}\, k \times x^2$$

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

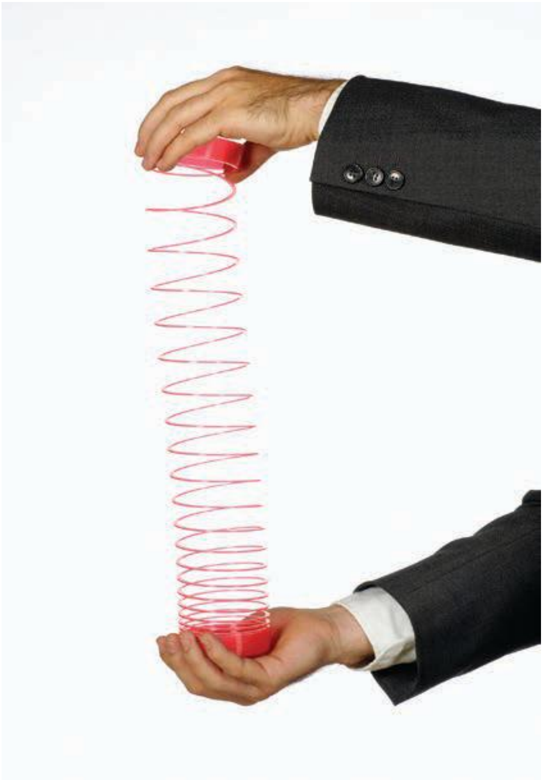

Figure 8.10 A stretched slinky has elastic potential energy. When released the slinky will return to its original position.

This equation shows us that the amount of elastic potential energy possessed by an object depends on the elasticity of the material as well as the displacement of the material due to compression or stretching. Again, some force (F) is is needed to stretch or compress the material and there is a displacement (s), thus work is being done. The amount of work is equal to the elastic potential energy where $W = \Delta U_E$.

Worked example 8.4

Elastic potential energy

A bow has an elasticity constant of 2000 N/m. It is stretched by 30 cm. How much elastic potential energy does the bow store?

Worked solution	
Thinking	**Working**
List the relevant data that has been provided.	$k = 2000$ N/m, $\Delta x = 0.30$ m
Recall the definition of elastic potential energy and the equation.	$U_E = \tfrac{1}{2}\, k \times \Delta x^2$
Substitute the relevant data into the equation.	$U_E = \tfrac{1}{2}\,(2000\ \text{N/m}) \times (0.30\ \text{m})^2$
Solve the problem, giving an answer with appropriate units.	$U_E = 90$ J

Figure 8.11 A stretched bow stores elastic potential energy.

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Try this 8.2

Recreate this 'fidget spinner' from the 1980s in four simple steps.

1 Find a button with a diameter of at least 5 cm (a piece of cardboard with two small holes about 1 cm apart will do too).

2 Thread about 60–80 cm of string through two of the holes in the button and tie it off, forming a loop like the one shown in Figure 8.12.

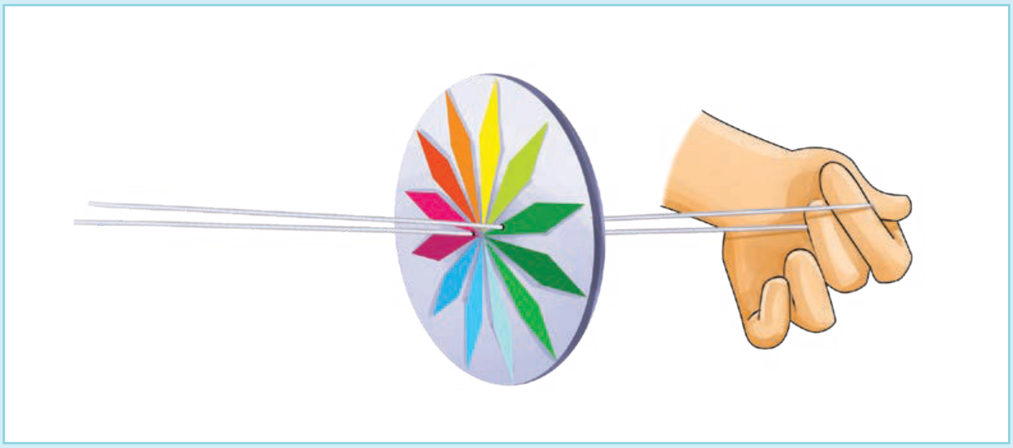

Figure 8.12 A paper spinner or 'woer woer' is a toy from the 1980s that uses elastic potential energy to create motion and sound.

3 Wind up your spinner by holding onto the strings and positioning the button in the middle. Then, using your wrists, swing the button in a vertical loop.

4 Release the potential energy with alternating high and low tensions in the string (created by moving your hands closer and pulling them further away from each other).

Quick check 8.3

1 Describe what word the 'potential' in potential energy means?

2 Other than gravitational and elastic, classify two other forms of potential energy and give an example of each.

3 A gymnast on a balance beam has a weight of 500 N. If the beam is 1.25 m above the ground, calculate her gravitational potential energy?

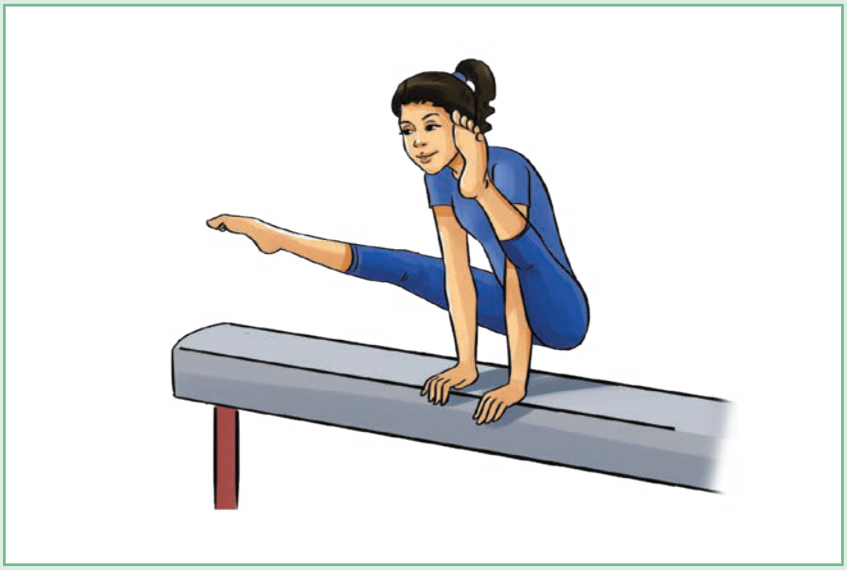

Figure 8.13 What is the gravitational potential energy of a gymnast?

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Section 8.1 questions

QUIZ

Remembering

1 Define energy.
2 Describe what kinetic energy is.
3 List three everyday objects that have elastic potential energy.

Understanding

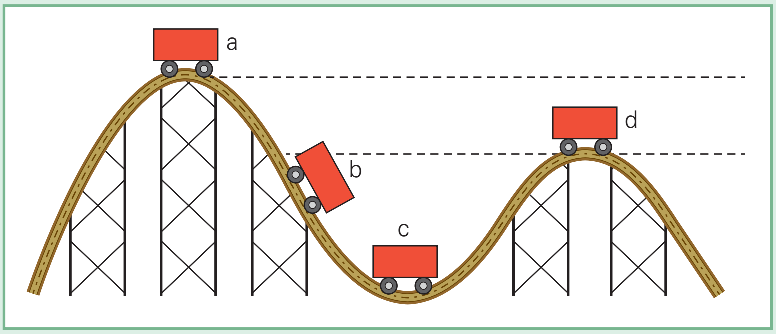
4 Classify the following as either possessing kinetic energy or potential energy:
  a the moving (or spinning) blades in a blender
  b books sitting in a bookshelf
  c hot water in a kettle
  d the sound coming from a radio
  e a cheeseburger.
5 Compare gravitational and elastic potential energy.

Applying

6 Calculate the displacement of a tennis ball hit with a constant force of 333 N by a tennis player who does 100 J of work doing so.
7 Demonstrate how work done relates to lifting an object against gravity using the formula $W = \Delta U_g$

Analysing

8 Outline the energy changes in the roller coaster below at points a, b, c and d.



9 Arrange the following items from having the most to the least amount of gravitational energy:
  a an apple hanging in a tall tree
  b an apple lying under a tree
  c an apple in a fruit bowl on a table.

Evaluating

10 Support the statement: 'The temperature of an object is directly related to the average kinetic energy of the group of molecules that make up that object'.
11 In the case of a person pushing against a rock wall, justify why no work is being done.

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8.2 Thermal energy

WORKSHEET

Have you ever gone to the beach on a really hot day to cool off and soon realised that you can't walk barefoot on the sand without running to the nearest patch of shade or water for some relief? On a hot day the temperature of sand that has been baking in the Sun can get so hot that it can burn your feet and cause painful blisters. How does the energy from the Sun heat the sand and cause its temperature to rise? What is **thermal energy** and what are we exactly measuring when we measure the temperature?

thermal energy
the total kinetic energy of all of the atoms that make up an object or system

Thermal energy is best understood when revisiting the particle model and understanding that the atoms that make up all matter are in constant random motion. All of that motion, which is in fact kinetic energy, gives an object its thermal energy. Thus, thermal energy is defined as the total kinetic energy of all of the atoms that make up an object or system. It is the energy contained within a system that is responsible for its temperature. The total amount of thermal energy that an object or system has depends on how fast the atoms are moving as well as on the number of atoms in that object or system. This means that an object with more atoms, thus more mass, will have a greater amount of thermal energy than another object whose atoms are moving at the same speed.

Figure 8.14 A young girl runs along the bathing boxes of the Mornington Peninsula, Victoria. Running can help feet from getting too hot on hot sand.

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Figure 8.15 The atoms in both the slice of quiche as well as the whole quiche are moving at the same speed, but as there are more atoms in the whole quiche, it has a higher thermal energy.

As you could work out from the example in Figure 8.15, the amount of random motion (and thus kinetic energy) that the atoms have determines the temperature of the quiches. Thermal energy results in an object, or a system, having a temperature that can be measured.

What is temperature?

Temperature is used daily to describe how hot or cold something is. We could try to define temperature as a measure of how hot or cold something is, but the concept of temperature in physics is a rather complicated one. For example, a metal tap feels colder than a wooden board despite them both being at room temperature. This is because metal is better at conducting heat away from the skin.

Try this 8.3

Take three large containers and fill one with room temperature water, one with warm (be careful that it is not too hot) water and the last one with cold fridge water. Place one hand in the cold water and the other in the warm water for two minutes. Take your hands out of the warm and cold containers and place both of them in the room temperature water. How does the water feel?

Something to think about:

1 Why did you leave your hands in the warm and cold waters for two minutes?
2 Why, when you put your hands into the room temperature water, do your hands detect different temperatures?

In physics we define **temperature** as a measure of the average kinetic energy of the particles that make up an object or system. Temperature is usually measured with a thermometer and shows how hot or cold something is. Three scales are commonly used to measure and describe temperature.

temperature the average kinetic energy of the particles that make up an object or system

In Australia we use the Celsius scale (°C), which was constructed relative to the freezing and boiling points of water at sea level. On the Celsius scale, the freezing point of pure water is 0°C and the boiling point of pure water is 100°C.

Figure 8.16 A metal tap feels colder than a wooden board, despite them both being the same temperature.

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The Kelvin scale (K), is a second scale that is used in physics as it is based around the movement or vibrations of the particles that make up an object or a system. According to the Kelvin scale, all particles stop moving, and no longer vibrate, at 0 K. This point is also known as absolute zero, and is equivalent to -273.15°C. This is a hypothetical value as it is impossible to reach, although scientist have come relatively close, reaching temperatures of less than a billionth of a Kelvin.

A third scale, Fahrenheit (°F), is commonly used in the United States but is not used in science.

Did you know? 8.1

Kelvin vs Celsius

The Kelvin scale defines zero as absolute zero, which means that zero on the Celsius scale (0°C) is now defined as the equivalent to 273.15 K, with a temperature difference of 1 degree Celsius equivalent to a difference of 1 K (the unit size in each scale is the same). This means that the boiling point of water, previously defined as 100°C, can now be defined as the equivalent to 373.15 K.

Explore! 8.2

How do thermometers work?

A thermometer is device that is designed and calibrated to measure the temperature. Common household thermometers consist of a thin glass tube sealed at both ends that is partially filled with a liquid, usually a red-coloured alcohol.

A thermometer functions because of the expansion and contraction of liquids at different temperatures, so the liquid rises and falls as the temperature changes. When thermal energy is transferred to the liquid in the thermometer (when in contact with a hotter substance), the particles of the liquid gain kinetic energy so the particles move and vibrate more rapidly, taking up a larger volume. As the glass tube is sealed, the expanding liquid has nowhere to go but up. Similarly, when thermal energy is transferred away from the liquid in the thermometer (when placed in a colder substance) the amount of kinetic energy possessed by the particles decreases, so the liquid contracts and lowers on the calibrated scale.

Calibration of a thermometer involves using two objects of known temperatures as reference points – usually the freezing point of pure water (0°C) and the boiling point of pure water at an atmospheric pressure of one atmosphere (100°C).

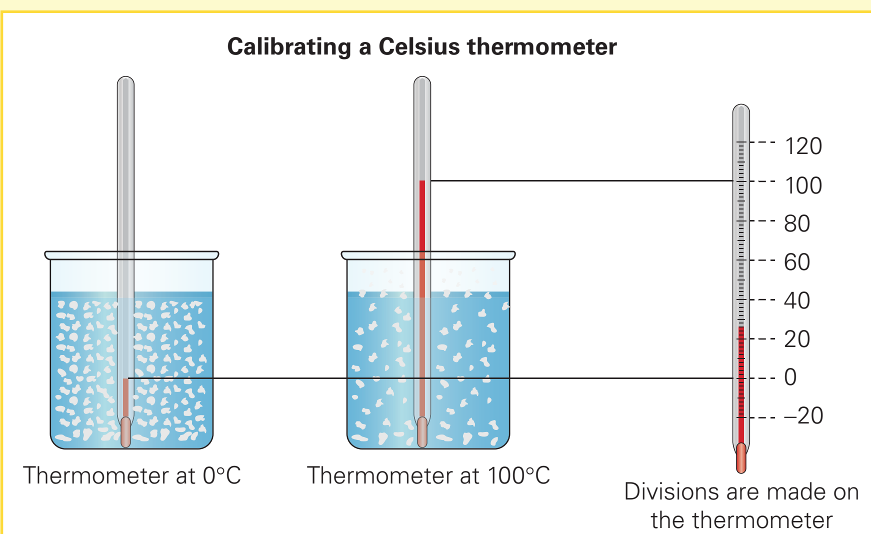

Figure 8.17 Calibration of a Celsius thermometer involves using two known temperature points.

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...continued

1 Explain, using the particle model, why the liquid expands and contracts when the temperature changes.
2 Older thermometers used mercury instead of alcohol. Research why mercury is no longer used.
3 A dial thermometer is a device that also relies on expansion and contraction of a substance to measure temperature. Use resources to research the mechanisms involved in the functioning of a dial meat thermometer as shown in the image.

Figure 8.18 Not cooked yet – a dial meat thermometer being used to ensure the chicken is cooked properly

In everyday language we use temperature and heat interchangeably, but in physics these terms have two different meanings. While temperature refers to the average kinetic energy of the particles that make up an object or system, **heat** refers to the thermal energy that is transferred between objects or systems due to a temperature difference. This transferred energy causes the particles in that object or system to vibrate faster, with more kinetic energy, and thus increasing the temperature.

heat
thermal energy that is transferred between objects or systems due to a temperature difference

Quick check 8.4

1 Compare the terms 'temperature' and 'heat'.
2 Construct a temperature scale showing the boiling and freezing points of water in degrees Celsius and Kelvin.

Practical 8.3

Making a thermometer

Note that you may have come across a similar practical in Year 8.

Aim

To demonstrate the effect of thermal energy on the liquid in a thermometer.

Materials

- round-bottom flask with a rubber stopper
- glass tubing
- food colouring
- Blu-Tack, moulding clay (or any material to make your thermometer airtight)
- permanent marker

Method

1 Write a suitable hypothesis.
2 Carefully bore a hole into the middle of the rubber stopper (large enough for the glass tubing to fit through).
3 Thread the glass tubing through the lid and seal where the tubing goes through the lid with Blu-Tack (or other material) to make it airtight.
4 Fill your container to the brim with water, adding a few drops of food colouring.

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...continued

5 Secure the stopper in place and seal the joins to make it airtight.
6 Using a dropper, add coloured water into the glass tubing to a level 5 cm above the container.
7 Mark the level of the water with a marker – this will be your room temperature reference temperature.
8 Hold the flask in your hands to warm up the water in the flask.
9 Record your observations.
10 Try cooling the water in the flask down by placing the flask in an ice bath.
11 Record your observations.

Results

Record your observations when the flask was heated and cooled.

Evaluation

1 Explain, using the particle model, why the water level in the glass tubing rises when the water in the flask is heated.
2 Compare your thermometer to a real thermometer.

Conclusion

1 Make a claim about liquid thermometers and heat based on this experiment.
2 Support the statement by using your observations and include potential sources of uncertainties in your measurement.
3 Explain how your observations support the statement.

Thermodynamics

Figure 8.19 An incandescent light globe that has been burning for some time is hot to the touch. This can be explained by thermodynamics.

Thermodynamics is the branch of physics that studies the effects of heat, energy and work on a system. You, like all living things, are an open system – that means you are constantly exchanging both matter and energy with your environment. It is this exchange of energy that would burn your hand if you tried to touch a burning light globe. Exchanges of energy like this, and all those that take place around you, can be described using the laws of thermodynamics.

thermodynamics the branch of physics that relates to the transfer and transformation of energy; in particular, thermal energy

Two bodies are said to be in **thermal equilibrium** if they are at the same temperature. When objects are in thermal equilibrium, there is no net transfer in thermal energy between them.

thermal equilibrium describes two bodies that are at the same temperature; and therefore, have no net thermal energy transfer

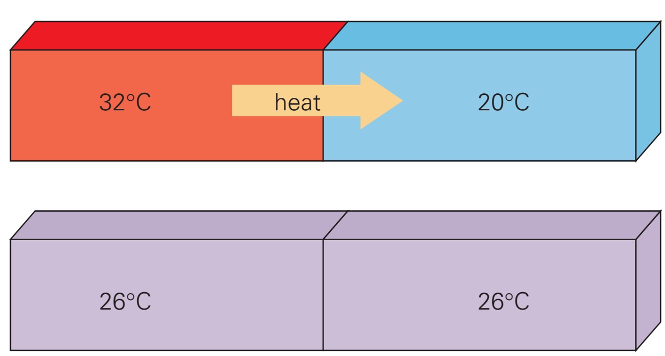

Figure 8.20 The top system (red and blue blocks) is not in thermal equilibrium while the bottom system (purple blocks) is in thermal equilibrium.

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The red and blue blocks in Figure 8.20 are not in thermal equilibrium because the red block has a higher temperature than the blue block. This results in a net movement (or transfer) of thermal energy from the object with a higher temperature to that of a lower temperature until thermal equilibrium is reached. The purple blocks are in thermal equilibrium as they are the same temperature. Thus, there is no net movement of thermal energy between them.

first law of thermodynamics thermal energy cannot be created or destroyed; it can only be transformed into other forms of energy or transferred to other objects

The **first law of thermodynamics** states that energy cannot be created or destroyed; it can only be transformed into other forms or transferred to other objects. Thus, it supports the notion of energy being transferred between objects. You would know this as the **law of conservation of energy**, which explains that the total amount of energy in an isolated system is constant. The hot light globe in Figure 8.19 must get its thermal energy from somewhere – and it does! Electrical energy is converted into thermal and light energy. This results in the glass bulb heating up, and transferring its thermal energy to your hand when you touch it. Thermal energy can move from one place to another in three different ways of heat transfer: conduction, convection and radiation.

law of conservation of energy energy cannot be created or destroyed; it can only be transformed into other forms or transferred to other objects

The Mpemba effect

Did you know? 8.2

Figure 8.21 The Mpemba effect in action. Hot water freezes instantly when exposed to below freezing conditions.

Named after Tanzanian Erasto Mpemba who, in 1963, while making ice-cream at school (in Year 9), observed that a hot custard mixture froze faster than a cold custard mixture.

The Mpemba effect is the phenomenon that warm water sometimes freezes more quickly than cold water. This counterintuitive effect has been observed and measured on many (but not all) occasions but scientists are still putting forward theories as to why and when it happens. While some theories have some merit, none are entirely convincing.

This effect has been the topic of scientific argument for 50 years, yet we are still unable to properly prove or explain it.

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Science as a human endeavour 8.1

The power of evaporation

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

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

Figure 8.22 Evaporation from lakes and oceans is an untapped energy source that could be the solution to our inconsistent power supply.

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

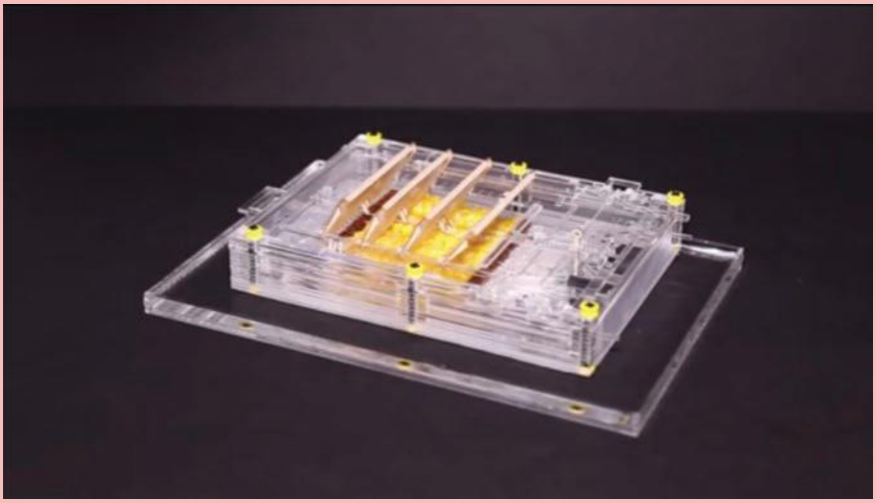

Figure 8.23 The evaporation engine floats on the surface of water and creates a piston-like back and forth movement as the water evaporates from the surface.

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

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

Quick check 8.5

1 Explain why there is no net transfer of heat when two bodies are at the same temperature.
2 Construct a flow diagram to show the energy changes in a lit light globe. Account for the law of conservation of energy in your answer.

Heat transfer

Sitting around a campfire, you can feel the warmth of the flames from a distance, and you do not need to touch the flames. How is this heat transferred to your hands?

Heat transfer is the movement of heat from an object of higher temperature to an object of lower temperature. The rate of heat transfer is faster when there is a larger temperature

Figure 8.24 Keeping warm around a campfire and roasting marshmallows require the transfer of heat.

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difference between the two objects. As thermal energy is transferred to an object with lower temperature (heat transfer), the particles within that object vibrate faster as they have more kinetic energy, which increases the object's temperature.

Three types of heat transfer are occurring simultaneously in Figure 8.24. As you sit around the campfire you feel an intense warmth on your skin – radiation. You also notice that the air around the fire is warm, and it gets warmer the longer you sit near the fire – convection is when the warm air moves, carrying thermal energy with it. Finally, when roasting your marshmallow over the flames you notice that heat is travelling down the metal fork which is starting to feel warm in your hands – conduction. What exactly are these types of heat transfer? Let us take a closer look.

VIDEO Conduction

Conduction

conduction transfer of thermal energy through a substance, or between substances, as a result of collisions between particles

Conduction is the transfer of thermal energy through a substance, or between substances, as a result of the collisions between particles. Heat is able to travel by conduction when particles with a large amount of thermal energy (so are vibrating rapidly) pass on that energy as vibrations to adjacent particles, causing them to gain thermal energy and vibrate faster. This can only happen if there is a temperature gradient, and it will continue to happen as long as there is a temperature gradient and contact between particles.

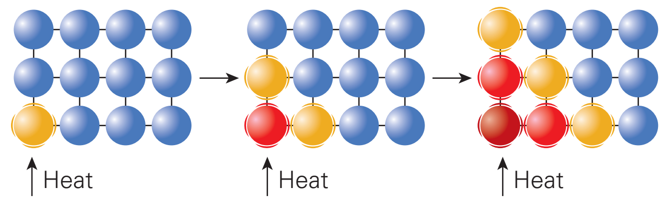

Figure 8.25 Heat transfer by conduction occurs when a particle with high thermal energy (and thus vibrating rapidly) transfers that thermal energy to adjacent particles.

Materials that are able to transfer heat easily via conduction are called **conductors**. Liquids and solids are usually better conductors of heat than are gases. This is because the particles of liquids and solids are more densely packed, which allows more collisions and thus more energy transfer. Gases are very poor conductors of heat as the particles in gases are far apart, so the probability of collisions and hence energy transfer is low. Materials that are poor conductors of heat are called **insulators**.

conductors materials that can transfer heat via conduction

insulators materials that are poor conductors of heat

Radiators keep cars cool

Explore! 8.3

In our homes, radiators radiate heat, keeping us warm. In cars, however, radiators are used to cool the engine and are thus part of the car's cooling system. Research how radiators in cars work to answer these questions.

1 Water runs through a long tube inside a car radiator. How does the temperature of the water change as it runs through the radiator?
2 What is the purpose of the aluminium fins in a car radiator? Why are the fins made of aluminium?
3 What method of heat transfer cools the water and heats up the radiator as the water flows through it?

Figure 8.26 Radiators prevent car engines from overheating.

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Practical 8.4

Heat transfer by conduction

Be careful

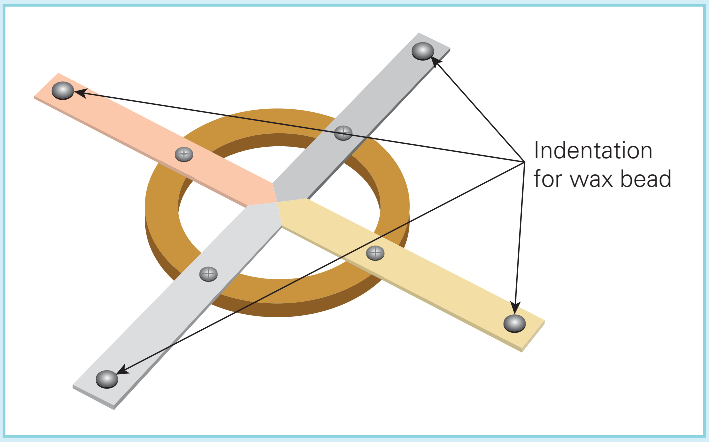
Ensure all equipment is properly cooled before handling.

Aim

To determine which material is the better conductor of thermal energy.

Materials

- conduction ring
- Bunsen burner
- heat mat
- retort stand
- boss head and clamp
- 4 wax beads
- stopwatch
- matches



Method

1. Write a hypothesis.
2. Copy the results table below.
3. Set up the Bunsen burner on top of the heat mat.
4. Place one wax bead into the small indentation at the end of each arm.
5. Set up the conduction ring using the retort stand, boss head and clamp to suspend the centre over the Bunsen burner.
6. Light the Bunsen burner and place it directly beneath the centre of the conduction ring so the flame is in contact with all the metal arms.
7. Time how long it takes for the wax at the end of the arms to melt. Record your results in the results table.

Results

	Material	Time for wax to melt (s)
Arm 1		
Arm 2		
Arm 3		
Arm 4		

Evaluation

1. Identify which arm melted the wax first.
2. State which arm melted the wax the slowest.
3. Which material was the best conductor? Give a possible explanation as to why this arm was the best conductor.
4. Using the particle model, explain why metals are good conductors of thermal energy.

Conclusion

1. Make a claim about materials and conductance based on this experiment.
2. Support the statement by using the data you gathered and include potential sources of uncertainty in your measurements.
3. Explain how the data support the statement.

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Convection

convection transfer of thermal energy due to the movement of particles in a fluid

VIDEO Convection

A second method of heat transfer is **convection**, which occurs in gases and liquids where the particles are free to move. Convection is the transfer of thermal energy due to the movement of particles in a fluid. Particles transfer energy by moving from areas of higher temperature to those of lower temperature. In Figure 8.27, the air conditioning system produces cold air, in which the particles are more tightly packed and thus more dense than in hot air. Due to the density difference, the cold air sinks and displaces the hot air. As the cold air sinks to the bottom, the only place for the hot air to go is up. The sinking cold air and rising hot air produced are examples of convection currents.

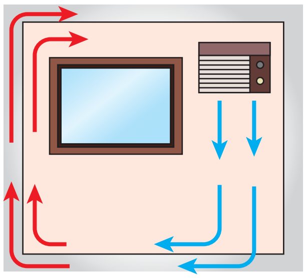

Figure 8.27 Convection currents in an air-conditioned room occur as the result of a difference in the amount of thermal energy (and thus density) of hot and cold air.

Practical 8.5

Convection in liquids

Be careful

Do not dispose of the potassium permanganate. All materials are to be collected to be disposed of safely.

Aim

To observe convection currents in a beaker of water.

Materials

- 500 ml beaker
- Bunsen burner
- heat mat
- tripod
- potassium permanganate (alternative: tea leaves)
- a thick straw
- forceps
- cold water
- gauze mat

Method

1. Copy the results table on the next page.
2. Set up the Bunsen burner and tripod on top of the heat mat.
3. Pour 400 mL of cold water into the beaker and place onto the gauze mat on top of the tripod stand.
4. Place the straw into the cold water, flush with the base close to the wall of the beaker. Using the forceps, drop a single potassium permanganate crystal down the straw into the water.
5. Carefully remove the straw without disturbing the water in the beaker.
6. Record your observations.
7. Place the Bunsen burner to one side of the beaker and light it.
8. Record your observations.

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Results

	Observations
Beaker before heat	
Beaker after heat	

Evaluation

1 Sketch and label the movement of the coloured water.
2 Use your understanding of convection currents to explain the motion of the water as it was heated.
3 Summarise the relationship between the temperature of a fluid and its density.

Conclusion

1 Make a claim about convection currents based on this experiment.
2 Support the statement by using your observations and include potential sources of faults with the experiment.
3 Explain how your observations support the statement.

Radiation

Some energy transfer methods do not require particles to facilitate the transfer of energy. **Radiation** is the transfer of thermal energy without the presence of particles of matter. An example of radiation is electromagnetic radiation (EMR), where energy is transferred via the propagation of electric and magnetic waves through space. All objects that possess thermal energy emit infrared radiation, which is invisible to the human eye but can be felt as warmth on your skin.

radiation
transfer of thermal energy without the presence of particles of matter

Figure 8.28 A thermal image of a person training on a stationary bicycle. Notice how hot their body temperature is (indicated in red), as well as how the heat is being transferred from the body to the surrounding air particles (indicated in green).

VIDEO
Radiation

Did you know? 8.3

Parker Solar Probe

NASA has launched a historic mission to the Sun. The Parker Solar Probe will travel through the Sun's atmosphere, closer to the surface of the Sun than any space probe has been before. The close proximity to the surface of the Sun means that the Parker Solar Probe will be subject to extremely hazardous conditions, particularly the solar radiation. The purpose of the mission is to better understand how energy and thermal energy move through the Sun's corona.

Read more about this NASA mission online, on the NASA website.

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Quick check 8.6

1 Explain the following:
   a Saucepans are made with copper bottoms.
   b The bottoms of saucepans are made as flat as possible.
   c The handles of saucepans are made of plastic or wood.
2 Describe how thermal energy from the Sun is transferred to Earth.
3 Illustrate with a diagram how heat is transferred by conduction.

Practical 8.6

Heat transfer by radiation

Aim

To investigate the effect of colour on the rate of heat transfer via radiation.

Materials

- 3 soft drink cans (one painted matte black, one painted matte white and one covered in foil)
- 3 thermometers or data loggers with a thermometer probe
- cold water
- funnel
- measuring cylinder
- retort stand
- boss head and clamp

Method

1 Write a hypothesis.
2 Copy the results table below.
3 Pour 100 mL of cold water into each can using a measuring cylinder and funnel.
4 Place a thermometer into each can. Use the retort stand, boss head and clamp to suspend the thermometer so that it does not touch the base of the can.
5 Record the initial temperature of the water in each can in °C in the results table.
6 Place the cans in the Sun or other warm location. Otherwise, a heat lamp or radiant electric heater could be used.
7 Measure the temperature with the thermometer every 5 minutes for the next 30 minutes and record results in the results table.

Results

	Temperature (°C)		
Time (min)	**Black can**	**White can**	**Foil can**
0			
5			
10			
15			
20			
25			
30			

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Evaluation

1 Using graph paper, draw a line graph to display your results.
2 Which can of water had the highest final temperature?
3 Based on the results of this experiment, what colours of clothing should people wear to stay warm in winter and cool in summer?

Conclusion

1 Make a claim about colour and heat transfer based on this experiment.
2 Support the statement by using the data you collected and include potential experimental faults.
3 Explain how the data supports the statement.

Section 8.2 questions

QUIZ

Remembering

1 Define thermal energy.
2 List the conditions required for conduction to occur.
3 State the law of conservation of energy.
4 Recall what thermodynamics is.

Understanding

5 Explain how an object with a higher temperature can have less thermal energy than an object that has a lower temperature.
6 Outline when thermal energy will no longer be transferred between two substances in contact.
7 Explain why a lake freezes at the top first, rather than throughout or at the bottom.

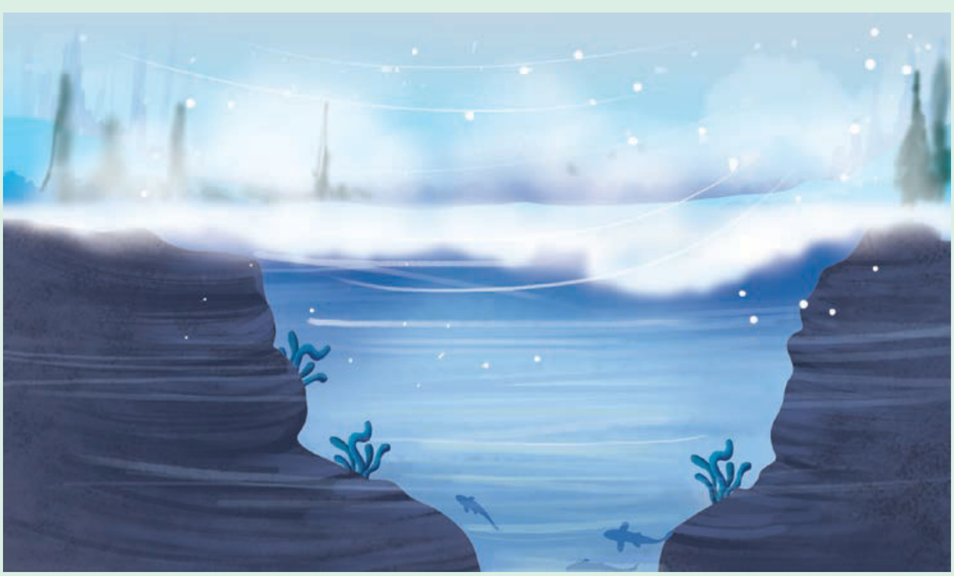

Figure 8.29 A frozen lake with unfrozen water beneath the surface

Applying

8 Predict how the amount of thermal energy received from the Sun would differ if Earth was half the distance away from the Sun as it is now.

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...continued

9 Classify the following as heat transfer by either conduction, convection or radiation:
   a a lava lamp flowing
   b thermal energy produced by a grill element in an oven
   c an ice cube melting in your hand.

10 Two cups of water have their temperature measured. One is 20°C and the other is 30°C. Using your understanding of temperature and particles, discuss how the movement of particles differ.

Analysing

11 Differentiate between insulators and conductors in terms of their ability to transfer heat.

12 Explain why the energy received from the Sun is by radiation and not convection or conduction.

Evaluating

13 Josh says insulation keeps out the cold. Critique this statement.

14 Convection occurs in liquids and solids. Deduce why convection does not occur in solids.

8.3 Energy transfers and transformations

WORKSHEET

Energy is constantly changing from one form to another. For example, the characteristic lights and sounds produced by fireworks are the result of such energy transformations. Thermal energy, in the form of a lit fuse, in addition to chemical potential energy, is transformed into heat, light and sound energy as well as kinetic and gravitational potential energy when a firework explodes.

Not all energy transformations are this complex. A toaster, for example, transforms electrical energy to thermal energy which toasts the bread by radiation. Regardless of how simple or complex the transformations are, energy is conserved in all energy conversions. This is to say, all conversions abide by the law of conservation of energy in that energy is neither created nor destroyed.

Figure 8.30 Fireworks are the result of many energy transformations.

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In Section 8.2 Thermodynamics, we saw that incandescent light globes transform electrical energy into thermal energy and light energy. However, they only convert about 10% of their electrical energy input into visible light energy. The remaining 90% is transformed into thermal energy. As producing thermal energy is not the main use of a light globe (producing light is), the thermal energy produced is said to be wasted energy. This loss of useful energy does not mean that energy has been lost, because the waste (thermal) energy is still accounted for according to the law of conservation of energy. However, the high proportion of wasted energy (90%) shows that the energy transfer is inefficient.

Aurora australis

Did you know? 8.4

Figure 8.31 Aurora australis

Similar to the better known Northern Lights (aurora borealis), the Southern Lights are the result of energy transformations caused when high energy electrons (and sometime protons) collide with particles in our upper atmosphere. In this transformation, ionisation energy is transformed into light energy in the form of photons emitted from ionised atoms returning to their ground state.

Energy efficiency

Hardly any energy conversion is 100% efficient – energy in some form is always lost to the system (In microscopic collisions, for example between gas particles, elastic collisions are commonplace.). Consider a rubber ball being dropped from a height onto a concrete surface. At its maximum height the ball possesses a large amount of gravitational potential energy. When the ball is dropped, this gravitational potential energy is converted to kinetic energy, which reaches a maximum just before the ball hits the ground. As the ball hits the ground, the kinetic energy is converted into elastic potential energy. This is converted back into kinetic energy as the ball bounces up again. If this system was 100% efficient, the ball would bounce back up to its starting height and have the same amount of gravitational potential energy as before being dropped. We know that this is not the case as with each bounce the ball reaches a lower maximum height until eventually the ball comes to a stop where it has zero energy.

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Figure 8.32 A rubber ball bouncing on a surface is not 100% efficient as energy is lost from the system.

Let's look at how energy is lost from this system. First, as the ball is falling towards the ground it is encountering air particles. Contact with these particles results in friction and heat – thus energy is lost as heat to the surrounding air particles. When the ball bounces, it creates a sound and there is also friction between the ball and the ground. Thus energy is lost due to the inefficient conversion between KE and GPE and back again. Therefore, with each successive bounce the ball has less energy than the preceding bounce. As a result, the ball slows down before coming to a stop when all of the energy initially possessed by the ball is lost to the system, entirely as thermal energy.

Calculating efficiency

The **efficiency** of a system, in terms of its ability to convert energy, is a measure of its ability to produce useful energy. **Useful energy** is defined as energy that can be used for a specific purpose. In the example of the bouncing ball above, kinetic energy and elastic potential energy are useful forms of energy. In contrast, heat and sound energy are by-products of the energy conversion (that is, wasted energy). Energy efficiency is most commonly expressed as a percentage and can be calculated using the following equation:

efficiency
a measure of the ability to produce useful energy

useful energy
energy that can be used for a specific purpose

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

Worked example 8.5

Efficiency

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

Worked solution	
Thinking	**Working**
List the relevant data that has been provided.	Useful energy output = 12 J, Energy input = 75 J
Recall the definition of efficiency energy and the equation.	Efficiency = (useful energy output/energy input) × 100
Substitute the relevant data into the equation.	Efficiency = (12 J/75 J) × 100
Solve the problem, giving an answer with appropriate units.	Efficiency = 16%

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Practical 8.7: Self-design

Investigating the efficiency of bouncing balls

Aim

To calculate and compare the efficiencies of balls that bounce.

Materials

As chosen by students but most likely to include:

- variety of bouncing balls
- equipment to measure the height of the bounce

Method

1. Copy the results table below.
2. Design an experiment to calculate the efficiency of a variety of balls that bounce by measuring the rebound height.
3. Write a hypothesis for your investigation.
4. List the dependent and independent variables.
5. Identify at least three relevant control variables and outline how you are going to control them.
6. Complete a risk assessment, considering at least two significant risks.
7. Write a method that includes all variables and equipment and accounts for repeat trials.
8. Complete the table of results.

Results

Initial height (m)	Final height 1 (m)	Final height 2 (m)	Final height 3 (m)	Average final height (m)	Initial *U* (J)	Final *U* (J)	Efficiency (%)

Evaluation

1. Compare the efficiency of your ball with the findings of another group in your class. Which is the most efficient type of ball?
2. Discuss the energy transformations that occurred during the bouncing of your ball, including any wasted energy.
3. Propose why certain types of balls are more efficient than others.

Conclusion

1. Make a claim about energy efficiency based on this experiment.
2. Support the statement by using the data you collected and include potential sources of error.
3. Explain how the data support the statement.

Sankey diagrams

A **Sankey diagram** is a flow chart that represents the flow of energy through a system. A Sankey diagram has a wide arrow at its base, which represents the energy input into a system. The flow diagram then branches off into two or more arrow heads, the size and thickness of which is directly proportional to the amount of output energy in that form. For example, Figure 8.33 on the following page shows a Sankey diagram

Sankey diagram
flow chart that represents the flow of energy through a system

for the incandescent light globe mentioned in Section 8.2 Thermodynamics, where only 10% of output energy was in a useful form.

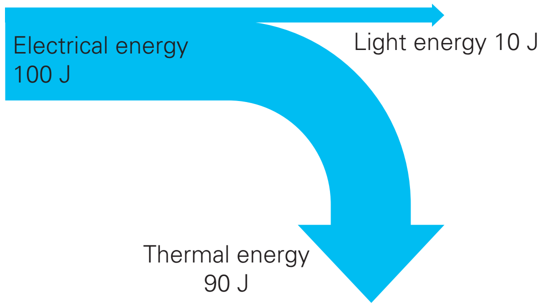

Figure 8.33 A Sankey diagram for an incandescent light globe showing the amount of input energy (100 J) as well as the amount of output energy in its various forms.

The Sankey diagram for an incandescent light globe shows that most of the electrical energy is transformed into thermal energy (thicker arrow) rather than light, which is a useful form of energy output. The thermal energy produced is said to be lost or wasted energy.

Quick check 8.7

1. Outline the energy changes that take place when you jump on a trampoline, and explain why you do not bounce back up to the same height after successive bounces.
2. Calculate the efficiency of an electric stove that has an input of 1500 J of energy and produces 200 J of light energy and 1300 J of thermal energy.
3. Draw a Sankey diagram for the electric stove in question **2**.

Practical 8.8: Self-design

Rube Goldberg machine

Introduction

Machines are useful – we use them to make tasks easier. However, some machines are definitely not as efficient or useful as others. These machines were named after Rube Goldberg, an American inventor and cartoonist. A Rube Goldberg machine is a type of machine that relies on a significant number of energy transfers and is designed to carry out a simple task in a very complicated and convoluted way.

Energy transfers and transformations occur throughout Rube Goldberg machines due to the chain reactions involved. An energy transformation is a change in energy from one form to another, and energy transfer is the movement of energy from one place to another.

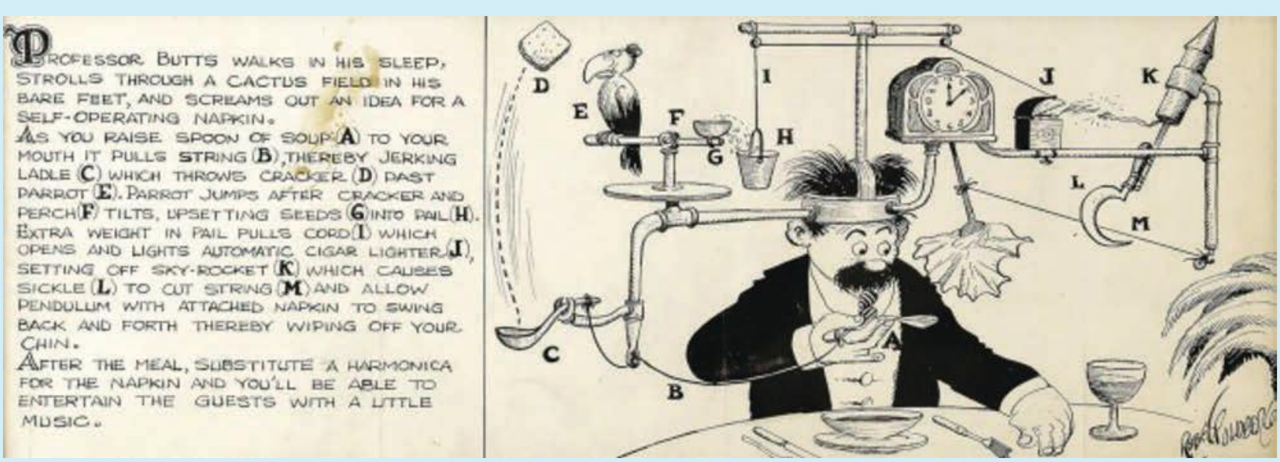

Figure 8.34 Original artwork for Rube Goldberg's 'self-operating napkin' machine

Aim

To design and construct a Rube Goldberg machine to complete a common task.

Be careful

Loose materials can be a slip hazard. Students are not to be a part of the Rube Goldberg machine.

continued…

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...continued

Materials

As chosen by students but may include:

- dominoes
- playing cards
- marbles
- rubber bands
- string
- springs
- toy cars
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- bouncy balls
- cans
- plastic bottles
- flat cardboard
- ramps
- books (preferably sturdy ones, such as old textbooks)
- sticky tape
- appliances (fans, lamps etc.)

Method

1. Identify a simple common task that you would like to be done by a machine.
2. Draw a plan of your Rube Goldberg machine.
3. Start building your machine, ensure that you test each step as you progress.
4. Once your machine is complete, make a video recording of it in action.

Results

Remember to take a video of your machine in action.

Evaluation

1. Explain the energy transfers and transformations which took place in your Rube Goldberg machine.
2. Compare your final machine to your plan. Which parts (if any) are different? Why did you change them?
3. How could you reduce the amount of waste energy produced by your Rube Goldberg machine to make it more efficient?

Conclusion

1. Make a claim about energy conversions based on this experiment.
2. Support the statement by using your observations and include potential sources of experimental faults.
3. Explain how your observations support the statement.

Section 8.3 questions

QUIZ

Remembering

1. Define useful energy.
2. Recall the energy transformations that occur when fireworks explode.
3. State what usually happens to wasted energy.

Understanding

4. A car has an energy efficiency of 35%. Explain what this means in terms of energy.
5. Incandescent light globes convert 10% of their input energy into light energy, while LEDs (light-emitting diodes) convert 60% of their input energy into light energy. Determine which type of light globe is more energy efficient.
6. As Jane slides down a playground slide, the amount of kinetic energy that she gains is less than the amount of gravitational energy that she loses.
   a. Predict where the missing energy goes.
   b. Consider what Jane can do to minimise the amount of wasted energy.

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...continued

Applying

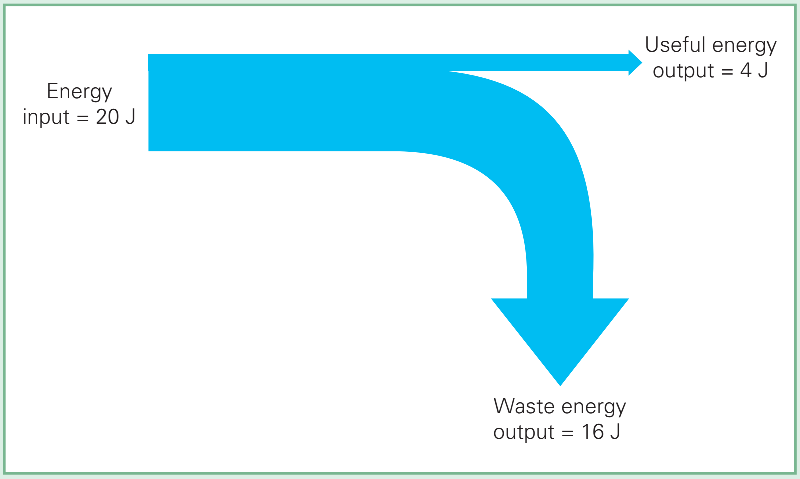
7 An organism uses 500 J of chemical potential energy stored in his body to produce 125 J of kinetic energy to climb a tree. Calculate the organism's efficiency.

8 Explain what the term 'efficiency' means.

Analysing

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

10 The Sankey diagram below is of a light globe.



a Identify the useful energy output that the light bulb is designed to produce.

b Describe the effect that the wasted energy has on the surrounding air.

c Calculate the efficiency of this light bulb.

Evaluating

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

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

Figure 8.35 Car heater used to warm a drivers hand

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8.4 Exploring energy in systems

WORKSHEET

Our understanding of energy conversions can be applied to systems. In this context, a **system** is defined as a portion of the universe that is being analysed. Within a system, energy is conserved and thus all energy conversions can be accounted for.

system
a portion of the universe that is being analysed

Let's have a look at the energy conversions of physical events in some everyday systems.

Figure 8.37 A pendulum tracing circles in sand as its motion decreases before coming to a stop due to friction

Pendulums

The pendulum is a classic example of the law of conservation of energy in action: gravitational potential energy is converted to kinetic energy and back, this repeats over and over again as the pendulum swings.

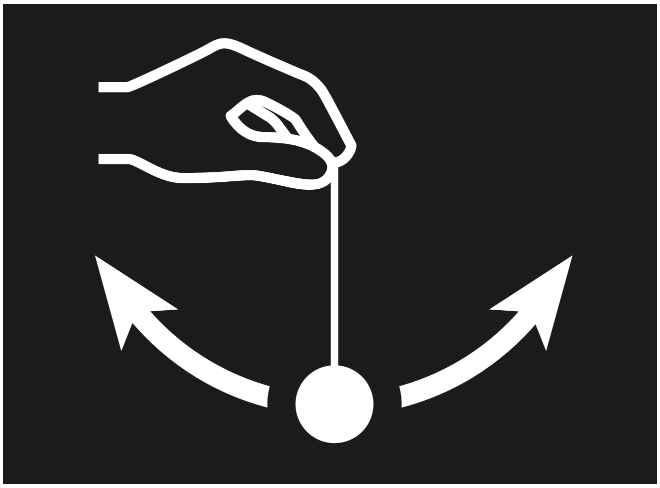

Figure 8.36 A pendulum

When we talk about a pendulum we are referring to a massless string attached to a pivot point with a bob on the other end. The bob is a dense object which accounts for all of the mass of the system. We ignore the effects of air friction acting on the pendulum and friction in the pivot. So this is an idealised system.

Pendulums are excellent models for systems where energy is successively transformed between gravitational potential energy and kinetic energy. When the mass is drawn upwards or outwards, the system gains gravitational potential energy. When the mass is released, the energy is converted into kinetic energy due to gravity pulling the bob down. Kinetic energy in the bob causes it to swing up in the opposite direction, during which its kinetic energy is once again converted into gravitational potential energy. This cycle repeats itself a number of times until, in a real pendulum, the bob comes to a rest.

The reason that the bob slows down and eventually stops is because, with each successive energy conversion, energy is lost to the system as heat and sound, primarily due to air resistance.

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Explore! 8.4

Perpetual motion machines

A perpetual motion machine is a hypothetical machine that remains in motion indefinitely. Many people have attempted to make a perpetual motion machine, but none will ever succeed as perpetual motion machines are physically impossible because we are unable to remove all forms of friction.

According to the first law of thermodynamics, energy cannot be created or destroyed. And energy needs to be applied to keep a machine moving indefinitely because of wasted energy. We are not able to remove all forms of friction – except in the microscopic world. Therefore, if no energy is applied to a system that eternally produces energy, that system will violate the law of conservation of energy.

Research perpetual motion machines to answer the following questions:

1 Is it possible to create a perpetual motion machine? Why or why not?
2 In superconductors, charge can flow without any resistance. It is possible to make a superconducting ring with a persistent current that will continue to circulate forever. Is this an example of a possible perpetual motion machine? Can we use this to do any useful work? Explain your reasoning.

Quick check 8.8

1 Describe how a playground swing can be considered a pendulum.
2 Explain why a person needs to be pushed on a swing to continue to reach the same height.
3 Using the law of conservation of energy, explain what happens to the energy lost in a system involving a pendulum.

Lifting and dropping

We saw earlier in this chapter that work is done on an object when a force applied causes it to move some distance. How can we apply this idea to a crane lifting and dropping objects such as the containers in Figure 8.38?

A crane is used to lift and lower heavy or large objects, such as the containers in a shipyard. Let us look a bit closer at the energy conversions that are taking place.

While a container is being lifted, it will have some kinetic energy as the object is in motion. Additionally, the container increases its height above the surface of Earth, so it gains gravitational potential energy. The law of conservation of energy states that energy cannot be created or destroyed, so where does this energy come from?

Figure 8.38 A crane lifting containers in a shipyard

We saw earlier that work is defined as the amount of energy transferred when an applied force causes an object to move some distance. So we can conclude that the energy gained by the container is due to work being done on it. The applied force in this situation would be the tension force in the chain lifting it up. Some initial work is required to set the container in motion, thus transferring kinetic energy to the system, and as more work is done on the container it gains more energy – gravitational potential energy.

What would happen if the chain broke and the container dropped to the ground? Naturally, there would be a change in gravitational potential energy as the container's height decreases. As there is a change in energy in the system, work is being done, so a force must be being applied. The force doing work on the container when it falls is the gravitational force, arising from gravity pulling the container down. From the law of conservation of energy, we know that the total energy in a system must be conserved. Thus, gravitational potential energy is converted into kinetic energy as the object accelerates towards the surface

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of Earth. Upon landing, the gravitational potential energy is reduced to zero, and all of the kinetic energy is converted into thermal energy and sound energy.

Quick check 8.9

1 Use a flow chart to illustrate the changes in energy that occur when a weightlifter lifts a barbell and then drops it.
2 Explain how work is done on a falling object.

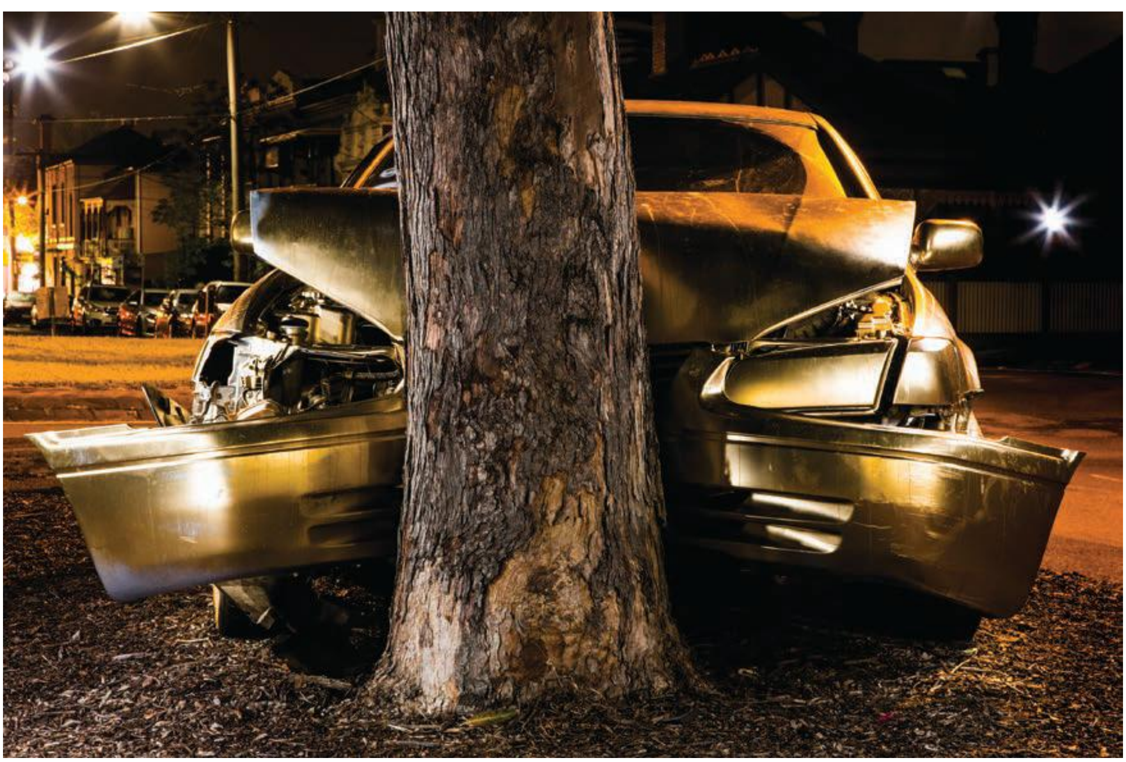
Cars crashes

Moving cars have large amounts of kinetic energy due to their motion, so what then happens to all of this energy if the car crashes?

During a collision, the objects involved in the collision transfer energy to each other and to the rest of the system. According to the law of conservation of energy, energy cannot be created or destroyed and can only be transferred to other objects or transformed into other forms. This holds true for collisions, so the large amounts of kinetic energy that moving objects hold have to go somewhere. The damage caused by collisions results from the transfer of large amounts of energy over very short distances and time intervals. Remember that work is defined as the amount of energy transferred when an applied force causes an object to move some distance. The size of the force is proportional to the amount of work done and thus also proportional to the amount of energy transferred. In other words, the more energy transferred the more force applied. Also, as the distances involved and the time involved is reduced, the forces involved increase.

As the force produced in a collision is the primary danger and cause of injury, what can we do to reduce it and thus reduce injury? Many safety features built into the design of cars aim to do just that. Let us look at some of those features.

Figure 8.39 A car after crashing into a tree



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Crumple zones

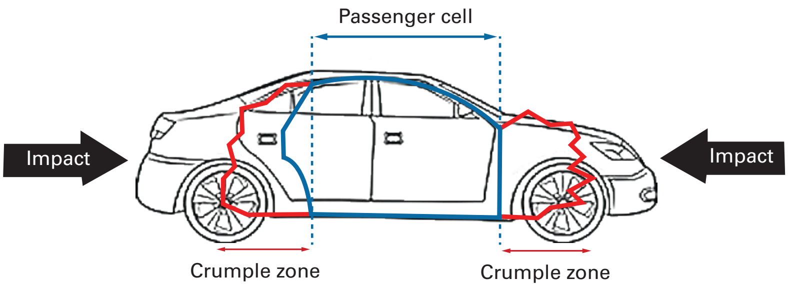

Figure 8.40 Crumple zones are usually located at the front and back of cars, and are designed to absorb some of the energy in a collision.

Crumple zones, as the name suggests, are sections of the car designed to crumple in a collision. They crumple when they absorb some of the energy transferred during the collision. This results in less energy being transferred, and thus less force applied, to the occupants of the car – reducing the severity of injuries. To protect the driver and passengers, the passenger cell or cabin is made of stronger materials that are not designed to crumple. Crumple zones are usually, but not limited to, the front and back of the car, as these are the sections of the car that are most likely to be affected by a crash.

By deforming, crumple zones not only absorb some energy (as work is being done to crumple the car) but also increase the time (and thus the distance) over which the collision occurs. As we know by looking at the equation for work ($W = Fs$), force is inversely proportional to its displacement. Therefore, by increasing the displacement we are decreasing the force applied.

In Figure 8.39 on the previous page, a car has crashed into a tree. What energy changes would have occurred in that collision? The car had kinetic energy from its initial motion, the magnitude of which depends on its mass and speed. After the collision, both the car and the tree are stationary and thus have no kinetic energy. From the law of conservation of energy, we know that energy is not destroyed, so work must have been done on the car to transfer that energy. It is the force of the tree on the car that brings it to a stop; and therefore, it is the work done by the tree on the car that reduces the car's energy to zero.

Seatbelts

In a collision or sudden stop, an unrestrained object will continue to move in its original direction until a force is applied to make it stop – this is Newton's first law of motion. Seatbelts make sure that the passenger stops moving in a collision by applying that force. As discussed above, the main purpose of car safety features is to reduce the size of the applied force and in doing so reduce the severity of injuries caused during collisions. Seatbelts have a three-point anchor system and are designed to increase the area over which the force is applied – by spreading the force, the potential for injury is reduced significantly. They also stretch slightly, and this increases the stopping distance and reduces the force on occupants.

Figure 8.41 A seatbelt is a safety device in car that prevents injuries by helping you come to a stop safely.

Air bags

Airbags are yet another car safety system designed to protect you in a collision by reducing the force applied in bringing you to a stop. As seatbelts only apply a force to the body, the head will continue in its original path of motion. Therefore, airbags are in place primarily to protect the occupants' heads from hitting the dashboard, steering wheel or windscreen.

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Airbags are cushions that inflate with a gas in the event of a collision. The inflated airbag increases the area over which the force is applied, as well as increasing the time and distance over which the force acts. All of these factors reduce the size of the force experienced by the occupant, which reduces the severity of injuries caused in a collision.

Figure 8.42 An airbag inflating on impact protects a man's head from hitting the steering wheel or windscreen.

Quick check 8.10

1. Identify what would happen if a car stopped suddenly and the occupant was not wearing a seatbelt.
2. Explain how energy is conserved in a collision.

Refrigerators

Refrigerators are wonderful inventions that we use daily to keep our food cold and fresh. They work by transferring thermal energy from inside the fridge to outside the fridge through the use of a coolant.

We know that thermal energy moves from objects with a high temperature to those of lower temperature until thermal equilibrium is reached. So, how do you move thermal energy from a cooler object to a warmer one? The answer is work. Doing work takes energy and requires a force to move something. The energy is provided by electrical energy, which is transformed into kinetic energy which causes the pumps to apply a force to the coolant, resulting in its circulation. Wasted energy would be thermal energy and sound energy.

Figure 8.43 A refrigerator is a common electrical appliance that uses the laws of thermodynamics to keep our food cold and fresh.

A refrigerator has a closed system of pipes filled with a liquid coolant which undergoes pressure changes to direct the thermal energy away from the fridge contents. The key to the functioning of a refrigerator is a coolant, or refrigerant. This is a substance with a low boiling point so it changes between the liquid and gas phases as it

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passes through the refrigerator system. The role of the compressor pump is to compress the coolant vapour. This raises the vapour's pressure and temperature. The compressed vapour gas is pushed through the coils of the condenser on the outside of the refrigerator. When the hot pressurised gas in the coils of the condenser meets the cooler air in, for example the kitchen, it becomes a liquid.

The now warm liquid cools down quickly as it expands rapidly through the expansion valve. This now very cool liquid goes into the evaporator coils inside the freezer and the fridge. The coolant absorbs the thermal energy inside the fridge when it flows through the evaporator coils, cooling down the air inside the fridge, and heating the coolant, which then evaporates to a gas again due to its raised temperature. This low-pressure vapour then flows back to the compressor pump, where the cycle starts all over again.

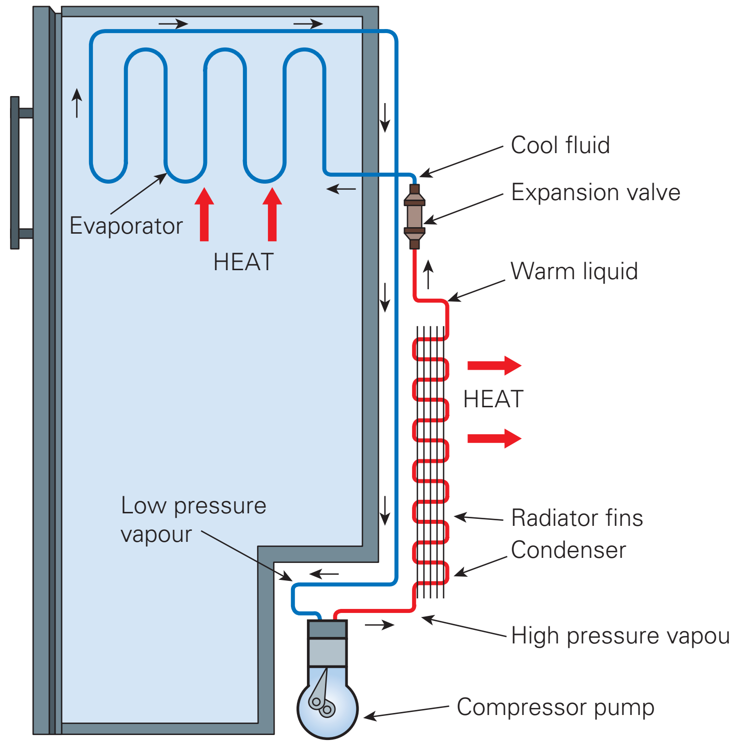

Figure 8.44 The cooling system of a refrigerator

Quick check 8.11

1 Explain how the changes in pressure facilitate the cooling of air inside a fridge.
2 Demonstrate the changes in energy that occur in a refrigerator system.
3 Explain why it is difficult to cool down a fridge that has been left open.

Section 8.4 questions

QUIZ

Remembering

1 Define a system.
2 List five examples of everyday systems that undergo energy changes.

Understanding

3 Identify where on a car you would find the crumple zones and describe why they are located there.
4 Explain why a seatbelt is needed to stop the occupant in a collision.

Applying

5 Explain why a real pendulum's motion is not infinite and thus will eventually come to a stop.
6 When an object is dropped, energy is being transformed, and thus work is being done. However, for work to be done, a force needs to be applied to the object. Propose the force that is responsible for work being done.

Analysing

7 Differentiate between the forces felt by occupants in a car collision in a car with and without an airbag.
8 Compare a playground swing to a pendulum.

Evaluating

9 Sports cars often have more crumple zones than other cars. Suggest a reason for this.
10 Justify why heating vents are often positioned on the floor while air conditioner vents are usually closer to the ceiling.

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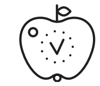
Review questions



Remembering

1 Complete the following questions by identifying the glossary term that each sentence defines.
  a The total kinetic energy of all of the particles that make up an object or system.
  b The transfer of thermal energy without the transfer of particles.
  c The average kinetic energy of all of the atoms that make up an object or system.
  d A flow chart that represents the flow of energy through a system.

2 List six different forms of energy, giving an example of (or where you would find) each.

3 State the first law of thermodynamics.

Understanding

4 Compare and contrast thermal energy and temperature.

5 Name the two types or categories of energy into which all of the various forms of energy can be placed.

6 Define work qualitatively and quantitatively.

7 Explain how an airbag can reduce the impact of a collision on a person.

Applying

8 A worker carries some timber up a staircase. The worker moves 9.6 m vertically and 22 m horizontally. If the timber weighs 45 N, calculate how much work was done.

9 Calculate the efficiency of a blender that converts 200 J of electrical energy to 120 J of kinetic energy and 80 J of thermal energy per second.

10 Predict what would happen if you had beeswax attached to one end of a metal skewer and you placed the other end of the skewer in a flame. Explain this prediction.

Analysing

11 Distinguish between useful and wasted energy.

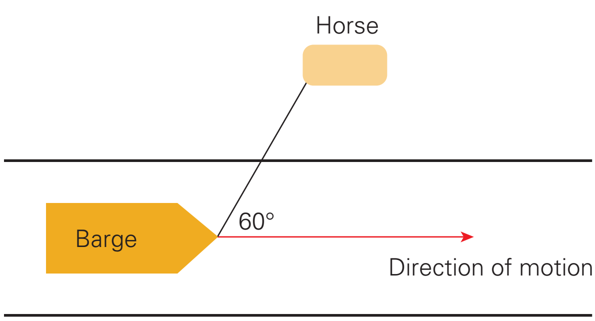
12 Outline how a refrigerator works.

13 A light globe uses 60 J of electrical energy to produce 3 J of light energy. Illustrate, with the use of a Sankey diagram, the amount of wasted energy and suggest what form this wasted energy will take.

Evaluating

14 Evaluate which contains more thermal energy: a coffee cup of boiling water or a bathtub of room temperature water?

15 A barge (a long boat with a flat bottom) is pulled down a canal by a horse walking beside the canal. If the angle of the rope is 60°, as shown, the force exerted is 500 N, and the barge is pulled 50 m, calculate how much work the horse did in pulling the barge in the direction shown. (Hint: the component of the force in the direction of motion is given by $F\cos\theta$).



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STEM activity: Building an instrument to measure the solar constant

VCSSU132 VCSSU104 VCMNA283 VCDSCD062 VCSIS110 VCSIS111

Background information

The Sun is the primary source of energy for our planet. Without the Sun, Earth would be a very different place indeed. For example, pretty much all the water on the planet would be frozen; the constant darkness would make the process of photosynthesis impossible; there would be no sunsets, sunrises or seasons. In summary, life as we know it would not be possible on our planet.

Solar energy has been harvested by organisms on Earth for billions of years. All the diversity and beauty you see in our biosphere today started when small organisms began to photosynthesise.

Today, we use technology and advances in science to capture solar energy to power our modern society. Fossil fuels such as coal and gas, our traditional energy source, were created millions of years ago when solar energy was converted into plant mass in huge forests. Then, as plants died, their matter was deposited and covered by other sediments, creating coal and gas deposits. However, we have recently developed technology capable of capturing solar energy through solar cells to produce electricity.

The Sun has been generating energy for around 4.6 billion years! But it is only relatively recently that scientists have managed to measure its mass, its distance from Earth and, importantly, the amount of solar energy that reaches our planet at a given moment. Interestingly, we can measure how much energy Earth receives from the Sun; this value has been described by scientists as the *solar constant* because the rate of transfer has remained at a generally constant rate since observations began in 1838.

Figure 8.45 Solar energy has the potential to revolutionise the energy sector worldwide as we work towards mitigating the effects of climate change.

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Design brief: Build an instrument to measure the solar constant.

Activity instructions

In this activity, you and your colleagues will collaborate and build an instrument capable of measuring the solar constant at your school over a certain period (for example, 20 minutes). You should record the data, reflect on possible errors throughout the important process of data gathering and discuss your findings with your peers. (Teachers, please see the Online Teaching Suite for a detailed guide for this activity)

Suggested materials

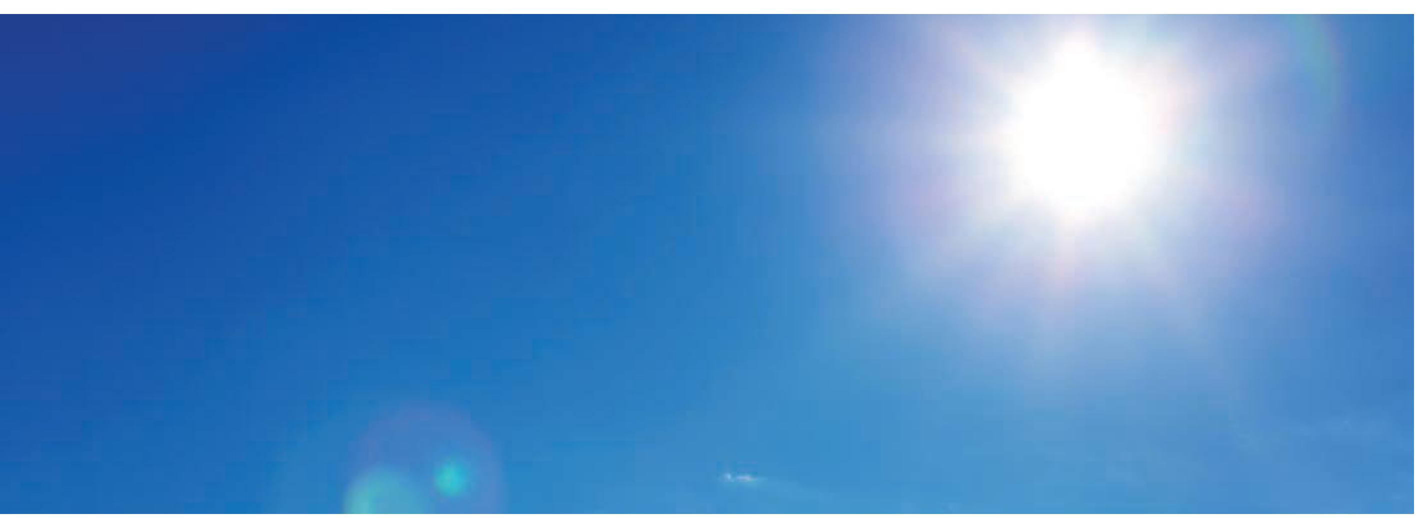
- clear beaker that holds at least 200 mL of water
- thermometer that reads between 0°C and 100°C
- black or blue water-soluble ink
- stopwatch
- scales accurate to at least one gram
- piece of cardboard to be placed under the beaker outside

Suggested location

School oval or soccer pitch on a sunny day

Evaluate and modify

1. Using your own words, explain how you could use the materials listed previously to create a simple instrument to measure the solar constant. Feel free to sketch, draw, describe and even design an instrument.
2. Collect and analyse your data set and calculate the following parameters:
   a. the change in temperature from the point where the temperature started to rise rapidly (for example, about 2–3 minutes into the experiment) to the point where it slowed down
   b. the elapsed time between these two points.
3. Use your own words to list as many dependent and independent variables in this activity as you can.
4. Reflect upon the potential measurement uncertainties or experimental faults introduced throughout the activity, including during data collection.



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Chapter 9 **Motion**

Chapter introduction

This chapter continues our exploration of the science of physics. Have you ever wondered how long it takes for sunlight to reach the Earth or how quickly a raindrop falls to the ground? These questions can be answered in the domain of physics – the study of the physical world. One of the most famous areas of physics is the study of how things move. What first comes to mind when you think of the word 'motion'? How do you describe objects that move? You live in a world filled with moving things. This chapter will help you understand the core ideas of how things move, how fast they travel and the forces that are at work.

Curriculum

The description and explanation of the motion of objects involves the interaction of forces and the exchange of energy and can be described and predicted using the laws of physics (VCSSU133)	
• recognising that a stationary object, or a moving object with constant motion, has balanced forces acting on it	9.4
• gathering data to analyse everyday motion produced by forces, for example, measurements of distance and time, velocity, mass, acceleration and force	9.1, 9.2, 9.3, 9.4
• investigating the effects of applying different forces, including Earth's gravitational force, to familiar objects	9.4

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Glossary terms

acceleration
average speed
constant speed
deceleration
displacement
distance
force
gradient
inertia
instantaneous speed
mass
net force
Newton's first law of motion
Newton's second law of motion
Newton's third law of motion
origin
speed
stationary
velocity
weight

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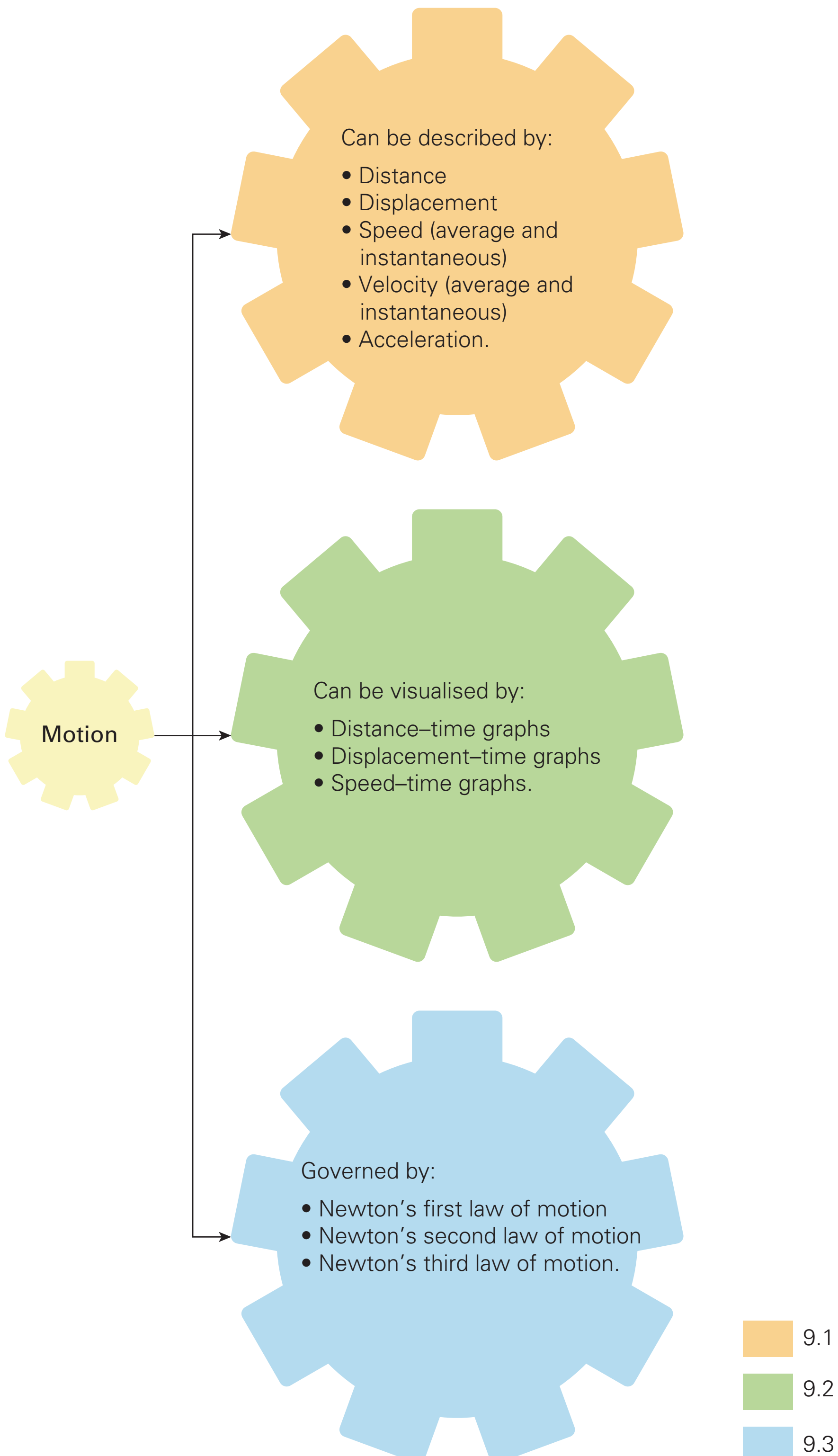
Concept map



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9.1 Describing motion

Everyday motion — **Try this 9.1**

You are surrounded by things that move. Make a list of all of the objects that you have interacted with today. What words come to mind when you want to describe the motion of an object to another person? Can you also determine some other units of measurement that are used to help describe physical quantities?

WORKSHEET

Distance

When motion is discussed, **distance** usually refers to how far something has travelled. The symbol *d* is used to denote the distance an object has travelled. For example, the soccer ball in Figure 9.1 has travelled a distance of 20 metres.

distance
total distance travelled measured in metres

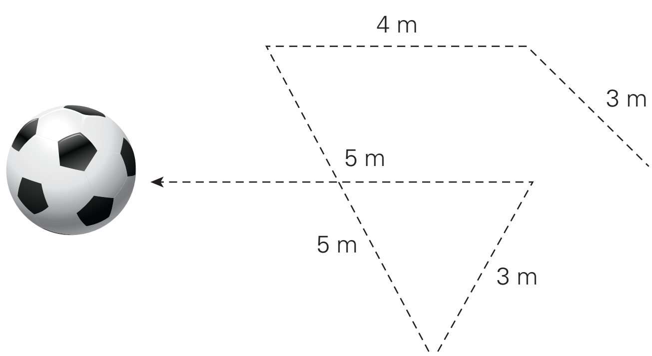

Figure 9.1 Distance travelled by a soccer ball

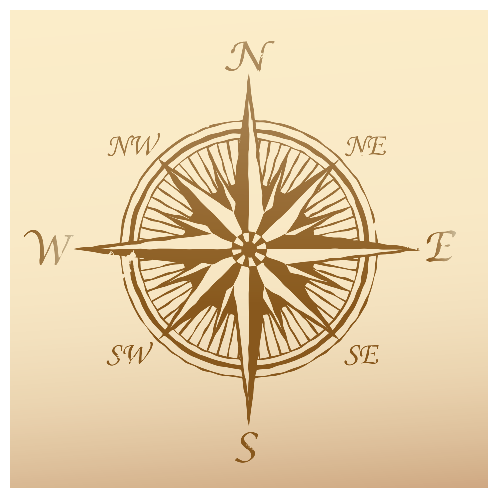

Figure 9.2 Often a compass bearing is used to describe the direction of displacement. However, simpler directions like left, right, up, down, backwards and forwards are sometimes used.

Displacement

Unlike distance, **displacement** describes how far and in which direction something has travelled from an initial starting point. Displacement is the change in an object's position from the initial point. Displacement is denoted with the symbol $\vec{d}$ and it has both size and direction – hence the arrow above the *d* to indicate it has a direction.

displacement
how far you are from where you started and what direction you are from where you started

Figure 9.3 shows a scenario where the direction of travel matters. You might know that you sailed 20 kilometres, but you will not know where you are unless you know the direction you sailed. If you sailed 20 km in the north-west direction, you would end up on island A, if you sailed east, you would end up on island B, and if you sailed south, you would end up on island C. You can see that sometimes direction matters.

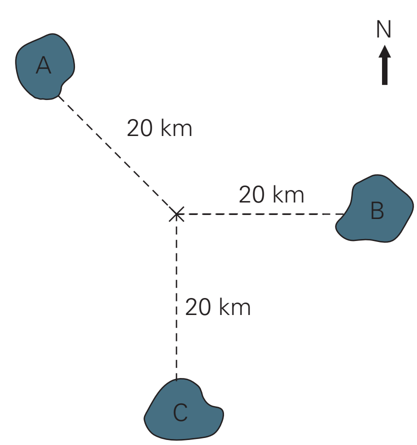

Figure 9.3 If you ended up on Island B, your displacement would be 20 km east from your starting position.

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Distance versus displacement

Often, knowing the displacement is more helpful than knowing the distance something has travelled. Displacement compares the initial position with the final position of an object in motion. If the final position is the same as the initial position, then the displacement is zero. Consider a person who walks six metres forwards from point A to point B, and then two metres backwards to point C. The distance that they have travelled is eight metres. However, since they have only ended up four metres from the starting position, the displacement from their starting point, A, is four metres forwards.

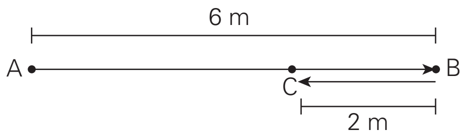


Figure 9.4 The walk described can be represented using arrows, where the length of the arrow symbolises the magnitude, and the direction of the arrow shows the direction of motion.

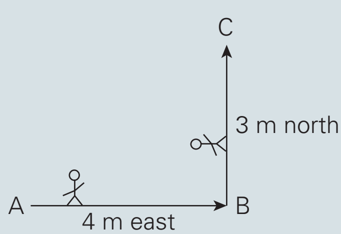
The total distance travelled from A to B is $d = 6 + 2 = 8$ m.

The displacement from A to B is $\vec{d} = 6 - 2 = 4$ m to the right.

Worked example 9.1

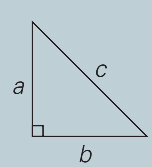
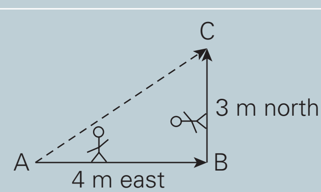
Distance and displacement

A person walks four metres east and then three metres north. That can be represented in a simple diagram as follows.



1 What is the distance travelled by the person?

2 What is the displacement?

Worked solution	
Thinking	**Working**
1) Distance	
Sum the two distances travelled to find the total distance that the person has travelled.	$d = 3\text{ m} + 4\text{ m} = 7\text{ m}$
2) Displacement	
Use Pythagoras's theorem to find the distance from A (the starting point) to C (the end point). $a^2 + b^2 = c^2$  $c = \sqrt{a^2 + b^2}$	 Using Pythagoras's theorem, find the distance from A to C. $AC = \sqrt{4^2 + 3^2}$ $= \sqrt{16 + 9}$ $= \sqrt{25}$ $= 5\text{ m}$

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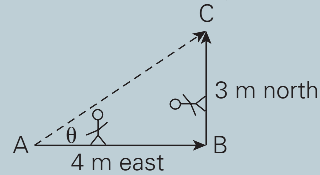
Worked solution	
Thinking	**Working**
You also need the direction travelled from the starting position to the final position.	To determine the direction requires trigonometry.  tan $\theta = \frac{3}{4}$ θ = 36.9° north of east Therefore, the displacement $\vec{d}$ is 5 m 36.9° north of east.

Did you know? 9.1

Measuring distance

Throughout history many systems have been used to measure distance. One of the earliest known standardised systems was in ancient Egypt, roughly 6000 years ago, where forearms, hands and fingers were used to measure distances between two objects.

A 'league' was a unit of distance used in medieval England. It originally meant the distance that a person could walk in an hour. Often this meant that people in different places had a different understanding of how far a league actually was. Today, most of the world uses the metric system which is standardised globally. In the metric system, the base unit for length is the metre which comes from the Greek *metron* meaning measure. One metre is the length that light travels through a vacuum in $\frac{1}{299\,792\,458}$ seconds.

Quick check 9.1

1 Define the terms distance and displacement.
2 Consider a classmate travelling between classrooms. From their initial classroom they travel west 100 m and then north 50 m, where they arrive at the intended classroom.
   a Draw a diagram that represents the problem.
   b What is the distance travelled by the student?
   c What is the displacement of the student to the nearest metre? Remember to also give an angle in your answer.
   d If the student then travels back to the initial classroom, what is their displacement?

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Speed

We have all used words or phrases to describe how quickly something travels, or maybe even to determine how long it will take to get from one place to another. **Speed** is a general term for how fast something travels. It is a measure of the rate at which an object travels a distance. In other words, it is the distance (d) travelled within a certain amount of time (t).

speed
change in distance divided by time

A rocket can travel at 11 km/s.

A cheetah can maintain a speed of 31 m/s.

The speed of a snail is more likely to be measured in units of cm/min.

The speed of cars is usually measured in km/h.

Figure 9.5 Examples of different speeds

Speed is used to judge how fast something is moving, or how far something will travel in a certain amount of time. Speed is commonly measured in units of metres per second (m/s), or kilometres per hour (km/h). However, depending on the motion, speed may sometimes be measured in m/min, cm/h, or even km/s.

Consider the examples of motion shown in Figure 9.5.

Speed is calculated as follows:

$$\text{average speed (m/s or km/h)} = \frac{\text{distance travelled (m or km)}}{\text{time taken (s or h)}}$$

$$\text{Or } v_{av} = \frac{d}{t}$$

A simple way to remember this equation is by using the average speed triangle shown in Figure 9.6.

Using the average speed triangle, you can derive formulas for:

- average speed $v_{av} = \frac{d}{t}$
- change in time $t = \frac{d}{v_{av}}$
- change in distance $d = v_{av} \times t$.

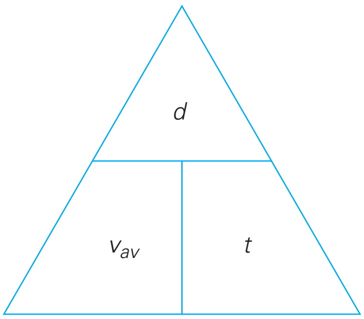

Figure 9.6 The average speed triangle

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Worked example 9.2

Average speed

Consider two runners who are in competing in a 100 m hurdles event. Runner 1 finishes in a time of 12.5 s. Runner 2 runs the race with an average speed of 7 m/s.

1 Who wins the race?

2 How long does it take Runner 2 to cross the finish line? Round your answer to two decimal places.

Worked solution	
Thinking	**Working**
1) Who wins?	
List the relevant information for Runner 1.	$d = 100$ m $t = 12.5$ s $v_{av} = ?$
Calculate the average speed using the formula for average speed.	$v_{av} = \frac{d}{t} = \frac{100\text{ m}}{12.5\text{ s}}$ $= 8$ m/s
Compare the average speed of each runner.	Runner 1: $v_{av} = 8$ m/s Runner 2: $v_{av} = 7$ m/s Since Runner 1 has a higher average speed, they finish before Runner 2 does. Therefore, Runner 1 wins the race.
2) Runner 2 time	
List the information that you have for Runner 2	$t = ?$ $v_{av} = 7$ m/s $d = 100$ m
Calculate the time taken for Runner 2 to complete the race using a rearranged average speed formula.	$t = \frac{d}{v_{av}} = \frac{100\text{ m}}{7\text{ m/s}}$ $= 14.29$ s
Interpret the solution, ensuring that you have correct units and decimal places.	It takes 14.29 s for Runner 2 to complete the 100 m hurdles race.

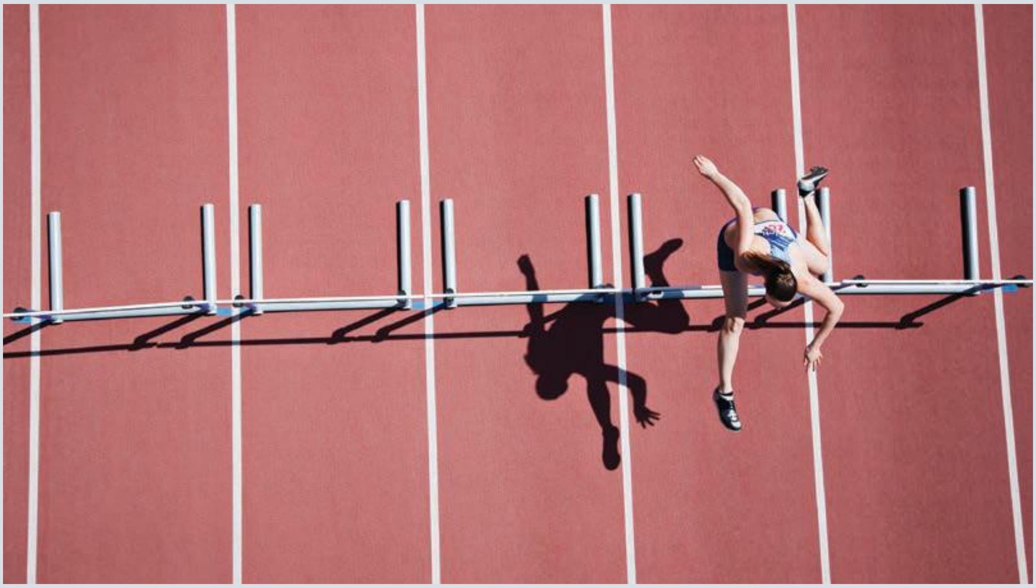

Figure 9.7 The fastest runner wins the race.

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Converting units

So far we have only used m/s for speed, but another common unit for speed is kilometres per hour (km/h), which is what most people use in cars. Here is a quick guide for converting units.

1 km = 1000 m

1 h = 3600 s

$$1\frac{\text{km}}{\text{h}} = \frac{1000\ \text{m}}{3600\ \text{s}} = \frac{1}{3.6}\ \frac{\text{m}}{\text{s}}$$

Multiplying both sides by 3.6 and swapping the sides to make 1 m/s the subject gives:

$$1\ \text{m/s} = 3.6\ \text{km/h}$$

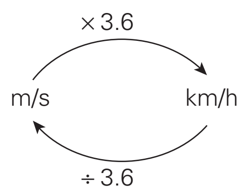

Figure 9.8 Converting m/s into km/h

To convert m/s to km/h, multiply by 3.6.

To convert km/s to m/s, divide by 3.6.

Quick check 9.2

Consider a cat and a dog that challenge each other to a 60 second race. Whoever travels the furthest in 60 s wins the race. The cat travels at an average speed of 4 m/s. The dog travels a total distance of 500 m in that time.

1 Does the dog or the cat travel further? Does the dog or cat win the race?
2 What is the average speed of the dog? Round to two decimal places.

Try this 9.2

Converting speed

Next time you are in a car, ask the driver to tell you how fast the car is travelling. Collect three samples at different speeds, and then convert each of them from km/h to m/s.

Are the results what you expected? Can you think of a scenario that would be appropriate to measure speed using m/s instead of km/h?

Did you know? 9.2

Speed of light

Light travels at a constant speed of 3×10^8 m/s. Nothing we currently know of can travel faster than light – it travels so fast that the distance between stars can be measured in units of light years. One light year is the distance that a beam of light travels in one year – equivalent to 9.46 trillion km!

Figure 9.9 Light travels faster than anything else.

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Average versus instantaneous

average speed
change in distance divided by change in time; usually measured in km/h or m/s

instantaneous speed
the speed at any particular instant

When talking about the speed that something travels, it can mean one of two things: **average speed** or **instantaneous speed**. It is important that we do not confuse the two.

Average speed is the measure of how fast something moves from point A to point B within a given time. Whereas, instantaneous speed is how fast something is travelling at a specific point in time.

Instantaneous speed can be determined using a radar gun or a speed camera. A speed detector calculates the average speed but over such a small time frame that it is essentially capturing the speed at that instant, therefore, it is called instantaneous. Another example of instantaneous speed detection is the speedometer in a car. The speedometer displays the speed at that instant in time. The driver gets instant feedback on how fast they are travelling.

Figure 9.10 Speed detectors can capture the speed of an object in a fraction of a second.

Velocity

velocity
change in displacement divided by change in time

Velocity is a term used to describe how fast something travels in a particular direction. Like speed, the common units associated with velocity are m/s or km/h. However, unlike speed, velocity is a measure of the change in displacement of an object within a certain amount of time. Sometimes velocity is preferable to speed because it has both size and direction. It is used as a measure of how quickly something travels in a specific direction. Aeroplane pilots and ship captains need to know their velocity so they can accurately navigate towards their destination.

Calculating velocity is similar to using the formula for speed, except distance travelled is replaced by displacement. The main difference between calculating speed and velocity is

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Figure 9.11 Terminal velocity is the highest attainable speed of a skydiver. It occurs when the skydiver is in freefall and the downward force of gravity is balanced by the upwards force of air friction so she is no longer accelerating. This skydiver's terminal velocity is at roughly 60 metres per second down to Earth.

that direction is important with the velocity, so displacement is used instead of distance. In the following formula, arrows are used to show that direction matters for velocity, and hence displacement is used, which also includes an arrow to denote that it has direction.

Mathematically, velocity can be described in the following ways:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

$$\vec{v}_{av} = \frac{\vec{d}}{t}$$

Worked example 9.3

Average speed versus average velocity

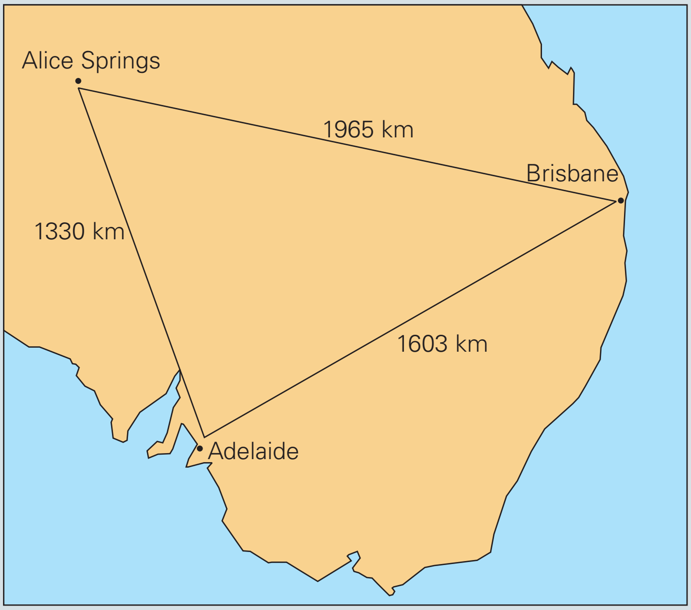

Figure 9.12

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Consider the triangle in Figure 9.12 made between Adelaide, Brisbane and Alice Springs. Imagine two aeroplanes that need to get from Alice Springs to Brisbane. Plane 1 travels directly to Brisbane. Plane 2 must stop in Adelaide before flying to Brisbane. It takes both planes 3.7 hours to reach Brisbane. The true bearing of Brisbane from Alice Springs is 106° clockwise from north.

1 What is the average speed of each plane?
2 What is the average velocity of each plane?
3 Which plane travels faster in the air?

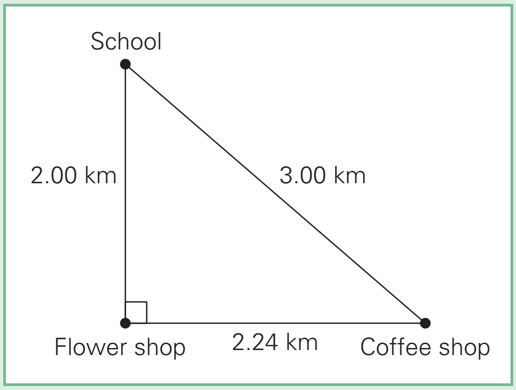
Worked solution

Thinking	Working
1) Average speed	
For average speed, use this formula: $v_{av} = \frac{d}{t}$	Plane 1: $v = \frac{1965}{3.7} = 531$ km/h Plane 2: $v = \frac{(1330 + 1603)}{3.7} = 793$ km/h
2) Average velocity	
For average velocity, use this formula: $\vec{v}_{av} = \frac{\vec{d}}{t}$	Plane 1: $\vec{v}_{av} = \frac{1603}{3.7} = 433$ km/h 106° clockwise from north Plane 2: $\vec{v}_{av} = \frac{1603}{3.7} = 433$ km/h 106° clockwise from north
3) Comparing speeds	
The plane with the greater average speed travels faster as it covers more ground in the same amount of time.	Plane 2 is faster in the air.

Quick check 9.3

Two students, Mia and Peter, leave school to meet at the local coffee shop. Peter decides to jog to the coffee shop, but also stops at a flower shop along the way. Mia decides to walk from school directly to the coffee shop. They arrive at the coffee shop at the same time, 30 minutes after they leave school.

1 How much further does Peter travel than Mia?
2 If it takes them both half an hour to reach the coffee shop:
   a What is Mia's average speed?
   b What is Peter's average speed?
3 Calculate their average velocities.



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Acceleration

When an object changes its velocity over a period of time, it can be said to have accelerated. Thus, acceleration also has a direction. In many problems we are only interested in the size (or magnitude) of the acceleration so we can then ignore its direction. **Acceleration** is the rate by which something increases or decreases its speed. Consider a car at a set of traffic lights. Initially it is stationary; we would say that it has an initial velocity of 0 km/h. Imagine that when the light turns green the car speeds up to 40 km/h in the next five seconds. This change in velocity means that the car has an acceleration.

acceleration
an object has acceleration when its velocity changes. Average acceleration equals change in velocity divided by the time taken. The most common unit is m/s^2 (metres per second per second).

Similarly, consider the car reaching another set of lights that have just turned red – it has to slow until it stops. When the car slows down, it decreases its speed over time; we call this **deceleration** (negative acceleration). For most purposes in science, 'acceleration' can be taken to cover both positive and negative acceleration.

deceleration
when an object is slowing down

Figure 9.13 Slowing to stop at a red light is negative acceleration, or deceleration.

An object that does not change velocity is travelling with a **constant speed**. Constant velocity occurs when the acceleration is zero.

constant speed
when an object is travelling at the same speed and is not accelerating or decelerating

If an object changes its velocity, then it is accelerating. When the object is moving in a straight line we can calculate its acceleration using the speed, as follows.

Mathematically, you can write acceleration in the following ways:

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

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

or

$$a = \frac{v_2 - v_1}{t}$$

Where v_2 is the final speed, v_1 is the initial speed and t is the time taken. Notice that $v_2 - v_1$ just represents the change in speed.

Using the acceleration triangle in Figure 9.14 is another helpful way to remember the formula for acceleration.

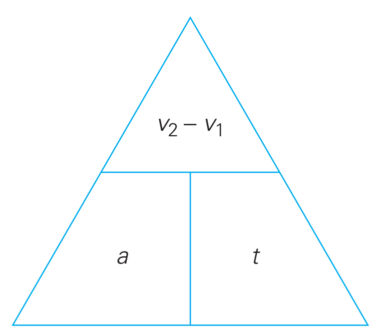

Figure 9.14 The acceleration triangle

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Using this acceleration triangle, you can derive formulas for:

- acceleration $a = \dfrac{v_2 - v_1}{t}$
- change in speed $t = \dfrac{v_2 - v_1}{a}$
- change in time $v_2 - v_1 = a \times t$

Worked example 9.4

Acceleration

Consider the motion of a dirt bike.

Figure 9.15 A dirt bike in motion

1 If it speeds up from rest in 3 seconds to 54 km/h in a straight line, calculate the acceleration.

2 If that same bike travelling at 54 km/hr comes to a stop in a straight line within 5 seconds. What is the acceleration? What does this mean?

3 If better brakes were installed on the bike, it could decelerate at quicker a rate of 10 m/s^2. Calculate how long it would take to stop if it was initially travelling at a speed of 72 km/h.

Worked solution	
Thinking	**Working**
1) Acceleration	
List the information that you have. Since the bike begins at rest, the initial speed is zero.	$v_1 = 0$ m/s $v_2 = 54$ km/h $= 15$ m/s $t = 3$ s $a = ?$
Calculate using the acceleration formula by substituting in all of the known values.	$a = \dfrac{v_2 - v_1}{t} = \dfrac{(15 - 0)}{3} = 5$ m/s^2
Interpret the answer.	The bike accelerates at a rate of 5 m/s^2 (5 metres per second, every second)

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2) Negative acceleration	
List the information. In this example the bike has an initial speed of 54 km/h, and a final speed of 0 km/h.	v_1 = 54 km/h = 15 m/s v_2 = 0 m/s t = 5 s a = ?
Substitute the known values.	$a = \frac{v_2 - v_1}{t} = \frac{(0-15)}{5} = -3\ \text{m/s}^2$
Interpret the solution and remember to include correct units.	Since there is a negative acceleration, the bike is decelerating at a rate of 3 m/s^2.
3) Faster stopping	
List the known information.	a = −10 m/s^2 v_2 = 0 m/s v_1 = 72 km/h = 20 m/s t = ?
Substitute the values into the acceleration formula.	$-10 = \frac{(0-20)}{t}$
Rearrange so that the unknown is the subject of the equation.	$t = \frac{-20}{-10} = 2\ \text{s}$
Interpret the solution.	It takes the bike 2 seconds to decelerate from 72 km/h to rest.

Try this 9.3

Car speeds

Next time you are in a car and travelling in a straight line, use the stopwatch on your phone to time the change in speed. Get the driver to read the speedometer to capture the instantaneous speed. Calculate the acceleration of the car under different circumstances using the formula for average acceleration in the following table. Remember not to distract the driver when doing this.

Test	Initial speed	Final speed	Time taken	Acceleration
Example:	0 km/h	10 km/h	5 s	$a = \frac{(0-10)\ \text{km/h}}{5\ \text{s}} = 2\ \text{km/hs}$
1				
2				
3				

Quick check 9.4

1 Define acceleration, deceleration and constant speed.
2 An object increases its speed from 5.2 m/s to 7.7 m/s in four seconds.
   a Calculate the acceleration of the object.
   b Assume that the object could decelerate at a rate of 1.5 m/s^2 (a = −1.5 m/s^2). Calculate the time it would take for the object to stop if it were initially travelling at 10 m/s (v = 10 m/s). Give your answer to two decimal places.

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Explore! 9.1

Harvesting energy from movement

Using movement to generate electricity is not a new idea. This involves converting kinetic energy into electrical energy via a generator. However, there have been many challenges in using portable energy harvesters to harvest energy from human motion. Conduct some research on the idea of harnessing energy from human motion (kinetic energy) and answer the following questions.

1. Describe the latest advances in this kind of technology.
2. Examine the possibilities and challenges this technology presents.
3. In your opinion, will this technology work in the future? Justify your response.

Practical 9.1

Ramps and cars

Aim

To investigate the effect of ramp height on the average speed of a crash trolley or model car.

Materials

- ramp at least 90 cm long
- stopwatch
- metre ruler
- 5 books of similar height that are wide enough for the ramp to sit on
- crash trolley or model car

Method

1. Copy the results table below.
2. Set up the ramp as shown in Figure 9.16. Use only one or two books for it to lean on initially.

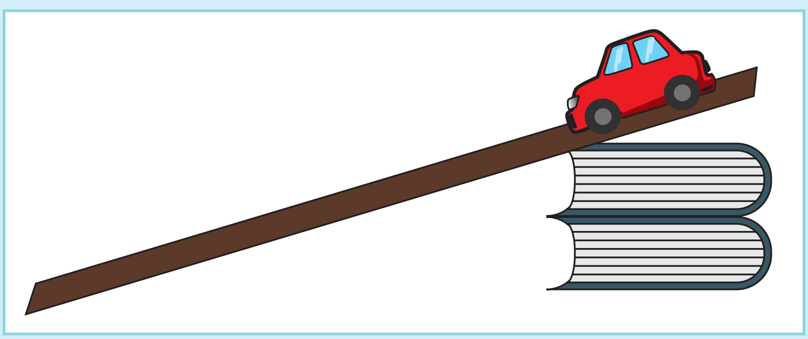

Figure 9.16

3. Measure the height of the ramp.
4. Use the stopwatch to measure how long it takes for a crash trolley or model car to roll down the ramp. Record the results in the results table.
5. Do this three times so you can average the results.
6. Repeat steps **3–5** using three, four and five books and record your results in the table.

Results

Ramp height	First time	Second time	Third time	Average
2 books				
3 books				
4 books				
5 books				

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Evaluation

1 What trend can you see based on the results?
2 Why was it good experimental technique to repeat the car roll three times for each ramp height?
3 Predict what would happen if you used a longer ramp with five books, but measured the time it took the car to roll the same length as it rolled using the previous ramp (as below in Figure 9.17). Can you test this out?

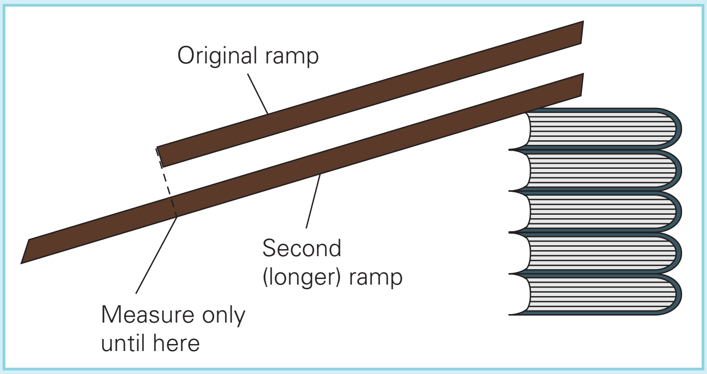

Figure 9.17

Conclusion

1 Make a claim about ramp height and speed based on this experiment.
2 Support the statement by using the data you gathered and include potential sources of error.
3 Explain how the data support the statement.

Section 9.1 questions

Remembering

1 What is/are the unit/s normally used for distance?
2 List the unit or units normally used for speed.
3 State the formula and unit for average acceleration in a straight line.

Understanding

4 Distinguish between distance and displacement. How are they similar?
5 Distinguish between speed and velocity. How are they similar?
6 Contrast average speed and instantaneous speed.

Applying

7 The average speed of a galloping horse is 40 km/h. If a horse is already travelling at that speed, how far will it travel in 2.3 hours?
8 If a person walks at an average speed of 4 km/h, how long will it take them to travel 50 m? Round your answer to the nearest second. Hint: First convert 4 km/h into m/s.
9 What is the acceleration of a car travelling at a constant speed of 50 km/h?
10 A sprinter starts from rest. In the first three seconds they reach a speed of 2 m/s. After the next 10 seconds they reach a speed of 6.5 m/s.
   a Calculate the average acceleration in the first three seconds, and round to two decimal places.
   b Calculate the average acceleration in the last 10 seconds.
   c When was the sprinter's acceleration the greatest? The first three seconds or that last 10 seconds?

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11 A car starts from rest and accelerates at a constant rate of 5 m/s^2 for five seconds.

a Calculate the final speed.

b Calculate the average speed. Because the speed increases at a constant rate, you can do this by using $(v_1 + v_2)/2$ to find the average speed.

c Calculate the displacement of the car after five seconds.

Analysing

12 Categorise the following as either acceleration, deceleration or constant speed.

Motion	Acceleration/deceleration/constant speed
A bike rider slowing down	
A text book sitting on a desk	
A sprinter taking off at the start of a race	
A dog running at 5 m/s forwards	
A car crashing into a brick wall	
A car rolling down a hill and gaining speed	

Evaluating

13 Imagine you were trying to figure out how efficient your car was in using petrol. Would you use distance travelled or displacement covered with one tank full? Explain your reasoning.

9.2 Graphing motion

WORKSHEET

You have now learned how to describe motion using scientific language and are also familiar with formulas to calculate average speed, velocity and acceleration of moving objects. In this section you will learn how to plot objects in motion onto a graph and use them to determine the displacement, speed and acceleration.

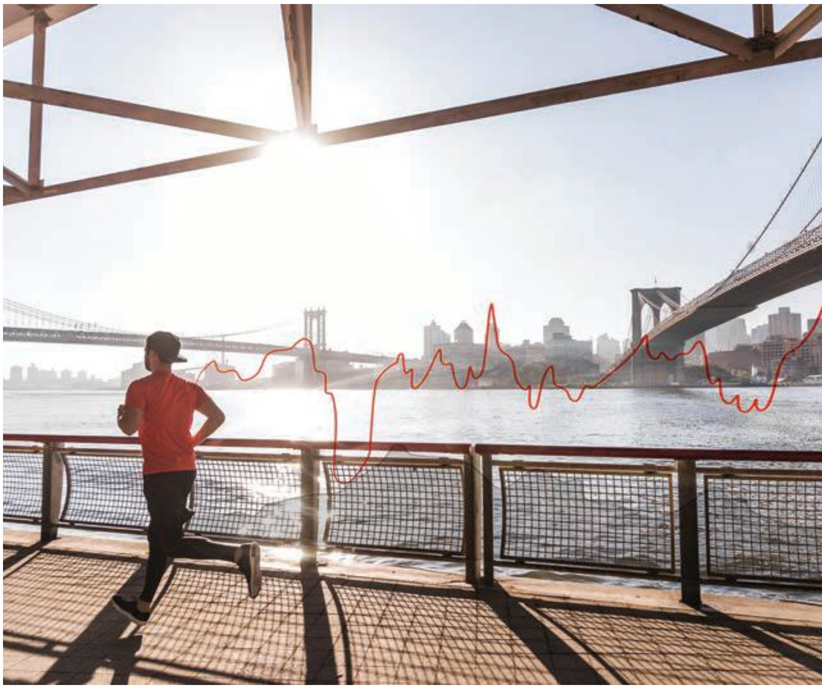

Figure 9.18 Graphing motion can give you a lot of information.

Distance–time graphs

Distance–time graphs show how far an object moves as time progresses. Distance travelled is on the vertical *y*-axis and time is on the horizontal *x*-axis. The **gradient** of the line indicates the speed of the object. Recall that:

gradient the gradient of a graph is the rise over the run

$$v_{av} = \frac{d}{t} = \frac{\text{rise}}{\text{run}}$$

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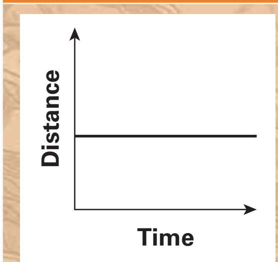
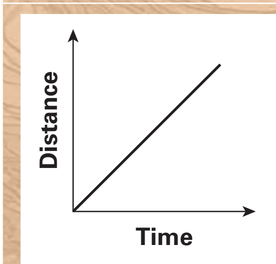
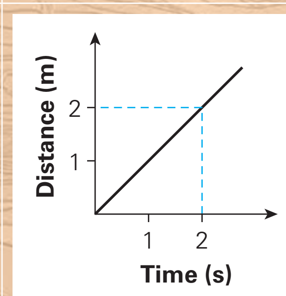
Table 9.1 shows some shapes you may see on a distance–time graph.

Shape	Explanation	Example
	Horizontal lines indicate that an object is **stationary**.	The $\frac{\text{rise}}{\text{run}}$ of horizontal lines is zero because the rise is 0 m. So the speed is 0 m/s.
	A straight line with a gradient indicates that the object is moving at a constant speed.	 $v = \frac{\text{rise}}{\text{run}} = \frac{2\text{ m}}{2\text{ s}} = 1\text{ m/s}$  $v = \frac{\text{rise}}{\text{run}} = \frac{1\text{ m}}{2\text{ s}} = 0.5\text{ m/s}$ The gradient of the first graph is steeper, which shows that object has a greater speed.

stationary not moving

Table 9.1 Two types of distance–time graphs

Figure 9.19 The distance-time graph of a Formula One race car would be different to a regular car driving down a busy road.

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Worked example 9.5

Distance–time graph

Take a look at the distance–time graph that shows Lin's walk in a straight line for six seconds.

1 Calculate her speed at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

2 When is Lin travelling the fastest?

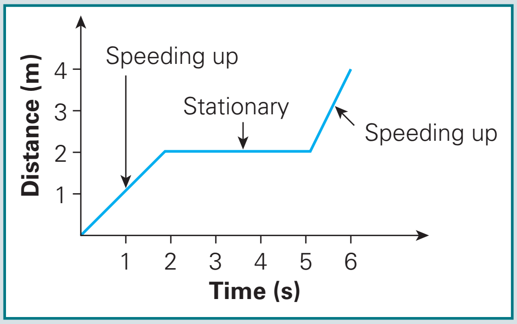

Figure 9.20

Worked solution	
Thinking	**Working**
1) Speed	
Select two points from each time interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the speed.	0 to 2 seconds: $v = \frac{\text{rise}}{\text{run}} = \frac{(2-0)\text{ m}}{(2-0)\text{ s}} = \frac{1\text{ m}}{1\text{ s}} = 1\text{ m/s}$ 2 to 5 seconds: Horizontal line indicates she is stationary. 5 to 6 seconds: $v = \frac{\text{rise}}{\text{run}} = \frac{(4-2)\text{ m}}{(6-5)\text{ s}} = \frac{2\text{ m}}{1\text{ s}} = 2\text{ m/s}$
2) Fastest interval	
The steeper line indicates a faster speed.	She travels the fastest from the 5th to the 6th second.

Quick check 9.5

1 Consider the distance-time graph of a moving object in Figure 9.21.

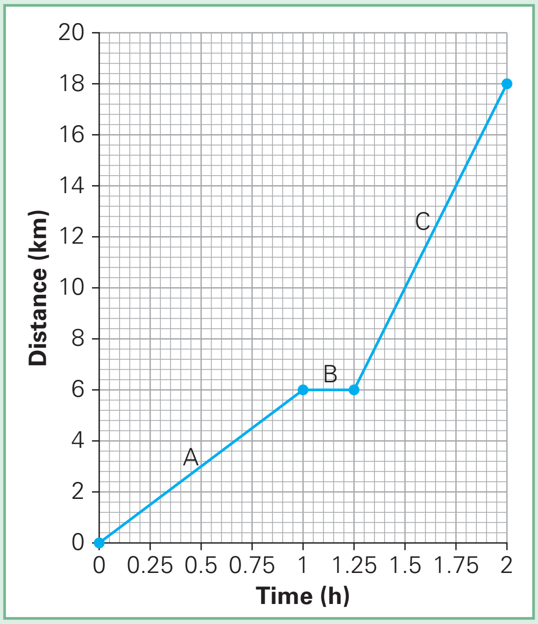

Figure 9.21

Calculate the average speed for each of the sections A, B and C. Then describe the motion of the object.

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Displacement-time graphs

Displacement-time graphs are similar to distance-time graphs, but they also show the object's location with respect to a starting point. In other words, they can show whether an object is moving away from, or back towards, its initial position over a period of time. The starting position is always located on the graph at the coordinate (0,0), and is referred to as the **origin**.

origin
the point at which the axes of a coordinate system intersect

Worked example 9.6

Displacement-time graph

Remember the distance-time graph for Lin's walk. Here is her displacement-time graph.

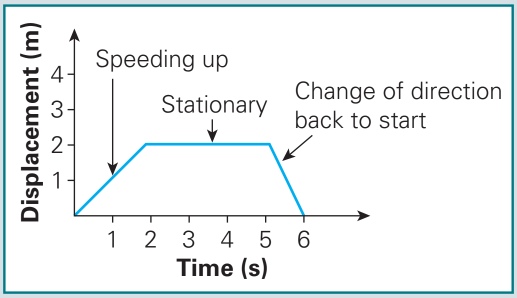


Figure 9.22

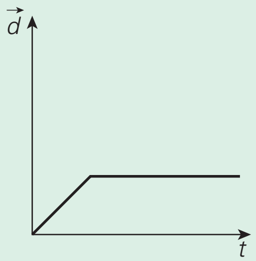
Describe her movements in relation to her starting point.

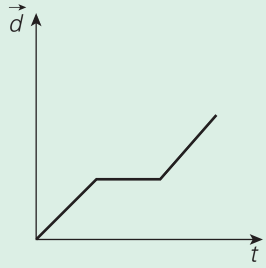
Thinking	Working
The displacement *y*-axis indicates how far from the start she is. In the distance–time graph, you could not tell which direction she was travelling, only that she was moving.	For the first two seconds, she moves away from her starting position. For the next three seconds she is stationary. In the final second she speeds up but moves back to the origin (her starting position).

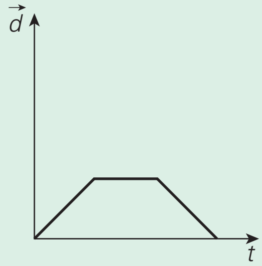
Worked examle

Quick check 9.6

1 Describe the motion of an object according to the following displacement–time graph shapes.

a


b


c


Try this 9.4

Displacement–time graph creative story

You have been handed a displacement–time graph; you have no idea what object or what motion it could be describing. Working in a group of two or three, your job is to create a story that matches the displacement–time graph in Figure 9.23.

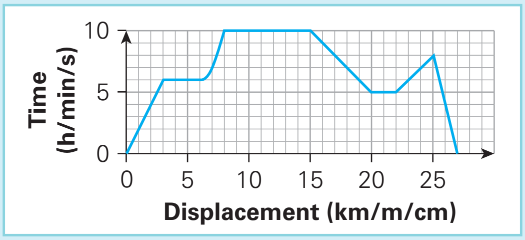


Figure 9.23

continued...

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You might consider a car in motion, a day in the life of a snail, or even the motion of seaweed as it drifts through the ocean. You should try to be as creative and as imaginative as possible. You may change the scale of either axis so that your story fits better. The aim is to try to describe all of the key features that you can see on the displacement–time graph. Remember to include words from this chapter like: constant speed, stationary, acceleration, at rest.

Challenge: If you have finished your story, calculate the speed at certain points along the path.

Speed–time graphs

Speed–time graphs show the speed of a travelling object as time passes. They are quite useful because they can be used to determine the distance travelled, the instantaneous speed and the acceleration of a moving object. Speed–time graphs have three important features.

- Instantaneous speed can be read directly from the graph at any particular point in time.
- The gradient between two points on a speed–time graph represents the average acceleration over that time interval of the object in motion.
- The area under a speed–time graph represents the distance that the object has travelled.

Reading instantaneous speed

Imagine that a speed detector is used to capture the instantaneous speed of an object in motion every second for a period of 10 seconds. The following table is created and then the data is represented on a speed–time graph.

Speed (m/s)	0	2	4	6	8	10	10	10	10	5	0
Time (s)	0	1	2	3	4	5	6	7	8	9	10

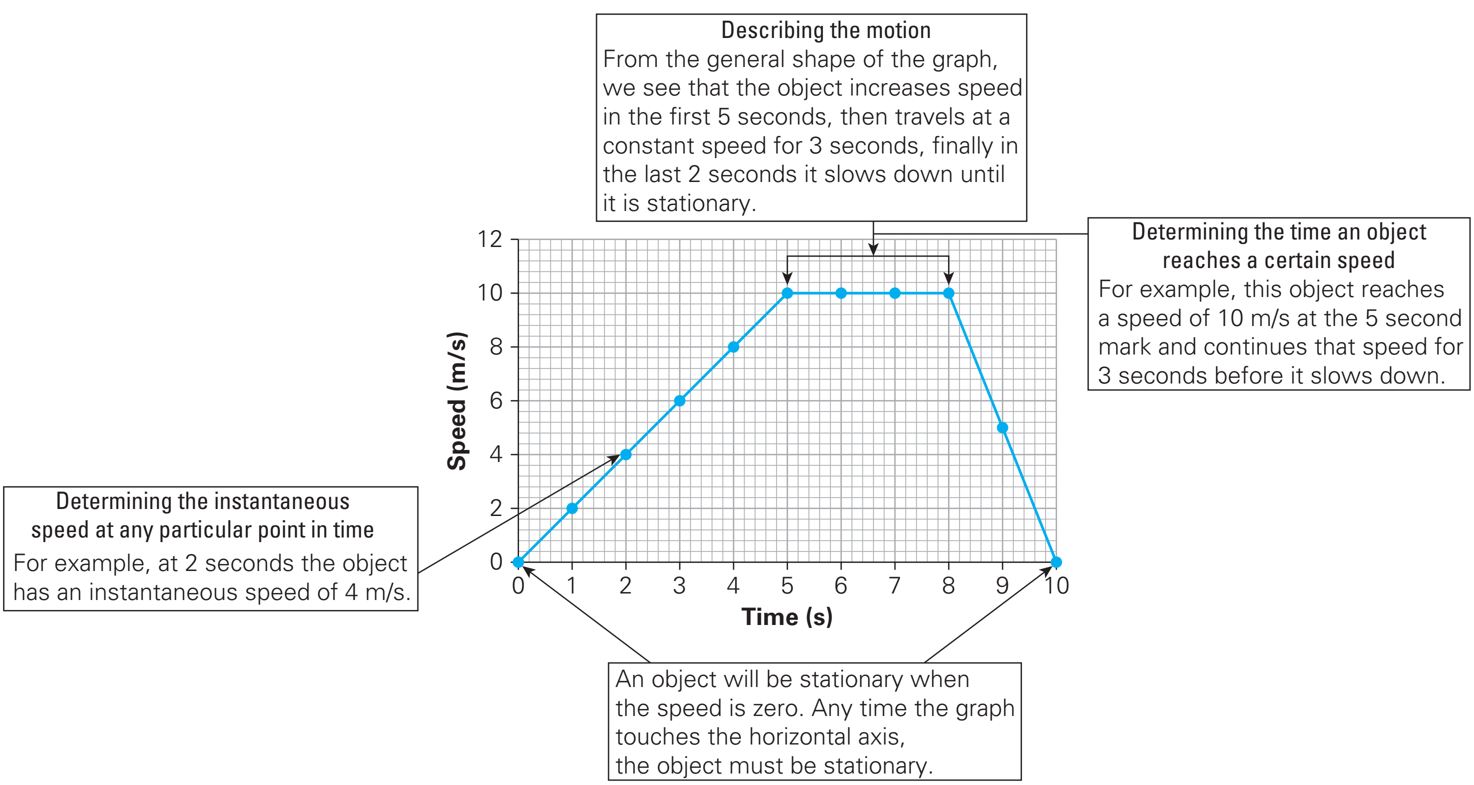

Figure 9.24 A speed–time graph tells you a lot about an object's motion.

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Finding acceleration from the gradient

Speed–time graphs have three common configurations, and you need to be able to distinguish between them. The three graphs in Table 9.2 help to identify when an object in motion is speeding up (accelerating), when an object is slowing down (decelerating), or when an object is travelling at a constant speed.

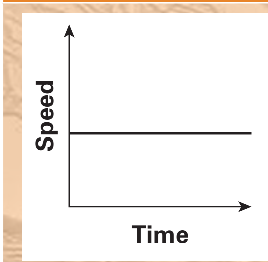
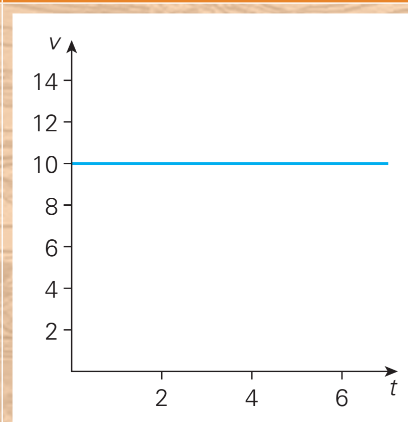
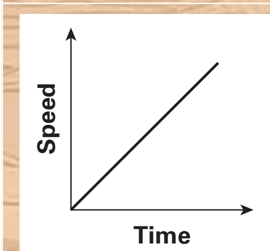
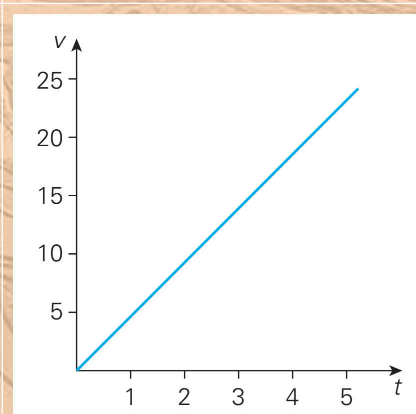
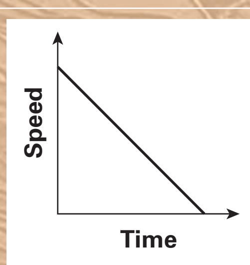
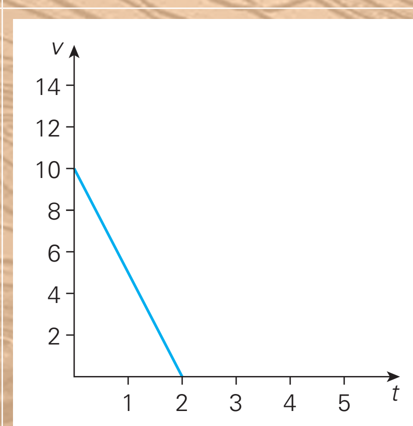
Shape	Explanation	Example
	Horizontal lines indicate that an object is travelling at a constant speed.	 $a = \frac{\text{rise}}{\text{run}} = \frac{0\text{ m/s}}{10\text{ s}} = 0\text{ m/s}^2$
	Positive gradient means positive acceleration (speeding up). The steeper the gradient the more the object accelerates.	 $a = \frac{\text{rise}}{\text{run}} = \frac{25\text{ m/s}}{5\text{ s}} = 5\text{ m/s}^2$
	Negative gradient means negative acceleration (deceleration). The steeper the gradient the quicker the object decelerates.	 $a = \frac{\text{rise}}{\text{run}} = \frac{-10\text{ m/s}}{2\text{ s}} = -5\text{ m/s}^2$

Table 9.2 Three types of speed–time graphs

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Calculating distance travelled

In some problems, you may be given the speed–time graph and asked to work out the distance travelled. The distance an object travels can be calculated by summing the area under the graph. Often it might be simpler to split the graph into smaller sections.

Calculating the distance **Worked example 9.7**

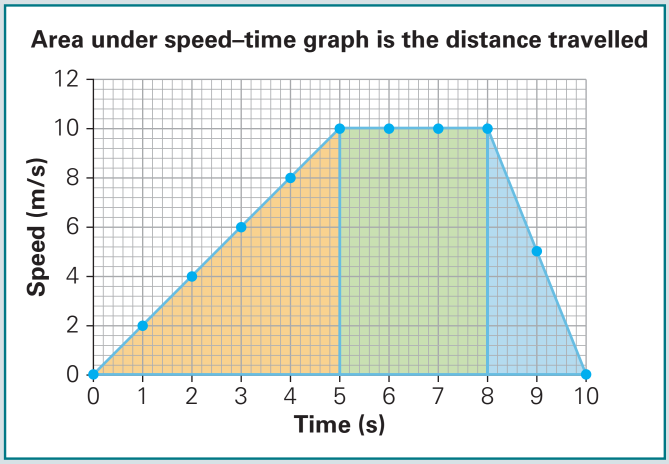


Figure 9.25

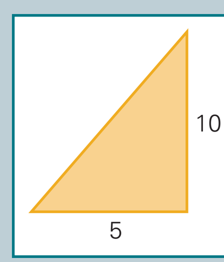
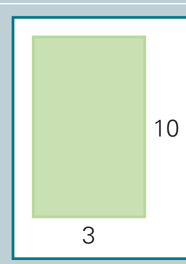
Consider this graph of an object in motion.

1 Calculate the distance travelled in the first five seconds

2 Calculate the distance travelled from $t = 5$ to $t = 8$.

3 Calculate the distance covered in the final two seconds.

4 What is the total distance covered by the object, over the entire 10 seconds?

Worked solution	
Thinking	**Working**
1) Distance in first five seconds	
Redraw the shape and label the known sides Calculate the area of a triangle is given by the formula $A_{\Delta}=\frac{1}{2}bh$ Interpret the area, and check that units are correct.	The area in the first five seconds can be described by the following triangle. $A_1=\frac{1}{2}(5)(10)=25$ This means that in the first five seconds the object travels 25 metres. 
2) Distance from $t = 5$ to $t = 8$	
Redraw the shape and label the known sides. Calculate the area of the rectangle given by the formula $A_{\square}=l\times w$. Interpret the solution with correct units.	The area under the graph between $t = 5$ and $t = 8$ can be described by the following rectangle. $A_2 = 3 \times 10 = 30$ This means that the distance travelled over this period is 30 metres. 

continued…

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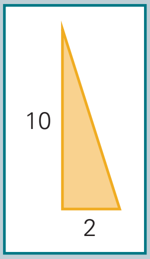
...continued

3) Distance in final two seconds	
Redraw and label the shape. Calculate the area. Interpret solution with correct units.	The area under the graphs in the final two seconds is represented by the following triangle.  $A_3 = \frac{1}{2}(2)(10) = 10$ In the final two seconds the object travels 10 metres.
4) Total distance covered	
Add up all of the area sections under the graph to get the total distance travelled.	Sum each of the areas for the total distance covered. $A_T = A_1 + A_2 + A_3$ $= 25 + 30 + 10$ $= 65$ Therefore, the total distance covered by the object over the 10 seconds is 65 metres.

Quick check 9.7

Consider the following speed–time graph.

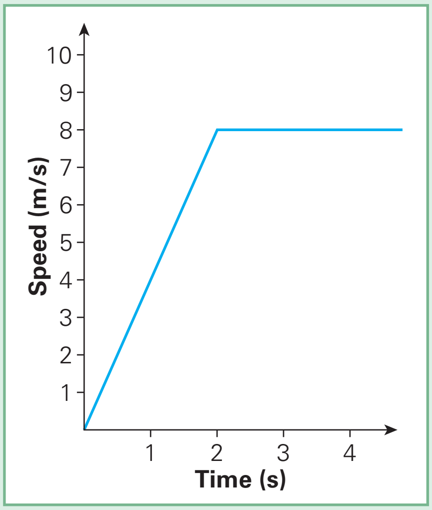


Figure 9.26

1. Describe the motion.
2. Calculate the acceleration over the first two seconds.
3. What is the acceleration between $t = 2$ and $t = 4$?
4. What is the distance travelled after the first two seconds?
5. How far has the object travelled after four seconds?

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Practical 9.2

Investigating the motion of students over 100 m

Aim

To investigate the speed profile of sprinters.

Materials

- stopwatch

Method

1. Copy the results tables below.
2. Choose at most five classmates to sprint 100 m.
3. Line up the remainder of your classmates at 20 m intervals along the 100 m track. Start the first sprinter.
4. Use stopwatches to capture the time from when a sprinter begins, to when they pass each 20 m interval. Ideally there will be at least two classmates at each interval so that an average of the times can be calculated. Record these results in a table.

Results

1. Complete the table of distance vs. time.
   Distance vs. time (seconds)

Student name	20 m	40 m	60 m	80 m	100 m

2. Calculate the average speeds and complete the table of average speed vs. time.
   Average speed (m/s) vs. time

Student name	20 m	40 m	60 m	80 m	100 m

3. Plot the distance–time and average speed–time graphs by drawing smooth trend lines.

Evaluation

1. Are the shapes of the graphs generally similar?
2. Describe what is happening at each 20 m interval in terms of speed.
3. Why do you think it was important to gather data from various classmates instead of just from one?
4. What are some potential sources of error (uncertainties or experimental method faults)?
5. Imagine if your classmates walked, hopped or crawled. Predict what the graphs would look like.

Conclusion

1. Make a claim about sprints and speed based on this investigation.
2. Support the statement by using the data you gathered and include potential sources of error.
3. Explain how the data support the statement.

Science as a human endeavour 9.1

Motion and gait analysis

Gait analysis is the study of human movement from one place to another. Research in gait analysis has applications in various conditions that affect human movement, such as Parkinson's disease and knee osteoarthritis. Accurate assessment can improve the movement of individuals who have undergone knee or hip replacement surgery.

continued...

...continued

Researchers in the wearHEALTH group at the University of Kaiserslautern, Germany, are developing a wearable system for analysing people's gait as they move around. By using sensors for acceleration and angular velocities, the technology can calculate the motion parameters of the hip, knee and ankle and also step lengths.

This technology could give users real-time information about their posture as they are walking. It has the potential to help people who have joint diseases and require hip or knee replacements as they go through rehabilitation and learn how to walk with the correct posture after the surgery.

Figure 9.27 Wearable and mobile technology can help people correct their posture even when they are not at gait rehabilitation centres.

QUIZ

Section 9.2 questions

Remembering

1 What does the gradient of a distance–time graph indicate?

2 What does the gradient of a speed–time graph indicate?

3 What does the area under a speed–time graph indicate?

Understanding

4 Describe what the shape of a displacement–time graph can reveal about an object's movements.

5 Describe what the shape of a speed–time graph can reveal about an objects movements.

Applying

6 The path of a caveman as he makes the trek to a nearby village then back to his cave, is shown on this displacement–time graph in Figure 9.28.

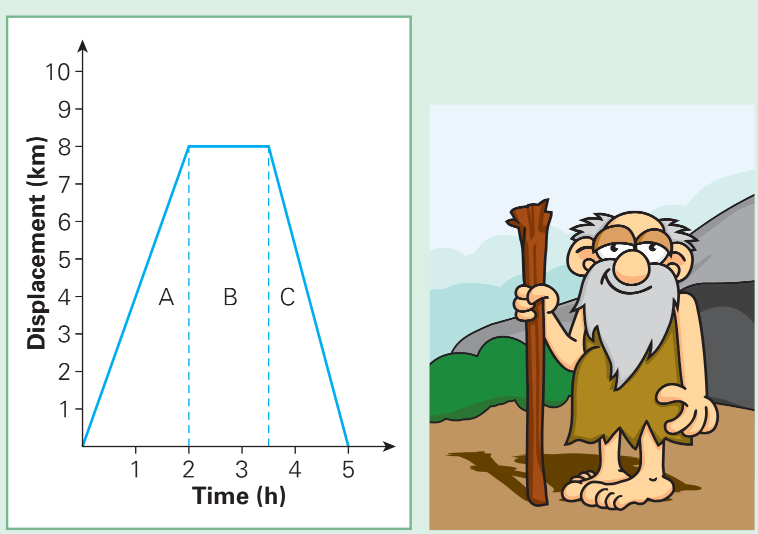

Figure 9.28

continued...

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...continued

a How far is the village from the cave?

b What is the velocity of the caveman as he walks from his cave to the village (section A)?

c How long does the caveman wait at the village (section B)?

d How quickly does the caveman return back to his cave once he leaves the village (section C)?

7 Consider the speed–time graph in Figure 9.29.

a Describe the motion of the object.

b Calculate the acceleration in the first three seconds.

c Calculate the acceleration for the next two seconds.

d Calculate the distance the object has travelled after five seconds.

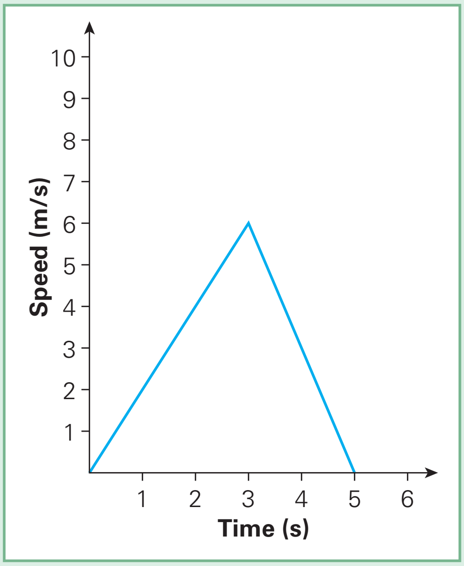

Figure 9.29

Analysing

8 Hundreds and thousands of animals in Australia are killed every year by vehicles.

a If a driver travelling at 90 km/h (25 m/s) takes 0.5 seconds to react, and they come to a stop according to the following speed–time graph, what is the total stopping distance?

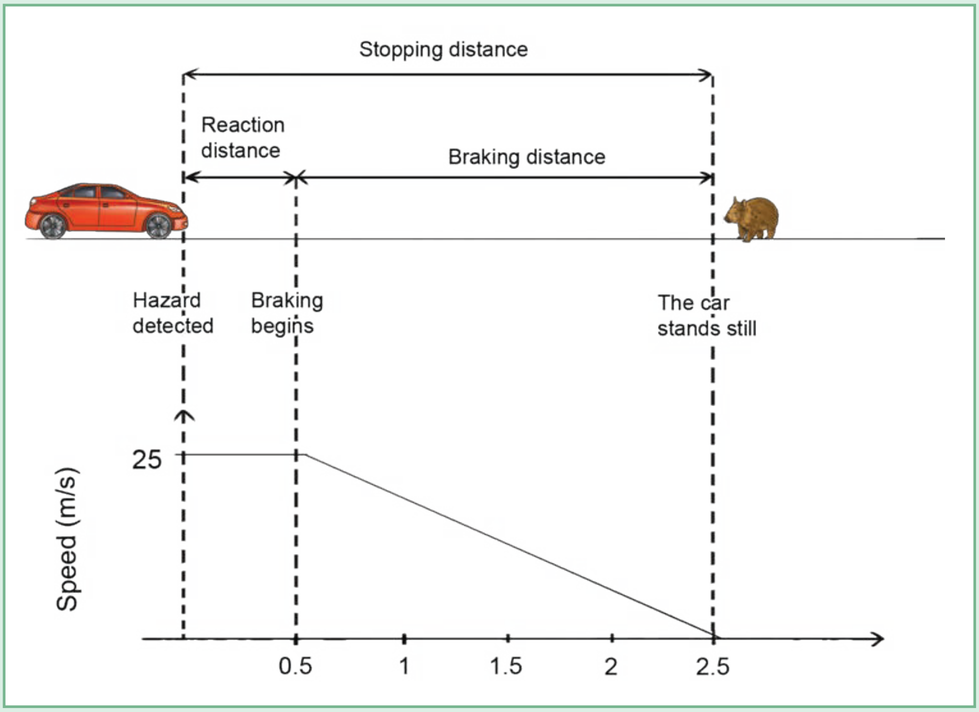

Figure 9.30

b If the reaction time was increased by 0.5 seconds, in other words the reaction time was one second, what would the stopping distance be?

c What can you infer about reaction times? What things can affect reaction time?

continued...

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...continued

Evaluating

9 Use the following table to draw the graph of the distance–time graph of an object. Based on the shape of the graph, what conclusions can we make about its movements? Evaluate whether we can tell in which direction it went and justify your response.

Time (s)	Distance (m)
0	0
2	2
5	3
7	3
9	4
10	5

9.3 Forces and Newton's laws of motion

WORKSHEET

VIDEO
Newton's first law

Sir Isaac Newton's three laws of motion

Newton's first law of motion

Newton's first law of motion, also known as the law of **inertia**, states:

> An object will remain at rest or travel at a constant speed in a straight line unless it is acted upon by an unbalanced force.

As you might remember from previous years of study, a force is a push or pull acting on an object. Put simply, a **force** is any interaction with an object that if left unopposed will cause the object to move. At any given time, multiple forces may act on any single object. These forces determine if the object will accelerate, continue to travel at a constant speed or remain at rest. Force has both magnitude and direction; it can be represented using the symbol F, and is generally measured in newtons (N).

If the forces acting on an object are balanced, meaning equal in magnitude (size) and in opposite directions, then the object will not change its motion. That is, if the object is at rest it will stay at rest, and if an object is travelling at a constant speed it will continue at a constant speed in the same direction. The term **net force** is used to describe the sum of all forces acting on an object. So that when the net force is zero ($F_{net} = 0$) it means that the forces are balanced and will not change the motion of the object. However, if the forces applied to an object are unbalanced ($F_{net} \neq 0$), then the object will either accelerate or decelerate or change direction.

Newton's first law of motion
an object will remain at rest or in uniform motion in a the same direction unless acted upon by an external force

inertia
a property of matter that keeps something in the same position or moving in the same direction unless acted upon by an external force

force
any interaction that, when unopposed, will change the motion of an object

net force
the sum of all the forces acting on an object

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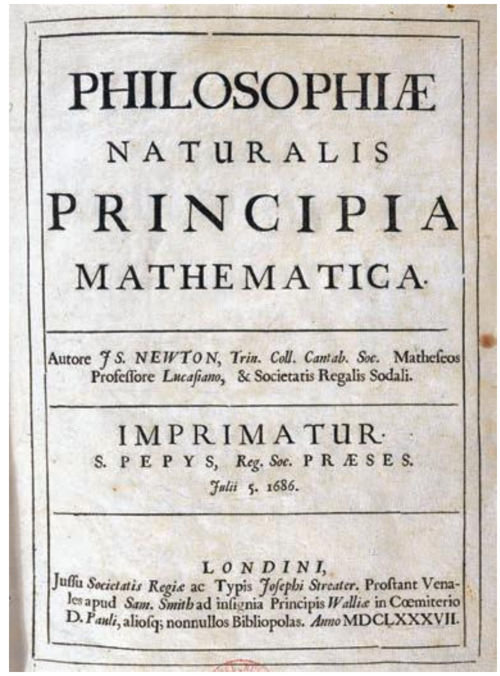

PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostant Venales apud Sam. Smith ad insignia Principis Walliæ in Cœmiterio D. Pauli, aliosq; nonnullos Bibliopolas. Anno MDCLXXXVII.

Figure 9.31 'I do not know what I may appear to the world; but to myself I seem to have been only like a boy, playing on the sea-shore, and diverting myself, in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.' Sir Isaac Newton, 1642–1727

$F_{net} = 0$	$F_{net} \neq 0$
The forces acting on an object are balanced and sum to zero. The motion of the object is not changed in speed or direction.	The forces on the object are unbalanced and sum to either a positive or negative number. The motion of the object changes. It either speeds up or slows down or changes direction depending on the direction of the net force.

Table 9.3 The effect of balanced and unbalanced forces

Inertia is responsible for the feeling that you get when you suddenly change motion in a car, train or aeroplane, or on a bike. At times when we travel at a constant speed, we hardly even recognise that we are moving. But when the vehicle that we are travelling in suddenly stops, turns a sharp corner or accelerates, we notice that our body moves unexpectedly. This is inertia! It is the tendency for objects to either stay at rest or continue travelling at a constant speed in the same direction.

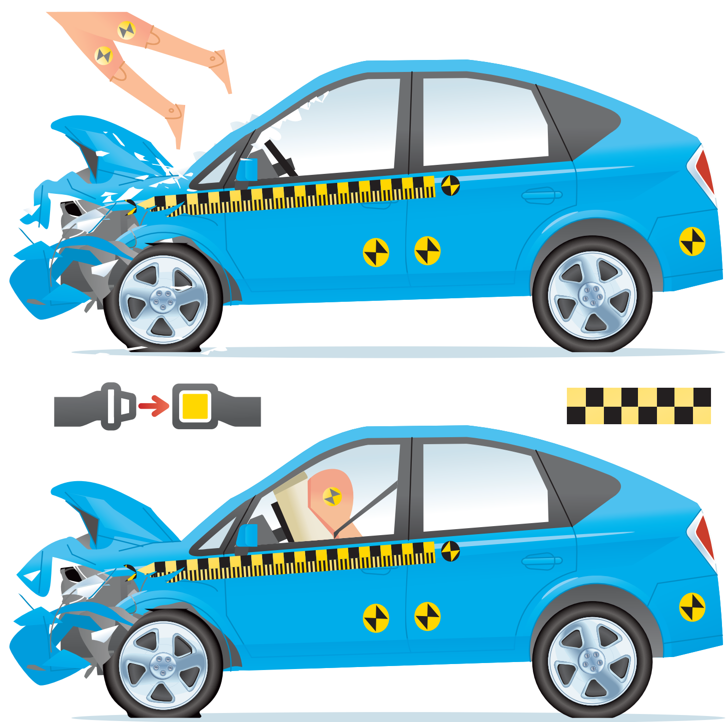

Figure 9.32 Consider travelling in a car at a constant speed. When the brakes are suddenly pressed, the car quickly slows down but our body continues to move forwards at the original speed. If it were not for seatbelts we would continue our motion towards the front window of the car.

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Inertia on bus rides

Try this 9.5

Imagine you are travelling in a bus. Try to re-enact and then describe how your body moves when travelling under different circumstances. Remembering that inertia is just an object's tendency to resist a change in motion, consider the forces acting on your body and the direction your body moves when:

1 the bus is stationary
2 the bus travels at a constant speed
3 the bus is travelling at a constant speed, then suddenly stops
4 the bus takes a sharp right or left hand turn
5 the bus accelerates after a set of lights turns green.

Figure 9.33 You can feel the effect of inertia when you travel on a bus.

VIDEO Newton's second law

WIDGET Newton's second law

Newton's second law of motion

Newton's second law of motion is a simple mathematical formula that describes the relationship between net force, mass and acceleration. Newton's second law states:

> The net force acting on an object equals the mass of the object multiplied by the acceleration.

It can also be written as:

net force = mass × acceleration

$$F_{net} = ma$$

Newton's second law of motion
an object acted upon by a force experiences acceleration in the same direction and proportional to the magnitude of the net force, and inversely proportional to the mass of the object

From this equation, the following three statements can be generated.

- The more massive the object, the greater the force needed to accelerate it.
- The greater the force applied to an object, the quicker it will accelerate.
- If the same force is applied to a more massive object, the acceleration will be less.

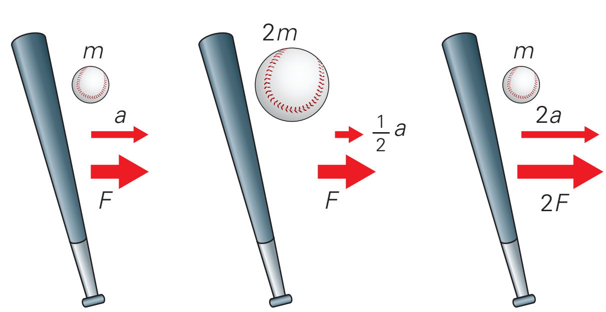

Figure 9.34 A baseball hit by a bat follows Newton's second law of motion.

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Imagine a hitting a baseball with a bat as in Figure 9.35. When a net force is applied to the ball it will accelerate. Consider what would happen if we were to swap the baseball with a larger baseball with twice the mass. Newton's second law tells us that if the same force were applied to larger baseball with twice the mass, it would not accelerate as much as the baseball because of the difference in mass. Lastly, if we were to apply a greater force on the baseball, it would increase the acceleration.

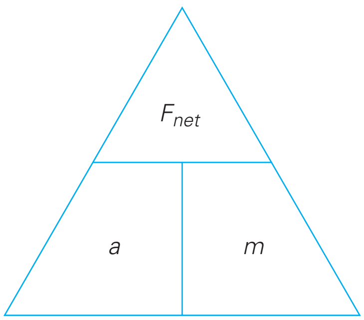

Figure 9.35 The force triangle

Using the force triangle (Figure 9.22), we have:

$$F_{net} = \frac{a}{m},\ a = \frac{F_{net}}{m},\ m = \frac{F_{net}}{a}$$

Newton's first law recognises that unbalanced forces acting on an object will result in a net force that accelerates the object. Newton's second law adds to this by letting you calculate the acceleration of the object if you are given the net force applied to the object and the mass of the object.

Worked example 9.8

Consider two students moving a table of mass 13 kg. One student pushes with a force of 30 N while the other pulls with a force of 80 N. Ignore all vertical forces and ignore frictional forces between the table and the floor.

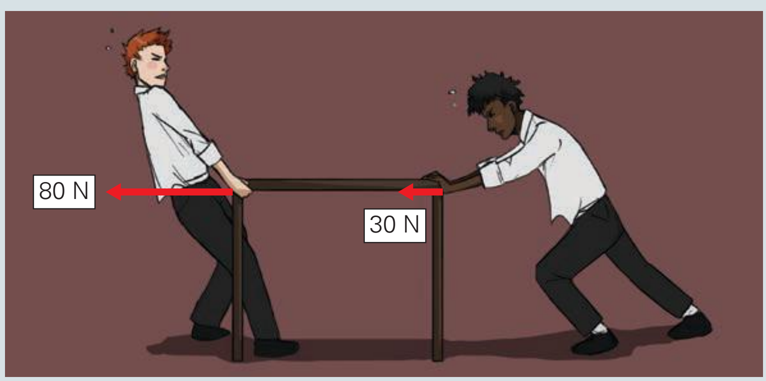

Figure 9.36

1 What is the net force and direction of the table?

2 What is the acceleration of the table?

Worked solution	
Thinking	**Working**
1) Net force	
Calculate the net force by simply adding all of the forces acting on the table. Since the surface of the floor pushes up on the table with the same force as the table pushes back on the floor, you can ignore the vertical forces. The only relevant forces acting on the table are the two in the horizontal direction. The net force is the sum of the two forces that the students exert on the table.	F_{net} = 30 + 80 = 110 N to the left There is effectively 110 N of force acting on the table towards the left direction.
2) Acceleration	
Newton's second law allows you to calculate how quickly the table will accelerate if you know what the mass of the table is. (In real life there would be a frictional force between the table and the floor acting against the motion. If in this example the frictional force was 50 N then the net force would be 60 N (110 N - 50 N) and the acceleration 60 N/13 kg = 4.62 m/s² to the left.)	$a = \frac{F_{net}}{m}$ $a = \frac{110\text{ N}}{13\text{ kg}} = 8.46\text{ m/s}^2$ to the left

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Newton's discovery of gravity

Newton came to believe that bodies attract other bodies. He concluded that there must be a force that pulls things towards each other, like the apple falling from the tree is attracted by earth. This force later became known as gravity. Based on his observations, Newton proposed that more massive objects will have a higher gravitational strength, which pulls objects towards them at a faster rate.

mass
mass is the quantity of matter in a body regardless of its volume or of any forces acting on it

weight
the weight (W) of an object is the force of gravity on the object and is defined as the mass times the acceleration of gravity: $W = mg$

Mass is a fundamental property of an object. Mass is measured in kilograms. However, **weight** is a force which is measured in newtons. In physics, weight is often called the 'force due to gravity', or the 'weight force'. To calculate the weight force, multiply the mass of the object by the acceleration due to gravity. For example, Earth's gravitational field pulls objects to its centre at a rate of 9.8 m/s^2 so a person with a mass of 70 kg will have a weight of 70 × 9.8 = 686 N.

In general, you can use the following equation to calculate the weight force

$$F_g = mg$$

Where F_g is the force due to gravity, also known as the weight force measured in newtons (N), m is the mass of the object measured in kilograms and g is the acceleration of the object due to gravity measured in m/s^2.

Remember the mass of an object is the same regardless of the strength of the gravitational field.

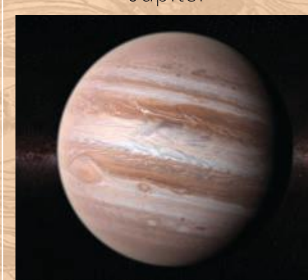
Earth	the Moon	Mars	Jupiter
			
g = 9.8 m/s^2	g = 1.6 m/s^2	g = 3.7 m/s^2	g = 24.8 m/s^2

Table 9.4 The acceleration due to gravity is different on different planets and their moons!

Did you know? 9.3

Alchemy

Aside from Newton's considerable contribution to the physical sciences, he had an obsession with alchemy that was not only illegal at the time, but would also be seen as absurd today. For most of his life, Newton was fixated on discovering a mythical substance called a philosopher's stone; a substance which he and others at that time believed could transmute base metals into gold. While that may seem ridiculous today, you have to remember that during the time of Newton, chemistry was in its infancy and the basic structure of elements was unknown. It is worth considering that it may have been his passion and perseverance in the face of failure that led Newton to become one of the most influential scientists in history.

Figure 9.37 Alchemists sought the philosopher's stone.

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Quick check 9.8

1 Calculate the force that is required to accelerate an object of mass 6 kg at 2.3 m/s^2.
2 Calculate the mass of an object that accelerates at 0.63 m/s^2 when it is pushed with a force of 20 N. Give your answer to two decimal places.
3 Consider a car of mass 1500 kg travelling at a constant speed. Calculate the deceleration when the brakes are applied with a force of 1200 N.

Practical 9.3: Self-design

Acceleration due to gravity

Aim

This practical asks you to design an experiment to measure the magnitude of the acceleration due to gravity in your area.

Materials

- a number of objects to drop (e.g. marble, steel ball bearing)
- 3 m long measuring tape
- smartphone with high-speed slow motion capabilities

Method

Work out, and write up, your procedure to determine accurately the magnitude of the acceleration due to gravity.
E.g. Tape the 3 m long measuring tape to a wall, drop different objects a number of times (perhaps three times for each object), try a few different dropping heights, undertake analysis of the high-speed videos.

Results

Make a table for all your results with the appropriate parameters.
Record all the collected data.
Analyse the data to produce an estimate of the magnitude of the acceleration due to gravity.

Evaluation

1 Do the different objects accelerate at the same rate? Why or why not?
2 How many trails were there of the same object?
Explain why you did this and what the variations were.
3 Did air resistance effect your results? Explain.
4 Explain why did you not measure the mass of the various objects that you were dropping?

Conclusion

1 Compare your results with the accepted value of the magnitude of the acceleration due to gravity in your local area.
2 Suggest any sources of error in your experiment.
3 Were there any ways the experiment you designed could have been improved? Explain.

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Explore! 9.2

Engineering cars to protect occupants

Car crashes can involve extremely large forces. Engineers have to design cars to minimise the impact of these forces on the occupants and improve their chances of surviving unscathed. Test crash dummies are fitted with accelerometers to determine the nature and size of the forces involved in a car crash.

1 Investigate the latest advances in car safety design and the design of test crash dummies.
2 Why do we not legislate that everyone must drive the latest and safest cars?
3 What are some of the reasons that car crashes occur even in safe cars?

Figure 9.38 Here is the result of a dummy not wearing a seatbelt in a 20 km/h crash!

Practical 9.4: Self-design

Force and mass

Aim

To investigate the effects of force and mass on acceleration.

Materials

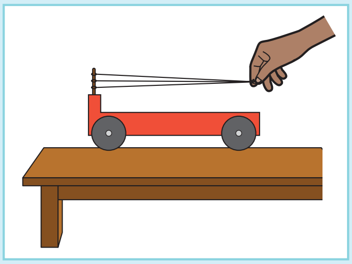
- crash trolley
- elastic bands
- weights
- tape
- stopwatch

Method

Design an experiment that investigates the effects of force and mass on acceleration. You can use increasing numbers of elastic bands to demonstrate increased force applied on the trolley.

Results

Remember to record your data.



Evaluation

1 As you increase force, what happens to acceleration?
2 As you increase mass, what happens to acceleration?
3 How can your experiment design be improved?
4 Identify any sources of error (experimental uncertainty or experimental faults).

Conclusion

1 Make a claim about force, mass and acceleration based on this experiment.
2 Support the statement by using the data you gathered and include potential sources of error (experimental uncertainty or experimental faults).
3 Explain how the data support the statement.

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Newton's third law of motion

Newton's first two laws examine the forces acting on a single object. **Newton's third law of motion** describes what happens to an object when it is acted upon by another object. The third law suggests that all forces come in pairs: an action force that acts on one object and a reaction force that acts on the other object. For example, if you were to push on a wall the wall pushes back just as hard – if it did not you would fall through! Newton's third law states:

Newton's third law of motion
for every action, there is an equal and opposite reaction

> For every action there is an equal but opposite reaction force.

There are many examples of these action–reaction pairs.

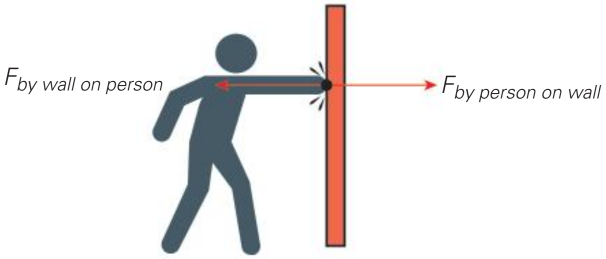

Figure 9.39 The action of pushing against a wall has a reaction force that pushes back on the person with the same magnitude.

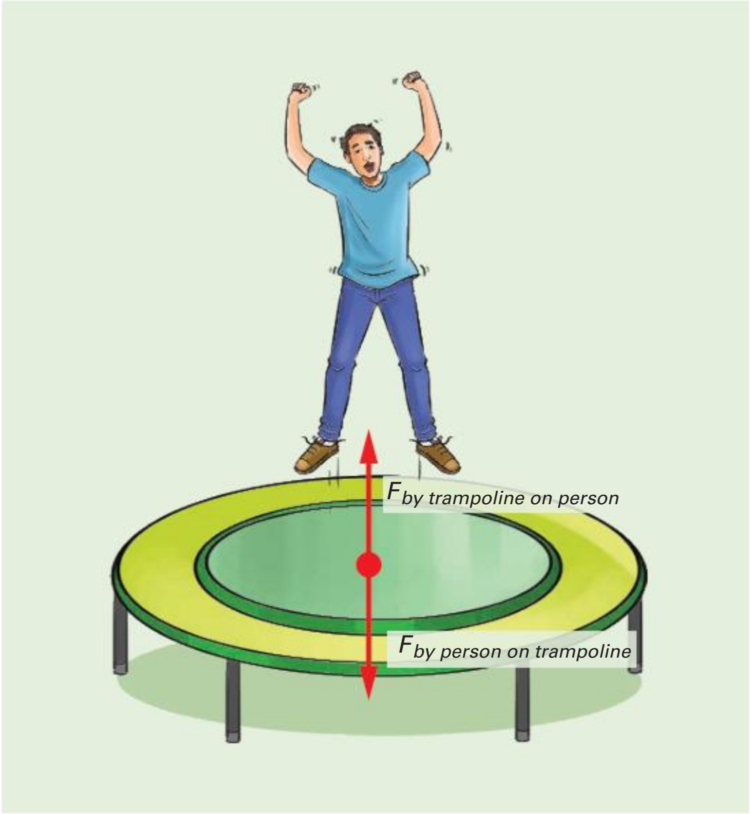

Figure 9.40 As a person jumps down on a trampoline they exert a force downwards on the mat when in contact with the mat. The mat then pushes back up with an equal but opposite force. This can cause the person to bounce back into the air.

Action–reaction pairs always act on different objects. For example, if the action force is the force the person's feet exerts on the ground (a contact force) then the reaction force is the contact force that the ground pushes up on the person's feet (or vice-versa). The action–reaction forces always act on different objects, in opposite directions and have the same magnitude. This means that an apple pulls Earth up with exactly the same force that Earth pulls the apple down!

Quick check 9.9

1 Copy this diagram and label with the action force and the reaction force.

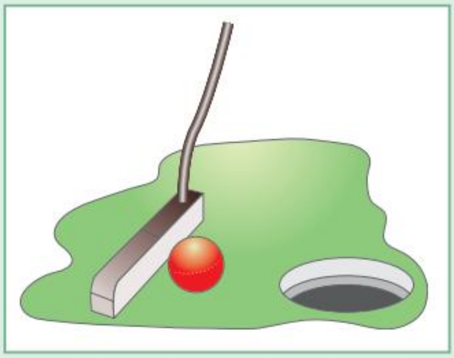

Figure 9.41

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Try this 9.6

Action–reaction pairs

Think of some action–reaction pairs that you are encountering now or that you have experienced today. A few examples are in Table 9.5. Can you think of the opposing force?

Action	Reaction
You are sitting on a chair.	
	The ground pushes against your foot in the direction you are walking.
You throw a ball against the wall.	

Table 9.5 Action and reaction forces

Practical 9.5: Self-design

Crash test eggs

Aim

To design and build a car with a safety features that will protect an egg from breaking during a collision.

Materials

As chosen by students but may include:

- rubber bands
- wheels
- craft sticks
- dowels
- plastic cups
- straws
- rubber bands
- string
- springs
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- plastic bottles
- flat cardboard
- sticky tape

Method

1. Research vehicle collisions, safety features of cars and the forces involved during a collision.
2. Based on your research, design and build a vehicle or device that has safety features to protect an egg during a collision.
3. Test your design by competing as a class to see whose crash test egg survives.

Results

Take a high speed video of your collision and slow it down to see the forces in effect.

Evaluation

1. Compare your safety device to a safety feature in a car.
2. Draw the forces acting on the egg during the collision.
3. What difficulties or errors did you encounter during this experiment? How could you improve the experiment to avoid these in the future?

Conclusion

1. Make a claim about safety based on this activity.
2. Support the statement by using your observations and include potential sources of error.
3. Explain how your observations support the statement.

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Section 9.3 questions

QUIZ

Remembering

1 Describe what is meant by the term inertia.

2 Describe the term 'net force'.

3 Describe the term 'weight'.

Understanding

4 If there is zero net force applied to an object that is travelling at a constant speed in a straight line, outline what happens to the object? Which of Newton's laws applies to the situation?

5 Contrast weight and mass.

Applying

6 A 50 kg person sits on a chair with feet dangling above the ground. Construct a diagram to represent the action–reaction pair of forces acting on the scenario and include labels to indicate the force quantities. (Remember that acceleration due to gravity $g = 9.8$ m/s^2.)

Analysing

7 Consider the action–reaction forces in the following scenario. Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass and Student 2 exerts a force of 220 N. Ignore frictional forces.

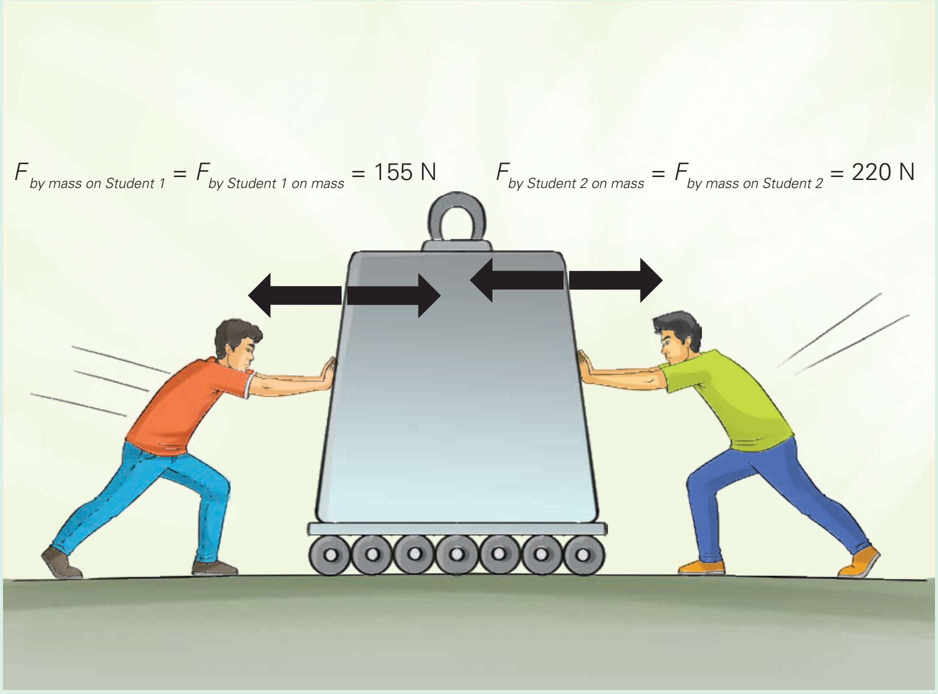

Figure 9.42

a What is the net force acting on the mass?

b In which direction will the mass move?

c Using Newton's second law, if the mass is 216 kg, calculate the acceleration of the mass.

Evaluating

8 Evaluate whether there are other action–reaction pairs in the system from the previous question. Can you quantify the forces?

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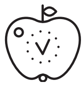
Review questions


SCORCHER

Remembering

1 List the different terms you have learned that can describe motion.
2 Recall what the gradient of a displacement–time graph indicates.
3 Describe Newton's three laws of motion.

Understanding

4 Give one example that demonstrates average speed and one example that demonstrates instantaneous speed.

Applying

5 Consider the times of one of Usain Bolt's record 100 m sprint.

Distance (m)	0	20	40	60	80	100
Time (s)	0	2.87	4.65	6.32	7.96	9.69

a Calculate the average speed of Usain Bolt for the entire 100 m. That is, from $t = 0$ to $t = 9.69$.
b Does he travel quicker in the first 40 m or the last 40 m? Give a reason why.


Figure 9.43

Analysing

6 Examine Figure 9.43. List all the action–reaction pairs you can infer.
7 Consider the path of a bungee jumper. For simplicity, assume that the path of motion is straight up and down.


Figure 9.44 A bungee jumper

As a person jumps from the platform, they accelerate towards the ground. They then decelerate when the rope tightens, then accelerate back up, and so on.

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The first 10 seconds of the jump are recorded on the following two graphs, where the origin represents the position of the jumper just before they leap from the platform.

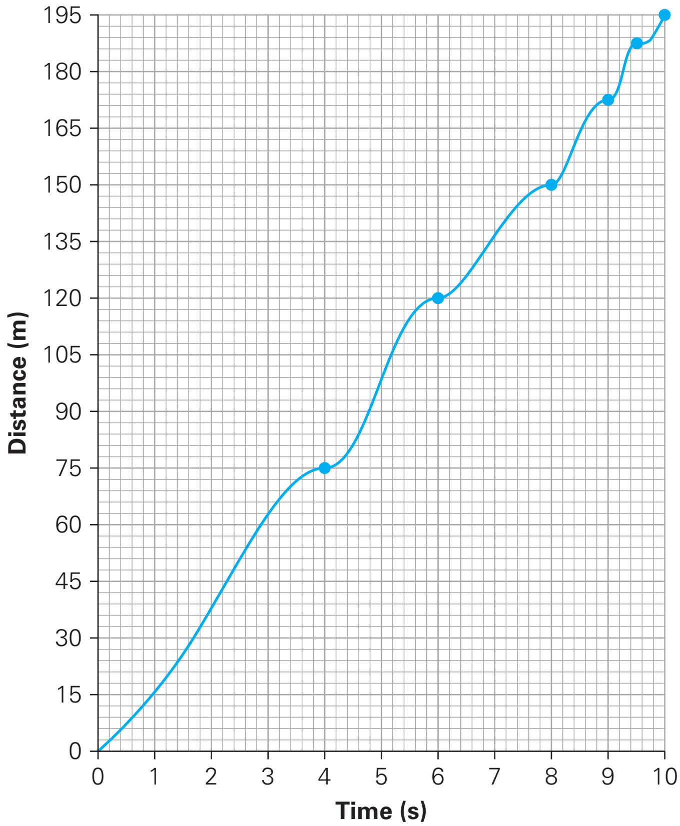

Figure 9.45

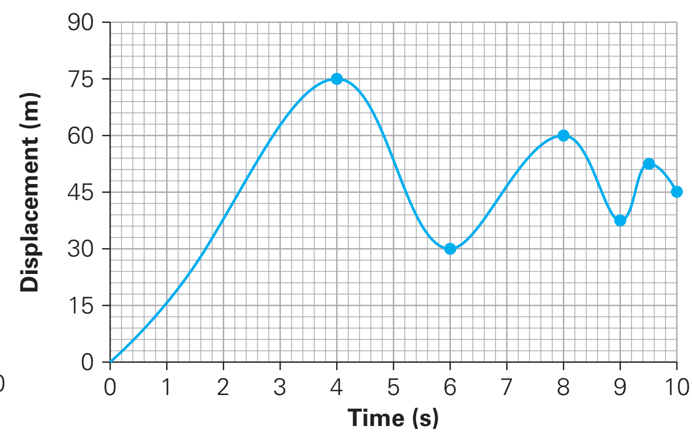

Figure 9.46

- **a** What is the distance that the jumper travels in the first four seconds?
- **b** What is the displacement of the jumper after four seconds?
- **c** What is the distance covered by the jumper in the first 10 seconds?
- **d** How far is the jumper from the platform after 10 seconds (what is the displacement)?
- **e** Calculate the average speed in the first four seconds.
- **f** What is the speed at the six second mark?

Evaluating

8 A car starts from rest and accelerates at a constant rate of 3 m/s^2 in a straight line for five seconds.

- **a** Calculate the final speed.
- **b** Calculate the average speed. Because the speed increases at a constant rate, you can do this by using $\frac{v_1 + v_2}{2}$ to find the average speed.
- **c** Calculate the distance the car had moved after five seconds.
- **d** Construct the speed—time graph for this scenario and use it to calculate the distance using the area under the graph.
- **e** What can you conclude from you answers to part **c** and **d**?

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STEM activity: Preventing motion sickness

Background Information

VCSSU103 VCDSTC048 VCDSCD049 VCDSCD051 VCSIS113

Motion sickness is a common condition usually experienced by people who are travelling. Almost everyone will experience motion sickness when subjected to intense motion. About one in three people are susceptible to motion sickness while driving or flying, and around 10 per cent of those sufferers are highly sensitive to motion.

The mechanisms responsible for motion sickness are not fully understood, but researchers suggest that motion sickness results from an interaction between the vestibular and the visual system. The vestibular system includes parts of the inner ear and brain, and is involved in controlling balance. The visual system includes the eyes; it processes what we see. Evidence suggests that motion sickness occurs when there is a conflict between the movement detected by the vestibular system and the visual input.

Figure 9.47 The driver of a car (left) is least likely to suffer from motion sickness because their sensory information (visual, sensory and even touch) all indicate accurate information. They are also correctly anticipating changes in motion (turning, accelerating, and decelerating). An aeroplane passenger (right) is susceptible to motion sickness as they are often caught unaware by sudden changes in the plane's motion.

Figure 9.48 Autonomous driverless cars will enable commuting time to be used for other things like entertainment or work. However, reading or doing anything with entertainment value may come at the cost of motion sickness. Automotive companies are continuously conducting research and development into various methods for addressing this.

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Design brief: Design a product as a solution for motion sickness.

Activity instructions

In this activity, you will work in groups (three to four maximum) to brainstorm and attempt to design potential solutions and products that could assist people with severe motion sickness symptoms. You should focus on solutions to prevent sensory conflict, and the consequent motion sickness.

Importantly, your design should be non-ingestible (not swallowed) and non-invasive (nothing is put inside the body), and it must not involve passing electric shocks. Consider cost and aim to make your design as affordable as possible. Use the evaluate and modify questions to ensure you have a well-thought out solution.

Suggested materials

- big pieces of paper
- markers
- access to the internet
- cardboard
- tape
- straws
- balloons
- ziplock plastic bags
- string

Evaluate and modify

1. Discuss with your classmates the effect of different modes of transport on motion sickness. For example, on which modes of transport (car, train, aeroplane, boat) have you experienced motion sickness? Why might someone experience motion sickness in a small boat but not on a cruise? Use the terms: acceleration, deceleration, change in motion, sensory or stimuli.
2. Research some of the current solutions that do not involve medication or electric shocks. Describe how you could make these solutions more affordable or viable for use now.
3. Propose a design and a method of building or developing your product. Your product could be conceptual, but a physical product is preferred. If your design can be built, then build a prototype.
4. Create a poster showcasing your solution and pitch it to the class as if you were seeking for investors. Ensure your pitch takes three minutes and explains:
   - why the product is needed
   - what the product is
   - what is unique about the product
   - why people will want to use it.
5. What questions might your 'investors' ask? How could you modify your design to address potential issues?

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Glossary

Chapter 1

accuracy how closely measures match the 'true' or accepted values

beneficence the responsibility of a researcher to maximise benefits and minimise harm to participants

confidentiality participants' data and results must be kept private

control group the group of participants who are not exposed to the independent variable (the experimental condition)

controlled variable an extraneous variable that is kept constant so as not to affect the dependent variable during an experiment

convenience sampling selecting opportunistic samples based on the ease of accessibility to the experimenter

dependent variable the variable that is measured to see if the independent variable has had an effect

double-blind procedure an experimental design where the participants and researchers are unaware of which experimental group the participant is in

ethics the standards used to appraise and guide what is considered as acceptable conduct

experimental group the group of participants who are exposed to the independent variable (the experimental condition)

external validity the extent to which results can be generalised and extrapolated to other contexts or populations

extraneous variable a variable other than the independent variable that can affect the dependent variable and thereby affect the experiment in an unwanted way

independent groups design a design in which two separate groups of participants are used in an experiment

independent variable the variable which is systematically manipulated or changed in order to investigate its effect on the dependent variable

informed consent where possible, participants are informed about the risks and procedures involved in an experiment and they sign to say they agree to participate

internal validity the confidence we have that the change in the dependent variable was solely due to the change in the independent variable

matched participants design a design in which similar participants are paired and then allocated to different groups

measurement uncertainty the range of values within which lies the true value

outliers extreme data values that do not seem to fit the rest of the data

placebo a fake or false treatment

placebo effect a phenomenon where participants who receive a placebo perceive a benefit or improvement

population (study) the entire group of people who form the larger group of research interest

precision how closely repeated measures agree with each other

random allocation participants are randomly placed in the control group or the experimental group

random sampling selecting samples that had an equal chance of being selected from the population

random stratified sampling the population is organised into sub-groups (strata) and then a random sample is selected from each group

random uncertainty error that occurs through inaccurate measurements (slightly high or slightly low)

repeatability how well the results align when the experiment is repeated under the same conditions

repeated measures design a design that uses the same participants for both/all conditions in the experiment

reproducibility how well the results align when the experiment is repeated by a different scientist

safety data sheet a document that provides information regarding hazardous chemicals and substances

sample a subset of participants selected from the population

significant figures the number of digits needed to be as exact or consistent as required

single-blind procedure an experimental design where the participants are unaware of whether they are in the experimental or control group

systematic uncertainty error that occurs through a poorly calibrated device (consistently high or consistently low)

titration a procedure used to determine the concentration of an acid or alkali solution

validity the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what it says it measures

withdrawal rights the right for a participant to leave a study at any time for any reason

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Chapter 2

allele different forms of the same gene

aneuploidy when an individual has one more or less chromosome

autosomes in humans, chromosome pairs 1 to 22

bioinformatics an analysis tool that is able to sort biological data using computers

chromosome a structure of tightly wound DNA

chromosome mutation a mutation involving large segments of DNA

codominance both alleles are expressed equally in the phenotype

complementary pairing adenine only binds with thymine and cytosine only binds with guanine

deletion a point mutation in which a nucleotide is deleted from the sequence

diploid a cell containing two sets of chromosomes

DNA genetic make-up that carries the instructions for life (deoxyribonucleic acid)

Down syndrome a genetic condition in which the individual has three copies of chromosome 21

embryo a zygote eventually turns into an embryo

fertilisation the fusing of an egg and sperm

gametes sex cells that combine to produce new offspring

gene a length of chromosome

gene therapy a process by which a copy of a functional gene is introduced into an organism

genetic engineering technology that allows genetic material to be manipulated and enables genes to be transferred between any two species

genetic screening genetic tests that are available for anyone in the population

genetically modified organism an organism that has had its genome altered by humans

genetics the study of inheritance

genome the full set of genes in an organism

genotype the combination of alleles for a gene inherited from our parents

germline mutation a mutation of DNA in gametes

gonads the sexual organs: testes in males and ovaries in females

haploid a cell containing only one set of chromosomes

heterozygous having two different alleles at a locus

homologous chromosomes matching chromosomes

homozygous having two identical alleles at a locus

hydrogen bonds chemical bonds that hold the two strands of DNA together

incomplete dominance a form of inheritance in which neither allele is dominant over the other

induced mutation a mutation produced by environmental factors

insertion a point mutation in which an extra nucleotide (or more than one nucleotide) is inserted into the DNA

inversion a point mutation in which two nucleotides reverse their order

karyotype a pictoral representation of an organism's chromosomes

locus the location of a gene on a chromosome

meiosis the process by which the gonads make the haploid gametes

mitosis the process by which diploid somatic cells make identical diploid copies of themselves to grow and repair

mutagenic causing mutations in DNA

mutation a change in the genetic code of a cell

non-disjunction when the chromosomes failed to separate correctly in meiosis

non-homologous chromosomes non-matching chromosomes

nucleotide a subunit of DNA

ova eggs

pedigree a chart formed to study patterns of inheritance over generations

phenotype the way an organism appears

point mutation a mutation in which a single nucleotide is changed

Punnett square a specialised grid to show crosses

reduction division cell division in which there is a reduction in the genetic material between parent and daughter cells

sex chromosomes in humans, the 23rd pair of chromosomes that determines the sex of a person

sexual reproduction reproduction involving sex cells

somatic cells the body cells of an organism

somatic mutation a mutation that occurs in somatic (body) cells

spontaneous mutation a naturally occuring mutation

substitution a type of point mutation in which one nucleotide is swapped for another

test cross a special type of cross-breeding test that can be used to identify whether an organism is homozygous or heterozygous for a dominant trait

transgenic organisms organisms that possess a 'foreign' gene or segment of 'foreign' DNA in their genome as a result of human experimentation

triplet three DNA bases that code for an amino acid

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trisomy when an organism has a third copy of a chromosome

zygote a fertilised egg produced by the fusion of male (sperm) and female (ovum or egg) gametes

Chapter 3

absolute dating determining the actual age of a material

adaptation characteristic that contributes to a species' suitability for its environment

analogous structures structures that have a similar function but evolved separately

artificial selection intentional breeding of plants and animals to produce desirable traits

biodiversity the variety of species, ecosystems and genes that exist in a particular area

biogeography the study of the geographical distribution of plants and animals

biostratigraphy a branch of stratigraphy focused on dating rock layers using the fossils found in them

direct (evidence) evidence that supports an assertion without intervening inferences

DNA hybridisation a technique that measures genetic similarity between two organisms

endangered a species that is in danger of becoming extinct

evolution the genetic changes in a population over a long period of time

evolutionary tree a diagram used to represent evolutionary relationships between organisms

extinct no longer existing

fertile able to reproduce

fossil the shape or impression of a bone, a shell, or a once living organism that has been preserved in rock for a very long period

fossil record the record of past life and evolution inferred from fossils

fossilisation the process of becoming a fossil

gene flow the movement of genetic information from one population to another

genetic drift a random change in the frequency of an existing gene in a population

half-life the length of time needed for the radioactivity of a radioactive substance to be reduced by half

homologous structures structures that are similar because they have evolved from the same ancestor

index fossil a fossil used as the base for dating the strata it occupied

indirect (evidence) evidence that requires inferences to be made

isotope an atom of the same element but with differing number of neutrons and hence differing atomic mass

natural selection the process that when applied to a population results in the continued existence of only the organisms that are best suited to the conditions in which they live

population (ecological) a group of a particular species living in the same geographical area at the same time

relative dating determining the order of past events without the specific age

reproductively isolated unable to breed successfully with related species due to genetic differences

selection pressure an external agent that affects an organism's chances of survival depending on their genotype (genetic variations)

selective breeding artificial selection

speciation the process by which new types (species) of living things are thought to develop from existing ones by evolution

species a set of animals or plants in which the members have similar characteristics to each other and can breed with each other

stratigraphy the branch of geology studying the rock layers

trace fossil a trace of an animal, such as footprint or imprint, that has become fossilised

variation genetic differences within a population

viable able to survive and reproduce

Chapter 4

activity series a series of metals ordered by their reactivity, from highest to lowest

alkali metals group 1 metals that form an alkaline solution when they react with water

alkaline earth metals group 2 metals that form an alkaline solution when they react with water

anion a negatively charged ion formed from the gain of electrons

cation a positively charged ion formed from the loss of electrons

covalent bond a strong bond almost always between two non-metals who share electrons, forming a molecule

displacement reaction when a more reactive metal removes a less reactive metal from its compound

electron smallest sub-atomic particle in an atom arranged around the nucleus in shells

electron shell houses the electrons which orbit the nucleus of an atom

electronic configuration the arrangement of an atom's electrons in the shells around the nucleus

element a species of atoms that have the same number of protons

ground state the lowest energy level of an atom

group the vertical columns in the periodic table

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halogens group 17 elements (for example, chlorine and iodine)

inert unreactive

ion a charged version of an atom, formed from the loss or gain of electrons

ionic bond a strong bond between an anion and a cation, formed via electron donation

metalloids elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

native metals elements that are found in their pure states in the environment

noble gases group 18 elements (for example, neon and krypton)

period the horizontal rows in the periodic table

transition metals the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

valence electrons the electrons in the outer shell of an element

Chapter 5

activation energy the minimum energy required for a successful collision and therefore to start a reaction

agitating stirring or shaking a mixture

aqueous a physical state of matter which means dissolved in water (for example, salt water)

biofuel a fuel that comes from living materials

catalyst speeds up a chemical reaction by lowering the activation energy, and does not get used up in the process

chlorofluorocarbons chemicals containing atoms of carbon, chlorine, and fluorine that are nontoxic and non-flammable

coefficients the large numbers placed before molecules in a chemical equation to ensure that it is balanced

collisions particles must collide for a chemical reaction to occur

concentrated solution a solution which contains a large amount of solute compared to solvent

concentration the amount of substance in a given space

diatomic two atoms bonded together

dilute solution a solution which contains a small amount of solute compared to solvent

formula equation a chemical reaction written using the formulas of the reactants and products involved

galvanising coating iron or steel with a protective layer of zinc

molecular equation a chemical reaction written using the bonding structure of the reactants and products involved

monatomic one atom, sometimes spelled 'monoatomic'

monomers single units that when joined together repeat to make a polymer

polymer a long chained molecule made of repeating sub units called monomers

products the chemicals produced in a reaction

reactants the chemicals which react together in a reaction

reaction rate the quantity of reactant or product used up or made per unit time; how fast the reaction goes

surface area the area of the outer part or surface of an object

word equation a chemical reaction written using the names of the reactants and products involved

Chapter 6

ammonification the process in which bacteria in the soil converts dead plant and animal material into ammonia

atmosphere the mixture of gases above the surface of Earth

biodiversity the variety of species, ecosystems and genes that exist in a particular area

biosphere all the areas on Earth and in its atmosphere that contain life

carbon sinks areas where carbon is stored (for example, fossil fuels)

carbon sources areas where carbon can be retrieved (for example, the atmosphere)

climate the average or prevailing weather conditions of an area over long periods of time

decomposers living organisms that break down dead organic matter

denitrification the process of converting nitrates into nitrogen gas to be released back into the atmosphere

enhanced greenhouse effect the intensifying of the natural greenhouse effect due to human activity

geosphere all the lifeless parts of Earth's surface, crust and core

glacial periods periods in Earth's history when a reduction in global temperatures is sustained for a long period of time

greenhouse effect the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

greenhouse gases gases that contribute to the greenhouse effect

hydrosphere all of the water found on Earth (for example, lakes and rivers)

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interglacial periods periods in Earth's history when a warming in global temperatures is sustained for a long period of time

keystone species a species that has a dramatically large impact on a particular ecosystem relative to its population

lithosphere the lifeless parts of Earth's crust and upper mantle only

nitrification the conversion of ammonia into useful nitrates by nitrifying bacteria

nitrogen fixation the conversion of atmospheric nitrogen into ammonia by nitrogen-fixing bacteria or lightning

stratosphere a layer of Earth's atmosphere above the troposphere containing the ozone layer

sustainable ecosystem a biological environment that is able to support itself without outside assistance

troposphere a layer of Earth's atmosphere which is closest to Earth's surface and where most of the weather occurs

weather the conditions in the air above Earth such as temperature, cloud, rain or wind, especially at a particular time over a particular area

Chapter 7

absorption spectrum a spectrum showing dark lines due to specific wavelengths that have been absorbed by a substance

arcsecond 1/3600th of a degree

astronomical unit the distance between Earth and the Sun

baseline a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

Big Bang the large explosion that scientists believe created the universe

black hole the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing, not even light, can escape

blue shift a spectrum shifted towards shorter wavelengths

B-V colour index the difference in brightness measured through blue and green filters, indicating the colour of a star

constellation a group of stars as seen from Earth that appear to form a familiar shape

continuous spectrum continuous range of colours/wavelengths

cosmic microwave background electromagnetic radiation left over from the early stages of the universe

dark energy a theoretical force responsible for accelerating the expansion of the universe

dark matter matter that does not emit light and is responsible for unidentified gravity in the universe

Doppler effect a change in the frequency of sound or light waves emitted from an object when its moves towards or away from an observer

emission spectrum a spectrum showing bright lines at wavelengths specific to emission from a substance

epoch of recombination the point in time where electrons and ions could combine to form atoms

exoplanet a planet orbiting a star that is outside the solar system

galaxy an independent groups of stars that are held together by gravity

geocentric a model of the solar system with Earth at the centre

Goldilocks zone the habitable zone around a star where the temperature is not too hot and not too cold

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

H–R diagram a graph where the star luminosity is plotted against spectral type/temperature (Hertzsprung–Russell diagram)

Hubble's law the further away a galaxy is, the faster it is moving away from Earth

light year the distance that light travels in one year (about 10 trillion km)

luminosity the intrinsic brightness of a celestial object

main sequence stars that convert hydrogen into helium at their cores

nuclear fusion the process of joining two nuclei to produce energy

observable universe the spherical region of the universe that can be observed from Earth because light has had time to reach Earth

optical telescope a device that collects and focuses light from the visible spectrum to form an image

parallax the effect by which the position of an object seems to change when it is observed from different locations

parsec the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

radio telescope a device that receives radio waves emitted by stars and other celestial objects

recessional velocity the relative rate at which a star is moving away from Earth

red giant a very large, bright, cool star that has run out of hydrogen at its core

red shift a spectrum shifted towards longer wavelengths

retrograde motion apparent backwards motion of a planet as seen from Earth

singularity a point at which an infinitely dense matter occupies an infinitely small space

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spectral class a group into which stars are classified based on their spectra/colour

supernova the explosion of a massive star

white dwarf a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

Chapter 8

conduction transfer of thermal energy through a substance, or between substances, as a result of collisions between particles

conductors materials that can transfer heat via conduction

convection transfer of thermal energy due to the movement of particles in a fluid

efficiency a measure of the ability to produce useful energy

elastic potential energy energy stored in an object due to its shape, usually resulting from the object either being compressed or stretched

energy the ability to do work

first law of thermodynamics thermal energy cannot be created or destroyed; it can only be transformed into other forms of energy or transferred to other objects

gravitational potential energy energy stored in an object due to its position above the surface of Earth

heat thermal energy that is transferred between objects or systems due to a temperature difference

insulators materials that are poor conductors of heat

kinetic energy energy possessed by an object due to its motion

law of conservation of energy energy cannot be created or destroyed; it can only be transformed into other forms or transferred to other objects

potential energy energy that is stored in an object due to its position and other factors, such as its mass, electric charge, and internal stresses

radiation transfer of thermal energy without the presence of particles of matter

Sankey diagram flow chart that represents the flow of energy through a system

system a portion of the universe that is being analysed

temperature the average kinetic energy of the particles that make up an object or system

thermal energy the total kinetic energy of all of the atoms that make up an object or system

thermal equilibrium describes two bodies that are at the same temperature; and therefore, have no net thermal energy transfer

thermodynamics the branch of physics that relates to the transfer and transformation of energy; in particular, thermal energy

useful energy energy that can be used for a specific purpose

work the amount of energy transferred when an applied force causes an object to move some distance

Chapter 9

acceleration an object has acceleration when its velocity changes. Average acceleration equals change in velocity divided by the time taken. The most common unit is m/s^2.

average speed change in distance divided by change in time; usually measured in km/h or m/s

constant speed when an object is travelling at the same speed and is not accelerating or decelerating

deceleration when an object is slowing down

displacement how far you are from where you started and what direction you are from where you started

distance total distance travelled measured in metres

force any interaction that, when unopposed, will change the motion of an object

gradient the gradient of a graph is the rise over the run

inertia a property of matter that keeps something in the same position or moving in the same direction unless acted upon by an external force

instantaneous speed the speed at any particular instant

mass mass is the quantity of matter in a body regardless of its volume or of any forces acting on it

net force the sum of all the forces acting on an object

Newton's first law of motion an object will remain at rest or in uniform motion in the same direction unless acted upon by an external force

Newton's second law of motion an object acted upon by a force experiences acceleration in the same direction and proportional to the magnitude of the net force, and inversely proportional to the mass of the object

Newton's third law of motion for every action, there is an equal and opposite reaction

origin the point at which the axes of a coordinate system intersect

speed change in distance divided by time

stationary not moving

velocity change in displacement divided by change in time

weight the weight (W) of an object is the force of gravity on the object and is defined as the mass times the acceleration of gravity: $W = mg$

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