

CAMBRIDGE

INTERACTIVE  
TEXTBOOK  
INCLUDED



Cambridge  
**science**  
for Western Australia

Brodie Reid  
Eddy de Jong  
Kerrie Ardley  
Emma Bone  
Gemma Dale

10



CAMBRIDGE  
UNIVERSITY PRESS



# Cambridge **science** for Western Australia

Brodie Reid  
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# How to use this resource

## Elements in the print book

You will see the following types of boxes throughout this book.

### Glossary

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

### Learning goals

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

### Explore!

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

### Did you know?

These are short facts that contain interesting information.

### Quick check

These provide quick checks for recalling facts and understanding content. These questions are also available as Word document downloads in the Interactive Textbook.

### 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

End of section question sets are under the following headings: Remembering, Understanding, Applying, Analysing and Evaluating. Action verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

## Hands-on activities

### Try this

Classroom activities help explore concepts that are currently being covered.

### Practicals

Classroom or laboratory activities and investigations help consolidate student understanding. These activities are also available as Word document downloads in the Interactive Textbook.

## End-of-chapter features

### Chapter review

#### Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
2.1 I can describe the structure of DNA and RNA.	2, 3	
2.1 I can recall the relationship between DNA, genes and chromosomes.	1	
2.1 I can recall the role of protein in living organisms.	5	
2.1 I can describe the processes transcription and translation in protein synthesis and DNA replication.	4, 12	
2.2 I can distinguish between haploid and diploid cells.	18b	
2.2 I can describe the process of mitosis.	9	
2.2 I can describe the process of meiosis, including how it causes variation.	13	
2.3 I can use a Punnett square to demonstrate how traits are inherited from parents.	14	
2.3 I can explain the difference between autosomes and sex chromosomes.	10	
2.3 I can explain how blood groups are an example of codominance.	16	
2.3 I can use a pedigree diagram to determine the type of inheritance that is occurring.	15	
2.4 I can explain the different types of mutations, including their causes and effects.	18c	
2.4 I can describe some ways in which DNA can be manipulated.	20	

Data questions help students apply their understanding, as well as analyse and interpret different forms of data linked to the chapter content. These questions are also available as Word document downloads in the Interactive Textbook.

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

Chapter review question sets are categorised under the following headings: Remembering, Understanding, Applying, Analysing and Evaluating. Action verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

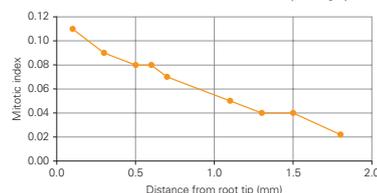
#### Data questions

A student prepared an onion root tip slide and examined the cells under a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

Stage of cell cycle	Number of cells recorded
Interphase	340
Prophase	13
Metaphase	4
Anaphase	3
Telophase	6

She then calculated the mitotic index for different areas of the root tip. The graph shows her results.



84 Chapter 2 GENETICS
STEM ACTIVITY DESIGNING AND PROTOTYPING AN ASSISTIVE DEVICE 85

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

**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 'encyclopedia' is not perfect. As with ancient scrolls transcribing text, errors are made each time a copy is produced. Errors in the genetic 'encyclopedia', or genetic code, are known as mutations. The different types of mutations can be thought of as spelling, punctuation or grammar errors. Mistakes cause variation 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 are cause scoliosis, but the cause of most scoliosis is unknown.

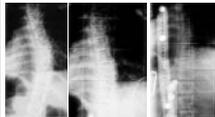



Figure 2.88 illustrates three designs that have been used for the treatment of scoliosis.

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

**Activity instructions**

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life for people with that condition. Consider how the product could 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
- penlid
- paper
- staple
- balsa wood
- plaster
- paper-mache
- chicken wire
- 3D printer
- cardboard
- poster paper

**Research and feasibility**

- 1 Research genetic diseases and as a group decide which genetic disease will be the focus.
- 2 Create a table of the causes and effects of the disease.

Genetic disease	Effects on part of body	Ideas to help
e.g. Muscular dystrophy	Reduced joint movement	Brace and orthotics for feet
Muscle loss		
e.g. Haemophilia	Whole body can be bruised easily	1 Creation of children's play mat
Blood doesn't clot effectively		2 Creation of some type of buffing edging that could be applied to furniture

**3** Find pictures or diagrams of current equipment used and annotate with features and characteristics that relate to existing people living with the disease.

**Design and sustainability**

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

**5** Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

**Create**

**6** Build a prototype of your design using available construction materials.

**Evaluate and modify**

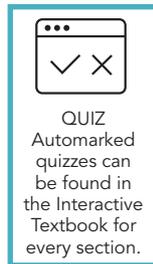
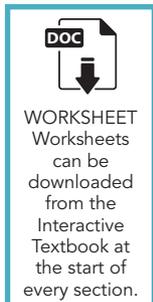
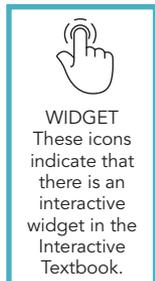
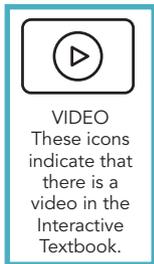
**7** Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.

**8** Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.

**9** Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

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

## Links to the Interactive Textbook



## Overview of the Interactive Textbook (ITB)

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

**Definitions** pop up for key terms in the text.

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

**Worksheets** are provided as downloadable 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 2.1

#### Extracting DNA from cells

**Time period**  
Approximately 1 hour

**Aim**  
To investigate and extract DNA from strawberries.

**Materials**

- plastic sandwich bag (or other material to contain strawberry and liquid)
- strawberry
- DNA extraction solution provided (10 mL)
- filter funnel and gauze (or other gauze-style filter)
- cold ethanol solution
- test tube (or small beaker)
- stirring rod
- plastic pipette

**DNA extraction mixture:**

- dishwashing liquid or shampoo (5 mL)
- table salt (0.75 g)
- water (45 mL)

#### Method

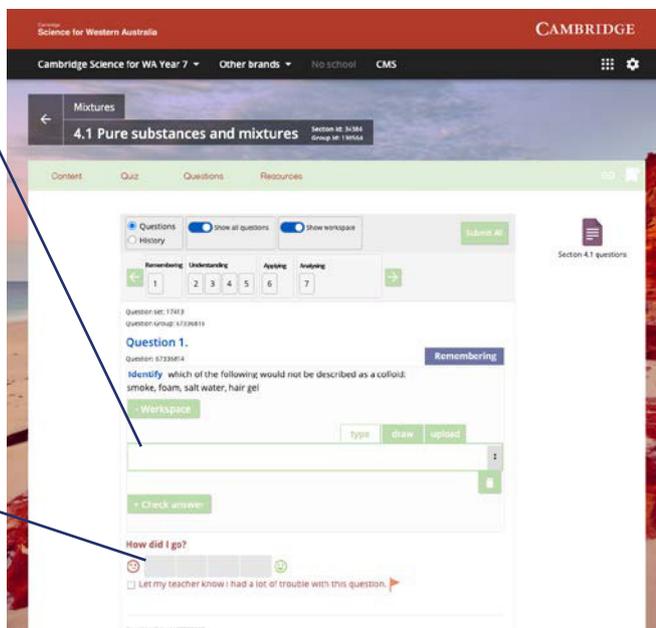
- Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
- Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
- Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.
- Pour the strawberry mixture through a filter funnel lined with gauze into a test tube.

#### Be careful

Wear safety glasses and a lab coat. Do not consume food items.

**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.

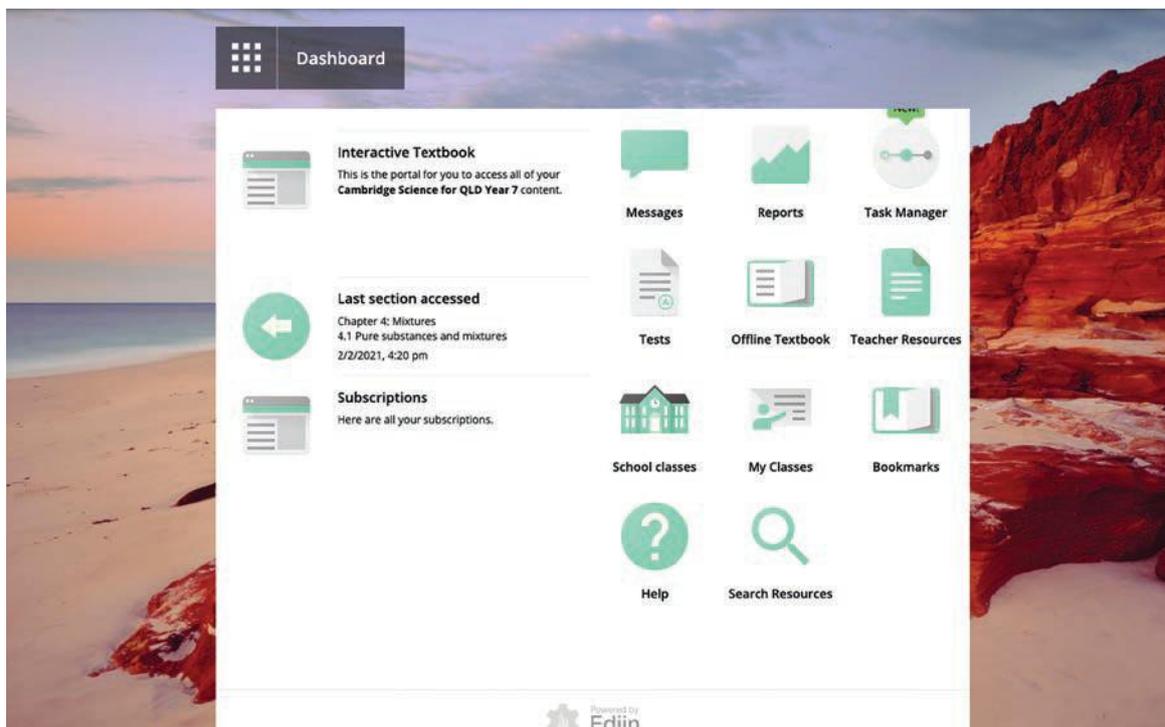
**Self-assessment tools** enable students to check answers, mark their own work, and rate their confidence level in their work. This helps develop responsibility for learning, and communicates progress and performance to the teacher. Student accounts can be linked to the learning management system used 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** for Practical skills, Investigations and STEM activities.



# Chapter 1

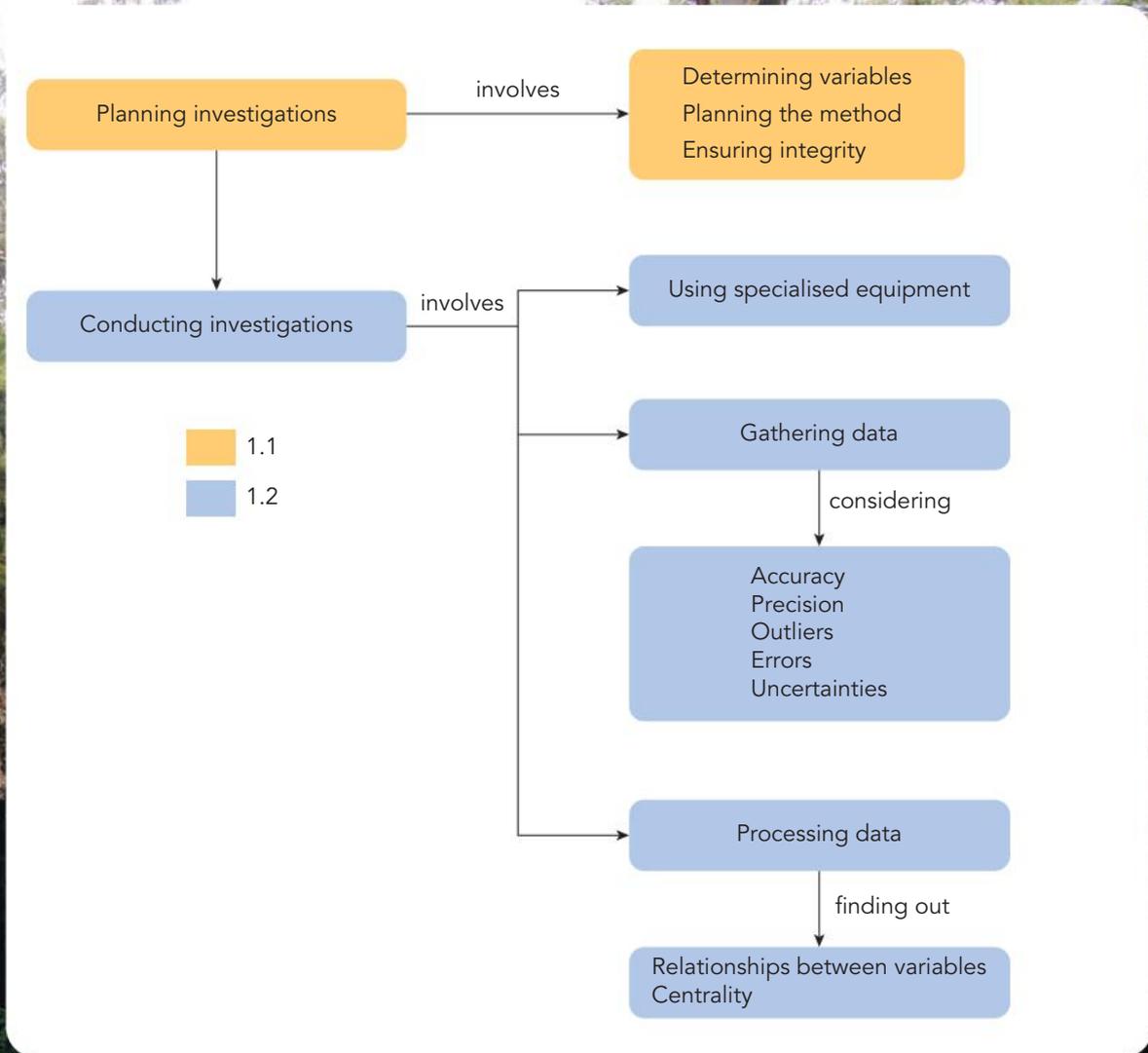
## Conducting effective investigations



### 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 if the results are to be seen as meaningful. 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.

# Chapter map



# 1.1 Planning investigations



## Learning goals

- 1 To be able to distinguish independent, dependent and controlled variables in a scientific investigation.
- 2 To be able to write a scientific hypothesis.
- 3 To explore the factors that affect the integrity, safety and ethics of a scientific investigation.

This section covers various aspects of planning an investigation. Deciding experimental variables, methods of collecting evidence, how to ensure the integrity of the experiment as well as safety and ethics all need to be carefully thought about before carrying out an investigation.

### STEP 1: OBSERVE AND ASK QUESTIONS

A research question may be identified once an area of scientific interest has been analysed.

### STEP 2: BACKGROUND RESEARCH

The introduction of a scientific report contains a concise version of a literature review or background information. 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 AND STATE VARIABLES

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 a haphazard guess without any prior knowledge – it is more of an educated guess. You should also state your independent, dependent and controlled variables.

### STEP 4: METHOD

An experiment may include controlled laboratory experiments, naturalistic observations, case studies, surveys and interviews. Conducting the experiment requires a specific method. The method usually contains at least three sections:

- Materials (lists the scientific apparatus required to conduct the experiment)
- Method (a step-by-step procedure of how the experiment is conducted). This may be a modified version of a previous experiment.
- Risk assessment (considers how to manage any risks in the experiment).

### STEP 5: PROCESSING OF SUFFICIENT AND RELEVANT 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. Error bars can be included to represent uncertainty in any measurements.

### 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 and the uncertainty and limitations of evidence should be identified.

### STEP 7: EVALUATION

This is a discussion of the reliability and validity of the experimental process. Suggested improvements and extensions to the experiment should be included.

### STEP 8: CONCLUSION

This is an insightful interpretation of experimental evidence through a justified conclusion that is linked to the research question.

### STEP 9: REPORTING THE RESULTS

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

## Experimental variables

Let's say you have a broad research question that has been developed from observations of the world around you: Does temperature affect the rate of a chemical reaction?

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

The **independent variable** is what is being manipulated by the experimenter in the experiment. You need to state exactly how it will be manipulated or changed. For example, if the independent variable within an experiment is the temperature of a chemical reaction mixture, then you could manipulate the variable by applying heat or cooling, and you would measure it with a thermometer.

The **dependent variable** is what is being measured in the form of the results of the

experiment. You need to identify the dependent variable and state how it will be measured. For example, in the experiment mentioned, the dependent variable is the time taken for the chemical reaction to be completed.

Sometimes other factors can affect the dependent variable and thus affect the experiment in an unwanted way.

The presence of these variables makes it difficult to conclude that the change in the dependent variable was solely caused by the change in the independent variable. Scientists seek to minimise these variables through precise research design and accurate procedures. When a potential influencing variable is eliminated by keeping it constant, it is referred to as a **controlled variable**.

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

**dependent variable**  
the variable that is measured with respect to a changed independent variable

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

Once you have identified the experimental variables, a hypothesis can be constructed using an 'If... then...' statement (Table 1.1).

Construct a hypothesis (a–d)			
a	b	c	d
If	independent variable changes	then	relationship to change in measured dependent variable
	state independent variable change		show an increase/decrease be greater than/less than be larger/smaller
<b>Hypothesis:</b> If the temperature of a chemical reaction is increased, then the time taken for the reaction to complete will decrease.			

**Table 1.1** How to construct a hypothesis using the 'If ... then ...' statement.



**Try this 1.1****Selecting variables**

Take the research question 'Does eating chocolate improve health?' Imagine a possible experiment you could conduct. Copy and complete the table below.

List variables here
Independent variable
Dependent variable
Controlled variables

**Quick check 1.1**

Describe the difference between independent, dependent and controlled 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 up this experiment 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 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.
- 3 Come up with a possible research hypothesis for this investigation using the 'If ... then ...' statement. Remember, it should be a prediction of what the results will be (including the independent variable and dependent variable), and as specific as possible.
- 4 List three variables that must be controlled in this experiment.
- 5 Explain why the above three variables should be controlled.



**Figure 1.2** Scientists conducting an experiment on alfalfa sprouts

## Methods of collecting evidence

In science, 'evidence' can take many forms. Sometimes, scientists may collect experimental evidence that is from a laboratory experiment or fieldwork. At other times, they may collect research evidence by looking at work that has already been written by other scientists and collating it into a new study.

## Experiments

You will have tested a number of your own theories over the years: 'If I stop drinking soft drink after dinner, then I'll sleep better', or 'If I don't have an extra serving of chips, then I'll have room for ice cream'. This is cause and effect, but causation can be difficult to prove, even if you have evidence from your own life that seems to prove your hypothesis. Scientists can set up specific experiments that are in controlled environments that allow relationships between variables to be examined. Controlled conditions are used to measure the impact that an independent variable has on a dependent variable, and scientists will attempt to control all other variables to ensure there is a systematic approach that is more reliable than everyday observations. Often, data will be collected with a datalogger. **Data logging**

allows scientists to measure data more accurately, or over a prolonged period.

Experiments can take place in a laboratory, but sometimes, scientists may have to do **fieldwork** out in the natural world. This involves evidence collection that takes place away from the controlled environment of a laboratory. Just like in a lab, scientists will observe and collect data, but as they are often prevented from directly manipulating the environment, it allows them to examine the way different theories interact with the real world. Scientists may have to venture out into the field for a number of reasons. Astrophysicists may need to visit remote astronomical observatories, such as the High Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory in Sierra Negra, Mexico. Environmental chemists may need to complete fieldwork to detect the presence and impact of chemicals in the environment. Marine biologists may need to locate, tag, and track marine animals and their migratory movements. For example, researchers at the University of Western Australia track the movements of tiger sharks at Ningaloo Reef to observe their daily activities.

### data logging

the process of using electronic equipment to collect data through sensors where information needs to be collected faster than a human can do independently, or where accuracy is essential

### fieldwork

practical work conducted by a scientist in a natural environment, rather than in a laboratory

**Figure 1.3** A tiger shark in Australian waters. Many tiger sharks are tagged and tracked by scientists as a part of their research.



## Science as a human endeavour 1.1

**Example of fieldwork**

Researchers at the Dugald River Mine in Queensland discovered that the native legume *Crotalaria novae-hollandiae* is hyperaccumulating zinc and have speculated that this could possibly allow phytomining to occur. Phytomining is the harvesting of metals from the living tissue of a group of plants known as hyperaccumulators. These plants retain metals in particularly high concentrations after the metals are absorbed through their roots. There are currently approximately 100 known hyperaccumulators and when these plants are burned, a bio-ore is produced in their ash, which often contains more than 25% metal. These plants could potentially offer an environmentally friendly method of extracting valuable metals from mining waste materials.



Figure 1.4 *Crotalaria novae-hollandiae*

**Modelling and simulations**

Sometimes, scientists want to investigate phenomena that cannot be directly experienced. A model is a simplified representation of an object, system or process. Models can be physical or digital and are designed to be similar to, but simpler than, what they are supposed

to be representing, while simultaneously attempting to approximate most of the relevant features of the real object.

Scientists may propose more than one model in order to explain circumstances. They may then argue the quality of the explanation and in the process the model will be gradually developed or rejected. Therefore, models are key to building knowledge in science, and it shows that scientific knowledge is continuously refined.

A good example of this is a globe. A globe is a model of Earth, and it is easy to see how the model has evolved through time. The first record of Earth being spherical was made in the 5th century BCE by the Ancient Greeks. Over 1500 years, this model was repeatedly updated, but every version was merely an artistic impression of what Earth looks like. However, this all changed when NASA started to use technology such as their Earth Polychromatic Imaging Camera (EPIC) to create highly detailed images of Earth.



Figure 1.5 On the left, the *Erdapfel*, translated 'Earth's apple', was created by Martin Behaim who lived in the late 15th century. It looks different from the globe we use today, because the Americas are not included, and some elements are the wrong size, shape and position. How do you think it compares to the image of Earth on the right taken in 1972 by the Apollo 17 spacecraft on the way to the Moon?

A simulation is used to bring a model to life, allowing scientists to determine how a particular object or phenomenon will behave. In a simulation, models are used to study existing or proposed features of a system. Simulations enable the study of system characteristics by allowing the manipulation of variables that could not be controlled in a real system. They are useful to study properties of a model of a real-life system that would otherwise be too complex, too large, too small, too fast, too slow, or too dangerous to change. While a model aims to be true to the system it has been developed to represent, a simulation can allow a model to experience far more states that would not necessarily be possible in the original system.

## Literature reviews

A literature review is a comprehensive summary of any previous research completed on a subject. It is written as an introduction to a topic you are investigating, forming the basis of your own research. In school, you will write an introduction that is a concise version of a literature review and should incorporate information from research papers, articles, books and any other source that is relevant to the area being researched. This enables you to describe and summarise your research area, while objectively evaluating the work to ensure that it is reliable and therefore worthy of inclusion. It is important that you acknowledge all previous work through the use of a bibliography, as a reader would assume that you have read, evaluated and summarised the work to produce a complete overview of the topic.

Sometimes, the same skills that are used to write a literature review can be extended to write a research paper. This is a longer publication that contains a summary of results of original research or an evaluation of research conducted by others. For example, a scientist may want to research the effectiveness of different bushfire management strategies. A combination of comprehensive fire records and previous studies done on the same topic would allow the scientist to evaluate the different strategies and develop their own conclusions.

### Quick check 1.2

Identify a potential purpose of the fieldwork that a geologist may have to carry out.

## Integrity of the experimental method

If a scientific experiment is to fairly test a hypothesis and answer a research question, then 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 sometimes conducted 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 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 method is so 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

	Repeatability	Reproducibility
<b>Definition</b>	The same scientist repeating single measurements gives similar values when using the same equipment and setting.	Another scientist repeating the entire experiment gets a similar final result.
<b>How to improve</b>	Modification of the experimental method, e.g. materials, equipment, procedure.	Repetition of each test conducted and averaging single measurements.
<b>How to test</b>	Repetition of single measurements while noting any changes in values measured.	Repetition of entire experiment and looking at differences in final results.

**Table 1.2** Importance of repeatability and reproducibility within experiments

#### validity

the degree to which the experiment addresses the research question, and whether it measures what it says it measures

overall outcome of the experiment can be used to assess these two concepts.

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 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 measurement. In the science laboratory, repeatability of results can sometimes be improved through repetition. The more similar the repeated measurements are, the more integrity the results have.

If on the next occasion you captured many 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

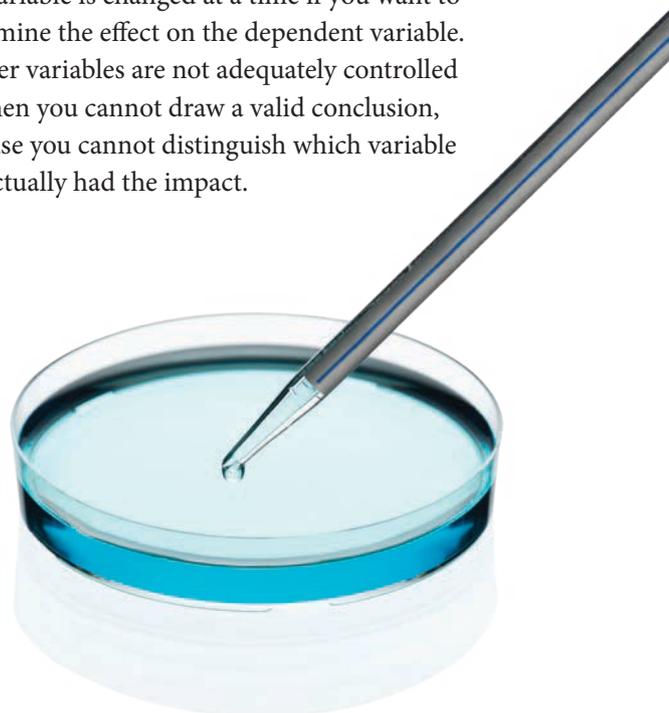
additional samples is an important process because it gives you an idea of the natural variability (or margin of error).

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. All factors other than the one being investigated must be kept constant. For example, an experiment that is testing the effect of temperature on enzyme action should not have one set of enzymes at 20°C and pH 4, and another at 40°C and pH 9. The validity of an experiment depends on both the experimental design and the procedure.

The validity of an experiment relates to how appropriately the experiment addresses the overall research question. 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 not adequately controlled for, then you cannot draw a valid conclusion, because you cannot distinguish which variable has actually had the impact.



### Quick check 1.3

- 1 Identify the correct words to complete the following sentences.
  - a 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.
  - b The likelihood that another scientist performing exactly the same experiment under the same conditions will generate the same results depends on \_\_\_\_\_.
- 2 Explain the importance of reproducing experiments in the field of science.

## Safe experimental practices

Whenever you are carrying out an experiment, it is your job to eliminate risks to health and safety, so far as is reasonably practicable, and if they cannot be eliminated, they need to be minimised. This can be done through the use of a risk assessment that allows you to identify, assess and control risks.

When assessing any risk, you need to consider two factors: a) the likelihood of the hazard actually occurring, and b) the level of harm that might result from the hazard. Experiments sometimes require the use of hazardous chemicals that could cause harm. A **safety data sheet** (SDS) must be provided during all experiments. The SDS is a document that provides teachers and students with 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 SDS provides precise information about how to use a substance during and after the experiment, including the associated health risks and how to dispose of waste products.

### Quick check 1.4

- 1 Recall what SDS stands for.
- 2 Explain why SDSs are essential within the science classroom.

## Ethical implications of animals

Animal ethics involves consideration of respectful, fair and just treatment of animals. The use of animals in science should consider three main principles.

**Replacement:** substituting conscious living animals with insentient materials such as plants and microorganisms, and invertebrates with less complex nervous systems

**Reduction:** using the minimum number of animals required to satisfy research statistical requirements

**Refinement:** decreasing the number of inhumane procedures applied to those animals that still have to be used in any procedures.

#### safety data sheet

a document that provides information regarding hazardous chemicals and substances

#### ethics

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

## Ethical implications of human participants

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.

In fields such as psychology, using people as participants is a critical source of data in

**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

**confidentiality**

participants' data and results must be kept private

**withdrawal rights**

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

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 participants must be voluntarily involved in the research, have **informed consent** and not be harmed by their involvement. All data must be kept **confidential** and all participants should have **withdrawal rights** – the option to withdraw at any point for any reason.

**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 in the United States. Research what took place in this experiment and outline the ethical rights that were followed and the ones that were breached.



**Figure 1.6** Philip Zimbardo at the 2015 opening night of *Stanford Prison Experiment*, a movie based on true events that happened during the 1971 experiment

**Quick check 1.5**

- 1 Define the term 'informed consent'.
- 2 Define the term 'withdrawal rights'.



## Section 1.1 questions

## Remembering

- 1 **Describe** the difference between repeatability and reproducibility in scientific experiments.

## Understanding

- 2 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 through the stomata. She set up the experiment below.

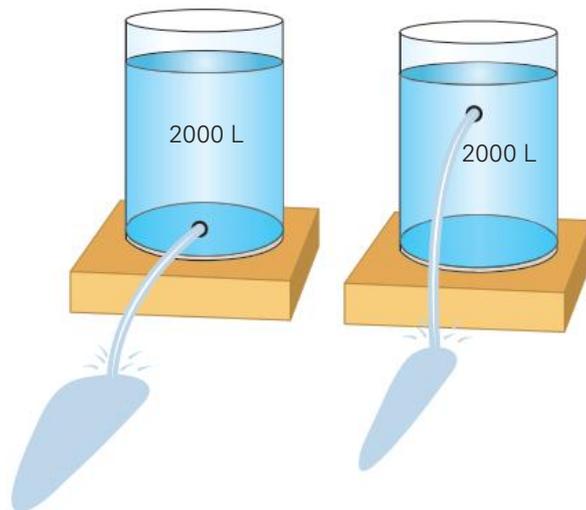


- a **Identify** the two independent variables manipulated in this experiment.  
 b **Identify** a relevant dependent variable in this experiment.  
 c **Identify** which set-up acts as a control to test all three factors.

## Applying

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

- a **Identify** the independent variable of this experiment.  
 b **State** three variables that must be controlled.  
 c The farmer repeated his experiment five times and found the same result: that the water flows more strongly from the lower hole in a water drum. **Explain** whether this is showing high or low repeatability and validity.



## Analysing

- 4 **Explain** why scientists may want to carry out fieldwork, rather than completing experimental work in a lab.  
 5 **Contrast** a model and a simulation.

## Evaluating

- 6 One example of a model is a globe. **Propose** another example of a model that has been updated over time.



## 1.2 Conducting and evaluating investigations



### Learning goals

- 1 To explore the use of specialised scientific equipment such as titration equipment and data loggers.
- 2 To be able to distinguish scientific terms, including accuracy, precision, error, uncertainty and outlier.
- 3 To be able to evaluate scientific data using measures such as mean, median, mode and range.

### Using specialised equipment

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

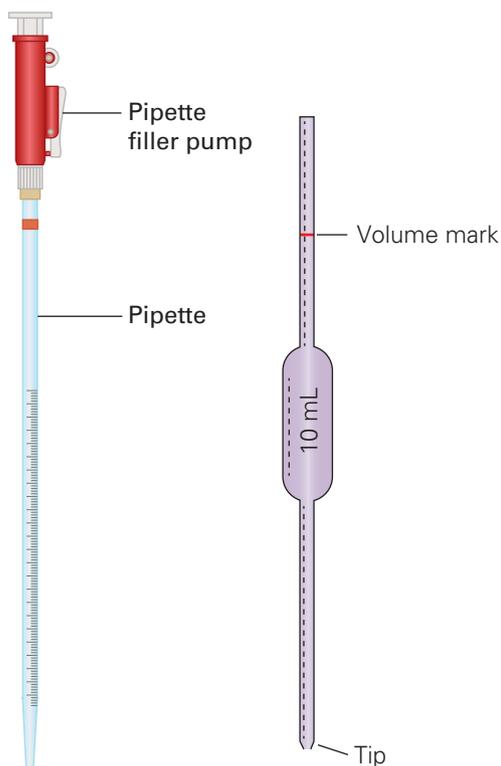
### Titration equipment

An **acid–base titration** is a specialised procedure used in the study of chemistry to generally determine the concentration of an acid or a base solution. It involves measuring the amount of one solution (an acid or a base) that is needed to neutralise a carefully measured amount of a second solution. Titrations require specialised equipment such as a pipette, burette, pH probe or data-logging device.

**acid–base titration**  
a procedure used to determine the concentration of an acid or a base 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.



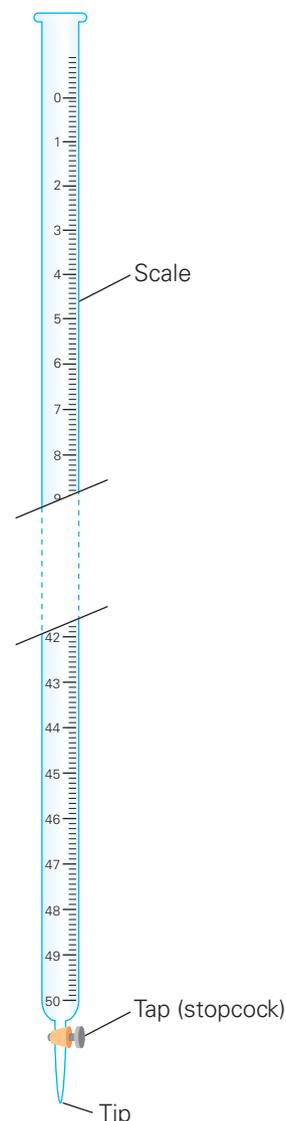
**Figure 1.7** A pipette filler pump (left) and a volumetric pipette (right)

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**Figure 1.8** A burette is set up in a retort stand to perform a titration.



**Figure 1.9** A burette

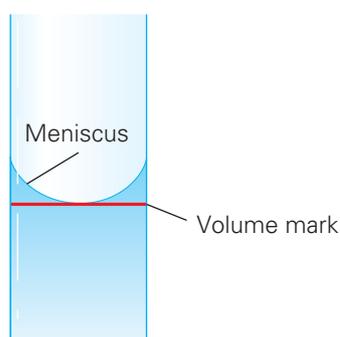
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To release the solution, the tap is placed in a vertical position and to stop the flow the tap is placed into a horizontal position.

### Instructions for using a 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 Turn the thumb wheel on the pipette filler pump to allow the solution to be drawn into the pipette.
- 4 Rinse the pipette with a small amount of the solution being used.
- 5 Draw up the solution 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 an accurate amount of your solution.



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

A pipette bulb may also be used with a pipette to withdraw and deliver solutions. Pipette bulbs can be quite tricky to use and can damage pipettes if not used correctly.

There are a few important 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, do not insert the pipette 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. Use a gentle twisting motion to remove the pipette safely without breaking.

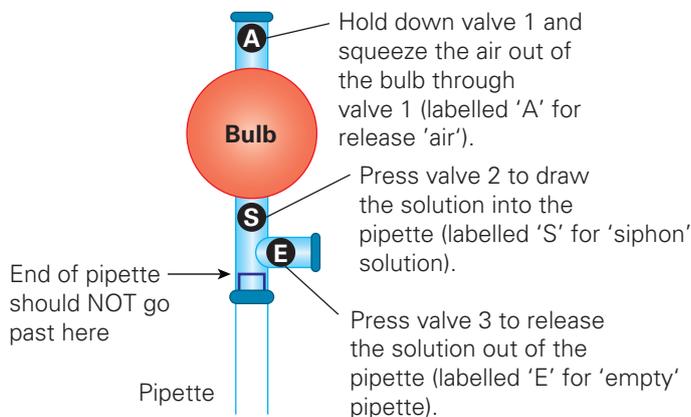


Figure 1.10 This diagram shows the correct way to use the three valves.

## Practical 1.1

### Titration skills

#### Materials

- 100 mL of 0.5 mol L<sup>-1</sup> sodium hydroxide solution
- 20 mL of 0.5 mol L<sup>-1</sup> hydrochloric acid solution
- 2 or 3 drops phenolphthalein indicator
- 2 beakers
- burette
- pipette
- funnel
- volumetric flask
- retort stand
- clamp
- white tile (to help detect colour change)

#### Be careful

Wear safety glasses and a lab coat.

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### Part 1: Practising 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 reading Figure 1.1 – 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.
- 4 Calculate the titre volumes in the following examples.

#### Example 1 (Figure 1.12)

Titre = final reading – initial reading

Titre = 37.91 mL – 0.21 mL

Titre = 37.70 mL

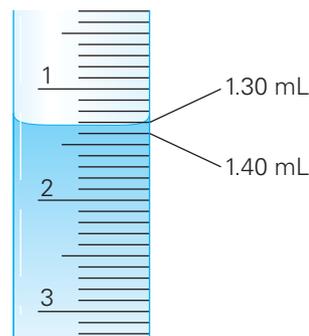
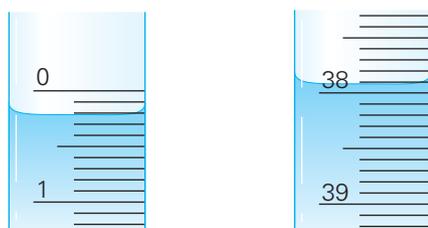


Figure 1.11 Reading a burette to two decimal places



Initial reading: 0.21 mL      Final reading: 37.91 mL

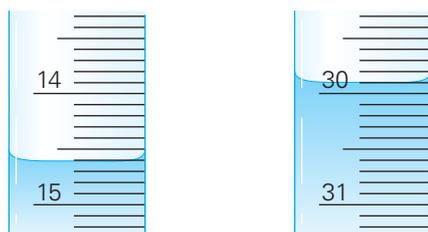
Figure 1.12 Calculating a titre volume from burette readings (Example 1)

#### Example 2: Try this one yourself (Figure 1.13)

Titre = final reading – initial reading

Titre =

Titre =



Initial reading: \_\_\_\_\_      Final reading: \_\_\_\_\_

Figure 1.13 Calculating a titre volume from burette readings (Example 2)

### Part 2: Using a burette

- 1 Measure 100 mL of 0.5 mol L<sup>-1</sup> 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, use a funnel to add approximately 5 mL of the sodium hydroxide solution from the beaker to the burette.
- 4 Open the burette tap to drain this solution into a waste beaker.
- 5 Using a funnel, add the 0.5 mol L<sup>-1</sup> 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.

continued...

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- 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 two decimal places. This is your initial scale reading.

**Note:** For practising 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.

### Part 3: Using a pipette

- 1 Rinse the pipette using a small amount of the 0.5 mol L<sup>-1</sup> hydrochloric acid by drawing the solution up above the volume mark of the pipette.
- 2 Pour this into another beaker.
- 3 Collect some fresh hydrochloric acid, again drawing the solution up above the volume mark of the pipette.
- 4 Carefully release the hydrochloric acid from the pipette until the bottom of the meniscus sits just on top of the volume mark.
- 5 Pipette the 20 mL hydrochloric acid solution into a volumetric flask.

### Part 4: Performing a titration

- 1 Add 2 or 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 person 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 end point. It is worth noting that the lighter the shade of pink, the more accurate your titration, as shown in Figure 1.14.
- 7 Record the final reading from the burette to calculate the volume of hydrochloric acid solution that has been added.
- 8 Repeat for another two trials.
- 9 Record the volume of sodium hydroxide solution for these trials to then calculate the mean volume. The table below can be used.

	Reading from burette (mL)			
	Trial 1	Trial 2	Trial 3	Mean
Initial reading				
Final reading				
Titre (final reading – initial reading)				



**Figure 1.14** Example of titration set-up for Part 4 of this experiment with pink phenolphthalein indicating that the end point has been reached

## Data loggers and probes

As mentioned previously, 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 error 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: Teacher demonstration

### Titration using a pH probe

#### Aim

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

#### Materials

Four different combinations of acid and base solutions for the class to test: strong acid–strong base, strong base–weak acid, strong acid–weak base, weak base–weak acid

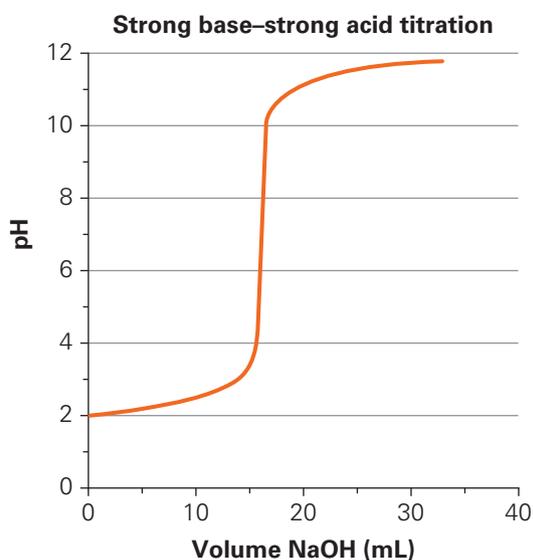
- pipette
- burette
- burette funnel
- conical flask
- retort stand
- burette clamp
- pipette bulb
- bosshead
- clamp
- wash bottle
- pH probe and data logger
- computer or laptop
- data-logging software

#### Method

Work in pairs or small groups. You will be provided with four different combinations of acid and base solutions to titrate. Decide who will be in charge of the continual stirring of the solution in the beaker and who will be in charge of releasing the base into the beaker using the burette.

#### Be careful

Ensure appropriate personal protective equipment is worn.



**Figure 1.15** A graph showing how the pH changes as a volume of sodium hydroxide (a strong base) is titrated into a strong acid

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- 1 Set up the burette and apparatus as shown in Figure 1.16 by using a clamp and a retort stand to secure the pH sensor.
- 2 Rinse the burette thoroughly with a few millilitres of the basic solution.
- 3 Fill the burette with approximately 50 mL of basic solution and record the precise volume.
- 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 data logger and pH sensor to the computer or laptop 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 base added in the computer program.
- 9 Slowly start to add some of the basic solution until the pH has risen approximately 0.2 units.
- 10 Wait for a stable pH reading and record the burette reading (volume of base 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 basic solution to the beaker, making sure to record the burette reading into the software after each increment.
- 13 When the pH is close to 10, add larger amounts of basic solution that raise the pH approximately 0.2 units.
- 14 Continue adding the basic 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 SDS.

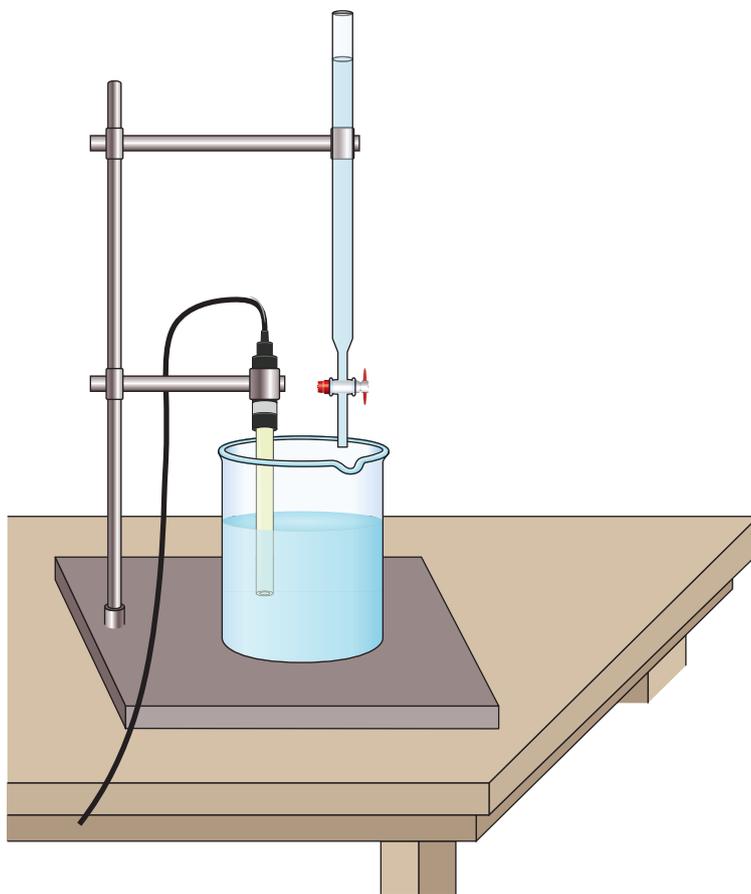


Figure 1.16 Experimental set-up

### Results

Print out your table and graph.

### Discussion

- 1 Compare the four graphs you have produced.
- 2 Discuss the different shapes of curves that were produced in relation to the strength of the acid and base combinations used.
- 3 Discuss whether this experiment would have been possible without the use of a data logger.
- 4 Propose any extensions or improvements that could be made to this experiment if you were to do it again.

### Conclusion

- 1 State a conclusion that can be made regarding the pH when a base is titrated into an acid.
- 2 Justify your conclusion by using the data you gathered.

## 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 reactant of a chemical reaction as 1.55 g, but the 'true' mass is actually 1.50 g, then you have a measurement error of 0.05 g. Choosing the best equipment and using a method that minimises 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.

Experimental **precision** refers to how closely repeated measurements agree with each other.

For example, if you record the mass of a product of a chemical reaction, and you conduct the experiment four times, getting results of 1.54 g, 1.55 g, 1.55 g and 1.54 g. The data shows low variation from the mean (it is clustered tightly) and can be said to be precise. Note that, even though this data is precise, it is not necessarily accurate. Precision does not give us an indication of how 'true' the data is; that is, how accurately it matches the actual values.

**Outliers** are extreme data values that do not appear to fit with the other recorded values. These values are often 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 dataset, within the scientific laboratory are:

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

We will come back to outliers in the data processing section below.

## Errors and uncertainties

### Quick check 1.6

- 1 Define the term 'outlier'.
- 2 If a dataset had a number of outliers, state if the data would have high or low precision.
- 3 Identify the missing word in the following sentence. An experiment is conducted and the results align very closely with the expected values, meaning the experiment could have high \_\_\_\_\_.

## Systematic and random errors

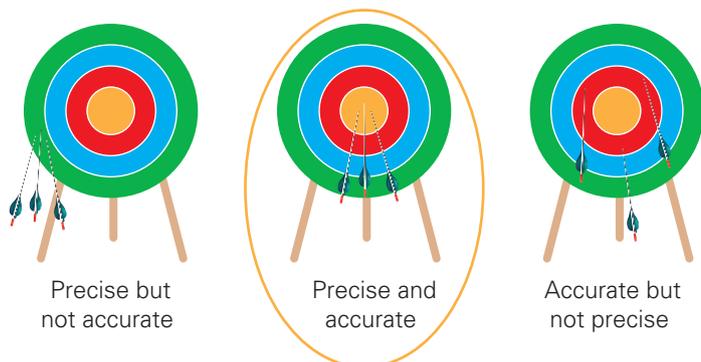
Measurements are never perfect. The accuracy of any measurement will always be limited by the apparatus being used, the skills of the person collecting the data, the method being used and the environment where the experiment is being carried out. Whenever we do an experiment, we are attempting to determine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

So, what are the possible reasons for the different values seen in our data? Mistakes are avoidable problems made by the person collecting the data, such as selecting the wrong

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

**precision**  
how closely repeated measures agree with each other

**outlier**  
an extreme data value that does not seem to fit the rest of the data



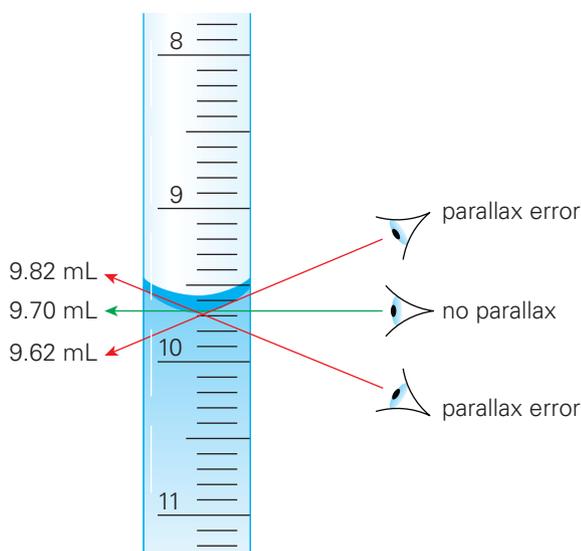
**Figure 1.17** A faulty piece of measuring equipment might consistently give wrong values, or 'miss the mark', like the target on the left. This measurement would be precise but the results are inaccurate and do not measure what they claim to measure; therefore, they have low validity.

piece of equipment or writing down results incorrectly. Although these are possible, a careful scientist should not make mistakes and would not include them in any report.

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

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

- **Instrument effects:** These are caused when a measuring instrument is faulty or has not been calibrated correctly. For example, if a scale used to measure a mass was not properly calibrated, so that all the readings were 3.00 g greater than they should be, then all the measurements of mass would be consistently overestimated by 3.00 g. This would lead to a systematic effect because the data is all wrong by the same amount each time a measurement is taken. A **zero calibration error** occurs when the initial value shown by a measuring instrument is not zero when it should be zero. For example, a scale may show 0.001 g, even when nothing is being weighed.
- **Environmental effects:** These are caused by external factors such as temperature or humidity. For example, the measurements taken using a metal ruler will differ depending on the temperature. At low temperatures the ruler will contract, whereas at higher temperatures it will expand. This means that the measurements would always be lower or higher than the correct value.
- **Observation errors:** These are caused by undertaking the wrong observations or reading instruments incorrectly. For example, a **parallax error** may be caused when the observer's eye is positioned at an angle to the



**Figure 1.18** The position where there is no parallax is the correct eye level for reading the measurement.

measurement markings, causing the data to be either larger or smaller than the correct value (Figure 1.18).

Even if careful experimental design removes systematic errors, **random errors** will still remain that will affect the accuracy of a measurement. These are caused by limitations of the measurement device and the observer and are equally likely to be positive or negative because they do not follow a regular pattern. They can be caused by the experimenter's inability to obtain the same measurement in exactly the same way to get exactly the same result. You may measure the mass of a piece of magnesium ribbon three times using the same balance and produce slight variation in your results: 1.36 g, 1.38 g and 1.39 g. **Reading errors** can also occur when a measurement falls between two measurement markers. An observer would have to estimate the true value, and this would differ between observers. Half of the results obtained would be estimates that are too large, and half would be too small. These effects are an unavoidable part of doing experiments, but the resulting error can be reduced by repeating the experiment many times and taking average values.

**systematic error**  
measured values are either consistently larger or smaller than the true value of the data

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

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

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

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

## Uncertainties

Due to random and systematic effects in the experimental process, there will always be a margin of doubt about any of your results. But how big is this margin? We have looked at how these can arise, but we need to be able to quantify them. This happens through estimating the uncertainty of any measurement. This is an interval around a measured value that quantifies that a repetition of our experiment will produce a new result that would lie within this interval.

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

*measured value*  $\pm$  *uncertainty*

where  $\pm$  means 'give or take'. This tells us the **absolute uncertainty**.

### absolute uncertainty

the size of the range of values in which the actual 'true value' of a measurement probably lies

### relative uncertainty

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

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

- The uncertainty in a scale measuring instrument is equal to the smallest increment of the instrument, divided by 2.



$$\text{uncertainty} = \frac{1 \text{ V}}{2} = 0.5 \text{ V} \quad \text{uncertainty} = 0.1 \text{ V}$$



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



$$\text{uncertainty} = 0.001 \text{ g}$$

**Figure 1.19** There are different rules for single measurements using analogue (left) or digital (right) instruments. Remember to include units!

- The uncertainty in a digital measuring instrument is equal to the smallest increment of the instrument.

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

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

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

Consider this example.

- You measured the length of your table (80.0 cm) using a metre rule.
- The absolute uncertainty is  $\pm 0.05$  cm.
- This uncertainty can then be included when communicating your results:
 
$$\text{Length} = 80.0 \text{ cm} \pm 0.05 \text{ cm.}$$
- The relative uncertainty is calculated by
 
$$\frac{0.05}{80.0} = 0.000625.$$
- This can then be reported as a percentage by multiplying by 100: Percentage uncertainty =

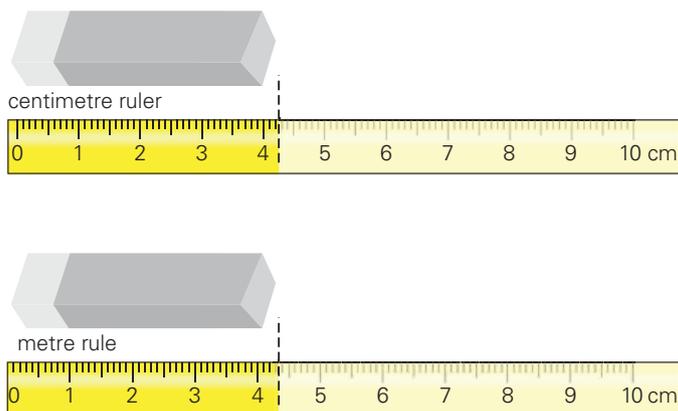
Now compare this result to measuring your eraser.

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

### Uncertainty when measuring length

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

If you were measuring the length of an eraser, you would place the eraser so it was aligned at zero on your ruler, so there is an additional  $\pm 0.05$  cm error (Figure 1.20). Therefore, the



**Figure 1.20** The uncertainty when measuring length can vary depending on the increments, the type of measuring device and how it is used.

total error for a centimetre ruler is  $0.05 \text{ cm} + 0.05 \text{ cm} = \pm 0.1 \text{ cm}$ .

However, if you decided to use a metre rule to measure the eraser, the 0 cm end is already aligned with one end of the eraser, so there is no uncertainty on that end. The other end of the eraser is somewhere along the rule. This means the total uncertainty is  $0 + \pm 0.05 \text{ cm} = \pm 0.05 \text{ cm}$ .

### Which uncertainty should be recorded?

Often, you will be completing an experiment that uses equipment *and* requires the recording of multiple measurements. The accuracy of your investigation should consider the unit in which you are measuring the dependent and independent variables, as well as the precision of the instruments you are using (Figure 1.21).

You should always record the largest source of uncertainty.



**Figure 1.21** Measurement tools vary in their precision.

### Quick check 1.7

- State the sort of uncertainty that each of the following scenarios represents.
  - A measuring tool is incorrectly calibrated and regularly underestimates the mass.
  - A measuring tool is not very precise and the temperatures vary by approximately 0.5 of a degree in either direction.
- Describe how the effect of random uncertainty can be reduced.

## Processing data

Once you have collected your data, you will need to process and describe it using descriptive statistics. Descriptive statistics provide basic information about your dataset and can indicate relationships between variables.

## Relationships between the variables

When you have graphed your data, you can determine if there are any patterns, trends or relationships. Remember that the independent variable needs to be plotted on the  $x$ -axis, and the dependent variable is plotted on the  $y$ -axis. Therefore, when you state any relationship, it must follow the pattern of 'As the (independent variable) (state how it changes), the (dependent variable) (state how it changed)'.

### mean

the sum of all the values divided by the number of values

### median

the middle value of the dataset after all the values have been ranked (sorted in ascending order). There should be as many numbers below the median as there are above

### mode

the most frequently occurring value in a dataset

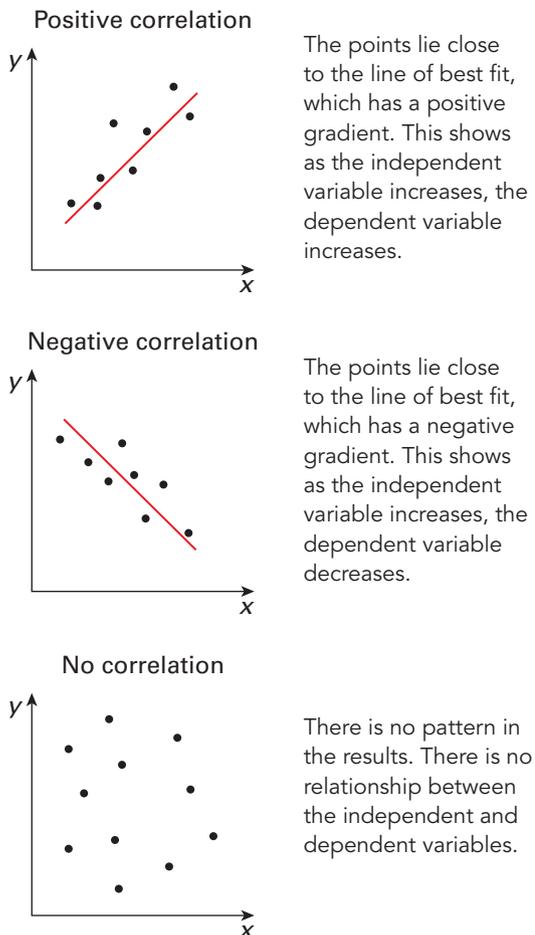
## Centrality: mean, median and mode

In descriptive statistics, we can measure the central tendency of a dataset by calculating an average. The mean, median and mode are different ways of describing the centre of a dataset, but they can often give very different stories about the data, especially when there are outliers present.

The **mean** is used to measure the centre of a dataset and is the most common statistic used when talking about averages. It is the sum of all the values collected, divided by the number of values present. However, it may not be a fair representation of the data as the mean is heavily influenced by outliers – values that are either very large or very small.

The **median** is an alternative way of measuring the centre of your data. Think about the median strip in the centre of a road. It is in the middle, with the same number of lanes on either side. In a set of data, the median is the value where an equal number of data points sit above it as below it. The median is the true middle of the data and is a good measure of the average when your data includes outliers.

The **mode** is the most frequently occurring value in a dataset. The mode is more rarely used than the mean and the median and therefore it will be referred to less often herein.



**Figure 1.22** The relationship between two variables can be positive, negative or have no correlation.

### Worked example 1.1

A group of students want to find out how long it takes to boil 500 mL of water using a particular brand of kettle. They replace the water after every boil and repeat it 9 times (to yield 10 results in total). Their results in minutes are:

2, 4, 4, 3, 2, 2, 3, 2, 13, 4

Determine the mean, median and mode of the dataset.

Working	Explanation
<b>Calculating the mean</b>	
$\frac{(2 + 4 + 4 + 3 + 2 + 2 + 3 + 2 + 13 + 4)}{10} = 3.9 \text{ minutes}$	To calculate the mean, we add the values collected. Then we divide it by the number of values collected, in this case, there are 10 values.
<b>Determining the median</b>	
2, 2, 2, 2, 3, 3, 4, 4, 4, 13	First, we need to order the values from smallest to largest.
2, 2, 2, 2, $\overset{\uparrow}{\underset{\downarrow}{3, 3}}$ , 4, 4, 4, 13	If there is an odd number of values, then we pick the middle number. In this case, there is an even number of values, so we must find the mean of the two middle numbers. Note that there is an even number of values on either side of the values in red: 4 on the left, and 4 on the right.
$\frac{(3 + 3)}{2} = 3 \text{ minutes}$	In this case, because the middle numbers are the same, the median is simply 3. If the middle numbers were 3 and 5, then the median would be $\frac{(3 + 5)}{2} = 4$ minutes.
<b>Determining the mode</b>	
<b>2, 2, 2, 2, 3, 3, 4, 4, 4, 13</b>	The most frequently occurring number is 2.

### Outliers

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

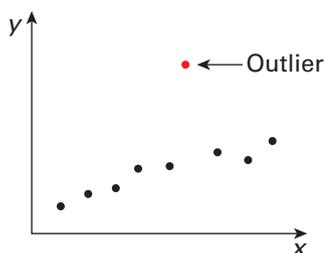


Figure 1.23 Outliers are often easily spotted in graph form.

### Range

We can also measure the dispersion of the data. This provides information about the spread of a particular variable's values. One way of doing this is to calculate the **range**, which is the difference between the smallest and largest values. Range bars can be plotted on graphs to visually represent this information. The larger the range bars, the more variation in the variable's values, suggesting that the data is less reliable. Usually, outliers are excluded from calculations.

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

**Worked example 1.2**

Using the data in Worked example 1.1, determine which data is a likely outlier, as well as the range of the data.

Working	Explanation
<p><b>Outliers</b></p> <p style="text-align: center;">Time taken to boil</p>	<p>Creating a line plot allows us to easily see that 13 minutes to boil is likely to be an outlier.</p>
<p><b>Range</b></p> <p><math>4 - 2 = 2</math> minutes</p>	<p>Excluding the outlier, 13 minutes, we subtract the largest value, 4, from the smallest value, 2. If we include the outlier, the range would be <math>13 - 2 = 11</math> minutes.</p>

**Quick check 1.8**

Calculate the mean, median, mode and range of the following dataset:  
17, 14, 18, 21, 21, 19, 12, 20, 16

**Evaluation**

The evaluation should be a critical and justified discussion of the reliability and validity of the experimental process. This involves a consideration of the quality of your data, where you should identify any outliers and give potential reasons for their cause. Any problems you have identified with your results need to be explained by considering the limitations imposed by the equipment and experimental techniques used. Remember that you should

be considering both random and systematic errors. Use your results to assess the accuracy of the data you collected. This can be assessed by looking at things like if the line of best fit closely aligns with your data, or if the range bars are large or small. You should also suggest and explain improvements and extensions that are logically derived from the analysis of your data.

**Conclusion**

The conclusion is where you should answer your original research question, stating whether your hypothesis is supported or not. You should start with a general statement that refers to your findings in a general way, but then justify this by using actual data from your results to support this statement. You can also use your own scientific knowledge to explain your results.

### Practical 1.3

#### Comparing the effect of indigestion remedies

##### Background

We already know from Year 9 that the stomach is an essential organ involved in the digestion of food. It achieves this by creating a highly acidic environment (pH of approximately 2 to 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 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

- hydrochloric acid (1 mol L<sup>-1</sup>)
- 3 different antacids
- titration equipment
- electronic balance
- spatula
- Congo red indicator
- watchglass

##### Method

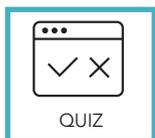
Design the method: Plan your experiment with a lab partner, taking into consideration:

- 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.



## Section 1.2 questions

**Remembering**

- 1 **State** the meaning of the term 'outlier'.
- 2 **Name** one specialised piece of equipment used in a titration.

**Understanding**

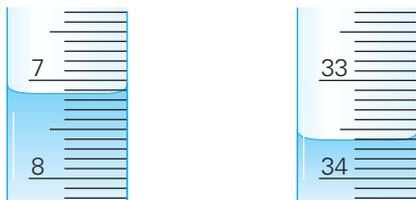
- 3 **Explain** how the use of a data logger can be beneficial to an experiment.

**Applying**

- 4 **Classify** the following errors as either random errors or systematic errors.
  - a Instrument error: A burette is leaking so every reading taken is 0.1 mL lower than the actual value.
  - b Human error: When recording the data, the researcher has a poor understanding of rounding decimals and consistently rounds them up to the nearest whole number.
  - c Instrument error: A set of scales is not very precise and the displayed mass is often out by 1–3 grams in either direction.
- 5 **Compare** the mean to the median of a dataset.

**Analysing**

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



Initial reading: \_\_\_\_\_ Final reading: \_\_\_\_\_ Titre: \_\_\_\_\_

**Evaluating**

- 7 Jake took 12 identical pots and 12 identical plants. In each of four pots he placed soil and 10 grams of fertiliser A and one plant. In each of another four pots he placed a plant, 15 grams of fertiliser B and the identical amount of soil as in the previous four pots. In each of 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. **Discuss** whether his conclusion is valid.

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
1.1 I can describe each stage of the experimental design process.	4	
1.1 I can identify independent, dependent and controlled variables.	2, 9b	
1.1 I can recognise the difference between reproducibility, repeatability and validity.	9d	
1.1 I can recognise the need to write a risk assessment before completing any experiment.	4	
1.1 I can describe the information found on a safety data sheet (SDS).	3	
1.1 I can describe the ethical requirements of working with humans and animals.	1	
1.2 I can describe the use and importance of specialised equipment such as burettes, pipettes and dataloggers.	7c	
1.2 I can recognise the difference between accuracy and precision.	7b	
1.2 I can recognise outliers in scientific data.	6c	
1.2 I can recognise the difference between systematic and random errors.	5, 7a	
1.2 I can calculate the mean, median, mode and range in scientific data.	6d, 6e	
1.2 I can define the absolute and relative uncertainty in a measurement.	7d	

## Review questions

### Remembering

- Name** three ethical principles that must be upheld by a scientist conducting research with human subjects.
- Define** the following terms:
  - independent variable
  - dependent variable
  - controlled variables.
- Recall** the information that is located on a safety data sheet (SDS).

### Understanding

- Describe** the method stage of the design process and why it is necessary to complete a risk assessment before completing the experiment.
- Explain** why repeating an experiment multiple times is considered a method to minimise random errors.



**Applying**

- 6 The table below shows the effect of changing the pH of a pond on the number of tadpoles in the pond.

pH of water	Number of tadpoles		
	Trial pond 1	Trial pond 2	Trial pond 3
8	45	44	43
7.5	69	71	70
7	78	80	81
6.5	88	85	89
6	43	43	43
5.5	23	24	5

- Identify** the independent variable and dependent variable of this study.
- Identify** the optimum pH for tadpole growth.
- Identify** an outlier in the data.
- Calculate** the mean and median number of tadpoles in a pond with a pH of 7.5.
- Calculate** the range of the number of tadpoles in a pond with a pH of 6.5.
- Construct** a graph of the number of tadpoles in trial pond 1 against the pH of water. Label the axes correctly and write an appropriate title.

**Analysing**

- 7 A faulty burette is being used during a titration and this causes all of the results to be overstated by 0.5 mL each time.
- Identify** the type of error present in the data.
  - Discuss** the effect of this error on the accuracy and precision of the collected data.
  - A burette is a specialised piece of equipment for a titration experiment. **Discuss** whether the equipment could be replaced by a measuring cylinder for this experiment.
  - A burette has an uncertainty of  $\pm 0.05$  mL per reading. **Describe** whether this value represents an absolute uncertainty or a relative uncertainty on a burette reading of 20.00 mL.
- 8 Read the following information and answer the questions below.
- Research has been conducted on the effect of short, daily exercise on mice and rats. The mice and rats were all exercised mildly for 10 minutes once a day. It was shown that the mice and rats developed more new brain cells when they exercised than when they did not exercise. These new brain cells were mostly located in or around the hippocampus, which is involved in creating and storing memory, improving memory and learning new things. Using the information, **categorise** the following variables as independent, dependent or controlled.
- Memory ability
  - Exercise intensity
  - Age of rodent
  - Undertaking exercise
  - Time taken to exercise

**Evaluating**

- 9 A Year 10 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 Year 10 male friends to be the participants. Two of them went without sleep for 24 hours 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 friends said they slept for their usual amount of time and were given the same memory test: 20 three-letter nonsense words to memorise for two minutes and then recall. Results are shown below.

	Mean recall score of three-letter nonsense words (out of 20)
Sleep-deprived group	5
Non-sleep-deprived group	11

- Write** a hypothesis for this experiment.
- List** the independent variable, dependent variable and two possible controlled variables in the experiment.
- Propose** a conclusion that can be drawn from the results obtained.
- Evaluate** the possible limitations to the validity of this experiment.

### Data questions

High school students were analysing the amount of ethanoic acid in a commercial vinegar sample and had made up a dilute solution of  $0.1 \text{ mol L}^{-1}$  ethanoic acid based on the concentration of ethanoic acid given on the bottle of vinegar. The students set up a titration with 20.00 mL of their ethanoic acid in a conical flask (via pipette) and filled a burette with  $0.1 \text{ mol L}^{-1}$  NaOH.

If the ethanoic acid content quoted on the vinegar bottle was correct, the students hypothesised that 'if 20 mL of  $0.1 \text{ mol L}^{-1}$  ethanoic acid is present, then 20 mL of  $0.1 \text{ mol L}^{-1}$  NaOH will be required to reach an end point'. The titration data from two students attempting six repeated trials is tabulated below.

Titration	Volume (mL) $0.1 \text{ mol L}^{-1}$ NaOH to end point	
	Student 1	Student 2
1	19.95	20.50
2	20.00	20.50
3	20.50	20.50
4	22.70	29.30
5	19.95	20.40
6	20.00	20.40
<b>Mean</b>		

- Identify** and circle any outliers in each student's trials.
- Calculate** the mean volume of NaOH required to reach the titration end point, after removing outliers for each student.
- The 'true' value for the titration given the actual concentration of ethanoic acid should have been 20.00 mL of  $0.1 \text{ mol L}^{-1}$  NaOH. **Recognise** the validity of this experiment in identifying the concentration of ethanoic acid.
- Identify** if any patterns occur in the results obtained by the students.
- Contrast** the data tabulated. Was each student accurate?
- Analyse** the data tabulated. Were the students precise?
- Justify** whether the data presented by students 1 and 2 provide evidence to support the hypothesis.
- Compare** the data fluctuations for each student. Do the data points fluctuate randomly above and below the true value or are they biased in one direction?
- Based on the data presented, **infer** whether the experiment was repeatable and reproducible.

# Chapter 2

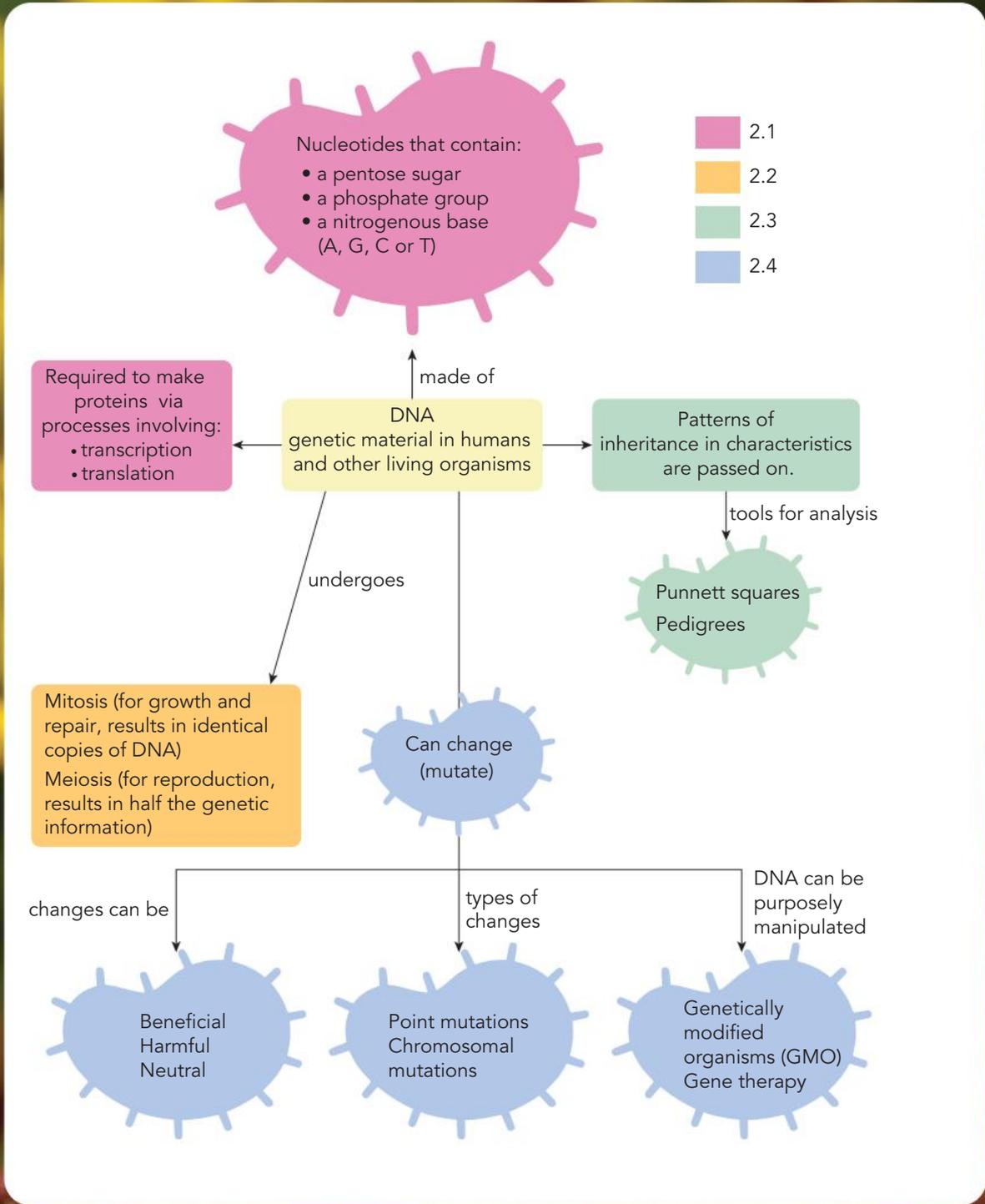
# Genetics



## Chapter introduction

Everyone is unique. That is thanks to the genetic make-up we all have within us, known as DNA. 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.

# Chapter map



# 2.1 Introduction to genetics and DNA



## Learning goals

- 1 To recall the components that make up the structure of DNA and RNA molecules.
- 2 To be able to identify how genes are related to DNA structure and chromosomes.
- 3 To recall the steps in which DNA is used to synthesise proteins.

## Genetics

### genetics

the study of inheritance

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

**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.

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.

## Practical 2.1

### Extracting DNA from cells

#### Time period

Approximately 1 hour

#### Aim

To investigate and extract DNA from strawberries.

#### Materials

- plastic sandwich bag (or other material to contain strawberry and liquid)
- strawberry
- DNA extraction solution provided (10 mL)
- filter funnel and gauze (or other gauze-style filter)
- cold ethanol solution
- test tube (or small beaker)
- stirring rod
- plastic pipette

DNA extraction mixture:

- dishwashing liquid or shampoo (5 mL)
- table salt (0.75 g)
- water (45 mL)

#### Method

- 1 Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
- 2 Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
- 3 Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.
- 4 Pour the strawberry mixture through a filter funnel lined with gauze into a test tube.

*continued...*

### Be careful

Wear safety glasses and a lab coat. Do not consume food items.

...continued

- 5 Discard the gauze and strawberry remains into a bin.
- 6 Add an equal volume of cold ethanol to the test tube using a plastic pipette.
- 7 Mix slowly the two layers of liquid with a stirring rod.
- 8 Collect the white solid that forms on the stirring rod. This is DNA.

### Results

Write observations for what occurs during each step of the method.

### Discussion

- 1 Describe whether the white solid could contain all of the DNA of the strawberry.
- 2 Visually compare the amount of solid you collected to that of other groups in the classroom. Were results consistent?
- 3 Describe the variables that were not made consistent between groups in the classroom.
- 4 Suggest any changes that could be made to the method to improve the quality of the recorded data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

### Conclusion

Draw a conclusion regarding the efficiency of this method at extracting all the DNA from a strawberry, based on yours and other groups' observations.

## Structure of DNA

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

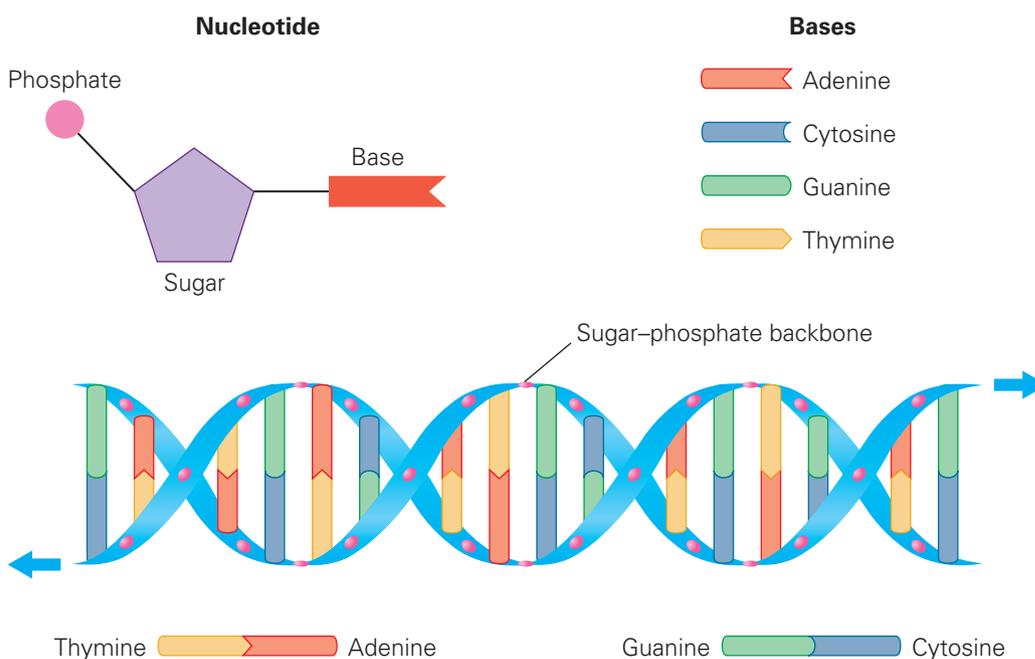
DNA is a long-chain molecule made up of numerous subunits called **nucleotides**.

A nucleotide of DNA has three major components:

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



**nucleotide**  
a subunit of DNA, consisting of a phosphate group bound to a deoxyribose sugar, which in turn is bound to a nitrogenous base



**Figure 2.1** The structure of DNA: the subunits called nucleotides join 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.

The nucleotides are bound together by condensation reactions to form a long single strand. Two strands then bind together (through **hydrogen bonds** between the nitrogenous bases) and 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 from one strand align towards the centre and interact with complementary bases on the other strand to form the rungs of the ladder.

#### hydrogen bonds

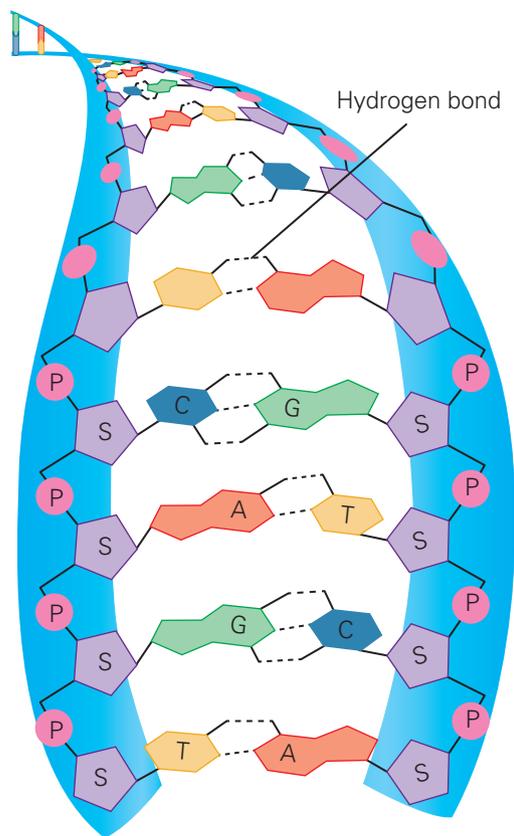
chemical interactions that hold the two DNA strands together

#### complementary base pairing

in DNA adenine only binds with thymine and cytosine only binds with guanine

What do you notice about the pairing of the nitrogenous bases in Figures 2.1 and 2.2? 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 cytosine (C) always pairs with guanine (G). One way to remember the A-T and C-G pairings is 'AT CoGee beach'. This pairing is called **complementary base pairing** and occurs due to 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 2.2 that guanine and cytosine both form three hydrogen bonds, while adenine and thymine only form two hydrogen bonds.

Both guanine and adenine have a double-ring structure, which means they are in the group of



**Figure 2.2** 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.

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).

### Try this 2.1

#### Modelling DNA using lollies

##### Materials

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

##### Instructions

- 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.

#### Be careful

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

*continued...*

...continued

- 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 jelly babies 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 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 Recall 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 nitrogenous bases ATATAGATAGATCAGACA, state the bases in its complementary strand.

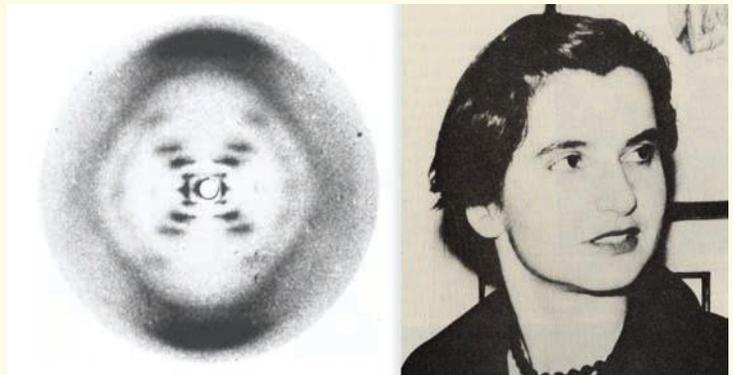
### Explore! 2.1

#### 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
- Francis Crick and James Watson
- Rosalind Franklin
- Maurice Wilkins



**Figure 2.3** 'Photo 51' shown (left) was taken by Dr Rosalind Franklin (right) and Ray Gosling at King's College London in 1952, confirming the helical structure of DNA. This later enabled the first correct model of the DNA structure to be built.

### What is a chromosome?

The DNA found in the nucleus of a cell usually looks like a bowl of spaghetti. However, when it is time for the cell to replicate, the DNA winds tightly around proteins called histones to form structures called **chromosomes**. Each molecule of DNA condenses to form one chromosome. Along the DNA strand are **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 each and every one of the proteins in our bodies! Proteins are fundamental to all of the chemical reactions in an organism, and also form much of the structure of a chromosome due to the histones that DNA wraps around.

**chromosome**  
a structure of tightly wound DNA

**gene**  
a section of DNA which codes for the synthesis of proteins

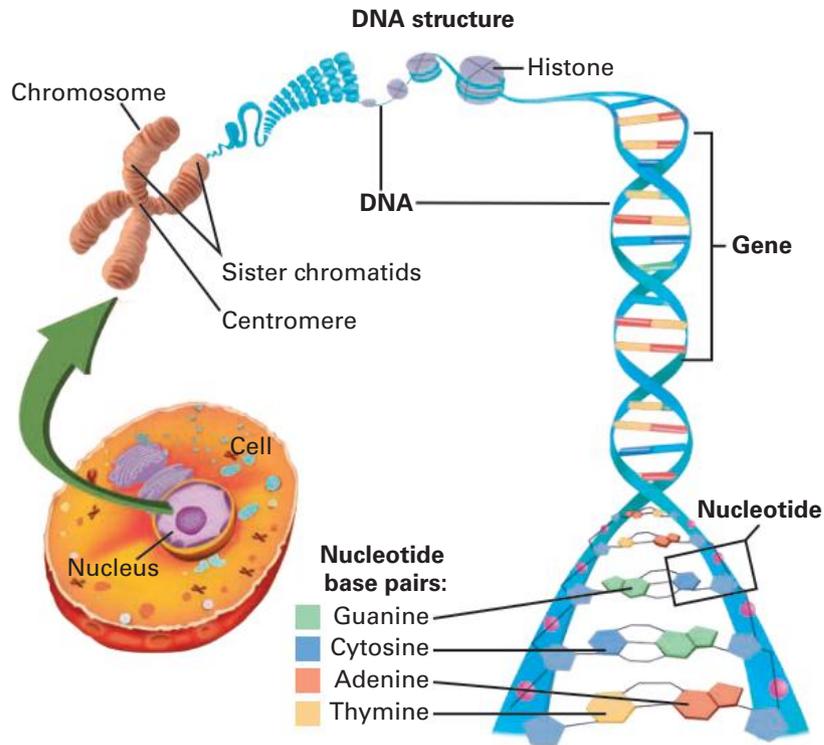


Figure 2.4 The relationship between DNA and chromosomes

You may be familiar with the X-shape of a chromosome, but this shape is only seen when DNA replication (when DNA is copied) occurs. Before replication, the chromosome appears as a single condensed DNA molecule. After replication, this produces two identical chromatids that are joined together by **centromeres** to form the distinct X-shape; these are then known as **sister chromatids**. They belong to the same chromosome. Figure 2.5 shows this.

**centromere**

a structure that holds two sister chromatids together

**sister chromatids**

two copies of the same chromosome, connected at a centromere

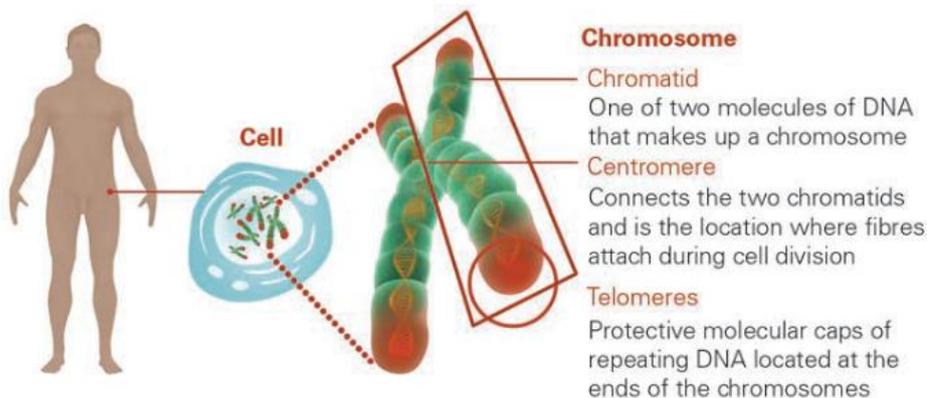


Figure 2.5 The distinct X-shaped chromosome, showing the two chromatids and the centromere

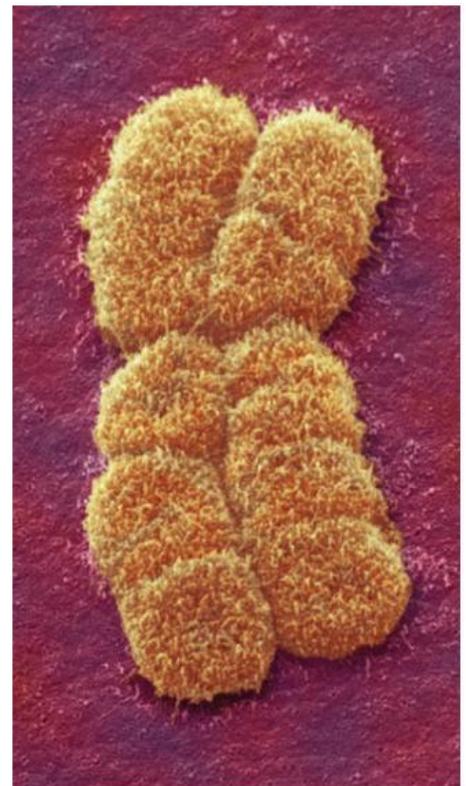


Figure 2.6 A scanning electron micrograph of a human chromosome. Notice the two identical chromatids joined at a centromere.

## Science as a human endeavour 2.1

### Professor Elizabeth Blackburn

Born in Hobart in Tasmania, 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. Professor Blackburn was awarded the 2009 Nobel Prize in Physiology or Medicine together with her colleagues Jack W. Szostak and Carol Greider.

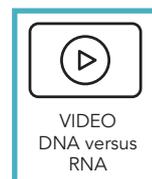


**Figure 2.7** Nobel Prize laureate Professor Elizabeth Blackburn was integral to the research on telomeres.

### Different forms of nucleic acids

There are four types of biomacromolecules: proteins, carbohydrates, lipids (fats and oils) and nucleic acids. 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 found within the cytoplasm.	Cytoplasm Nucleus Ribosomes
Different forms	DNA Mitochondrial DNA (mtDNA) Chloroplast DNA (cpDNA)	Messenger RNA (mRNA) Transfer RNA (tRNA) Ribosomal RNA (rRNA)

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

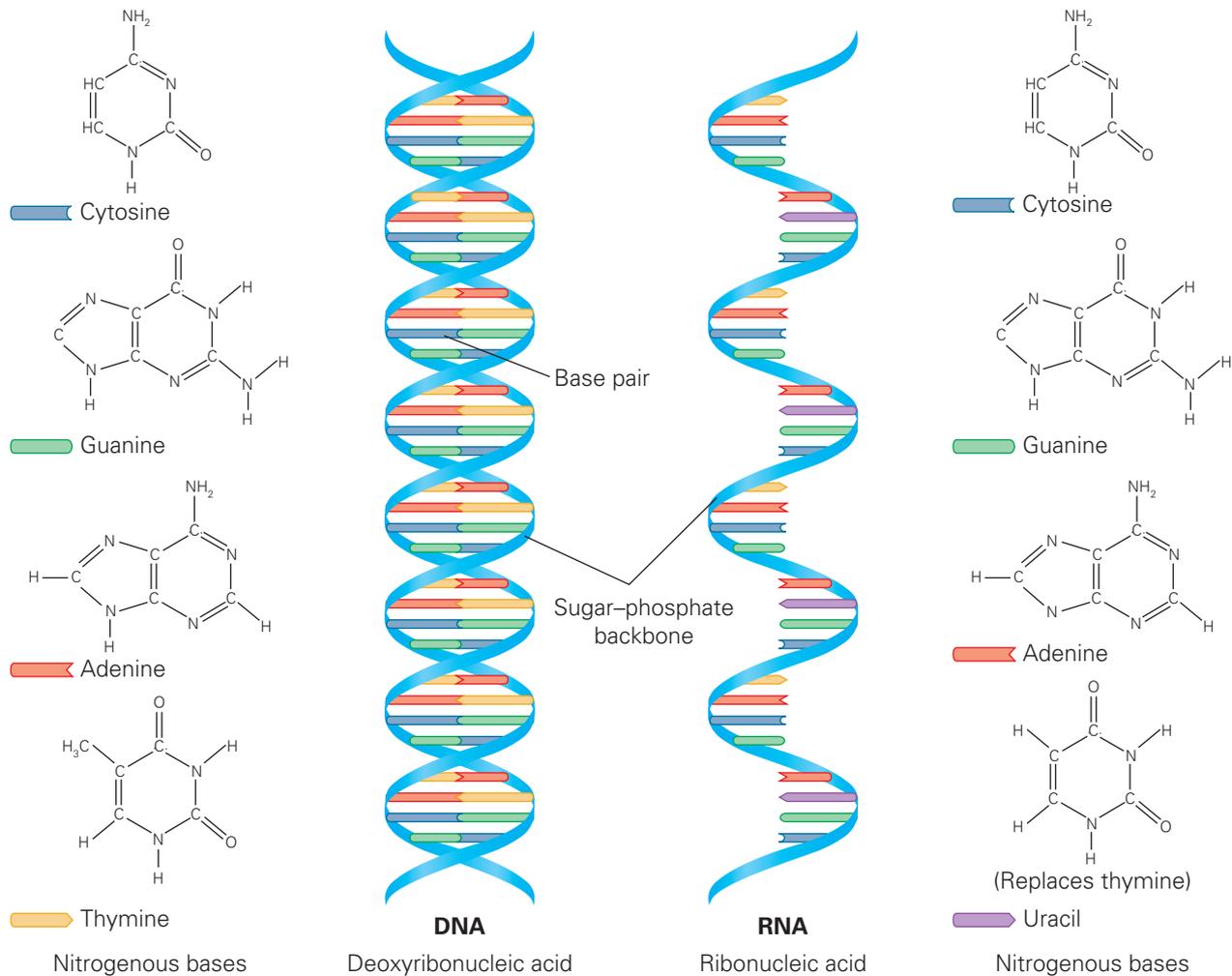


Figure 2.8 DNA and RNA

### Quick check 2.2

- 1 Describe the relationship between chromosomes, genes, DNA and base pairs.
- 2 Contrast the structures of DNA and RNA.

## The purpose of DNA: making proteins

### Why do we need proteins?

Proteins are complex molecules that play a critical role in many body functions. We make use of approximately one billion proteins every day, just to function normally. Proteins are the main structural component of cells; they can build and repair tissue, and may include enzymes to break down substances. Protein molecules have different

roles in the body; for example, haemoglobin transports oxygen around our body and hormones regulate our glucose levels and development. Collagen and keratin are structural proteins, making up the structural components of organs. Amylase and lipase are catalytic proteins that help control the rates of reactions. Other proteins help us fight pathogens and move our muscles.

## Explore! 2.2

### Protein functions

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

Protein	Function
Collagen	
Actin	
Haemoglobin	
Amylase	

## The link between DNA and proteins

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

### Quick check 2.3

- 1 Recall why proteins are important.
- 2 Describe 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; that is, the instruction in the DNA is converted into a protein. Thus, 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).

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.

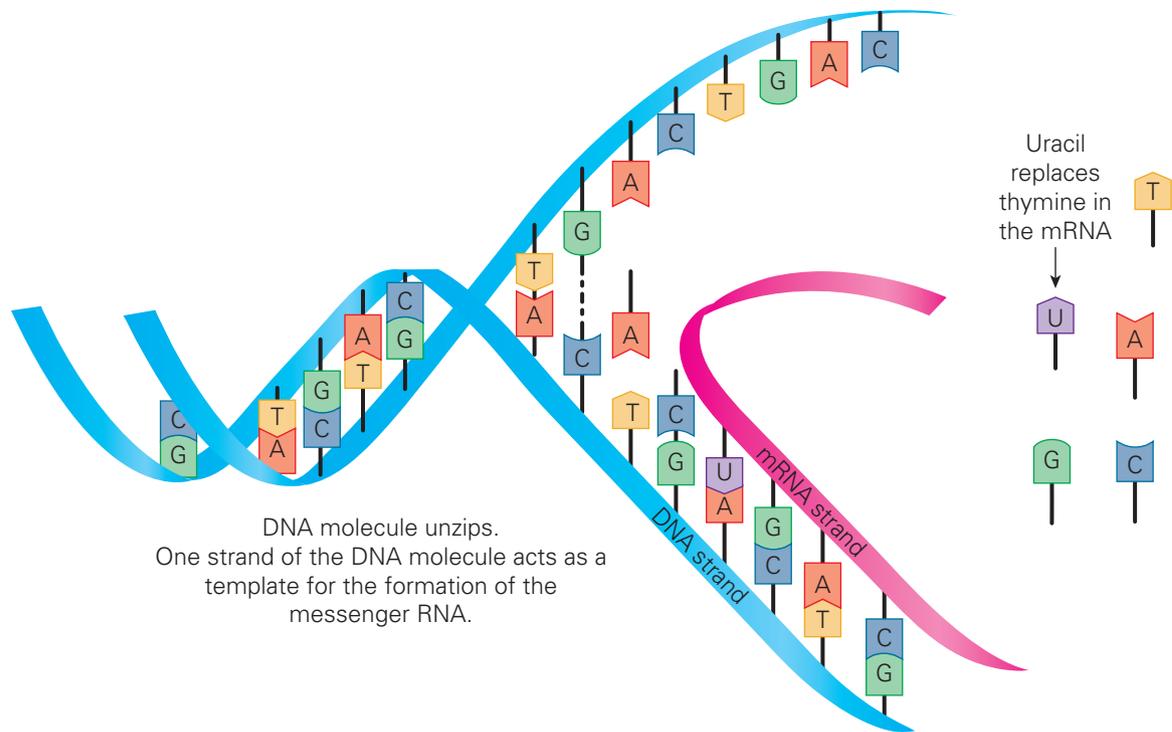
### Transcription

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. Transcription begins when an enzyme (RNA polymerase) binds to the gene being copied. This signals to the DNA double-stranded helix to unwind, which allows the enzyme to read the code on one of the DNA strands (called the DNA template strand). As the enzyme reads the code, it builds a complementary copy of the gene using RNA nucleotides, C, G, A and U. RNA follows the same complementary pairing as DNA, with one exception. Where DNA has the nitrogenous base thymine (T), RNA has uracil (U). The resultant single-stranded RNA formed is called messenger RNA (mRNA). When the mRNA peels away from the DNA template strand, the DNA double strands rejoin and re-form a helix. The mRNA can then leave the nucleus and go to the site of protein production, the ribosomes.

**base triplet**  
three DNA bases that code for an amino acid

**transcription**  
the first stage of protein synthesis where the base sequence of DNA is copied into mRNA

**translation**  
the second stage of protein synthesis where a sequence of mRNA is translated into a sequence of amino acids



**Figure 2.9** 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												



WIDGET  
Building a  
protein

#### Translation

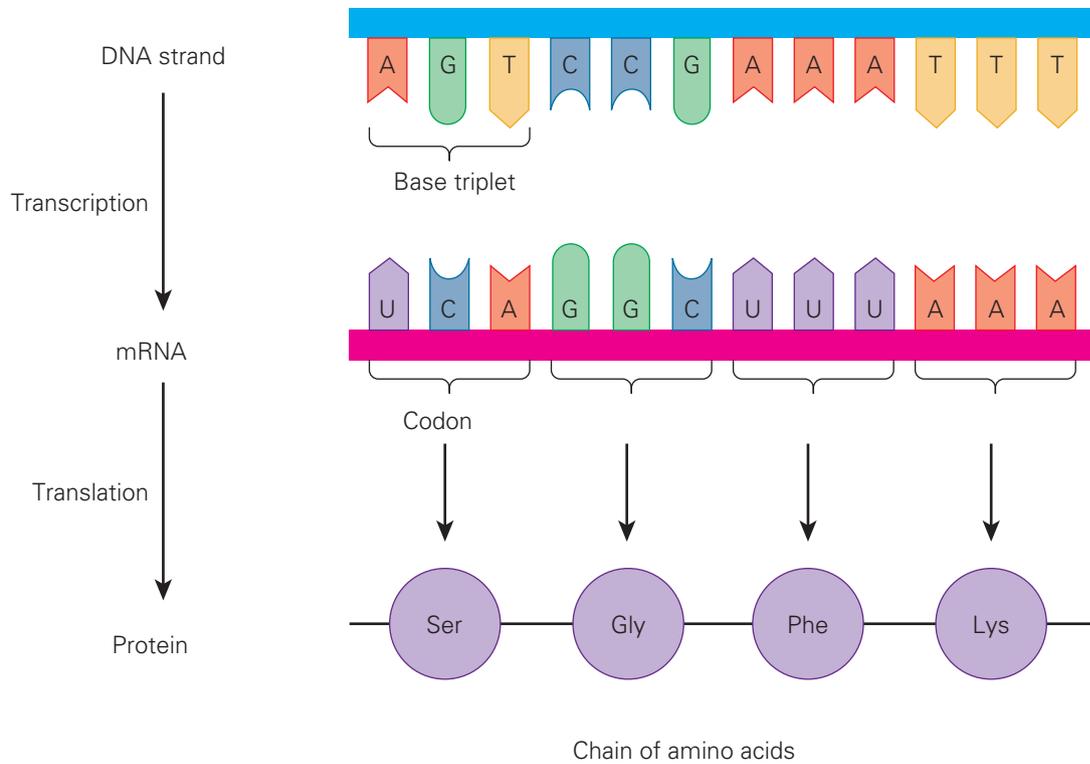
Once mRNA reaches the ribosomes in the cytoplasm, it must be 'decoded' or translated so that the necessary protein can be made. The nitrogenous bases in the mRNA are decoded in groups of three called **codons** (base triplets in the original DNA template strand). Each codon in the mRNA specifies which amino acid is added to the polypeptide chain – remember, it is a chain of amino acids that we call a protein. The process of translation is simplified in Figure 2.10 and involves several enzymes and another type

of RNA called transfer RNA (tRNA). tRNA occurs at the ribosomes, which may be freely floating in the cytoplasm or attached to the endoplasmic reticulum (ER) in the case of rough ER. Each tRNA molecule is responsible for transporting one specific amino acid towards the ribosome for delivery.

Table 2.2 shows the 20 different amino acids that make up the range of proteins we have in our world. Using this table, you can identify the amino acid that a codon codes for. For example, if the first codon of your mRNA strand is AUG,

#### codon

three nucleotides (base triplet) on mRNA that code for an amino acid



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

you look up the A on the left and the U at the top and find where they intersect. At that spot is a box containing four different codons. You then read left 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.

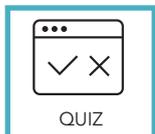
		2nd letter in the codon					
		U	C	A	G		
1st letter in the codon	U	UUU   Phe (F) UUC UUA   Leu (L) UUG	UCU   Ser (S) UCC UCA UCG	UAU   Tyr (Y) UAC UAA   STOP UAG   STOP	UGU   Cys (C) UGC UGA   STOP UGG   Trp (W)	U C A G	
	C	CUU   Leu (L) CUC CUA CUG	CCU   Pro (P) CCC CCA CCG	CAU   His (H) CAC CAA   Gln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

### Quick check 2.4

- 1 The following codons are found in a strand of DNA: TAA TTA TCG ACT ACT AGC. State the complementary mRNA strand.
- 2 Contrast transcription and translation.
- 3 Explain why you do not need to read the code on both strands of DNA when transcribing DNA into mRNA.

### Section 2.1 questions



#### Remembering

- 1 **Name** the basic building blocks or subunits of DNA.
- 2 **Recall** where proteins are created (synthesised) in the cell.
- 3 **Recall** the name for the shape of DNA.
- 4 **Illustrate** and label a nucleotide.
- 5 **Recall** the four bases found in DNA and the complementary base pair rule.
- 6 **Recall** why all mRNA strands start with the codon AUG.

#### Understanding

- 7 A template strand of DNA is found to contain the following bases:  
TAC GGA TCA TCG TGG GAA GCA GGC ATT
  - a **State** the complementary DNA strand.
  - b Using the above template strand of DNA, **state** the bases on the mRNA strand.
  - c Using Table 2.2 of amino acids, **identify** the amino acids that this strand of DNA would code for.

#### Applying

- 8 **Describe** the purpose of DNA.
- 9 **Describe** the relationship between DNA, genes and chromosomes.
- 10 **Explain** how the body produces so many proteins with only four different nitrogenous bases.
- 11 **Explain** how the genetic information found in the chromosomes within the nucleus of a cell reaches the ribosomes for protein synthesis.
- 12 Draw a flow chart to **summarise** the key steps in transcription and translation.

#### Analysing

- 13 **Contrast** the structures of mRNA and DNA.
- 14 **Differentiate** between a structural protein and a catalytic protein, providing examples of each.

#### Evaluating

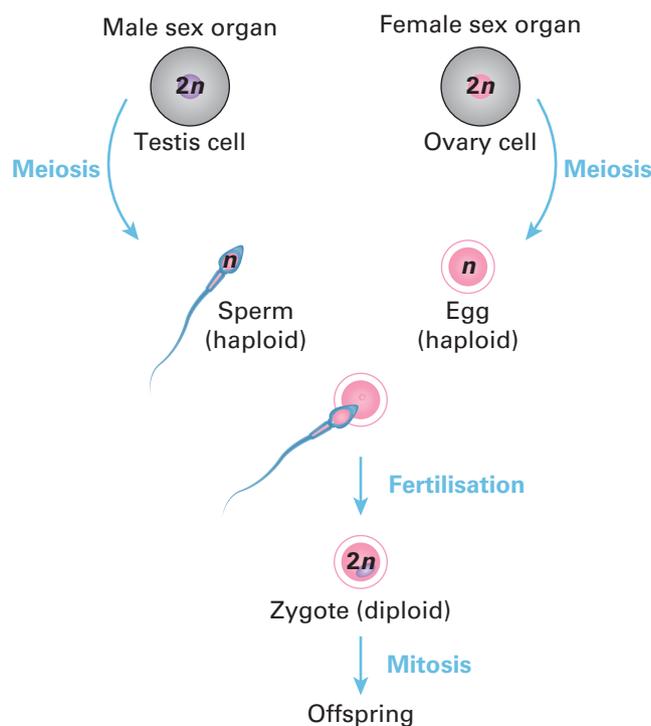
- 15 A template strand of DNA is found to contain the following bases:  
TCC TGA TGA TGG GGG GCA AAA CGC GTA  
Something went wrong during the transcription of this template strand and the mRNA strand contains the following bases:  
AGG ACU ACU ACC CUC CGU UUU GCG CAU
  - a **Determine** the mistake in the mRNA strand above.
  - b **Propose** the outcome of this mistake on the protein produced.
- 16 **Propose** what may occur if there was a problem with a certain protein in your body.

## 2.2 Passing on genetic information

### Learning goals

- 1 To be able to recall the steps involved in DNA replication.
- 2 To be able to describe the stages of cell division in mitosis and meiosis.
- 3 To be able to identify the autosomes and sex chromosomes in a karyotype.

Two different forms of reproduction occur among organisms: asexual and **sexual reproduction**. 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 and as the number of cells increases, they begin to take on special functions. Eventually, the zygote becomes the **embryo** of the organism.



**Figure 2.11** Sexual reproduction involves gametes from a male and a female combining to form a zygote.

You will notice that Figure 2.11 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 all diploid.
- **Meiosis** is the name of the process by which the gonads make the haploid gametes.
- **Mitosis** is the name of the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair.

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 sets of chromosomes 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.



**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 becomes an embryo

**haploid ( $n$ )**  
a cell containing only one set of chromosomes

**diploid ( $2n$ )**  
a cell containing two sets of chromosomes

**somatic cells**  
the body cells of an organism

**meiosis**  
the process by which the gonads make the haploid gametes

**mitosis**  
the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

### 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 2.12** 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's body (somatic) cell contained 54 chromosomes, calculate how many chromosomes would be found in their gametes.

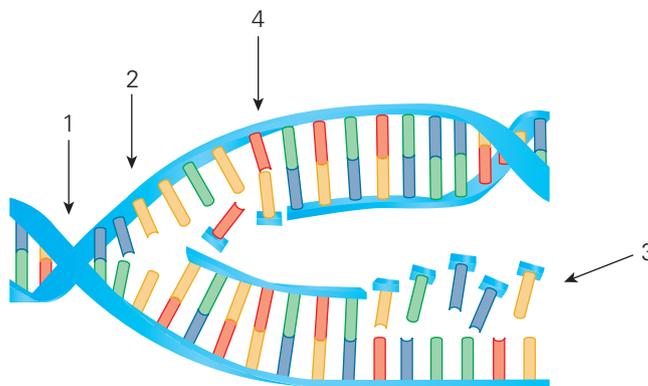
## How does DNA replicate?

Before a cell divides, the DNA has to be replicated (copied) to provide two copies of each chromosome. This occurs before mitosis and meiosis. This process of DNA replication has to occur perfectly (without any errors); otherwise, the code in the DNA might be affected and faults in replication can lead to mutations. The steps involved in DNA replication are summarised below and in Figure 2.13.

- 1 The DNA molecule begins to unwind with the help of a multi-enzyme complex.
- 2 The DNA then 'unzips' down the middle between the nitrogenous bases, breaking the hydrogen bonds. This step occurs with the help of an enzyme called DNA helicase. 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 called DNA polymerase 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 very important because

it means the two new strands of DNA will be identical to the original one that unzipped.

- 4 The newly added nucleotides are connected with new hydrogen bonds, which results in two identical strands of double-stranded DNA being formed. Each new strand is one-half of the original strand and one-half that was newly built. For this reason, replication is sometimes described as being semi-conservative.



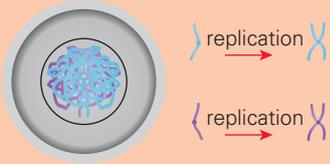
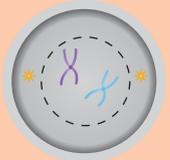
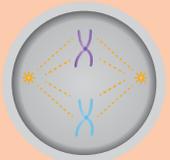
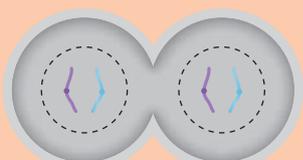
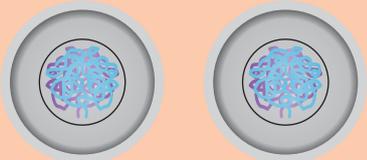
**Figure 2.13** DNA replication: (1) the DNA must first unwind and (2) unzip and then (3) the new DNA nucleotides can be added following complementary pairing rules. (4) This results in two identical strands of DNA.

### Quick check 2.6

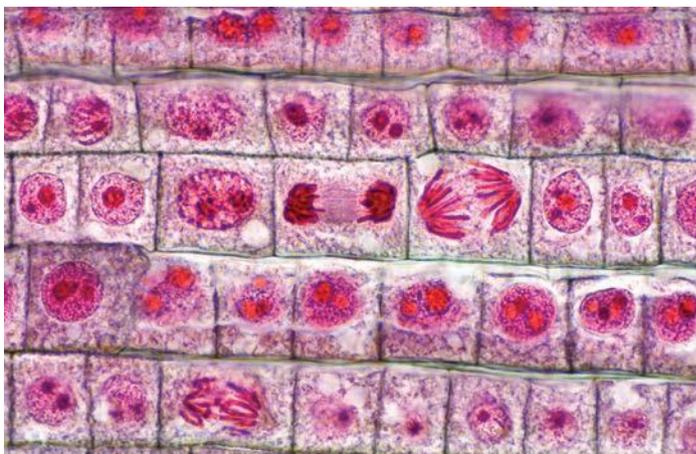
- 1 Explain the purpose of DNA replication.
- 2 Summarise the steps of DNA replication.

## Mitosis

Mitosis 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 ( $2n$ ) parent cell divides into two cells that are genetically identical (so also diploid), called daughter cells. This sequence is shown in Table 2.3. The stages of mitosis include interphase, prophase, metaphase, anaphase, telophase and cytokinesis. The stages can be compacted to 'IPMAT' to help you remember their order. Within the human body, every cell is produced via this process, with the only exception being the formation of gametes, or sex cells, which are produced by meiosis and result in haploid ( $n$ ) cells.

The stages of mitosis			
Before mitosis	Interphase $2n$		<ul style="list-style-type: none"> <li>• Parent cell is diploid.</li> <li>• DNA replication occurs.</li> <li>• Chromosomes are not visible.</li> <li>• The cell gets bigger.</li> <li>• Organelles replicate.</li> </ul>
Stages of mitosis	Prophase		<ul style="list-style-type: none"> <li>• The nuclear membrane breaks down, DNA winds up and becomes distinct chromosomes.</li> <li>• Spindle fibres begin to form.</li> </ul>
	Metaphase		<ul style="list-style-type: none"> <li>• Chromosomes are arranged along the centre of the cell.</li> <li>• Each chromosome is attached to a spindle fibre by the centromere.</li> </ul>
	Anaphase		<ul style="list-style-type: none"> <li>• The chromatids split at the centromere and are pulled to either end of the cell by the spindle, centromere first.</li> <li>• Spindle fibres then begin to disappear.</li> </ul>
	Telophase		<ul style="list-style-type: none"> <li>• The nuclear membrane re-forms around the two sets of chromosomes, forming new nuclei. The chromosomes decondense and are no longer visible.</li> </ul>
After mitosis	Cytokinesis $2 \times 2n$		<ul style="list-style-type: none"> <li>• Division of the cytoplasm starts, the cell pinches in half, and the cell divides into two genetically identical diploid daughter cells.</li> </ul>

**Table 2.3** The stages of mitosis



### Quick check 2.7

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

**Figure 2.14** 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?

## Practical 2.2

### Observing cells in a dividing root tip

#### 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

- 1 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 sharp pencil and to document the magnification the sketch is taken at.
- 2 The mitotic index is a quantitative expression of the amount of cell division that a particular tissue is undergoing. It is the ratio of the number of cells undergoing mitosis to the number of cells that are not undergoing mitosis. It can be calculated using the following equation:

$$\text{Mitotic index} = \frac{\text{number of cells in the field of view undergoing division}}{\text{total number of cells in the field of view}}$$

Calculate the mitotic index for the tissue sample you have observed in your microscope.

- 3 Using the field of view in your microscope, complete the table and calculate the percentage of cells in each cell cycle stage.

Cell cycle stage	Number of cells in that stage	% of cells in that stage
Interphase		
Prophase		
Metaphase		
Anaphase		
Telophase		
<b>Total number of cells</b>		

- 4 Use the calculated percentages to predict which cell cycle stage is the longest and which is the shortest in your sample of cells. Explain your answer.

#### Discussion

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

#### 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.

## Meiosis

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

The process of meiosis begins with a parent cell, which is diploid ( $2n$ ), and results in four 'daughter' cells (the gametes), which are haploid ( $n$ ). Because of this reduction in genetic

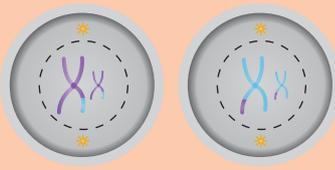
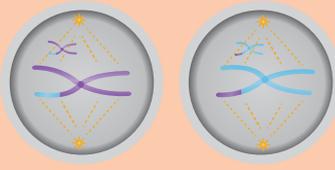
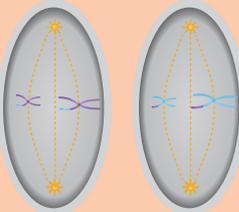
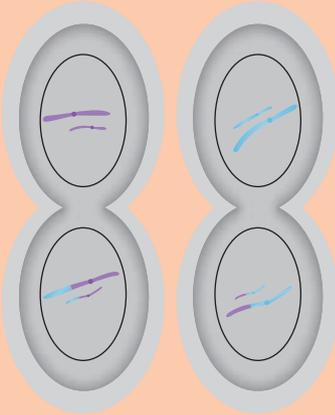
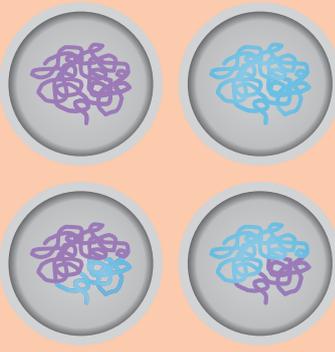
material between the parent and daughter cells, meiosis is also known as a **reduction division**.

**reduction division**  
a 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 into distinct stages, as shown in Table 2.4.

Meiosis I		
Interphase $2n$ (before meiosis)		<ul style="list-style-type: none"> <li>• Parent cell is diploid (<math>2n</math>).</li> <li>• The DNA is replicated and copied (<math>4n</math>).</li> </ul>
Prophase I		<ul style="list-style-type: none"> <li>• The nucleus 'disappears', the DNA winds up and chromosomes become visible.</li> <li>• Crossing over can occur.</li> </ul>
Metaphase I		<ul style="list-style-type: none"> <li>• 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.</li> </ul>
Anaphase I		<ul style="list-style-type: none"> <li>• The matching chromosomes of a homologous pair are pulled to opposite ends of the cell by the spindle fibres.</li> <li>• Spindle fibres disappear.</li> </ul>
Telophase I		<ul style="list-style-type: none"> <li>• The cell membrane pinches in.</li> <li>• The nuclear membranes re-form.</li> <li>• Two separate nuclei form.</li> </ul>
Cytokinesis		<ul style="list-style-type: none"> <li>• Cell pinches completely into two diploid (<math>2n</math>) daughter cells.</li> </ul>

**Table 2.4** The stages of meiosis I

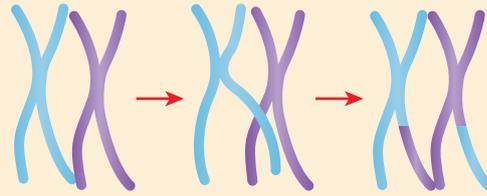
Meiosis II		
Prophase II		<ul style="list-style-type: none"> <li>Nuclear membranes disappear and spindle fibres re-form in both cells.</li> </ul>
Metaphase II		<ul style="list-style-type: none"> <li>Chromosomes move into the centre of the cell where spindle fibres attach to each chromatid.</li> <li>The centromeres start to divide.</li> </ul>
Anaphase II		<ul style="list-style-type: none"> <li>The chromosomes are pulled apart and the chromatids are pulled to opposite sides of the cell.</li> <li>The spindle fibres disappear.</li> </ul>
Telophase II		<ul style="list-style-type: none"> <li>The nuclear membrane re-forms.</li> <li>The chromosomes are no longer visible.</li> </ul>
Cytokinesis $4 \times n$		<ul style="list-style-type: none"> <li>Both cells pinch in half to produce four genetically different haploid daughter cells (<math>n</math>), each containing half the amount of DNA as was in the parent cell.</li> </ul>

**Table 2.5** The stages of meiosis II

## Did you know? 2.3

**Creating variation**

You might have noticed in Table 2.4 that at prophase I of meiosis I 'crossing over can occur'. 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 leads to more genetic variation between the gametes.



**Figure 2.15** Crossing over during prophase I results in the formation of **recombinant** chromosomes with new combinations of alleles.

**homologous chromosomes**  
matching chromosomes

**allele**  
one of two or more different forms of a gene

**recombinant**  
produced by combining genetic material from different places

## Quick check 2.8

- 1 Describe why the process of meiosis is also known as 'reduction' cell division.
- 2 Recall where meiosis occurs in humans.
- 3 Explain why crossing over is an important process during meiosis.

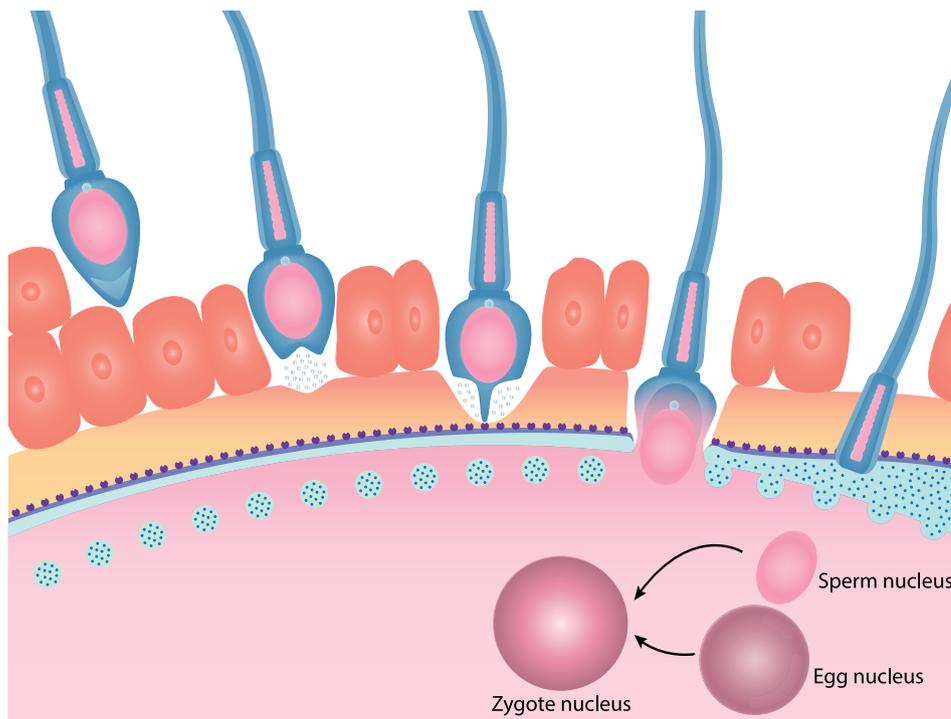
**Fertilisation**

Gametes that have a haploid number of chromosomes and are 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

foetus) has 23 pairs of (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 egg, and half of its genetic information from the sperm.

**fertilisation**

the fusing of an egg nucleus and sperm nucleus



**Figure 2.16** Once the sperm fertilises the egg, the nucleus of the sperm and the egg fuse.

## Explore! 2.3

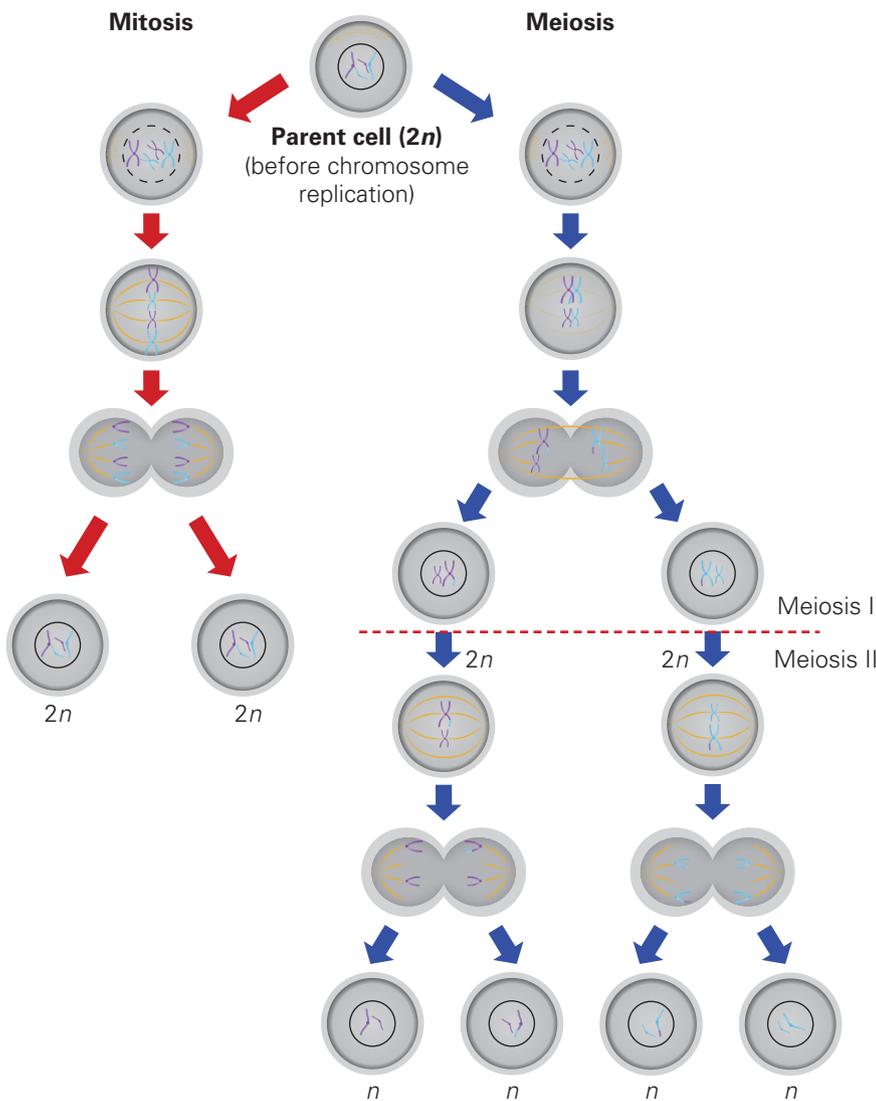
## Two types of twins

There are two different types of twins, which vary greatly in the way they form.

- 1 Name the two types of twins and explain 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.

## Quick check 2.9

- 1 Define the following terms: meiosis, fertilisation, zygote, haploid and diploid.
- 2 Identify the missing words in the following sentence.  
Male gametes are called \_\_\_\_\_, whereas female gametes are called \_\_\_\_\_.



**Figure 2.17** A diagram summarising the processes of mitosis (making copies of somatic cells) and meiosis (making gametes)

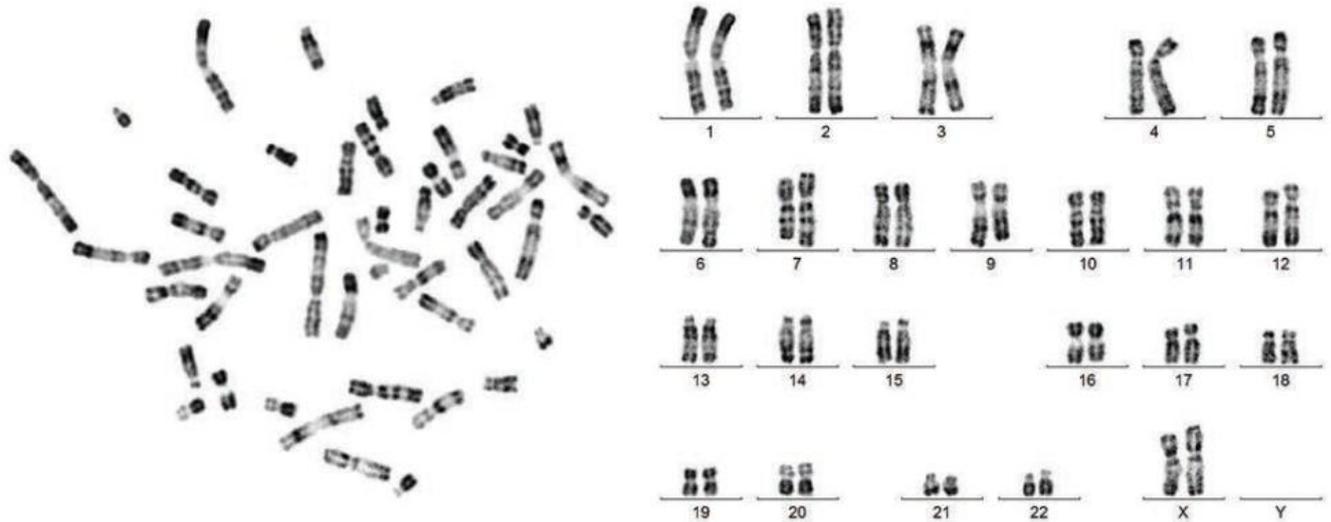
## Meiosis versus mitosis

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 haploid ( $n$ ) daughter cells containing unique genetic material and half the number of chromosomes of the parent cell. Mitosis produces two diploid ( $2n$ ) daughter cells with identical genetic material to the parent cell.

## 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



**Figure 2.18** 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).

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.

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

The chromosomes always exist in pairs within the body cells because one was received from the male parent (paternal) via the sperm, and one was received from the female parent (maternal) 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 2.18 how homologous chromosomes (paired chromosomes) have the same length, centromere position and gene band patterns.

### 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.

### 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).

#### karyotype

a pictorial representation of an organism's chromosomes

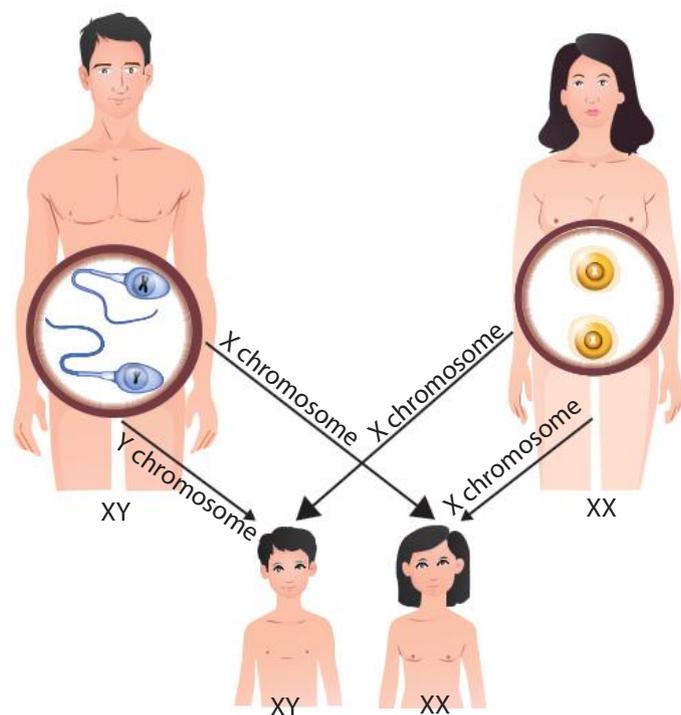
**non-homologous chromosomes**  
non-matching chromosomes

#### autosomes

in humans, chromosome pairs 1 to 22

#### sex chromosomes

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



**Figure 2.19** 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 determines the sex of the child.

## Practical 2.3: Investigation

### What are the chances?

#### Aim

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

#### Useful formula

$$\text{Theoretical probability (\%)} = \frac{\text{number of favourable outcomes (e.g. heads)}}{\text{total number of all possible outcomes (e.g. heads and tails)}} \times 100$$

$$\text{Experimental probability (\%)} = \frac{\text{number of favourable outcomes (e.g. heads)}}{\text{total number of all experimental trials (e.g. heads and tails)}} \times 100$$

$$\text{Percentage error (\%)} = \frac{(\text{experimental probability} - \text{theoretical probability})}{\text{theoretical probability}} \times 100$$

#### Materials

- coin

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Calculate the theoretical probability of landing heads during the toss.
- 3 You will now calculate the experimental probability of your own experiment by tossing the coin 50 times, recording the number of heads and tails in the table.

#### Results

- 1 Calculate the experimental probability of receiving a head and a tail based on both the experimental data for your own and the class results.
- 2 Calculate the percentage error comparing the difference between the theoretical and experimental probabilities for both your own data and the class data.
- 3 Optional: Graph the relationships between the number of trials and percentage error.

	Individual results	Class results
Number of heads		
Number of tails		
Total number of trials		
Experimental probability		
Percentage error		

#### Discussion

- 1 Compare the experimental probability between your own and the class results.
- 2 If a head represents the Y chromosome and a tail represents the X chromosome, explain how accurately this models the process of fertilisation. What would the coin represent?
- 3 Make a claim about the chances of conceiving a male or female based on this activity.
- 4 Discuss if increasing the number of trials affects the percentage error of the experiment.

### 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).

Jack jumper ants (*Myrmecia pilosula*) are unusual because they have the lowest possible number of chromosomes. Female ants are diploid with their full **genome** on two sets of chromosomes. However, males are haploid and develop from unfertilised eggs ( $n = 1$ ).



**Figure 2.20** Jack jumper ants are a venomous ant species native to Australia.

**genome**  
the full set of genes in an organism

### Try this 2.3

#### Can you sort chromosomes into a karyotype?

Go online and find a 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 Compare mitosis and meiosis. You may use a Venn diagram.
- 2 Recall a definition for karyotype.

### 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.

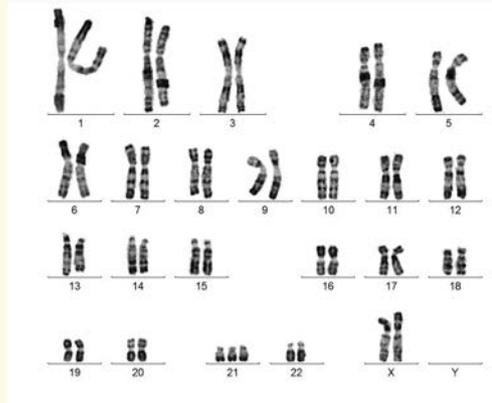
**Down syndrome**  
a genetic condition in which the individual has three copies of chromosome 21

## Explore! 2.4

### Chromosomal abnormalities

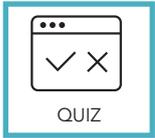
Many things can be wrong with a karyotype. One of the best known abnormalities is trisomy 21 or **Down syndrome**, where the foetus has three copies (instead of two) of chromosome 21.

- 1 Research other chromosomal abnormalities and the syndromes associated with each.
- 2 Choose one other syndrome that is a result of a chromosomal abnormality and outline the associated symptoms.



**Figure 2.21** Karyotype of a female with Down syndrome. Note the three chromosomes in position 21.

## Section 2.2 questions



### Remembering

- 1 **State** one key difference between mitosis and meiosis.
- 2 **Recall** the phase of meiosis when pairs of matching chromosomes separate.
- 3 **State** the name of the syndrome that arises from trisomy 21.
- 4 **State** what the term 'homologous chromosome' means.

### Understanding

- 5 **Explain** why gametes need to be haploid.
- 6 **Explain** what is meant by the term 'reduction division'.
- 7 **Explain** why a missing part of a chromosome may lead to a disorder or syndrome.
- 8 **Explain** why the cells produced during meiosis are considered to be unique.

### Applying

- 9 **Differentiate** between mitosis and meiosis. Include details on where they occur, their purpose and features of the daughter cells.
- 10 **Contrast** the daughter cells produced in mitosis versus meiosis.
- 11 **Illustrate** a diagram to represent the steps of mitosis for a cell with two pairs of chromosomes. Be sure to use a different colour or shading pattern for each pair of chromosomes.

### Analysing

- 12 **Contrast** anaphase I in meiosis and anaphase in mitosis.
- 13 **Contrast** prophase I and prophase II in meiosis.

### Evaluating

- 14 **Critique** the following claim: 'It is the male that determines the sex of his child.'
- 15 **Predict** the chances of a woman giving birth to a girl if she has already given birth to three boys, giving reasons for your response.

## 2.3 Patterns of inheritance

### Learning goals

- 1 To be able to define the terms homozygous, heterozygous, dominant and recessive with respect to genetic inheritance.
- 2 To be able to interpret a Punnett square or pedigree to identify a possible genotype and phenotype.
- 3 To explain the codominance of blood groups.



Many cultural groups have an understanding of inheritance patterns, recognising how traits can be passed down to the next generations. Traits and illnesses can appear in the children of closely related parents. So, many Aboriginal and Torres Strait Islander cultural groups developed complex and sophisticated kinship systems that allow individuals to understand who they are and how they fit into the social structure and even the universe. These kinship systems determine not only whom individuals can or cannot marry, but they also how individuals behaviourally relate to other individuals, and the responsibilities each person has towards others, natural resources and the land.

### Inheriting traits from our parents

Genetic instructions (genes) are passed down to offspring by parents. This is called heredity or inheritance. Chromosomes exist in pairs, and are made up of DNA containing genes, so it is 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



**Figure 2.22** This artwork from Kakadu National Park shows Namondjok, a Creation ancestor who broke kinship laws.

## Did you know? 2.5

**The genome**

The genome refers to all the genetic material in the chromosomes of an organism, including its genes and DNA sequences. The human genome is made of approximately 3.2 billion nitrogenous bases, which make up about 20 000 genes on 23 pairs of chromosomes. Other organisms have different genome sizes.



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

**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

Genes are sections of DNA that code for a particular protein that 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.

For example, take the trait of having a widow's peak hairline. This trait is controlled by a single gene that is represented using two alleles: the allele of the dominant trait, which is the presence of a widow's peak (we assign it the capital letter 'W' to show it is dominant), and the allele for the recessive trait, which is the lack of a widow's peak (we assign this allele a

lower-case 'w' to show it is representing the recessive trait). If you inherit the dominant allele (W) from both parents, you are said to be homozygous dominant for that trait and your genotype will be WW. If you inherit the non-widow's peak allele (w) from both parents, you are said to be homozygous recessive for that trait and your genotype will be ww. If you inherit a widow's peak allele (W) from one parent and a non-widow's peak allele (w) from the other parent, you are heterozygous for that trait and your genotype will be Ww.



**Figure 2.24** This girl has a widow's peak (v-shaped peak) in the centre of her hairline.

A trait or characteristic is described as **dominant** if you need only one allele for it to be expressed (WW or Ww). For a **recessive** characteristic, the allele needs to be inherited from both parents in order for it to be expressed (ww).

The interaction of an organism's genotype with the environment results in its **phenotype**, or its physical appearance. So in this example, the presence of a widow's peak or lack of a widow's peak is the person's phenotype for that trait.

Always remember that genes and alleles refer to the genotype, and the physical appearance of the trait refers to the person's phenotype.

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.

**dominant**

a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

**recessive**

a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

**phenotype**

the way an organism appears

### Quick check 2.11

- 1 Define the following terms: locus, allele, genotype and phenotype.
- 2 Explain why your genotype indicates you will have pale skin, but your phenotype is red skin.

### Practical 2.4: investigation

#### Inherited features

##### Aim

Use data to determine whether some key characteristics are dominant or recessive traits.

##### Materials

- mirror

Optional extension: collect information from other students or family members for further validity analysis.

##### Method

##### Part 1: Prepare the results table

Copy the table shown in the results section into your science journal.

##### Part 2: Collect data on the variables

- 1 Identify whether you possess each of the inheritable features described below.
- 2 Record your results in the table.
- 3 Find out how many members of your class have the same features as you do. Record your results in the table.

Optional: Find out how many members of your family display the traits.

- a Attached earlobes: are your earlobes attached or unattached to the side of your head?
- b Darwin's tubercle: do you have a point on your ear as shown in Figure 2.25? 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 as shown in Figure 2.24?

*continued...*

...continued



**Figure 2.25** The presence of a bump on the outer rim of the ear called 'Darwin's tubercle' is due to a combination of genetic and environmental factors.



**Figure 2.26** Can you roll your tongue?



**Figure 2.27** This man has an obvious gap between his top front teeth.



**Figure 2.28** The second toe is longer than the big toe on this foot.

- d Tongue roll: can you roll your tongue as shown in Figure 2.26?
- e Front tooth gap: is there a definite gap between your two top front teeth as shown in Figure 2.27?
- 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 as shown in Figure 2.28?

## Results

### Collate the data for analysis of the variables

- 1 Calculate the total number of people sampled in this survey.
- 2 Calculate the percentage presence of the trait in your family and within the class.
- 3 Draw an appropriate graph(s) to compare the percentage presence of each trait within your family compared to the whole class.

Feature	Trait present in you? (Y/N)	Number of family members with trait	% presence of trait in family	Number of class members with trait	% presence of trait in class	% presence of trait in total sample
Attached ear lobes						
Darwin's tubercle						
Widow's peak						
Tongue roll						
Front tooth gap						
Mid-digital hair						
Long second toe						
Sample size = (Total number of people surveyed)	1					

continued...

...continued

### Discussion

- 1 Describe which traits were commonly found in your family.
- 2 Describe which traits were commonly found in the class.
- 3 Describe which traits were commonly found in the whole sample.
- 4 Do your findings support the idea that a feature such as tongue-rolling is inherited? Explain your answer.
- 5 Predict from the data which traits are likely to be recessive and dominant. Justify your answer with data.
- 6 If you repeated the survey on the same people, would you get a similar result? Support your answer by relating back to the theory behind inheritance of traits.
- 7 Can reliable conclusions and predictions be drawn from the results?
- 8 Compare the values between your family and the class. Were there any significant differences with some traits? Justify your answer with data.
- 9 Compare the values between your family and several other student family results. Were there any significant differences with some traits? Justify your answer with data.
- 10 Can valid conclusions as to which traits are dominant and recessive be drawn from this data? Justify your response.
- 11 Sample size is a factor that commonly affects data in small surveys. Discuss how this relates to the activity.
- 12 Can you identify possible limitations of this method? Justify your answer.
- 13 Suggest any changes that could be made to the method to improve the quality of the data in future surveys. Justify your suggestions by explaining how each change will improve the data quality.

## Determining chances of inheritance

### Gregor Mendel

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 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 cross-breeding 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 on to their offspring via the gametes. For example, a heterozygous, tall pea 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.



**Figure 2.29** Gregor Johann Mendel (1822–1884) was the founder of heredity, using pea plants to show dominant and recessive traits within the field of genetics.

**Punnett square**  
a specialised grid to show genetic crosses

**Worked example 2.1****Cross between a pure-breeding tall plant and a pure-breeding dwarf plant**Parents:  $TT \times tt$ 

gametes	T	T
t	Tt	Tt
t	Tt	Tt

You will notice that all the predicted  $F_1$  offspring (shaded) have the genotype Tt.

We can write this as:

$F_1$  genotype: 100% Tt

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

$F_1$  phenotype: 100% tall plants.

**Worked example 2.2****Cross between two of the hybrid  $F_1$  plants from worked example 2.1**Parents:  $Tt \times Tt$ 

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 offspring is homozygous for the abnormal protein.

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

**Worked example 2.3****Cross between two individuals unaffected by Huntington's disease**Parents:  $hh \times hh$ 

gametes	h	h
h	hh	hh
h	hh	hh

$F_1$  genotype: 100% hh

$F_1$  phenotype: 100% unaffected

**Worked example 2.4****Cross between an individual with Huntington's disease and an unaffected individual**

Parents:  $Hh \times hh$  (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 a condition called sickle cell anemia. If a homozygous recessive female mates with a heterozygous male, what are their chances of producing offspring with sickle cell anemia?

## Quick check 2.12

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

## Test cross

A **test cross** can be used to test whether an organism showing a dominant trait is homozygous or heterozygous. It involves observing the offspring of the individual in question if it mates with a homozygous recessive individual (for example, aa). This essentially means the individual of unknown genotype mates 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 or 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).

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<sub>1</sub> genotype: 100% Bb

F<sub>1</sub> 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<sub>1</sub> genotype: 50% Bb; 50% bb

F<sub>1</sub> phenotype: 50% black; 50% white

This means if approximately 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.

## 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

## Quick check 2.13

- 1 Explain the importance of a test cross.
- 2 Silky feathers in a bird species is caused by a gene with a trait recessive to normal feathers. If you had a normal-feathered bird, describe a way to determine whether it is heterozygous or homozygous. Use Punnett squares to help with your answer.

### Try this 2.5

#### Positive or negative

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

#### Instructions

In this activity, we will use coloured counters and felt-tipped pens to model the passing of Rh alleles from heterozygous individuals to their offspring.

- 1 Copy the results table 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 Rh blood type; that is, able to produce gametes (eggs or sperm) of the type D and d in equal proportions.
- 3 Find a partner in the room with a different coloured counter.
- 4 Make an unbiased toss of your two counters to produce an offspring. The labels facing 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			
<b>Total numbers across the class</b>			

#### Analysis

- 1 Using the class data, calculate the probability of obtaining the offspring genotypes:
  - a DD
  - b Dd
  - c dd
- 2 What are the proportions of the different genotypes in your group of 16 children compared to those generated across the whole class? Discuss whether or not this is expected.
- 3 A woman with Rh-positive blood insisted that she was the daughter of a rich, elderly couple who both had Rh-negative blood. Use a Punnett square to show your working out to explain whether this woman's statement could be valid.

## 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). 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 a 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  $X^H X^H$ , a **carrier** female would be  $X^H X^h$ , and a female with haemophilia would be  $X^h X^h$ . On the other hand, an unaffected male would be  $X^H Y$  and a male with haemophilia would be  $X^h Y$ . As there is no gene for this condition found on the Y chromosome, we do not write H or h next to the Y.

**carrier**  
an individual with a recessive allele for a disease, but who does not have the disease due to being heterozygous

### 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  $X^B X^b$  and of a colourblind male is  $X^b Y$ .

Parents:  $X^B X^b \times X^b Y$

gametes	$X^B$	$X^b$
$X^B$	$X^B X^B$	$X^B X^b$
$Y$	$X^B Y$	$X^b Y$

$F_1$  genotype: 25%  $X^B X^B$ ; 25%  $X^B Y$ ; 25%  $X^B X^b$ ; 25%  $X^b Y$

$F_1$  phenotype: 25% normal vision female; 25% normal vision male; 25% carrier normal vision female; 25% colourblind male

### Try this 2.6

#### Sex-linked inheritance

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

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

## Codominance

**codominance**  
both alleles are expressed  
equally in the phenotype



VIDEO  
Give an  
example of  
codominance

When you have two equally dominant alleles for a trait, they will both show up in the heterozygote. This is called **codominance** – both the alleles in this situation are expressed equally in the phenotype. Look at the picture of the chickens in Figure 2.30.

The colours black and white are equally dominant (their alleles are both given capital letters), so when you cross a pure black chicken with a pure white chicken, you get a heterozygote. In the heterozygote, both colours are expressed equally, so you get a speckled chicken with black feathers and white feathers.

			
<b>Genotype</b>	WW	BB	BW
<b>Phenotype</b>	White	Black	Speckled

**Figure 2.30** 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.

### Did you know? 2.6

#### Kings Park's 'Anniversary gold'

To commemorate the 50th anniversary of the Western Australian Botanic Garden in 2015, plant breeders at the Botanic Garden released a unique flowering kangaroo paw, *Anigozanthos manglesii*, 'Anniversary gold', bred through controlled pollination methods. The plant is unique because it has flowers that are both yellow and green, whereas other *Anigozanthos manglesii* plants only have flowers of a single colour. The plant breeders would have had knowledge of the inheritance of dominant and recessive alleles in this type of plant when breeding to observe this phenotype.



**Figure 2.31** *Anigozanthos manglesii*, 'Anniversary gold' in Kings Park, Western Australia



VIDEO  
Blood types

## Blood types

In humans, blood type is a codominant trait. Our red blood cells have 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  $ii$ .

$I^A$  and  $I^B$  are both dominant over  $i$ , but equally dominant when together.

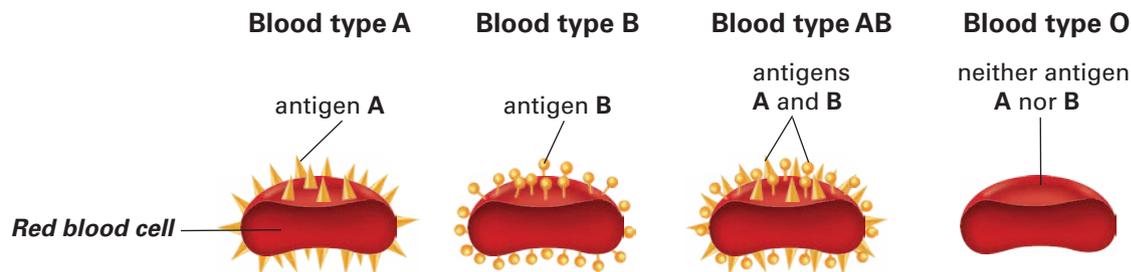


Figure 2.32 Illustration of the different antigens on the surface of red blood cells of different types

### Worked example 2.6

#### Cross between heterozygous blood type A and heterozygous blood type B

Parents:  $I^A i \times I^B i$

gametes	$I^A$	$i$
$I^B$	$I^A I^B$	$I^B i$
$i$	$I^A i$	$ii$

$F_1$  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** is a form of inheritance in which neither of the alleles is dominant over the other, resulting in a third phenotype which is a combination of both alleles. The colour of eggplant fruit is an example of incomplete dominance. Breeding deep purple eggplants with light green or white eggplants results in violet fruit.

- 1 The 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 two other examples of incomplete dominance.



Figure 2.33 Deep purple (left), violet (middle) and light green eggplants (right).

**incomplete dominance**  
a form of inheritance in which neither allele is dominant over the other, producing a third phenotype

## Quick check 2.14

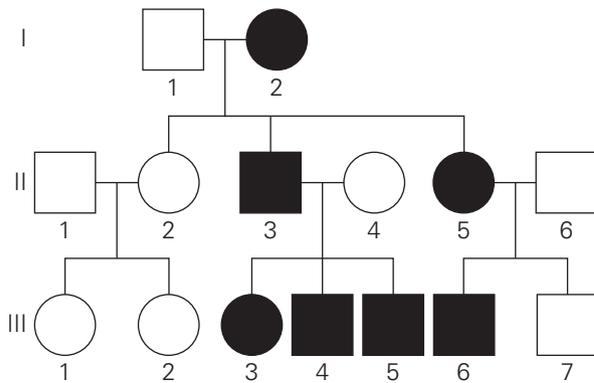
- 1 Explain why males are more likely to be affected by recessive X-linked disorders than females.
- 2 Describe what is meant by 'codominance' in genetics.

## Pedigrees

To study patterns of inheritance in humans, geneticists investigate the frequency and occurrence of a particular gene over many generations to determine whether the traits are dominant or recessive. The chart formed is called a **pedigree** and it is just like a family tree.

**pedigree**  
a chart formed to study patterns of inheritance over generations

You can see in Figure 2.34 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.



**Figure 2.34** 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).

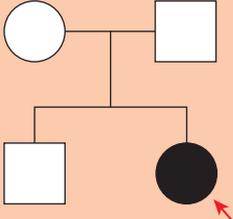
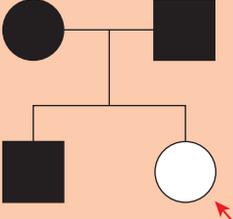
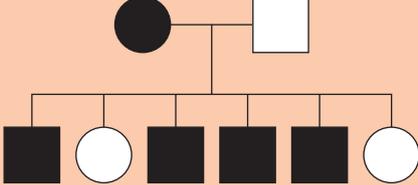
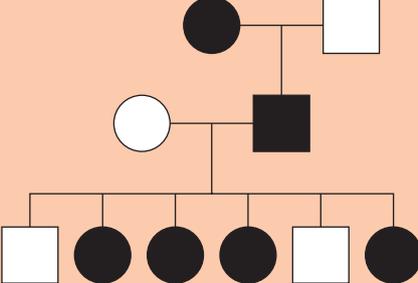
The symbols used are:

- Unaffected female
- Unaffected male
- Female with the trait being investigated
- Male with the trait being investigated
- Carrier of trait or
- Mated represented by a horizontal line
- Vertical line connects offspring to parents

## Reading a pedigree

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

- A trait that is common in a population is not necessarily dominant.
- 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 is the case 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 <i>cannot</i> 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 on to her daughters and sons.	X-linked hypophosphatemic rickets

**Table 2.6** Different modes of inheritance and how to identify them in a pedigree chart

## Did you know? 2.7

**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.

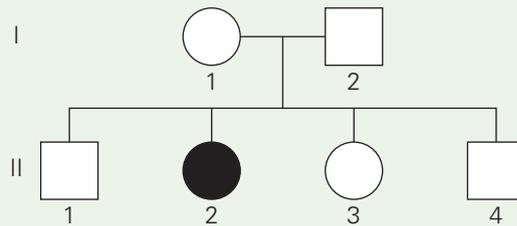
Queen Victoria was a carrier of haemophilia B, which is X-linked recessive. She passed this gene on to two daughters and one son.



**Figure 2.35** Chopin and Queen Victoria both had genetic disorders.

## Quick check 2.15

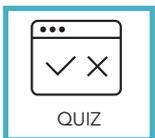
- 1 Study the pedigree chart in Figure 2.36. It illustrates the inheritance of cystic fibrosis in humans.



**Figure 2.36** Pedigree chart

- a Identify a piece of evidence that suggests that this condition is recessive and not dominant.
- b Identify the genotype of individuals I-1, I-2, II-1 and II-2.
- c Suppose individual II-2 marries a man who does not have cystic fibrosis but is a carrier for the condition. Determine the chance of having a child with cystic fibrosis and the chance of having a child without cystic fibrosis. Use a Punnett square to show how you arrived at your answer.

## 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 **Name** an example of codominance and of incomplete dominance.

**Understanding**

- 4 The pedigree chart in Figure 2.37 shows the inheritance pattern of a disease that is caused by a single gene.
  - a **Identify** the sex of the person labelled II-5.
  - b **State** whether the disease is dominant or recessive, giving reasons for your answer.
  - c **State** the genotype of individual II-5, giving reasons for your response.

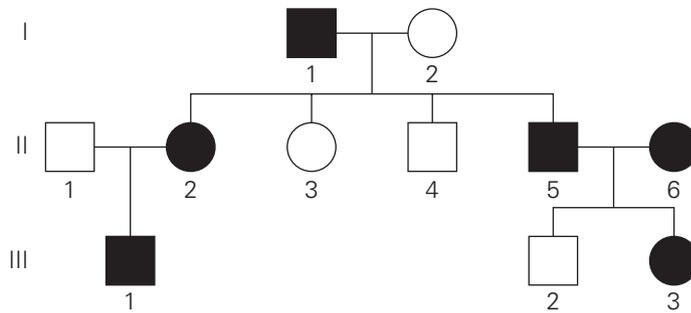


Figure 2.37 Pedigree chart

- 5 Dimples are dominant to no dimples.
- Select appropriate letters for these alleles.
  - Identify the genotype and phenotype of a person who is:
    - homozygous recessive for dimples
    - heterozygous for dimples
    - homozygous dominant for dimples.

### Applying

- Describe what pedigrees are useful for.
- Explain how sex linkage is different from other types of inheritance.
- Explain why, for a particular characteristic, two homozygous recessive individuals can only produce homozygous recessive children.
- Explain what is meant by the term 'carrier'.
- Explain why a test cross is useful.
- Describe what is meant by the statement 'nature versus nurture'.

### Analysing

- Contrast codominance and incomplete dominance.
- The pedigree chart in Figure 2.38 shows the inheritance patterns for haemophilia. Haemophilia is an X-linked recessive disorder.

Use evidence from the pedigree to **justify** that haemophilia is recessive.

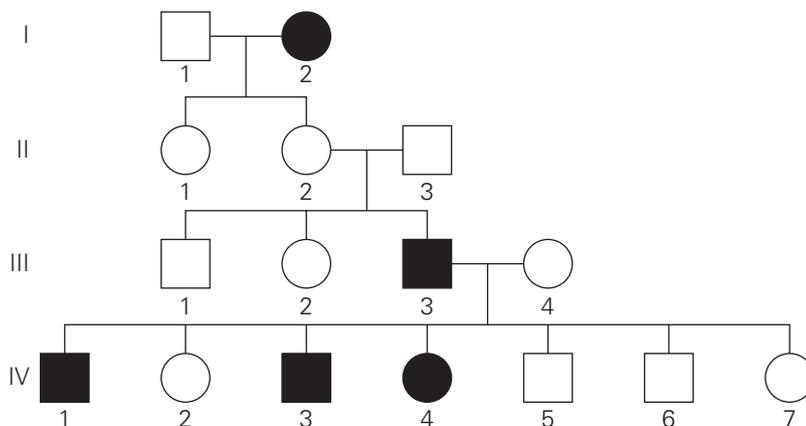


Figure 2.38 A haemophilia pedigree

### Evaluating

- 14** In fruit flies, eye colour is determined by an autosomal gene. The red eye allele is dominant over the white eye allele.
- Select** appropriate letters for the alleles.
  - Using a Punnett diagram, **determine** the offspring when a male heterozygous fly mates with a female homozygous recessive fly.
  - Decide** the genotypic and phenotypic ratios of the offspring.
- 15** In mice, black fur is dominant to brown fur. Mice with black fur can be either homozygous or heterozygous.
- Propose** how you would find out if a mouse with black fur was homozygous or heterozygous. Support your response with a Punnett square.
- 16** A brown-eyed male and a blue-eyed female produced all blue-eyed children. **Discuss** whether that means blue eyes is the dominant trait.

## 2.4 Changes in DNA



### Learning goals

- To be able to distinguish germline and somatic mutations.
- To be able to recall types of point and chromosomal mutations.
- To explore the applications of the manipulation of DNA mutation.

#### 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

#### spontaneous mutation

a naturally occurring mutation

#### induced mutation

a mutation produced by environmental factors

#### mutagenic

causing mutations in DNA

#### germline mutation

a mutation of DNA in gametes, which can be inherited

#### somatic mutation

a mutation that occurs in somatic (body) cells, which cannot be inherited

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 structure and 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**).

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**.

## Did you know? 2.8

### 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 than usual rates of miscarriages, premature births and congenital birth defects in regions where Agent Orange had been used. Male Vietnam veterans who had been exposed to the chemical during the war had a higher than average 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 2.39 An aeroplane spraying Agent Orange



Figure 2.40 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 and create a list of environmental mutagens.
- 2 From the list created in Question 1, divide your mutagens into categories according to their source, such as chemical mutagens, radiation and mutagens in food.



Figure 2.41 Radiation from the Sun can cause mutations in the DNA of skin cells.

## Beneficial, harmful 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 – harmful.** Harmful 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 or advantageous 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, recall where it must occur.
- 2 Explain why a mutation in a somatic cell does not get passed onto the next generation.

## Point mutations

### substitution

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

### insertion

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

### deletion

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

### inversion

a point mutation in which the order of two nucleotides is reversed

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

another (for example, ATG becomes ACG). This mutation only changes the DNA code for a single amino acid. Or it could code for the same amino acid (this is called a silent mutation). An example of a disease caused by a substitution mutation is sickle cell anaemia.

- An **insertion** mutation occurs when an extra nucleotide (or more than one) is inserted into the DNA sequence (for example, ATG becomes ATCG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a disease caused by an insertion mutation is fragile X syndrome.
- A **deletion** mutation occurs when a nucleotide is deleted from the sequence (for example, ATG becomes AG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a disease caused by a deletion mutation is Duchenne muscular dystrophy.
- An **inversion** mutation occurs when two nucleotides reverse their order in the DNA (for example, ATG becomes AGT). This mutation only changes the DNA code for a single amino acid, or it could code for the same mutation (silent mutation). An example of a disease caused by an inversion mutation is haemophilia.

### Try this 2.7

#### Remembering deletions

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

For example:

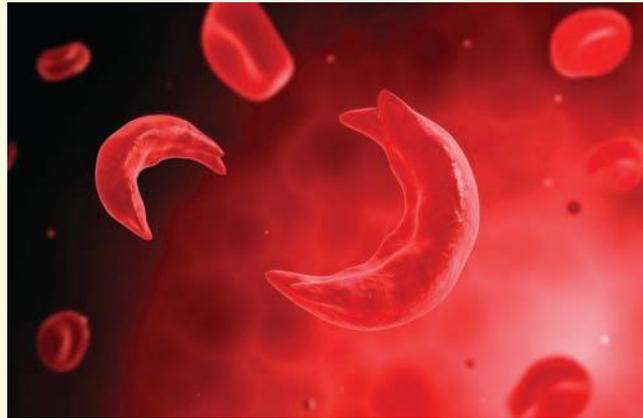
- normal code: WING
- deletion: WIG
- insertion: WRING.

## 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.

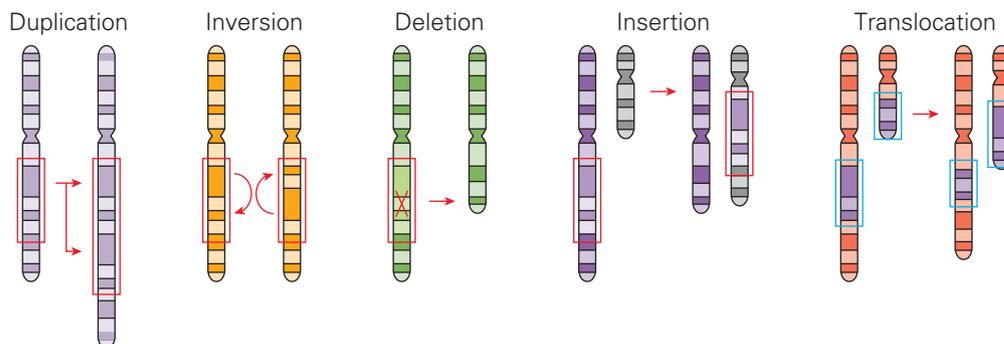
- 1 Which amino acid is changed?
- 2 It is an example of both a harmful and a beneficial mutation. Explain what these terms mean.
- 3 Why is it harmful in a non-malarial zone and beneficial in a malarial zone?



**Figure 2.42** Red blood cells are misshapen in people with sickle cell anaemia.

**Chromosomal changes****Chromosomal mutations**

If a mutation occurs in a gene on one of a 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. The different types of chromosomal mutations are illustrated in Figure 2.43.



**Figure 2.43** The five different types of chromosome mutation. Can you identify what is changing in each type?

**Chromosome number abnormalities**

Certain individuals may have one more or one less chromosome 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**).

**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

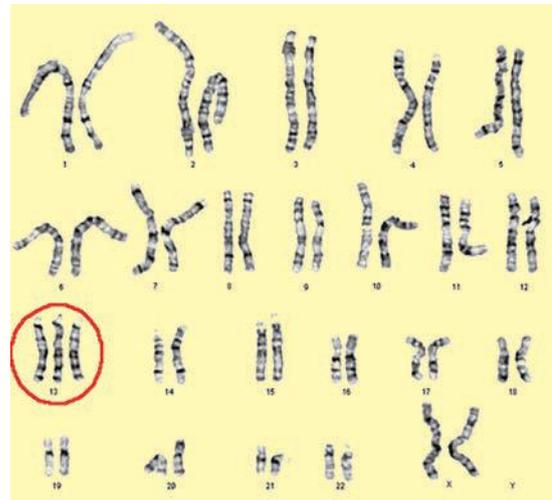
**non-disjunction**  
when the chromosomes failed to separate correctly in meiosis

**aneuploidy**  
when an individual has an abnormal number of chromosomes

**trisomy**  
when an organism has a third copy of a chromosome

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.

**Figure 2.44** There are other types of trisomy apart from trisomy 21. Trisomy 13 and 18 result in more severe conditions. Which trisomy is depicted here?



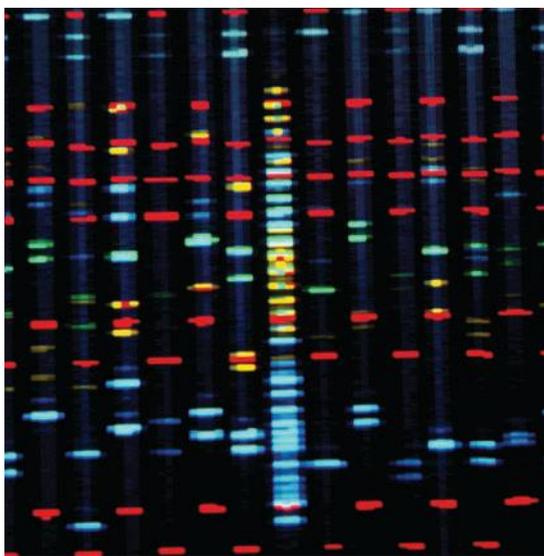
### Quick check 2.17

- 1 Describe a substitution point mutation.
- 2 Recall what the term 'aneuploidy' means.

## 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 that confers higher risk for a disease, and whether they are at risk of passing a genetic mutation on to their children.

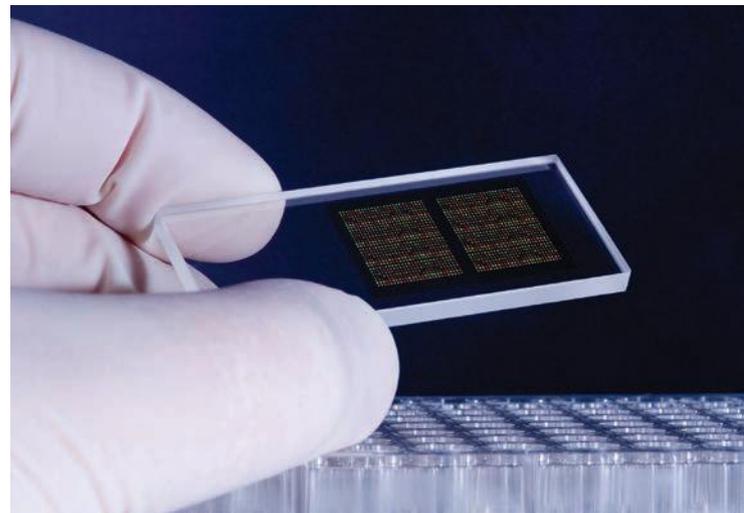
**genetic screening**  
genetic tests that are available for anyone in the population



**Figure 2.45** A DNA sequence or 'genetic fingerprint' on a computer monitor. 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** 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



**Figure 2.46** A DNA microarray, commonly known as DNA chips, are a collection of tiny spots containing DNA fragments.

tested for cystic fibrosis, phenylketonuria and hypothyroidism. 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** 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.

With increasing knowledge about the human genome and disease-causing genes, we can gain an incredible amount of 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?

### Try this 2.8

#### The great debate!

Divide your class into teams and engage in a debate about genetic testing.

You may wish to consider the following scenario during 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 viewpoint of all people involved.

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

### Explore! 2.8

#### Non-invasive prenatal testing

During pregnancy, 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, it 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 a pregnant mother choose to have NIPT?

### Science as a human endeavour 2.3

#### 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 indicates 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 2.47** Genetic screening can identify risks of mutations.

**Quick check 2.18**

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

**Manipulating DNA**

**Genetic engineering** technology allows scientists to manipulate genetic material and transfer genes between different organisms. One of the most exciting developments of the last decade is CRISPR (which stands for ‘clusters of regularly interspaced short palindromic repeats’), a technology that can edit genetic material quickly and cheaply. Developed by Jennifer Doudna and Emmanuelle Charpentier, CRISPR has almost endless potential, including editing crops so they are more nutritious or able to survive in different conditions, curing genetic diseases, producing powerful new drugs or even resurrecting extinct species. This technology was awarded the Nobel Prize in Chemistry in 2020.

**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.

Some genetic changes are helping to alleviate global malnutrition and disease. A type of rice called golden rice has been engineered to prevent blindness in children from vitamin A deficiency. Another type of GM rice had been developed that has four times more iron than normal rice.

**Transgenic organisms**

**Transgenic organisms** (TGOs) are another type of genetic modification.

These organisms possess a ‘foreign’ gene, or a segment of ‘foreign’ DNA, in their genome, as a result of human experimentation. Scientists have transferred human genes into bacteria and cows, and bacterial genes into cotton plants. They are examples of transgenic organisms.

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, and thus optimise the chance of pregnancy.

The supply of this recombinant FSH is more reliable, larger and purer than the FSH traditionally derived from human urine.

**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?



VIDEO  
CRISPR

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

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

**transgenic organism**  
an organism that possesses a ‘foreign’ gene or segment of ‘foreign’ DNA in its genome as a result of human experimentation

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

## Quick check 2.19

- 1 Recall what GMO stands for.
- 2 Describe the process of gene therapy.

## Try this 2.9

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.

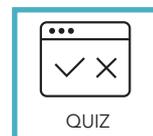


**Figure 2.48** Glass Gem corn is an heirloom corn. Heirloom crops are non-GM varieties that were commonly grown during earlier periods in history and are not used in large-scale modern agriculture.

## Section 2.4 questions

## Remembering

- 1 If a mutation is to be passed on to the next generation, **state** where it must have occurred.
- 2 **Define** the term 'mutagen'.
- 3 **Recall** the definition of a genetically modified organism.



## Understanding

- 4 Using the table below, answer the following questions.

		2nd letter in the codon					
		U	C	A	G		
1st letter in the codon	U	UUU   Phe (F) UUC   UUA   Leu (L) UUG	UCU   UCC   Ser (S) UCA   UCG	UAU   Tyr (Y) UAC   UAA   STOP UAG   STOP	UGU   Cys (C) UGC   UGA   STOP UGG   Trp (W)	U C A G	
	C	CUU   CUC   Leu (L) CUA   CUG	CCU   CCC   Pro (P) CCA   CCG	CAU   His (H) CAC   CAA   Gln (Q) CAG	CGU   CGC   Arg (R) CGA   CGG	U C A G	
	A	AUU   Ile (I) AUC   AUA   Met (M) AUG   START	ACU   ACC   Thr (T) ACA   ACG	AAU   Asn (N) AAC   AAA   Lys (K) AAG	AGU   Ser (S) AGC   AGA   Arg (R) AGG	U C A G	
	G	GUU   GUC   Val (V) GUA   GUG	GCU   GCC   Ala (A) GCA   GCG	GAU   Asp (D) GAC   GAA   Glu (E) GAG	GGU   GGC   Gly (G) GGA   GGG	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 **State** the mRNA strand that was copied from the original DNA strand.
- c **State** the new mRNA strand produced from the mutated DNA strand.
- d **State** whether the amino acids stay the same or change.
- e Another mutation occurs, whereby a C was added to the beginning of the above original DNA strand: CGTC GGG ATT CGG CTC  
**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.

### Applying

- 5 **Explain** what will happen if a nucleotide is deleted from the sequence of nucleotides within a gene.
- 6 **Explain** what usually results when mutations occur in non-germ (somatic) cells.
- 7 **Explain** whether or not all mutations are detrimental/harmful.
- 8 **Explain** how a mutated gene can lead to a genetic disorder.
- 9 **Illustrate** a diagram to outline how non-disjunction may occur and cause aneuploidy.

### Analysing

- 10 **Contrast** a genetically modified organism and a transgenic organism.
- 11 **Contrast** a spontaneous mutation and an induced mutation.

### Evaluating

- 12 Using the DNA sequence ACAATTGGTAGCTGAGTTGGCCCGTA, **create** an example of the following mutations:
    - a substitution
    - b inversion
    - c deletion
    - d insertion.
  - 13 **Discuss** why the substitution of one nucleotide may not be as critical to the functioning of the protein as deletion or insertion of a nucleotide.
  - 14 **Propose** 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.
-

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
2.1 I can describe the structure of DNA and RNA.	2, 3	
2.1 I can recall the relationship between DNA, genes and chromosomes.	1	
2.1 I can recall the role of protein in living organisms.	5	
2.1 I can describe the processes transcription and translation in protein synthesis and DNA replication.	4, 12	
2.2 I can distinguish between haploid and diploid cells.	18b	
2.2 I can describe the process of mitosis.	9	
2.2 I can describe the process of meiosis, including how it causes variation.	13	
2.3 I can use a Punnett square to demonstrate how traits are inherited from parents.	14	
2.3 I can explain the difference between autosomes and sex chromosomes.	10	
2.3 I can explain how blood groups are an example of codominance.	16	
2.3 I can use a pedigree diagram to determine the type of inheritance that is occurring.	15	
2.4 I can explain the different types of mutations, including their causes and effects.	18c	
2.4 I can describe some ways in which DNA can be manipulated.	20	

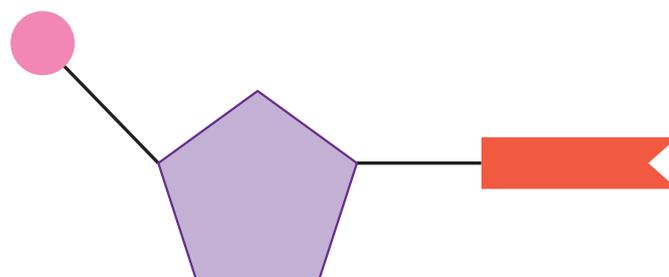
## Review questions

### Remembering

- 1 **State** the relationship between a gene and DNA.
- 2 **Recall** the name of the three-dimensional structure of DNA.
- 3 **Name** the nucleotide base pairs that exist in DNA and in RNA.
- 4 **Identify** the parts of the nucleotide on the diagram shown.
- 5 **State** where transcription and translation occur during protein synthesis.

### Understanding

- 6 **Describe** the importance of protein synthesis in living organisms.
- 7 **Explain** why males have more chance than females of inheriting an X-linked recessive trait.



- 8 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. Show your working using a Punnett square.
- 9 **Describe** the stage of anaphase during mitosis.
- 10 **Distiguish** between human autosomes and sex chromosomes.
- 11 **State** how many chromosomes you would expect to find in a:
- human somatic cell
  - human gamete
  - human somatic cell with Down syndrome.

### Applying

- 12 When cells reproduce themselves, the DNA is replicated. **Explain** why this is necessary.
- 13 **Explain** how meiosis is able to cause genetic variation by 'crossing over'.
- 14 Using a Punnett square, **determine** 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 ( $X^B X^b$ )	
		gametes	$X^B$
Normal vision male ( $X^B Y$ )	$X^B$		
	Y		

- 15 **Construct** a pedigree with the following information and outline the genotypes of each individual.
- 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 have the disease. Remember that Huntington's disease is an autosomal dominant genetic disorder.

### Analysing

- 16 A baby was handed in at a police station. Later, two different women claimed to be the baby's mother. Blood studies revealed that woman 1 was blood type A, and that woman 2 was blood type AB. The baby was blood type O. **Deduce** which woman could possibly be the baby's mother, and which woman can be ruled out completely. Show your working.
- 17 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 chondrodystrophy.
- 18 The table below shows a number of different organisms with their chromosome numbers.

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

- Identify** the organism with the highest number of chromosomes.
- State** the haploid number of the onion.
- The human has 46 chromosomes. **Contrast** chromosomal mutations and point mutations and their effect on the human genotype and phenotype.

### Evaluating

- 19 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.
- 20 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.
- Evaluate** how this information would affect your life.
  - Discuss** how this scenario is different from knowing about a disease that is not influenced by environmental and lifestyle factors.

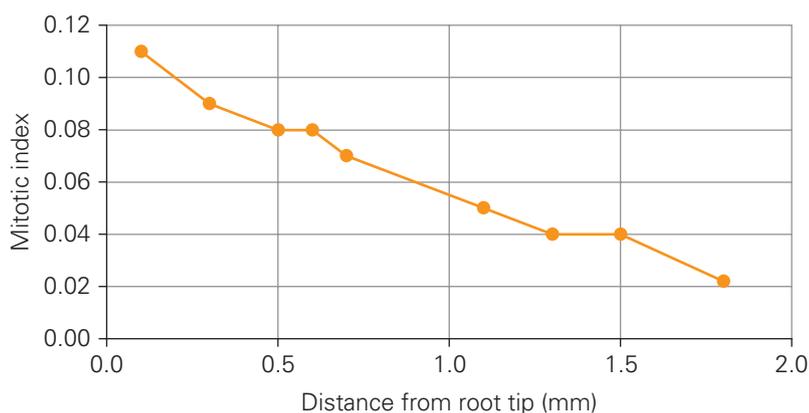
### Data questions

A student prepared an onion root tip slide and examined the cells under a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

Stage of cell cycle	Number of cells recorded
Interphase	340
Prophase	13
Metaphase	4
Anaphase	3
Telophase	6

She then calculated the mitotic index for different areas of the root tip. The graph shows her results.



- 1 The mitotic index of dividing tissue is calculated with the following formula:

$$\text{Mitotic index} = \frac{\text{number of cells seen that were undergoing mitosis}}{\text{total number of cells seen}}$$

**Calculate** the mitotic index of the tissue shown in the table.

- 2 The duration of any phase of the cell cycle can be calculated with the following formula:

$$\text{Phase duration (minutes)} = \frac{\text{number of cells seen in that phase}}{\text{total number of cells seen}} \times \text{cell cycle duration of the organism}$$

The cell cycle duration for the onion is 24 hours.

**Calculate** the duration of metaphase.

- 3 **Identify** the trend shown in the graph.
- 4 **Extrapolate** the data in the graph to estimate the mitotic index of the cells found at 2 mm from the root tip.

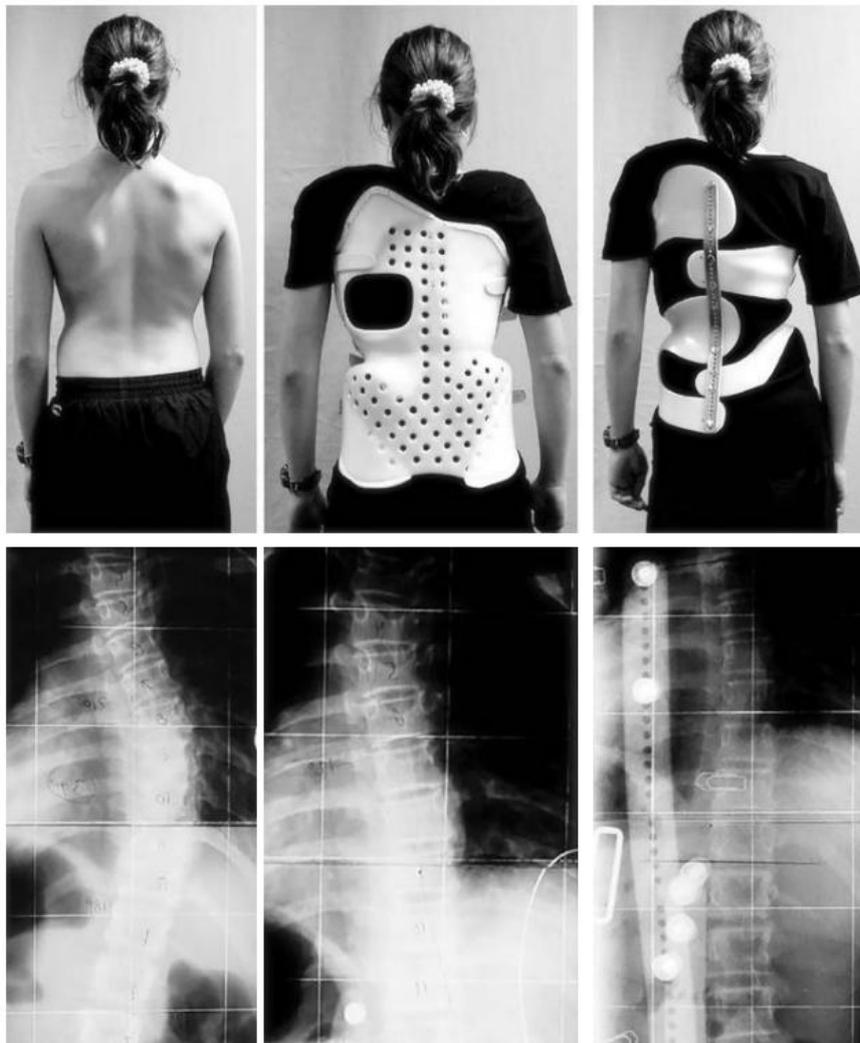
## STEM activity: Designing and prototyping an assistive device for individuals with a genetic disease

### 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 transcribing 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 2.49** Various brace designs can be used for the treatment of scoliosis.

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

### Activity instructions

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

### Suggested materials

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

### Research and feasibility

- 1 Research genetic diseases and as a group decide which genetic disease will be the focus.
- 2 Create a table of the causes and effects of the disease.

- 3 Find pictures or diagrams of current equipment used and annotate with features and characteristics that relate to assisting people living with this disease.

### Design and sustainability

- 4 Sketch potential design solutions (at least two) and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current aids or tools (if any)?
- 5 Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

### Create

- 6 Build a prototype of your design using available construction materials.

### Evaluate and modify

- 7 Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.
- 8 Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.
- 9 Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

Genetic disease	Effects on part of body	Ideas to help
e.g. Muscular dystrophy Muscle loss	Reduced joint movement	Brace and orthotics for feet
e.g. Haemophilia Blood doesn't clot effectively	Whole body can be bruised easily	<ol style="list-style-type: none"> <li>1 Creation of children's play suit</li> <li>2 Creation of some type of buffing edging that could be applied to furniture</li> </ol>

# Chapter 3

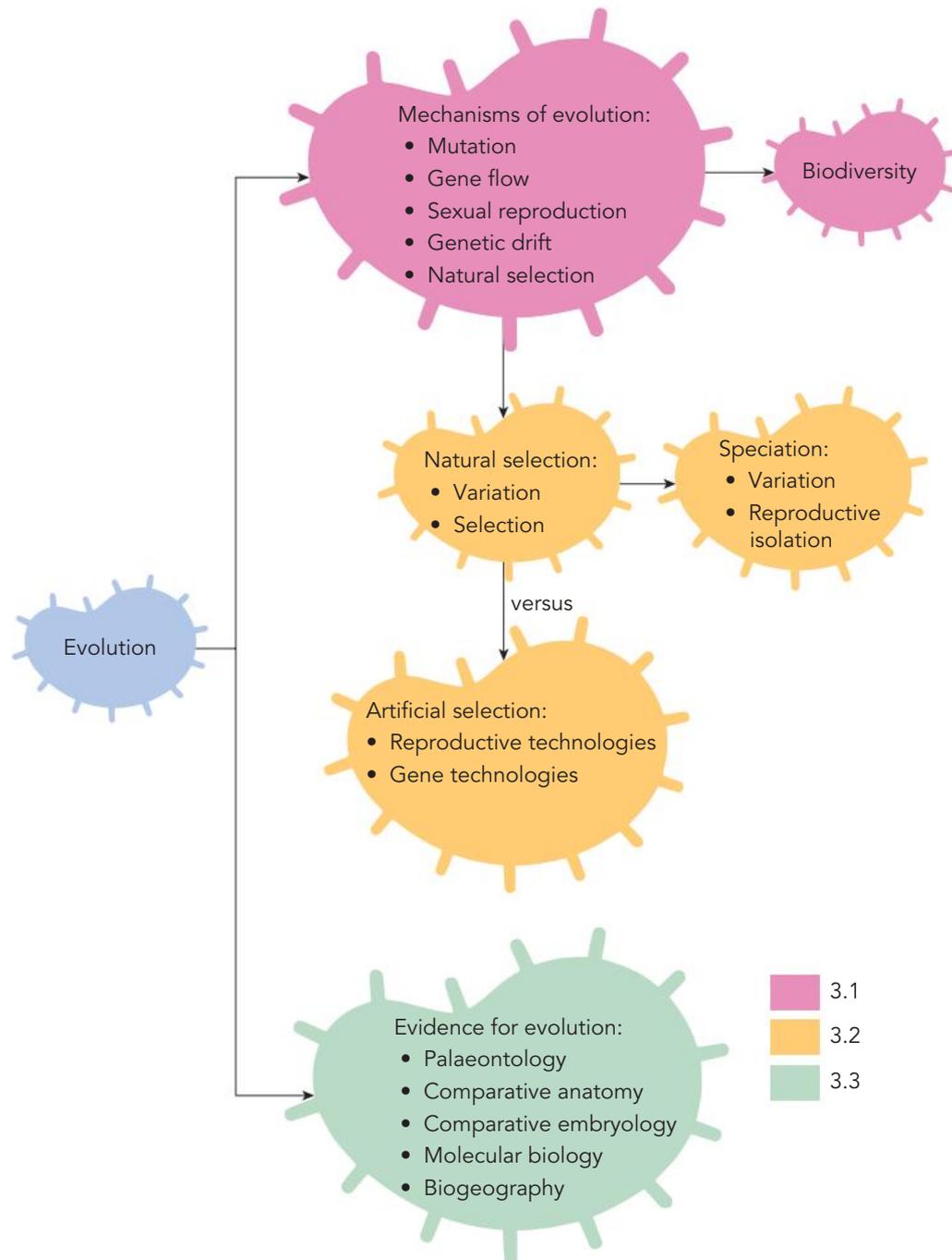
# Evolution



## 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.

# Chapter map



# 3.1 Evolution



## Learning goals

- 1 To describe how evolution can take place through five key mechanisms.
- 2 To explore how biodiversity has changed over time.

**Evolution** refers to the genetic changes in a population over a very long period of time. When scientists refer to a **population**, they mean the members of a single species living in the same region (geographical area) at the same time. Evolution is understood by looking at the variation of 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

### adaptation

a characteristic that contributes to a species' suitability for its environment

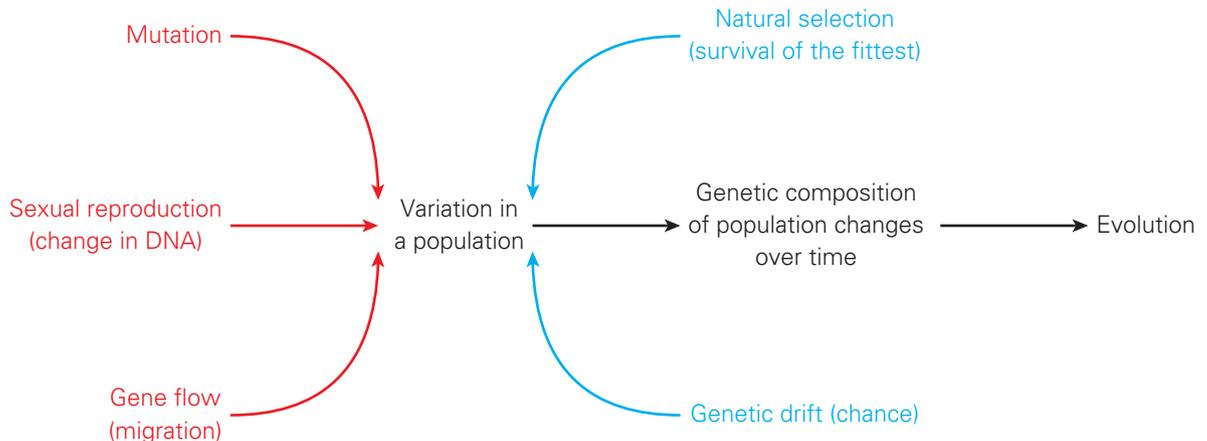
**Variation** occurs when members of a population differ in one or more characteristics. For example, we notice many types of variation in humans, such as skin and hair colour, height, blood types and fast or slow metabolism.

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

## 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:

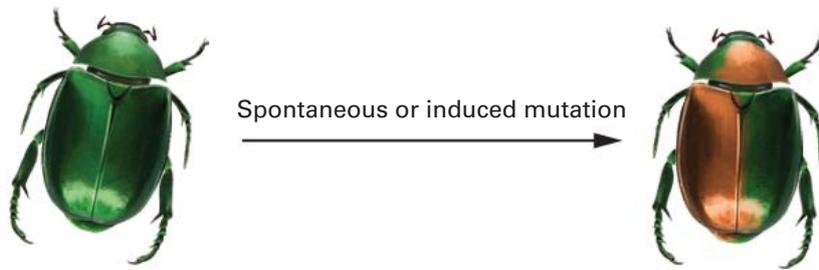
- mutation
- gene flow
- genetic drift
- natural selection
- sexual reproduction – including the processes of 'crossing over' in meiosis and the random combination of genetic information from two parents (as discussed in Chapter 2).



**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.



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

Mutation is a random process in that the change can occur anywhere in a length of DNA. Mutations may have various effects on the phenotype of organisms, ranging from no change at all through to large changes. These large changes include genetic diseases that are associated with a loss of function that can negatively affect the individual's chance of survival, meaning they are often not passed on to future generations. However, in some circumstances, some mutations that are usually detrimental or harmful can produce a positive outcome if they occur in certain areas.

Genetic disease	Some of the outcomes
Albinism	No or little colour in skin, hair and eyes Reduced sun protection
Cystic fibrosis	Thickening of mucus that lubricates organs such as those in respiratory and digestive systems 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 variation 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.

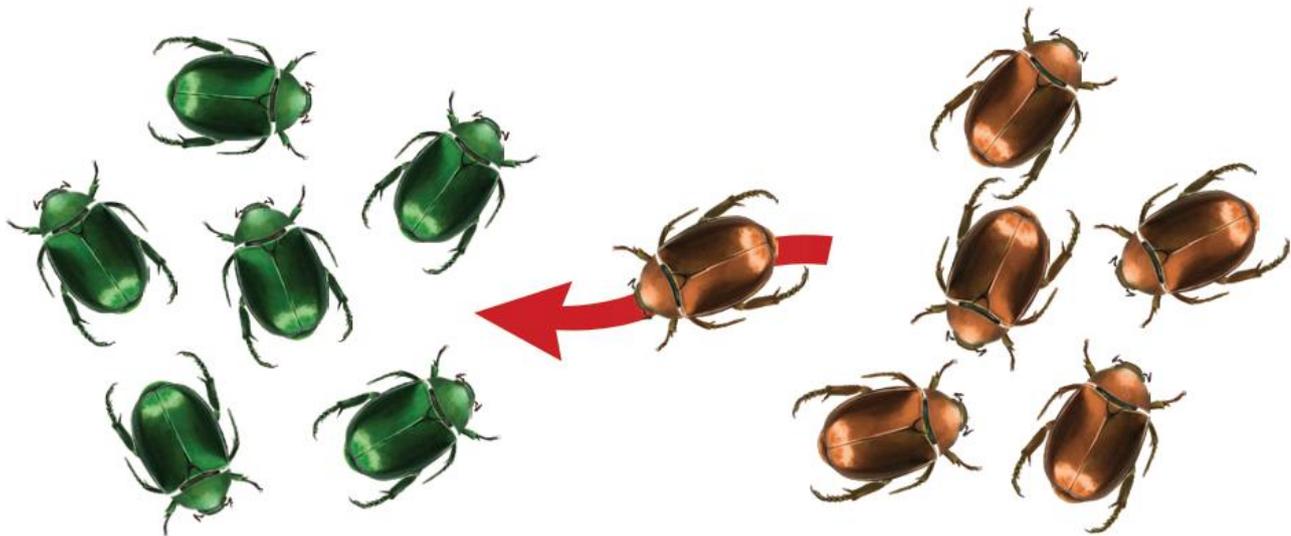
### Did you know? 3.1

#### Thyroxine

Researchers have found that approximately half of the Aboriginal people of Western Australia have a specific genetic composition that promotes production of different amounts of thyroxine, a hormone that regulates metabolism, including body temperature. This provides an advantage in areas that can regularly exceed 45°C.

**Figure 3.3** Marble Bar is Australia's hottest town located in the Pilbara region of Western Australia where temperatures in excess of 45°C are common during December and January.





**Figure 3.4** 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.

#### gene flow

the movement of genetic information from one population to another through migration

#### genetic drift

a random change in the frequency of an existing allele in a population

#### founder effect

the decrease in genetic diversity that occurs when a small population is separated from a larger one

### Gene flow

Another way genetic variation can be introduced into 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.

### Did you know? 3.2

#### Dugongs and gene flow

The largest population of dugongs in the world lives around the northern regions of Australia and feeds 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 3.5** A mother dugong (*Dugong dugon*) and her calf at Ningaloo Reef, Western Australia

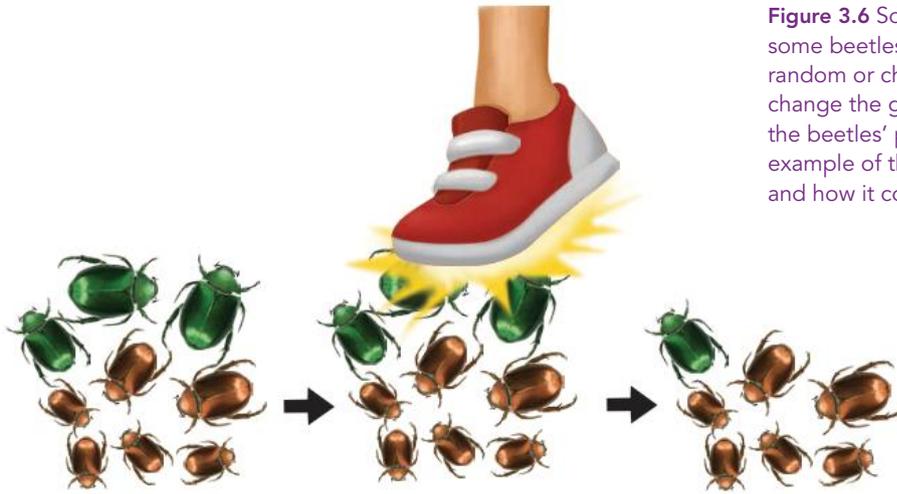


VIDEO  
Mutiny on the Bounty  
and its link to  
genetics

### Genetic drift

**Genetic drift** is an evolutionary mechanism that produces random changes in allele frequencies in a population over time. Genetic drift is always happening in all populations, but the effects are greater in smaller populations. Two extreme examples of genetic drift are

the founder effect and the bottleneck effect. The **founder effect** occurs when a small number of individuals leave a population and establish their own colony. A population 'bottleneck' reduces the size of at least one generation of the population. The genetic variation, or allele frequency, in these individuals differs from that



**Figure 3.6** Someone standing on some beetles by accident is a random or chance event that can change the genetic composition of the beetles' population. This is an example of the bottleneck effect and how it contributes to evolution.

in the original population, where some alleles are over- or underrepresented in terms of their frequency. The **bottleneck effect** may be caused by a chance event, such as habitat destruction or an environmental disaster that results in the deaths of many organisms, leaving behind a small, random assortment of survivors. In both cases, 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.

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



**Figure 3.7** Some variations within a species are less likely to be passed on to the next generation because they have a disadvantage.

### 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 – are far more likely to survive and pass on their genetic information. So 'fittest' does not mean who can do the most push-ups, it means the organisms that have the genetic information most suited to a particular environment will survive and pass on these genes to their offspring. For example, look at Figure 3.7. These beetles live in the leaf litter on the forest floor and have 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 by the birds. The brown beetles have the best colour for surviving (adaptation), which means they will be more likely to survive and pass on their genetic information to their offspring.

**bottleneck effect**  
when the size of a population is rapidly decreased, often due to factors such as natural disasters or human activities such as overhunting

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



**Try this 3.1**

Summarise the five mechanisms of evolution you have learned about 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 terms 'evolution', 'population', 'variation' and 'adaptation'.
- 2 Identify the five mechanisms of evolution.

**biodiversity**

the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur

**species diversity**

the number and abundance of different species in a given area

**genetic diversity**

the range of genetic traits within a species

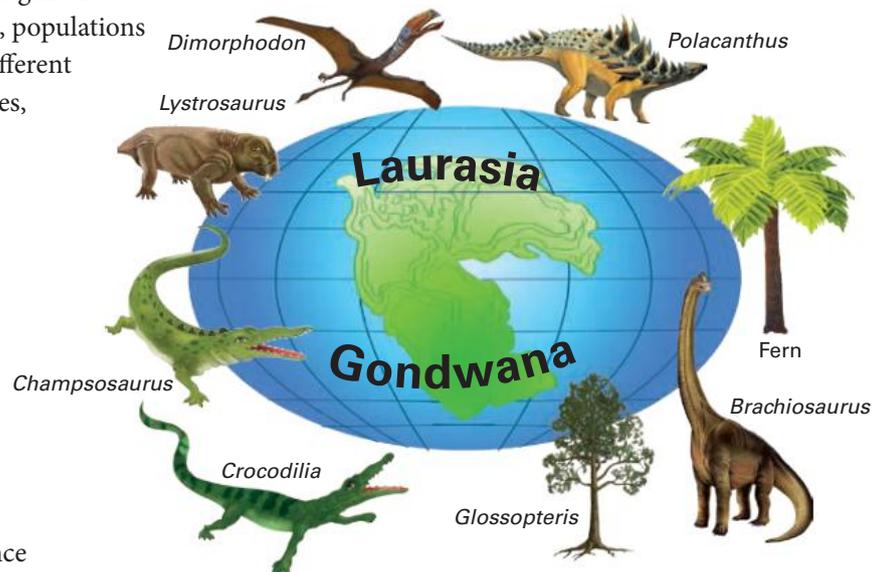
### Biodiversity as a consequence of evolution

**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 that they become a different species, increasing biodiversity. Therefore, it is evolutionary processes that have resulted in the biodiversity we see today.

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 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.



**Figure 3.8** This map shows the supercontinent Pangaea before it separated into a northern Laurasia and a southern Gondwana.

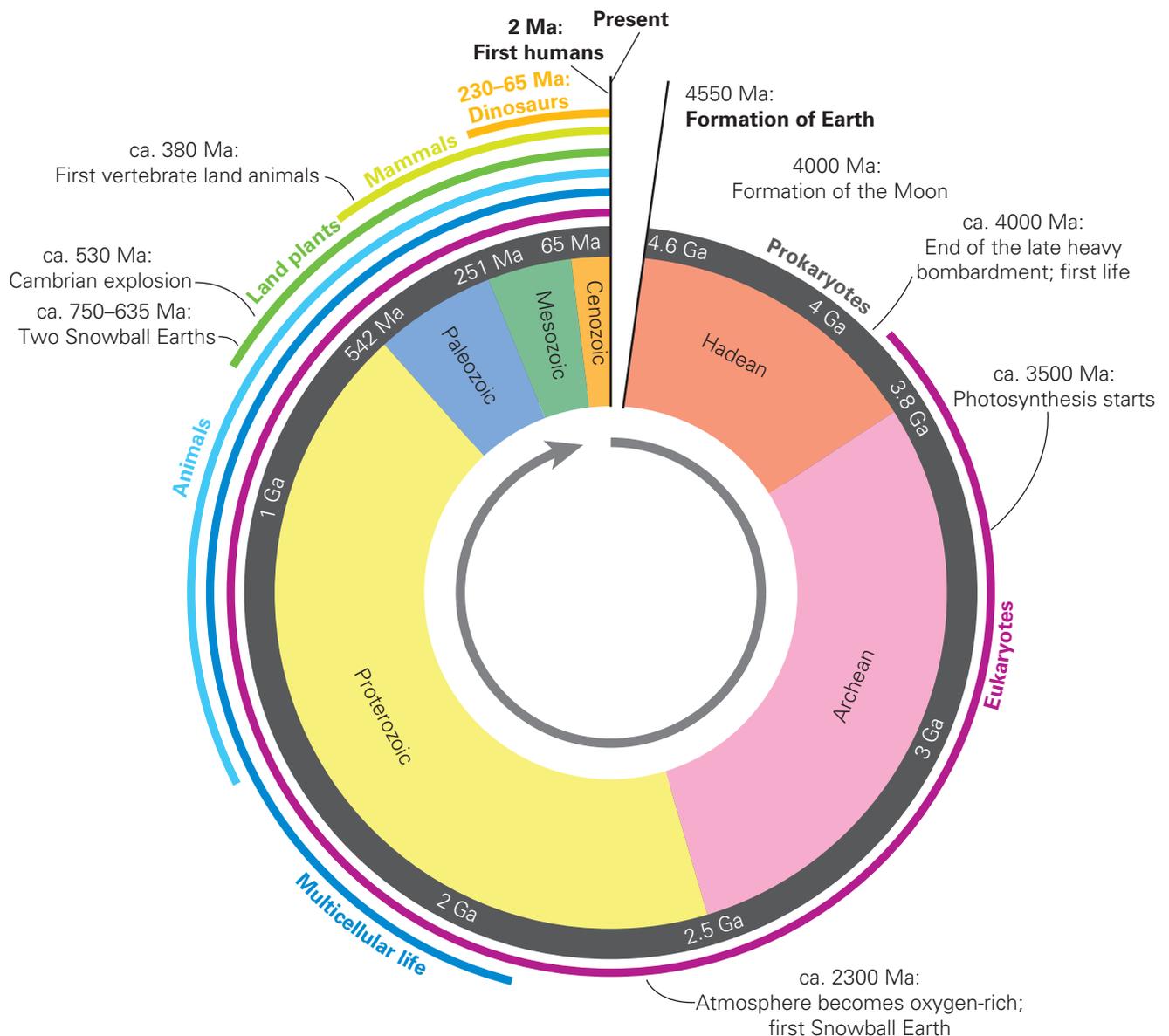
As the continents moved across the surface of Earth, so too did their combination of plants and animals. This movement not only created geographical barriers (like oceans, mountain ranges and large rivers), but over time it also brought new combinations of species together.

### Quick check 3.2

- 1 State what is meant by the term 'biodiversity'.
- 2 Recall what supercontinent Australia was once part of.
- 3 Explain how the movement of continents led to 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 3.9 shows a timeline of the major stages in the development of life on Earth.



**Figure 3.9** 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.

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 of mass extinction, while volcanic activity has been implicated in at least four. Here are some hypothesised causes for the biggest mass extinctions on Earth:

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

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

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

### 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.

**biota**  
the animal and plant life in a particular region at a particular time

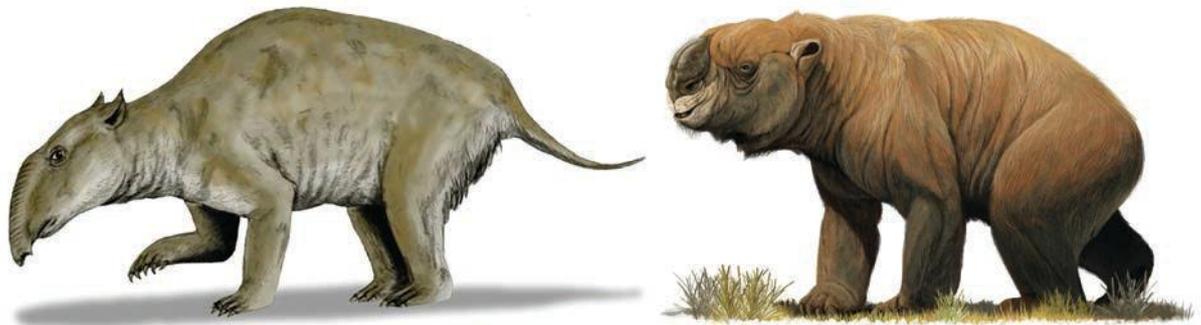
**megafauna**  
large animals with a body mass of over 45 kilograms

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 conditions when glaciers retreat; these are called 'interglacial cycles'. Periods of lower 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 more than 2 billion years ago, and the most recent one began approximately 3 million years ago – and continues today. So, we are currently living in a warm interglacial cycle that began about 11 000 years ago.

The fossil record suggests that the Australian megafauna went extinct after the arrival of Aboriginal Australians.

Giant marsupials (mammals who carry their young in pouches), reptiles and birds once roamed Australia too. One such marsupial is *Diprotodon optatum* (Figure 3.10). With a shoulder height of 1.8 metres and weighing close to 3 tonnes, it 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.



**Figure 3.10** Reconstructions of *Palorchestes azael* (left) and *Diprotodon optatum* (right), the largest known marsupial, two examples of extinct species classified as Australian megafauna.

## Maintaining biodiversity

Maintaining biodiversity is extremely important, and loss of it due to human actions can have huge impacts on ecosystems and result in loss of species that are 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 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 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.

**endangered**  
a species that is in danger of becoming extinct

**extinct**  
no longer existing

Many zoos have captive breeding programs 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.

### Did you know? 3.3

#### 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 the 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 3.11 A platypus swimming in a creek

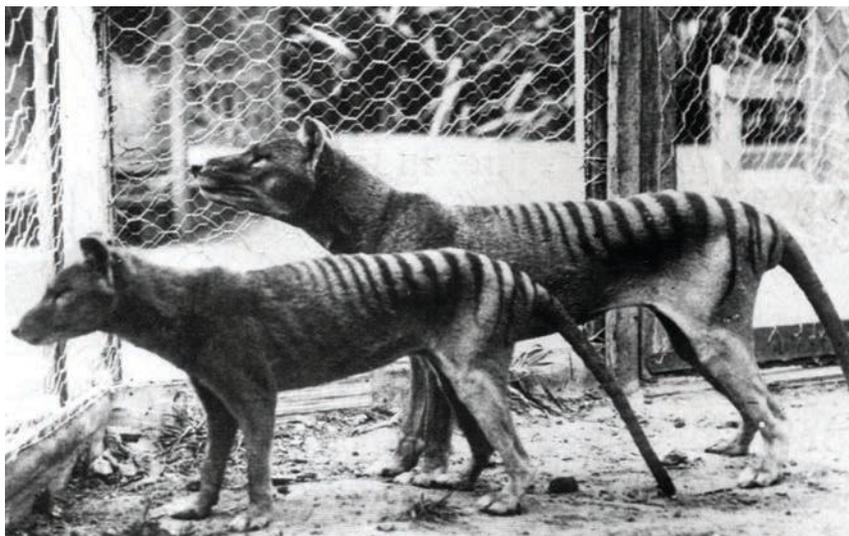


Figure 3.12 The now extinct Tasmanian tiger, or thylacine (*Thylacinus cynocephalus*) is pictured in an enclosure at the Hobart Zoo, Tasmania, in 1933.

### 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?



**Figure 3.13** The Christmas Island pipistrelle (*Pipistrellus murrayi*) (left) is the first Australian mammal to go extinct in the past 50 years. In contrast, the Tasmanian orange-bellied parrot (*Neophema chrysogaster*) (right) has been prevented from going extinct through a captive breeding program.

### 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. Recent research published in 2018 by scientists at La Trobe University in Victoria has revealed which mammal species are now most vulnerable to cats and foxes. The scientists hope that their research can help governments by directing conservation efforts to prevent these vulnerable species from becoming extinct. 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 numbat, northern 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.



**Figure 3.14** Two vulnerable Western Australian mammal species: the northern quoll (*Dasyurus hallucatus*) (left) and numbat (*Myrmecobius fasciatus*) (right)

### Quick check 3.3

- 1 Define the terms '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.

### 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 **Recall** where variation in a population comes from.

#### Understanding

- 6 **Identify** an example of variation in a species that:
  - a increases the species' chances of survival
  - b decreases the species' chances of survival
  - c does not affect the species' chances of survival.

#### Applying

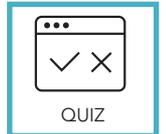
- 7 **Explain** how mutations contribute to variation within a species and, consequently, evolution.
- 8 **Explain** how gene flow can contribute to a change in the genetic composition of a population.
- 9 **Summarise** how a change of only one nucleotide in DNA can result in a different phenotype and eventually cause evolution.
- 10 **Explain** how extinctions can stimulate new biodiversity among species.

#### Analysing

- 11 **Distinguish** between species diversity and genetic diversity.
- 12 **Distinguish** between extinct species and endangered species.

#### Evaluating

- 13 **Discuss** 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. **Decide** if this suggests the species had low or high genetic biodiversity and give reasons why this would occur.



## 3.2 Natural and artificial selection



### Learning goals

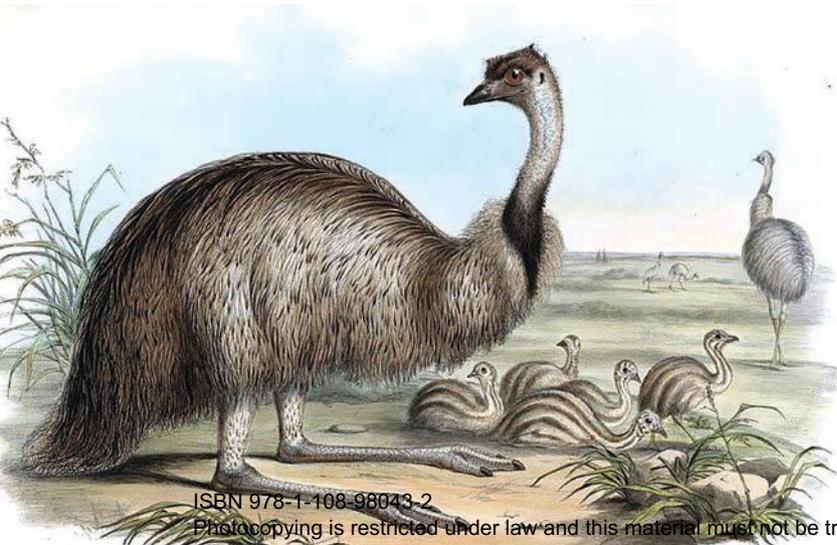
- 1 To be able to recall the steps in the process of natural selection.
- 2 To be able to outline the factors that lead to speciation.
- 3 To describe some examples of artificial selection.

In Section 3.1, you read that there are five mechanisms of evolution: mutation, gene flow, genetic drift, natural selection and sexual reproduction. In this section, we will look at natural selection in more detail. Recall from the previous section that evolution and natural selection apply to populations and 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, at the age of just 22, the young naturalist Charles Darwin boarded the ship 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 recorded the plant and animal species of the island.



**Figure 3.15** John Gould published the first comprehensive survey of birds in Australia. He was accompanied by his wife, Elizabeth Gould, who was a talented ornithologist and illustrator in her own right. The image below was taken from his book, *The Birds of Australia*, published throughout 1840 and 1848 in seven volumes.



On his return to London, Darwin needed help in identifying some of the bird specimens that he had collected. Initially, he took little interest in his collection of finches, but this changed when the eminent ornithologist John Gould classified them as 12 new species. Gould had noticed that they showed great variation in their beaks. It was his observations that helped Darwin with the development of his theory of evolution.

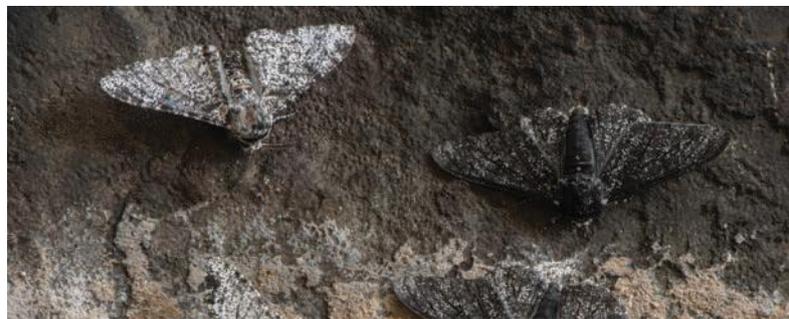
Darwin speculated that although the different islands had similar animals and plants, many animals and plants seemed to have specialised features that meant they were better suited to their local environments. Each finch species' beak was suited to eating the particular food source that was available in the habitat they occupied on their island. Darwin explained how species change over time, using the theory we know today as 'natural selection'.

### The process of natural selection

Most species produce more offspring than can survive. This is often referred to as 'overproduction'. Organisms then compete for limited resources in the environment such as food. This sets the scene for the process of natural selection.

The following steps outline the process of evolution through natural selection.

- 1 Genetic variation naturally exists in the population due to processes such as sexual reproduction, crossing over, mutations and gene flow.
- 2 This genetic variation means that some individuals within the population have traits better suited to their environment.
- 3 Individuals with favourable traits are more likely to survive and reproduce than others of their species and pass on those traits to



**Figure 3.16** 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 light tree bark. The picture on the right shows the moths against dark tree bark.

the next generation. We say those favourable traits are ‘selected for’ by environmental (or selection) pressures – that is, the process of natural selection.

- Over time, the individuals with the favourable traits become more numerous in the population. That is the process of evolution by natural selection.

An example of natural selection is the case of the light and dark peppered moths (*Biston betularia*) in Britain. There are two varieties within the one species – one is light coloured, the other is dark coloured – and the colour is genetically determined. Look at the moths in Figure 3.16 – the light-coloured variety of the peppered moth initially had the favourable trait (we can say the light-coloured moth was at a **selective advantage**) as it blended well with the lighter lichen-covered bark of the trees. This meant when a hungry bird (the selecting agent) came by, it would be more likely to see the dark-coloured moth and eat 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 now better camouflaged against the trees and not as easily spotted by predators. Now the roles were reversed: the light-coloured moths were at a disadvantage and their numbers fell. The darker moth was the ‘fittest’ or best adapted in this

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

#### Quick check 3.4

- Recall where Charles Darwin collected his finch specimens.
- Outline the four steps involved in the process of evolution by natural selection. Explain 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 are different from others, and those differences provide an advantage or disadvantage for survival and reproduction. All around us, organisms are producing offspring that vary. This variation can make an individual better or less 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.

#### selective advantage

a characteristic that enables an organism to survive and reproduce better than other organisms in a population

#### 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



Figure 3.17 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** because they determine which variations provide individuals with better survival chances.



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.

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.

### Try this 3.2

#### Drug-resistant bacteria and traditional medicines

Antibiotics are medicines used to prevent and treat bacterial infections. However, some bacteria have mutations that mean they are resistant to the effects of the drugs. The World Health Organization has identified antibiotic resistance as one of the greatest threats to human health today, potentially causing up to 10 million deaths per year by 2050 if left unaddressed.

Currently, some researchers are focusing on studying traditional bush medicines, which have been used by Aboriginal Australians for generations, as alternatives to pharmaceutical antibiotics. Plants such as tea tree (*Melaleuca alternifolia*) and emu bush (*Eremophila* sp.) have been found to have the same strength as some established antibiotics and may provide a solution for the current resistance crisis.

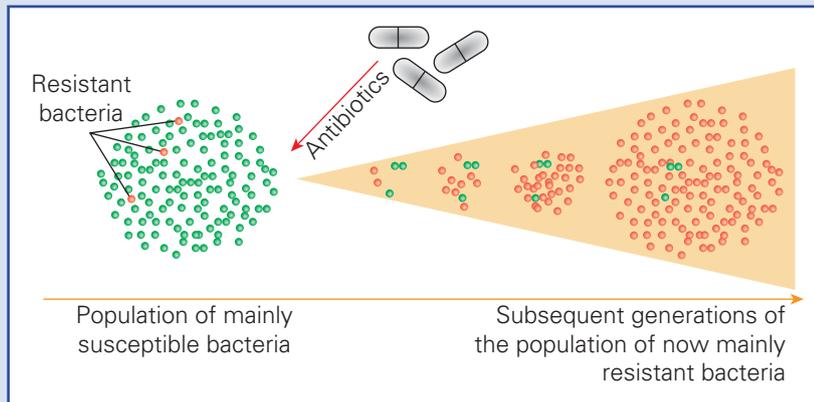


Figure 3.18 *Eremophila longifolia* is one of many species of plants that can be referred to as 'emu bush'.

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Consider the following diagram carefully and then answer the questions that follow.



- 1 What variation between bacteria can you see in the original population?
- 2 Which variation is selected for (the fittest)? 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.

### Explore! 3.2

#### Bush medicines

The diagram in Try this 3.2 demonstrates how bacteria can become resistant to certain drugs. The combination of evolutionary pressures and high use of antibiotics in contemporary society has seen the emergence of strains of diseases that are resistant to many drugs.

Aboriginal and Torres Strait Islander peoples have an extensive knowledge of bush medicines, which has been developing over millennia through observation and experimentation, and which has been passed down to each subsequent generation. Now, there is increasing research directed at identifying chemical compounds in traditional medicines for use in pharmaceuticals.

Unfortunately, there has been a historical problem of Aboriginal and Torres Strait Islander peoples used only as informants, rather than considered as collaborators in the production of new medicine. However, there is now a greater appreciation for the valuable input that Aboriginal and Torres Strait Islander communities provide.

Conduct some research into at least one of the plants in Figure 3.19 used in Aboriginal pharmacopeia to find out:

- what ailment it treats
- which part of the plant is used as a remedy or medicine
- how it is processed
- what new medicines (if any) scientists are trying to develop using the plant.

continued...



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**Figure 3.19** Left to right, top to bottom: tea tree (*Melaleuca alternifolia*), corkwood tree (*Duboisia myoporoides*), kangaroo apple (*Solanum laciniatum*), balga or grass tree (*Xanthorrhoea preissii*), pulgur or harsh hakea (*Hakea prostrata*), marri or red gum (*Corymbia calophylla*)

## Practical 3.1: Investigation

### Modelling genetic drift, natural selection and gene flow

#### Aim

To simulate genetic drift, natural selection and gene flow in a population of jellybeans and analyse the consequences of each.

#### Be careful

Do not consume food items.

#### Materials

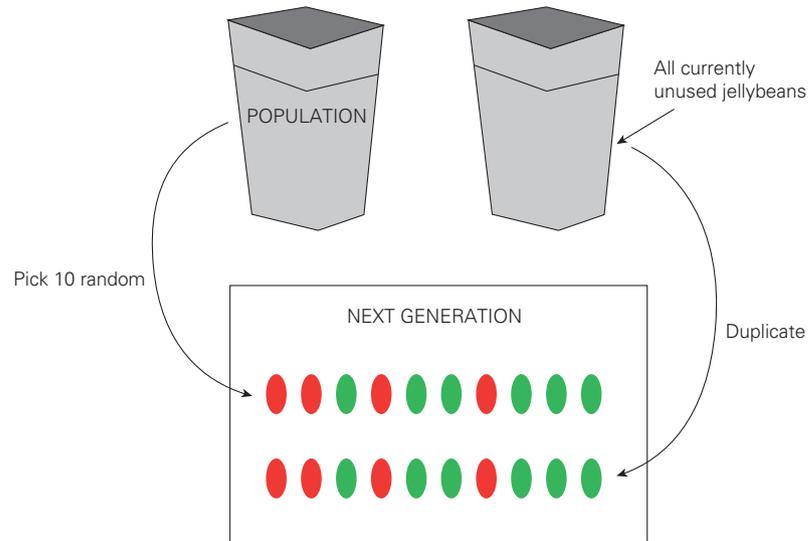
- Jellybeans: 20 red, 20 green and 20 blue (or anything similar e.g. coloured paper)
- 2 cups, one labelled 'Population'
- 1 piece of paper labelled 'Next generation'

#### Method for genetic drift

- 1 Place 10 red jellybeans and 10 green jellybeans in your 'Population' cup. These represent the alleles of the population. Place all other jellybeans in the other cup for unused jellybeans. Record the current population in your results table.
- 2 With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the 'Next generation' piece of paper. These are the alleles that will be passed on.
- 3 Duplicate the 10 jellybeans (e.g. if you picked out 4 red and 6 green, pick out another 4 red and 6 green from the other cup and place them on the paper.)
- 4 Record this in the next row of your results table.
- 5 Throw the remaining beans from your 'Population' cup into the cup for unused jellybeans, and place the new generation alleles on the piece of paper into the 'Population' cup.
- 6 Repeat steps 2–5 until you have 10 rows of data, or until one colour is eliminated.

continued...

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**Method for natural selection**

- 1 Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
- 2 Imagine that green has a selective disadvantage (the opposite of a selective advantage). Pick out 3 green jellybeans from the population and move them into the cup for unused jellybeans.
- 3 With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the piece of paper.
- 4 Duplicate the 10 jellybeans on the piece of paper. Record this in the next row of your results table.
- 5 Throw the remaining beans from your 'Population' cup into cup for unused jellybeans, and place the new generation alleles on the piece of paper into the 'Population' cup.
- 6 Repeat steps 2–5 until you have 10 rows of data, or until one colour is eliminated.

**Results for genetic drift and natural selection**

Generation	Number of alleles	
	Red	Green
1	10	10

**Method for gene flow**

- 1 Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
- 2 Add 5 blue jellybeans into the 'Population' cup.
- 3 With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the piece of paper.
- 4 Duplicate the 10 jellybeans. Record this in the next row of your results table.
- 5 Throw the remaining beans from your 'Population' cup into the cup for unused jellybeans, and place the new generation alleles on the piece of paper into the 'Population' cup.
- 6 Repeat steps 3–5 until you have 10 rows of data, or until two colours are eliminated.

**Results for gene flow**

Generation	Number of alleles		
	Red	Green	Blue
1 (before migration)	10	10	0

continued...

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### Discussion

- 1 Plot your results on a graph. There should be one each for the genetic drift, natural selection and gene flow simulations.
- 2 Describe what happened in each case. How do the results compare to what you would expect for each process?
- 3 Did your results show any colour becoming extinct in your population?
- 4 Compare your results for genetic drift with those of another classmate or group. Account for any contradicting trends in the results.
- 5 Propose what step 5 could represent in the genetic drift simulation.
- 6 Propose what step 2 could represent in the natural selection simulation.
- 7 Propose what step 2 represents in the gene flow simulation.
- 8 Imagine that the introduced blue allele also had a selective advantage in the gene flow simulation. How would you simulate this scenario?
- 9 Imagine that there was a mutation in one of the jellybeans that turned it orange. How could this affect future generations?
- 10 What assumptions have we made about the red, green and blue alleles in this simulation?
- 11 Can reliable conclusions and predictions be drawn from the results? Justify your answer.
- 12 List some limitations of this simulation compared to what happens in real life. Justify your response.
- 13 What are some ways the simulations can be improved?

### Quick check 3.5

- 1 Variation is essential for the process of natural selection to occur. Explain what 'variation' means, including where it comes from in a population.
- 2 Define the term 'selection pressure' and how it contributes to natural selection.

## Speciation

### speciation

the process by which new types (species) of living things are thought to develop from existing ones by evolution

### species

a group of organisms 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

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 and genetically

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,



**Figure 3.20** The offspring of a female horse and a male donkey is a mule, which cannot reproduce. This is evidence that horses and donkeys are two different species.

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.

## 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

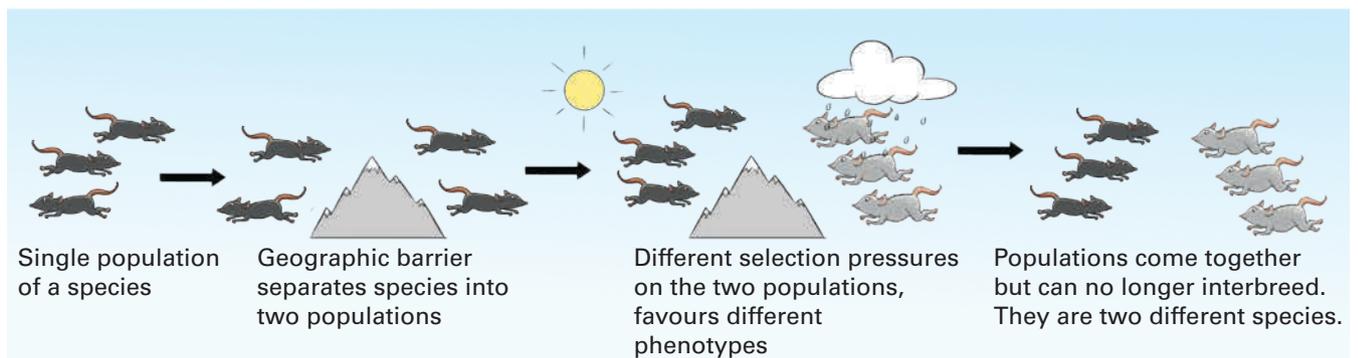


Figure 3.21 Natural selection can cause speciation.

## Science as a human endeavour 3.2

### Rock wallabies

There are four subspecies of black-footed rock wallabies (*Petrogale lateralis*) in Western Australia. They are different species, meaning that they cannot reproduce to create fertile and viable offspring. These subspecies had been geographically isolated (Perth region, the Kimberley, the Wheatbelt, and the islands off the coast of Esperance), which resulted in distinct genotypes and unique phenotypes with regards to colours of their fur and markings on their chests.



Figure 3.22 A black-footed rock wallaby (*Petrogale lateralis*)

## Quick check 3.6

- 1 Define the term 'species'.
- 2 Speciation can occur as a consequence of natural selection with one additional step. Recall what must also occur and its role in speciation.
- 3 Describe how you could determine if two populations were the same species.

## Try this 3.3

**Speciation story time**

With a classmate, take turns telling stories of speciation. You may like to use the images in Figure 3.23 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 3.23** 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**  
intentional breeding of  
plants and animals to  
produce desirable traits

**selective breeding**  
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 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 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.

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.



**Figure 3.24** Artificial selection in action: each of these organisms was selectively bred for particular characteristics.

**Did you know? 3.4****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 3.25 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 make 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 3.26 (Left to right) British bulldog, greyhound, chihuahua, chihuahua, Leonberger, chihuahua, King Charles spaniel, schnauzer, Yorkshire terrier, schnauzer: they are all the same species!

**Human reproductive technologies**

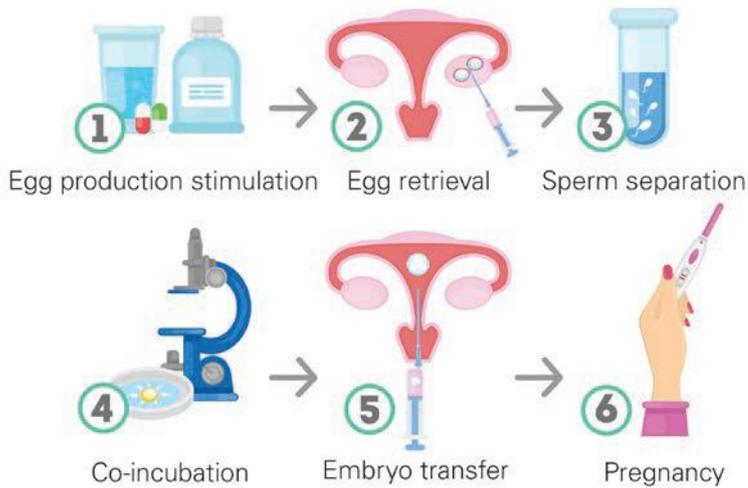
To assist human reproduction today, we use many reproductive technologies that involve artificially selecting the genetic information that is passed to the next generation. In this way, we humans are affecting the biodiversity of the human race and consequently affecting our own evolution.

For example, in vitro fertilisation (IVF) involves selecting viable sperm and combining them with eggs in a test tube. After fertilisation, the healthiest embryo is selected for development and the remainder are frozen.

Medical technology lets us genetically test embryos prior to their implantation and genetically screen babies. Using these technologies can change the genetic composition of the human population in the next generation. Evolution takes an extremely long time, so we will not actually see the results of our actions for thousands to millions of years!

**Gene technologies**

Gene technology lets us transfer genes from one individual or species to another. Two of these technologies are gene therapy (in which a



**Figure 3.27** The process of IVF artificially selects the eggs, sperm and embryos that have the best chance of survival.

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).

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 3.28** Four types of genetically modified blue carnation are grown and sold in Australia.

### Science as a human endeavour 3.3

#### Editing 'bad' genes out

Researchers in Switzerland have used a new gene editing tool to correct gene mutations. They have only been successful with mice at this stage, but their success means a lot for sufferers 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 3.29** 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 Contrast natural selection and artificial selection.
- 3 Discuss whether artificial selection increases or decreases variation and therefore biodiversity.
- 4 Explain how reproductive technologies can affect human biodiversity.

### Section 3.2 questions

#### Remembering

- 1 **Recall** 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.
- 3 **State** the different sources of variation in an individual and in a population.
- 4 **Identify** three examples of abiotic selection pressures and three examples of biotic selection pressures.

#### Understanding

- 5 **Name** some different ways that technology can affect the biodiversity of the human population.
- 6 **Describe** what is meant by the term 'selective advantage'.
- 7 **Summarise** the three processes in speciation.

#### Applying

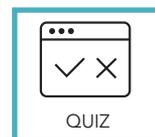
- 8 **Explain** why variation is necessary for natural selection to occur.
- 9 **Explain** why isolation is necessary for speciation to occur.

#### Analysing

- 10 Tomato breeders have created the sweetest and juiciest tomato ever. **Reflect** on how they would have done this, given that they started with a not-so-sweet and not-so-juicy crop of tomatoes.
- 11 **Distinguish** between artificial and natural selection, providing examples for each.

#### Evaluating

- 12 The Galapagos finches have similar features but are recognised as distinct species. **Propose** a test that could be used to identify if two similar kinds of finch are different species or subspecies of the one species.
- 13 **Determine** how speciation, biodiversity and evolution are linked.
- 14 **Decide** 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



### Learning goals

- 1 To be able to list evidence for evolution from six fields of science.
- 2 To be able to describe that radiometric dating of fossils relies on nuclear decay processes.

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 that can help ascertain where a species may have originated from

Table 3.3 Sources of scientific evidence for the theory of evolution

#### 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 of time

#### direct evidence

evidence that supports an assertion without intervening inferences

#### indirect evidence

evidence that requires inferences to be made

#### trace fossil

a trace of an animal, such as footprint or imprint, that has become fossilised

#### fossilisation

the process of forming a fossil

#### fossil record

the record of past life and evolution inferred from fossils

### Palaeontology

The term **fossil** refers to any parts of, or impressions made by, a plant or animal that is preserved following death. Normally, an organism decomposes after it dies, and after a time, no trace of it remains. On rare occasions, evidence of the organism is preserved in the form of a fossil.

Fossils may be the hard parts of an organism, like its bones and teeth (called **direct evidence**), or evidence of an organism's presence, like footprints, burrows and faeces (called **indirect evidence** or **trace fossils**). The process of forming a fossil is called

**fossilisation**. However, because fossilisation is rare, and 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.



Figure 3.30 This marine reptile fossil of the Triassic period, named *Pachypleurosaurus*, was found high in the Swiss Alps.

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 the 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,





**Figure 3.31** Dinosaur tracks at Lark Quarry Conservation Park

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.

### Fossilisation

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, need to be reduced. For example, many bacteria that cause decomposition will die in the absence of oxygen or water, or under



**Figure 3.32** Shown here is the skull of Owen's Ninja Turtle (*Ninjemys oweni*), an extinct large stem-turtle from the Pleistocene period in Queensland. Despite the turtle weighing over 200 kg and having a horned head, it was a herbivore.

- 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.

### Types of fossils

Trace fossils are important tools in understanding extinct animals as they give some insight into the behaviour of the animals, how they lived and how they interacted with the environment. Trace fossils 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 State two sources of evidence for evolution.
- 2 Recall 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 Describe what is meant by a 'trace' fossil.

## Did you know? 3.5

## Living fossils?

Charles Darwin coined the phrase 'living fossils' and, despite it not being a scientific term, it has remained in use. It describes modern species of plants and animals that survived mass extinctions and ice ages. They are almost identical to species that lived in ancient geological ages. Examples include the Wollemi pine, stromatolites, mountain shrimp and the Australian ghost shark.



**Figure 3.33** Stromatolites (layered rock-like mats of cyanobacteria) were discovered in Hamelin Pool in the Shark Bay area of Western Australia in 1961.

## 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 to the age of other fossils. For example, it can tell you that fossil X is older than fossil Y, but it cannot tell you the actual numerical age of the fossil. Relative dating is used to order 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

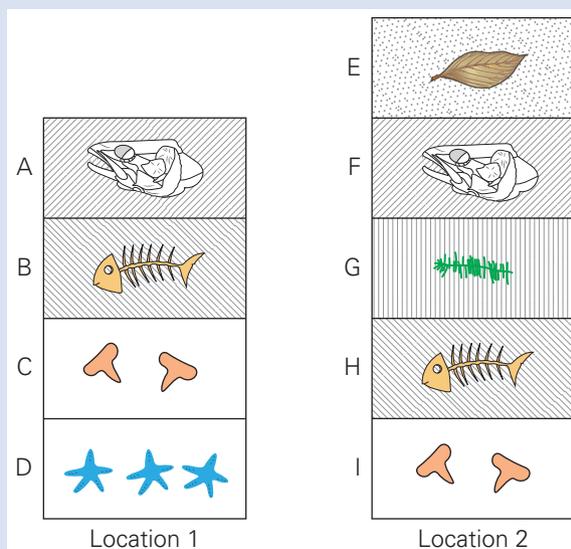
## Try this 3.4

## Stratigraphy

The diagrams in Figure 3.34 represent the strata (rock layers) found at two different locations (1 and 2). Each layer has a letter associated with it and you can see the different fossils found in each layer. Knowing that the youngest layers are on the top and the oldest underneath, 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 3.34** 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.



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. Some of these organisms became fossilised in sedimentary rocks. Geologists have studied the order in which fossils appeared and disappeared through time and rocks. This study is called **biostratigraphy**.

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.

Figure 3.35 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 occurring radioactive isotopes (**radioisotopes**). These isotopes are known to exist in living things, and have a known rate of radioactive decay. By measuring the amount of radioactive isotope left in the sample, 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** and is unique to each isotope. Knowing this helps us determine the best isotope to use to work out the absolute age of a fossil. The longer the half-life, the older the fossil or rock that can be dated.

#### biostratigraphy

a branch of stratigraphy focused on dating rock layers using the fossils found in them

#### index fossil

a fossil used as the base for dating the strata it occupied

#### absolute dating

determining the actual age of a material

#### radioisotope

a version of a chemical element that has an unstable nucleus and emits radiation during its decay to a stable form

#### half-life

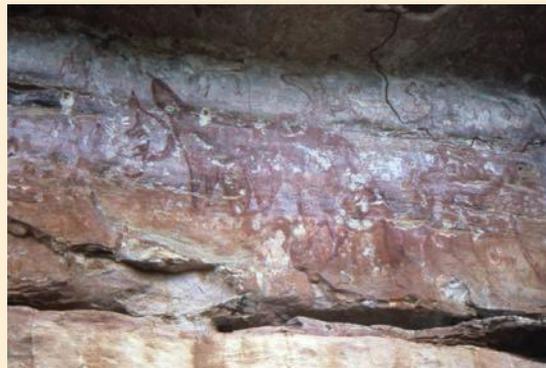
the length of time needed for the radioactivity of a radioactive substance to be reduced by half

Radioactive isotopes (parent to daughter)	Half-life (years)	Estimated age range of fossils they can date
Carbon-14 to nitrogen-14	5730	Up to 60 000 years ago
Uranium-235 to lead-207	710 000 000	1000 to 1 million years ago
Potassium-40 to argon-40	1300 000 000	500 000 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.

### Did you know? 3.6

*Zygomaturus trilobus* was a large wombat-like marsupial, approximately the size of a bull. Dating using uranium shows that a fossil specimen of *Zygomaturus* died 33 000 years ago. We know that Aboriginal peoples arrived in the same area at least 50 000 years ago. Uranium dating shows that people and megafauna coexisted for at least 17 000 years. This coexistence is further supported by paintings in Arnhem Land rock shelters, of species such as *Genyornis newtoni* and *Palorchestes parvus*.



**Figure 3.36** The painting of the megafauna species *Palorchestes* displays two prominent tufts of chest hair and is accompanied by a smaller (younger?) version of the same animal.

### Try this 3.5

#### Modelling half-lives

##### Materials

- 100 M&Ms or counters with one side marked (do not consume M&Ms after they have been handled)
- graph paper
- plastic container with lid
- plastic tray
- gloves

##### Instructions

- 1 Draw the table shown in the results section into your science journal.
- 2 Predict the number of M&Ms that will 'decay' into daughter isotopes each time trial. Place all 100 M&Ms parent isotopes on your plastic tray with the 'm' side up.
- 3 Record your original number of parent isotopes in your results table for time 0.



Parent isotope → m-side up, radioactive

Daughter isotope → m-side down, stable

- 4 Place all the isotopes in the plastic container and shake for 10 seconds.

*continued...*

...continued

- 5 Pour your isotopes back on to 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 means for each time.
- 10 Calculate the percentage of undecayed parent isotopes for each time period.
- 11 Draw a graph of the time (x-axis) versus the percentage undecayed parent isotopes (y-axis) using the class results.

Time	Number of removed daughter isotopes	Number of remaining parent isotopes	Percentage undecayed parent isotopes $\frac{\text{Number of remaining parent isotopes}}{100} \times 100$	Class mean percentage undecayed parent isotopes
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

- 12 Calculate the half-life of your isotope by using your graph to identify the time in which half of the parent isotopes had decayed into daughter isotopes.

### Quick check 3.9

- 1 Describe relative dating.
- 2 Define the terms 'stratigraphy' and 'index fossil'.
- 3 Describe absolute dating.
- 4 Name one isotope that could be used to accurately measure the absolute age of a fossil estimated to be 14 000 years old.

## 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.

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 potential 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.



**Figure 3.37** New fossils are providing key insights into the evolution of modern lizards and snakes.

**Comparative anatomy**

There can be a remarkable diversity of forms among 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, having 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.

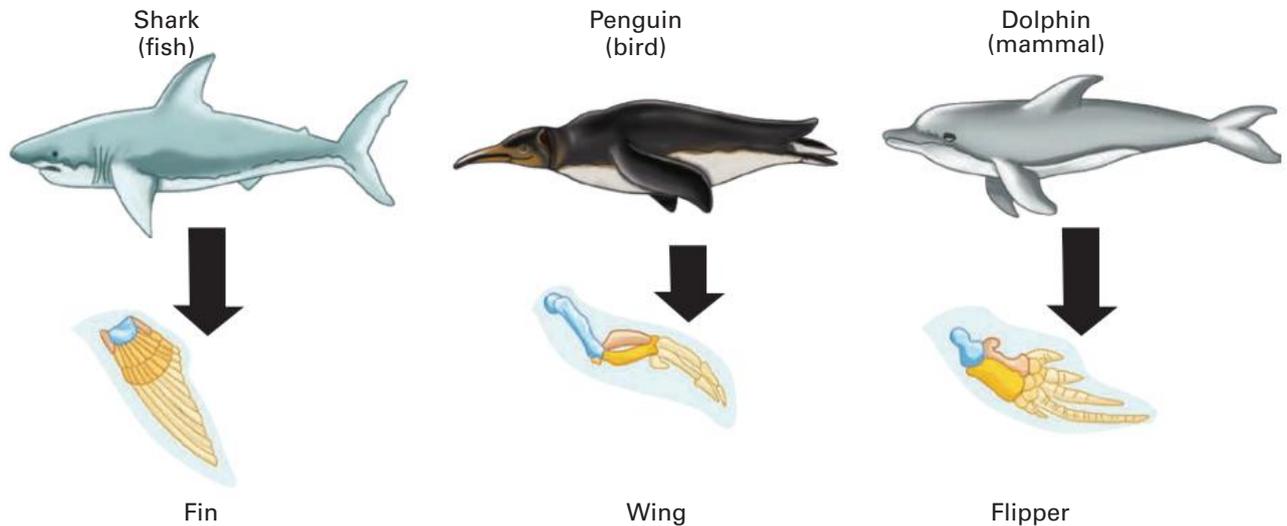


**Figure 3.38** A sugar glider (top) and a flying squirrel (bottom) have many common characteristics, but they are not closely related.

**analogous structure**  
a structure that has a similar function but evolved separately

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 have some common physical characteristics?

The characteristic 'wings', which are flaps of skin, are known as **analogous structures**. These are structures that have a similar function but have evolved independently. The two organisms have evolved from different ancestors but in similar environments, so the same selection pressures



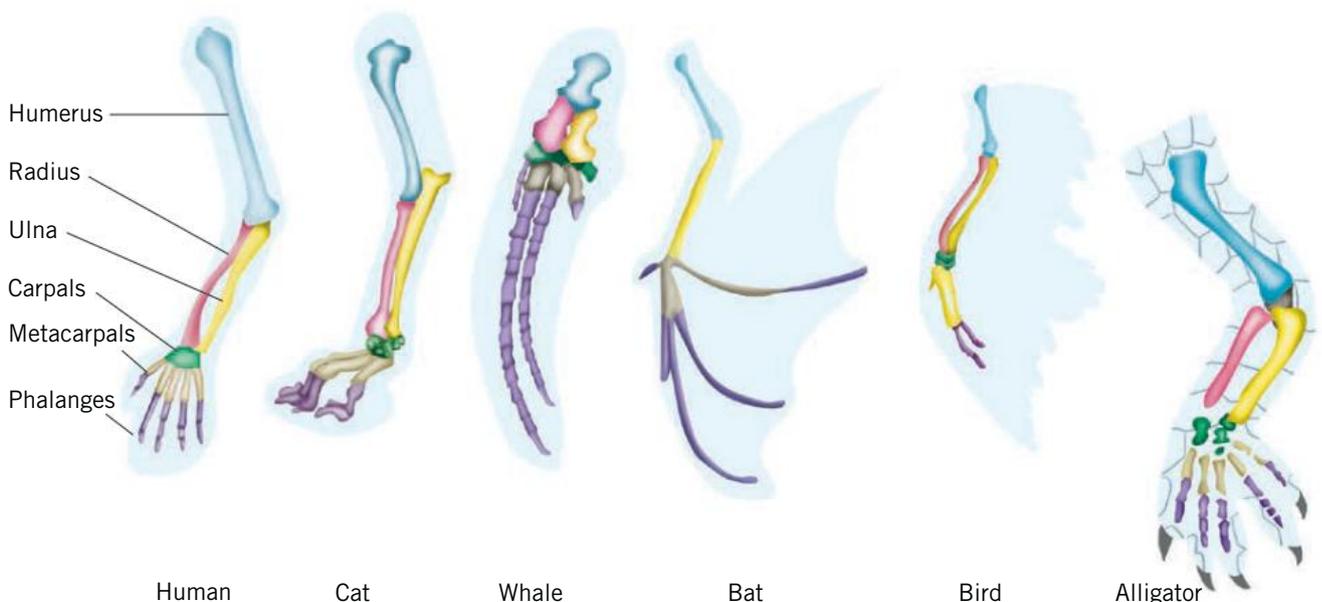
**Figure 3.39** The shark, penguin and dolphin have analogous structures; that is, structures with the same function. These arose because they live in similar environments and face similar selection pressures.

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 3.39). The shape of their fin (or the wing of the penguin) is adapted for swimming through water. The three types of animals faced similar selection pressures in their aquatic environment, and evolved into a similar shape, but they do not share a recent common ancestor.

**Homologous structures** are structures that organisms inherit from a common ancestor. ‘Homo’ comes from the Greek word *homos*,

meaning ‘same’, hence they inherited the same general body plan from the same ancestor. We say these structures have a common evolutionary origin. Homologous structures have similar underlying anatomy, but have evolved in different ways over time due to different selection pressures. An example of a homologous structure is the pentadactyl (five fingered) limb. The limbs of different tetrapod vertebrates (amphibians, reptiles, birds and mammals) show basic similarities in the bones present and how they are arranged, even though the limbs may serve different functions (Figure 3.40).

**homologous structure**  
a structure that is similar because it has evolved from the same ancestor



**Figure 3.40** The limbs of different tetrapod vertebrates have a common structure and are called homologous, despite having different functions, such as grasping, swimming or flying.

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.

### Quick check 3.10

- 1 Describe analogous structures, providing an appropriate example.
- 2 Describe homologous structures, providing an appropriate example.

### Practical 3.2

#### Dissection of a chicken wing

##### Aim

To compare the structure of a chicken wing to the structure of a human arm.

##### Materials

- fresh chicken wing
- dissecting board
- dissecting scissors
- probe
- disposable gloves
- human skeleton model

##### 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.
- 4 Identify the muscles of the wing and see if you can work out how each one is attached to the bones of the wing.
- 5 Look for the tendon, which is white and tough and attaches the muscle to the bone.
- 6 Try squeezing the muscle in the wings and observe what happens to the bones. You may notice there are two muscles which can flex or extend the wing.
- 7 Look at the surface of each bone where it forms a joint. It should appear white, shiny and slippery – this is called cartilage. Can you find the cartilage at the joint between the humerus and the radius and ulna?

##### 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.

*continued...*

##### Be careful

Take care when using scissors and probes. Ensure benches are cleaned and hands are washed before leaving the laboratory.

...continued

- 3 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.

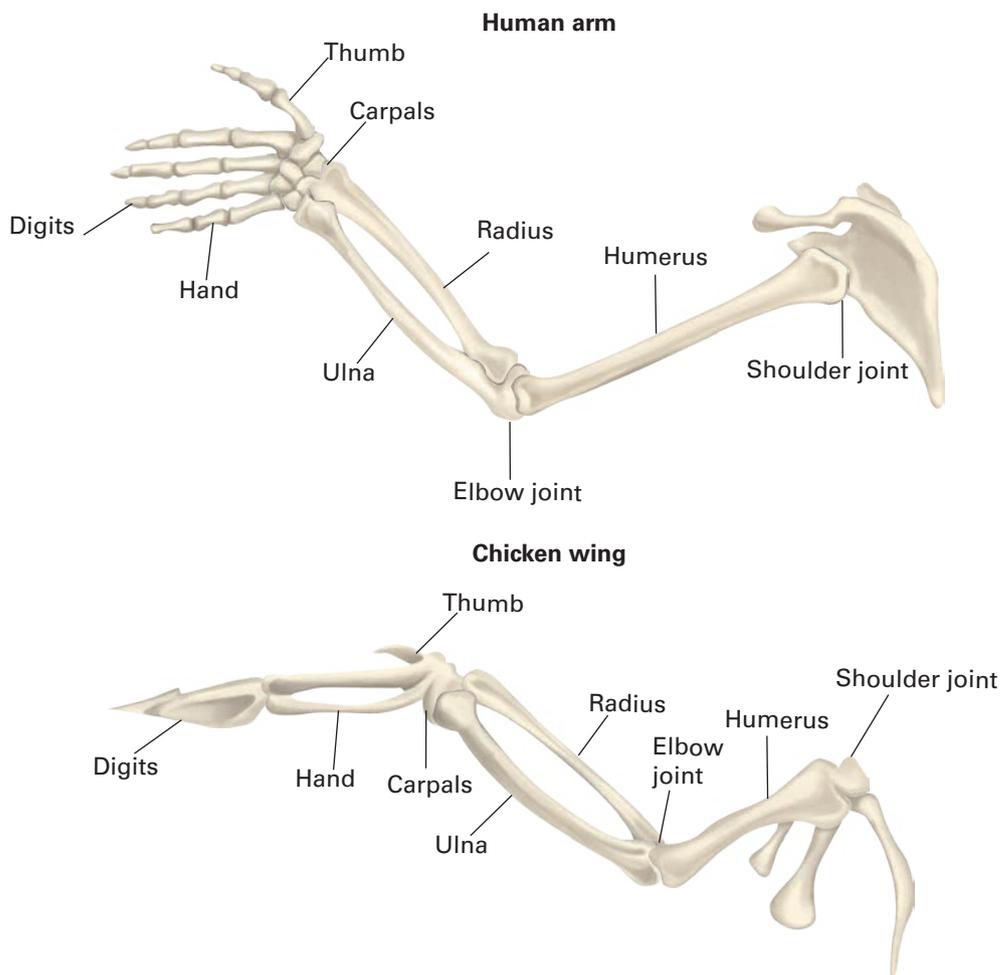


Figure 3.41 A human arm and a chicken wing

### Discussion

- 1 Compare the structure of a chicken wing with that of a human arm.
- 2 Define the term 'analogous structures' and explain what they can tell us about the evolution of a species.
- 3 Define the term 'homologous structures' and explain what they can tell us about the evolution of a species.
- 4 Would the chicken bones and human bones be considered homologous or analogous structures? Discuss.

## Evolutionary trees

**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 3.42.

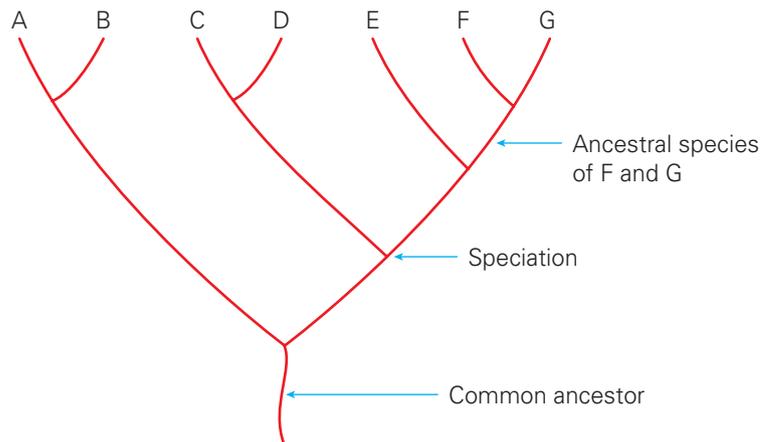


Figure 3.42 An example evolutionary tree

For example, humans, chimpanzees and gorillas all have thumbs that are very similar anatomically and are considered to be homologous (Figure 3.43). 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 are to giant pandas.

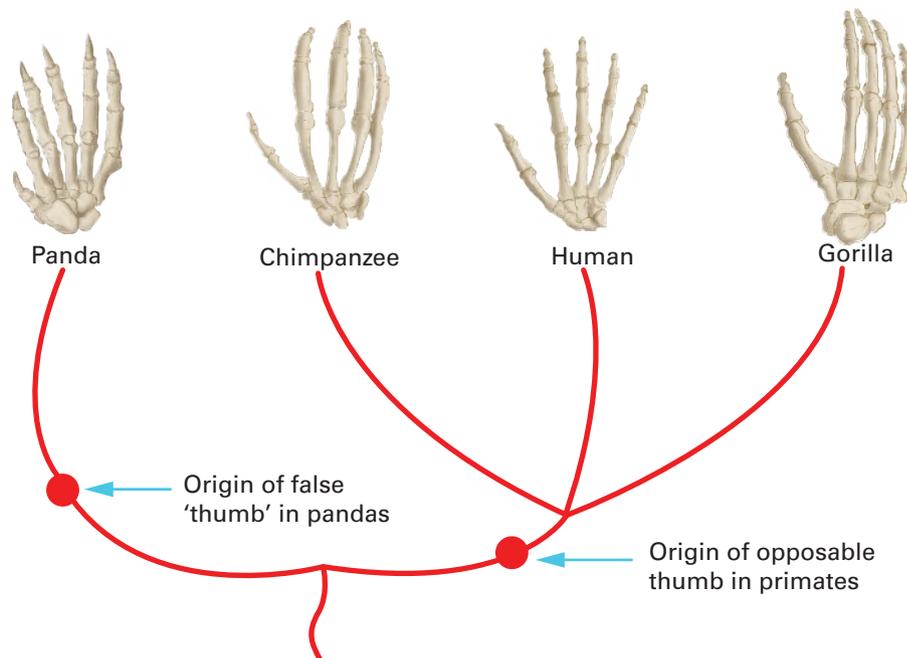


Figure 3.43 An evolutionary tree showing how their homologous opposable thumbs mean that humans, chimpanzees and gorillas have a recent common ancestor

## 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. 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.

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 Describe an evolutionary tree.
- 2 Explain how embryology provides evidence for evolution.

## Molecular biology

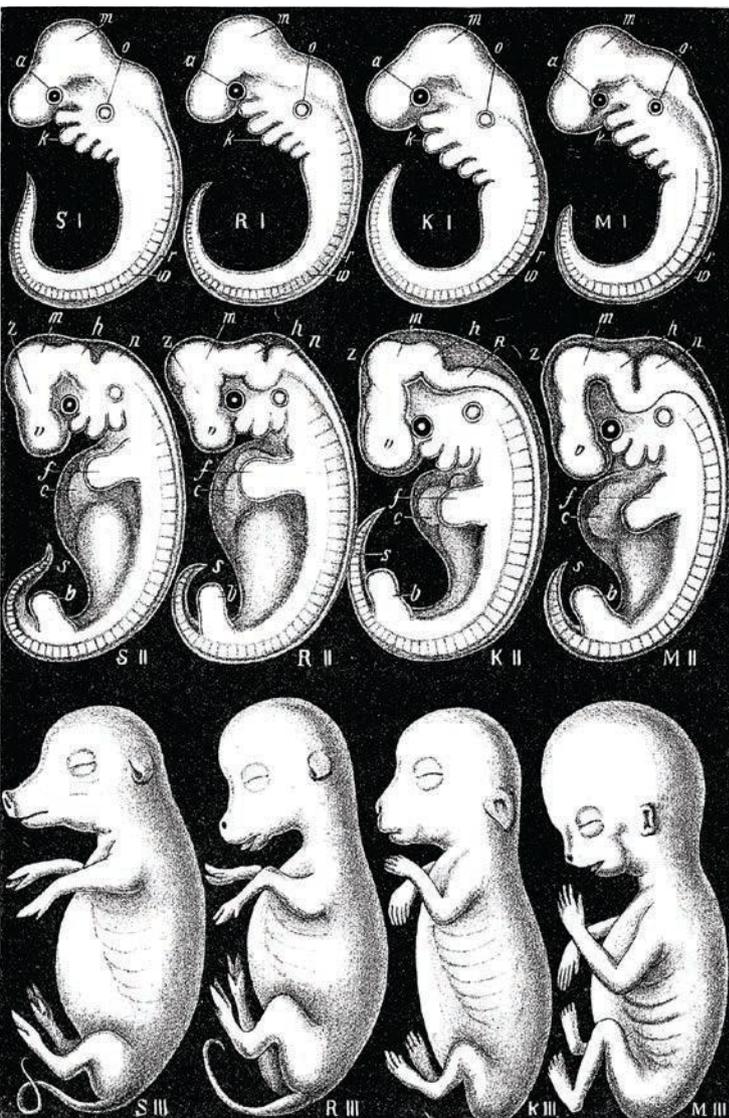
Substances that are found in most or all living things are very useful in the investigation of evolutionary relationships. For example, all living things contain DNA, so it is commonly used to compare organisms. This is what the study of molecular biology is all about – investigating DNA, its code and 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.

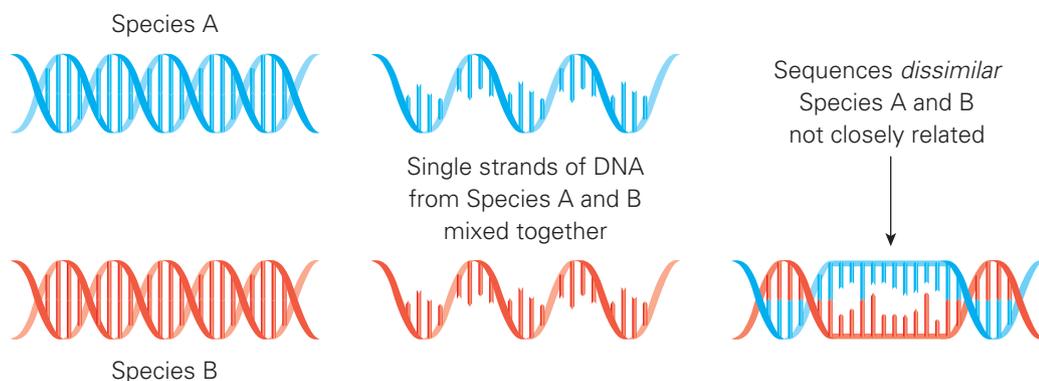
### DNA analysis

**DNA hybridisation** is a technique to compare the DNA sequences of two species to find out how closely they are related. First, as seen in Figure 3.45 on the next page, 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.

**DNA hybridisation**  
a technique that measures genetic similarity between two organisms



**Figure 3.44** Comparative embryology drawings of embryos at three stages from (left to right): a pig, cow, rabbit and human

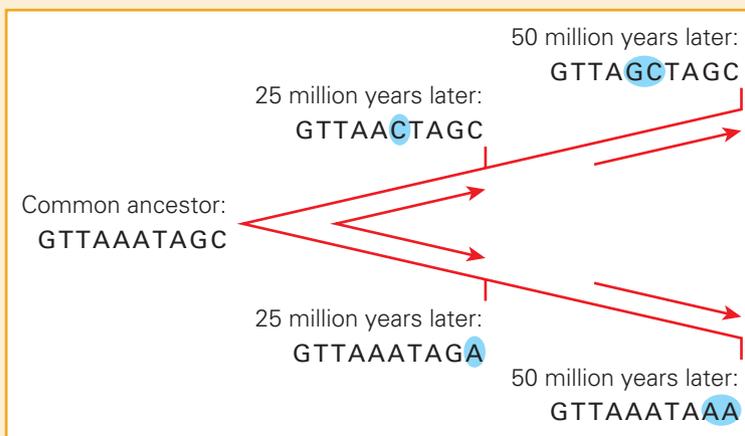


**Figure 3.45** The process of DNA hybridisation allows scientists to determine the relatedness of two organisms by comparing their DNA.

**Did you know? 3.7**

**Molecular clocks**

The molecular clock concept says that mutations accumulate in biomolecules at a roughly constant rate because they occur by chance. Due to this, we can use this mutation rate to deduce the time when life forms diverged. The biomolecular data that is normally used for calculations are DNA nucleotide sequences, including those found in mitochondrial DNA (mtDNA), the DNA found in the mitochondria.



**Figure 3.46** 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.

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

### Quick check 3.12

- 1 Describe DNA hybridisation and how it provides evidence for evolution.
- 2 Describe how the number of differences in the amino acid sequence for cytochrome c can be used to establish the relationship in evolutionary terms between organisms.

## Biogeography

**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.

**biogeography**  
the study of the geographical distribution of plants and animals



**Figure 3.47** (Left to right, top to bottom) While the emu and cassowary can be found in Australia, the rhea live in South America and the ostrich in sub-Saharan Africa.

## Quick check 3.13

- 1 Define the term 'biogeography'.
- 2 Explain how biogeography provides evidence for evolution.



VIDEO  
The changing  
evolution of  
humans

## 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 kingdom Animalia, phylum Chordata, class Mammalia, order Primates, family Hominidae, genus *Homo* and species *Homo sapiens*.

The primates living today gradually evolved over 65 million years from ancestral

primates that were small tree-dwelling mammals. Humans did not evolve from apes and monkeys, but 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.

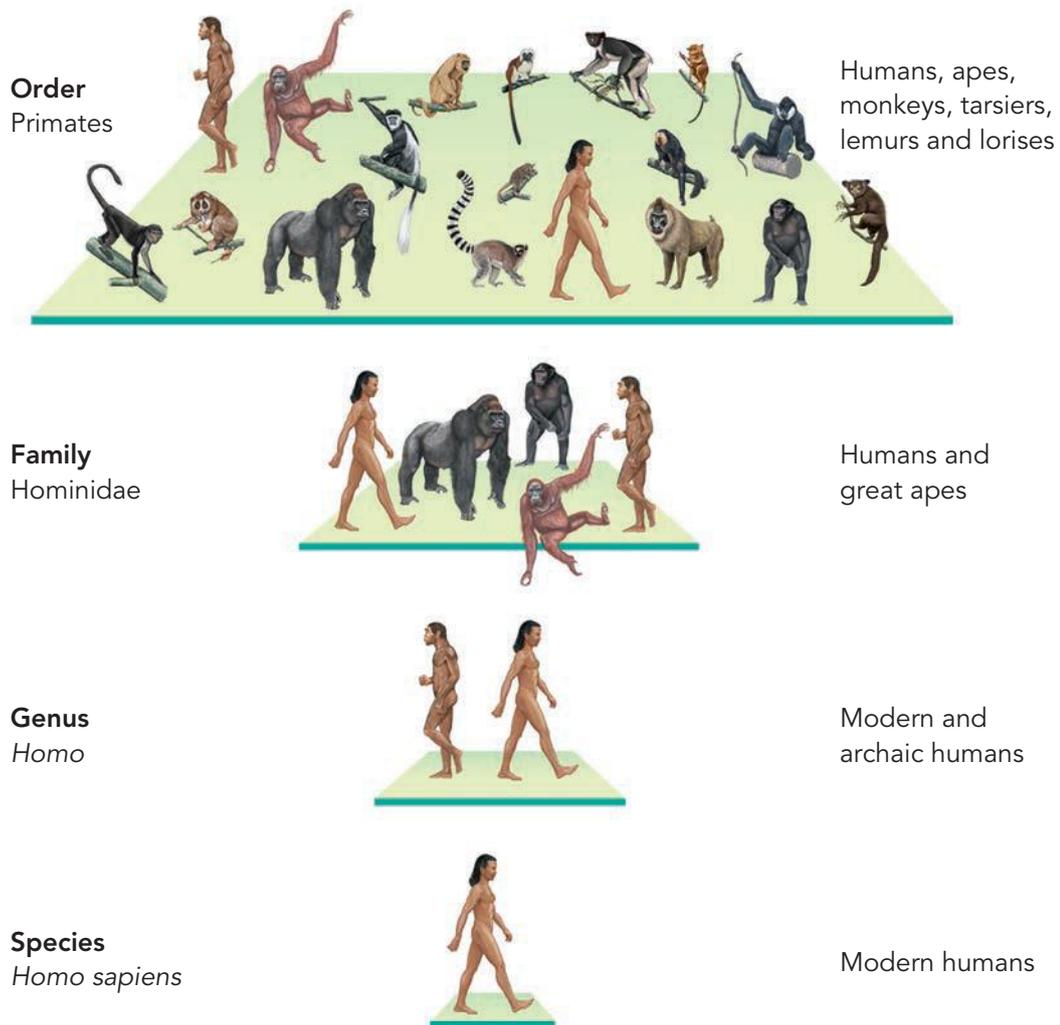
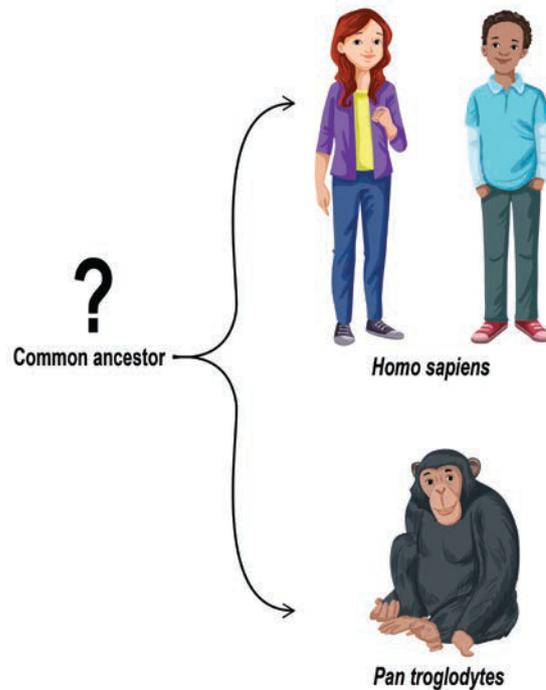


Figure 3.48 Classification of *Homo sapiens* within the order Primates

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 3.49** The biologist and anthropologist Thomas Henry Huxley (1825–1895) was the first to suggest that humans and other species were related.

### Explore! 3.5

#### Evidence for human evolution

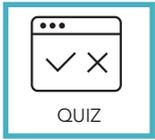
In this section you have learned all about the different ways that we can gather evidence about evolution: palaeontology, comparative anatomy, embryology, molecular biology and biogeography. However, we have not investigated how they informed us about human evolution.

- 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.



**Figure 3.50** An archaeological excavation uncovers human remains

## Section 3.3 questions

**Remembering**

- 1 **Name** five sources of evidence for evolution.
- 2 **Recall** what is meant by the term 'fossil'.
- 3 **Recall** what the term 'biogeography' refers to.

**Understanding**

- 4 **Describe** analogous structures, providing an example.
- 5 **Explain** how the scales of reptiles and the feathers of birds are considered homologous structures.
- 6 **Explain** how DNA hybridisation can show that two organisms share a common ancestor.

**Applying**

- 7 **Summarise** why fossils of soft-bodied organisms are relatively rare.
- 8 Figure 3.51 represents the layers of rock found within a cave. **Identify** the layer (1 to 5) where you would expect to find the oldest group of fossils, giving reasons for your answer.

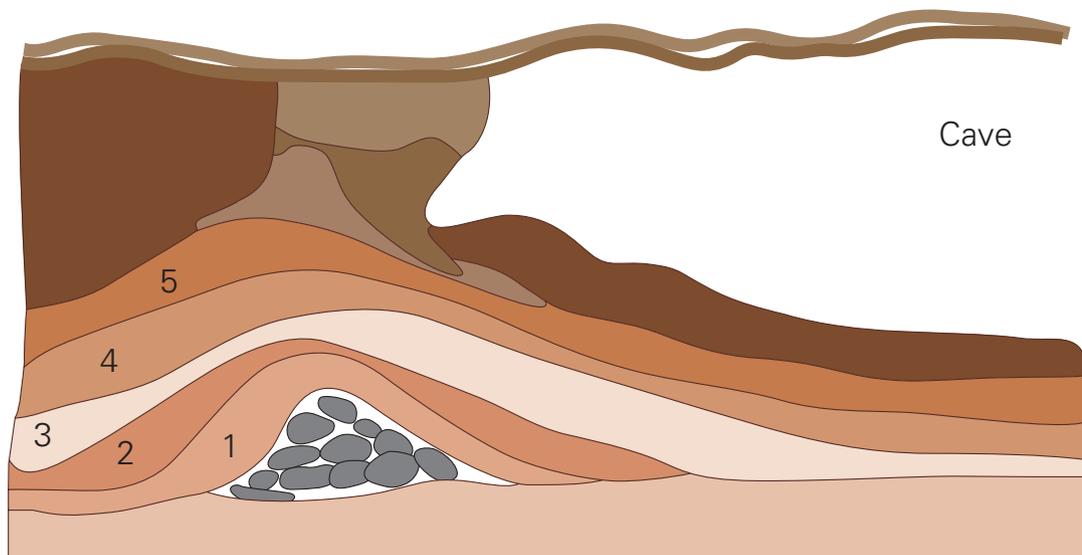


Figure 3.51 Layers of rock within a cave

- 9 **Distinguish** between absolute and relative dating techniques.

**Analysing**

- 10 Figure 3.52 on the following page shows a timeline for the evolution of some dinosaurs. The average mass of each dinosaur is shown in brackets under its name. **Identify** the appropriate dinosaur for each statement.
  - a The dinosaur that lived the longest time ago is the \_\_\_\_\_.
  - b The dinosaur(s) that evolved from *Agilisaurus* is/are the \_\_\_\_\_.
  - c The dinosaur from which *Camarasaurus* evolved is the \_\_\_\_\_.
  - d The dinosaur with the largest average mass is the \_\_\_\_\_.

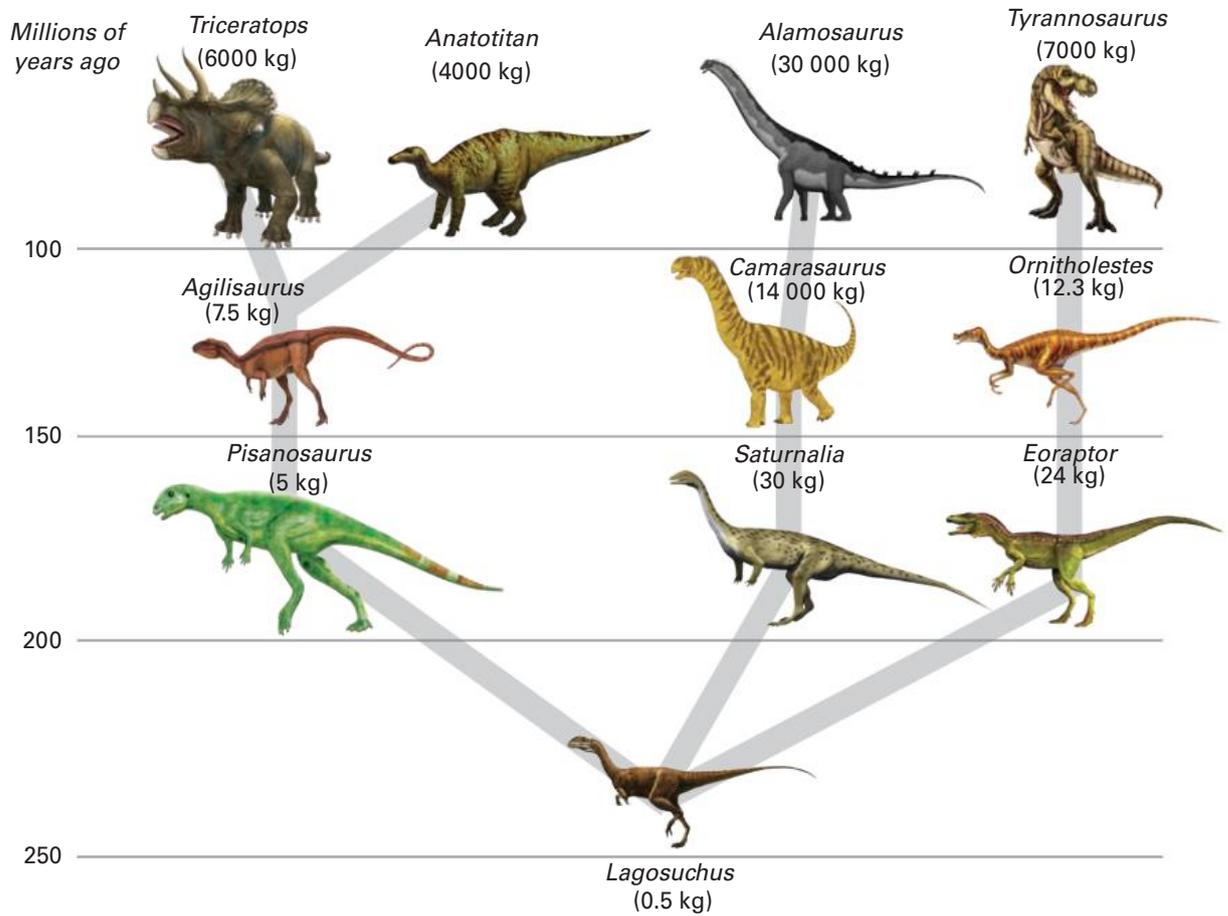


Figure 3.52 Timeline for the evolution of some dinosaurs

- 11 The chronogram in Figure 3.53 shows the evolutionary relationship between some freshwater fish.

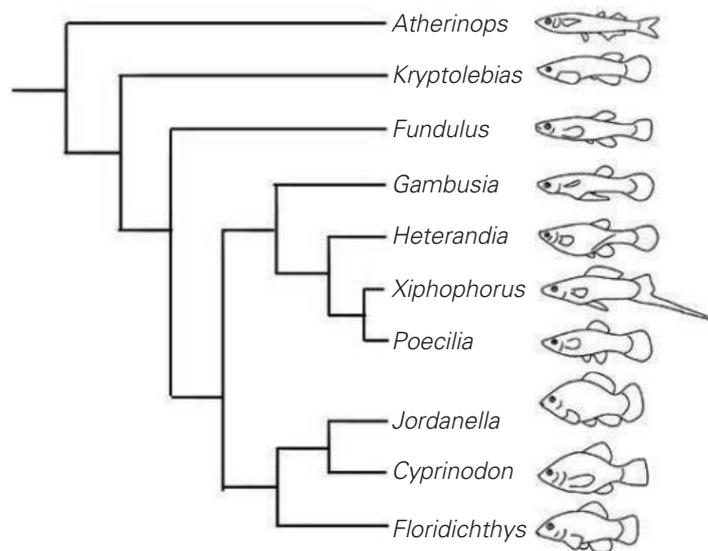


Figure 3.53 Chronogram showing evolutionary relationship between some freshwater fish

- a Infer which genera is most distantly related to *Poecilia*.  
 b Between the genera *Cyprinodon* and *Fundulus*, infer which is more closely related to *Poecilia*.

**Evaluating**

12 The table below shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees and a Neanderthal.

	Human 2	Chimpanzee 1	Chimpanzee 2	Neanderthal
Human 1	15	77	76	20
Human 2		79	80	27
Chimpanzee 1			23	72
Chimpanzee 2				71
Neanderthal				

- Based on the table, **deduce** which organism is most closely related to the Neanderthal.
- Based on the table, **deduce** which organism is the least closely related to the Neanderthal.
- Decide** which method could be used to estimate the absolute age of the Neanderthal fossil.
- Decide** which method could be used to estimate the relative age of the Neanderthal fossil.



Figure 3.54 A skull of *Homo neanderthalensis*

- 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.
- Create** a concept map that shows the links between the different ways we can gain evidence for evolution. Include information on how each method sheds light on evolution.

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
3.1 I can recall the definition of evolution.	1	
3.1 I can describe the five drivers of evolution (mutation, gene flow, genetic drift, natural selection, sexual reproduction).	1	
3.1 I can describe the concept and importance of biodiversity.	2	
3.1 I can describe some reasons for species becoming endangered or extinct and propose ways to minimise this problem.	12	
3.2 I can explain how speciation occurs.	6	
3.2 I can distinguish between artificial and natural selection.	11	
3.3 I can recall the main evidence for evolution.	5, 8	
3.3 I can explain how the nuclear decay of carbon-14 is used to date fossils.	7	

## Review questions

### Remembering

- 1 **Define** the terms 'evolution', 'gene flow', 'genetic drift' and 'natural selection'.
- 2 **Explain** the terms 'biodiversity', 'species diversity' and 'genetic diversity'.

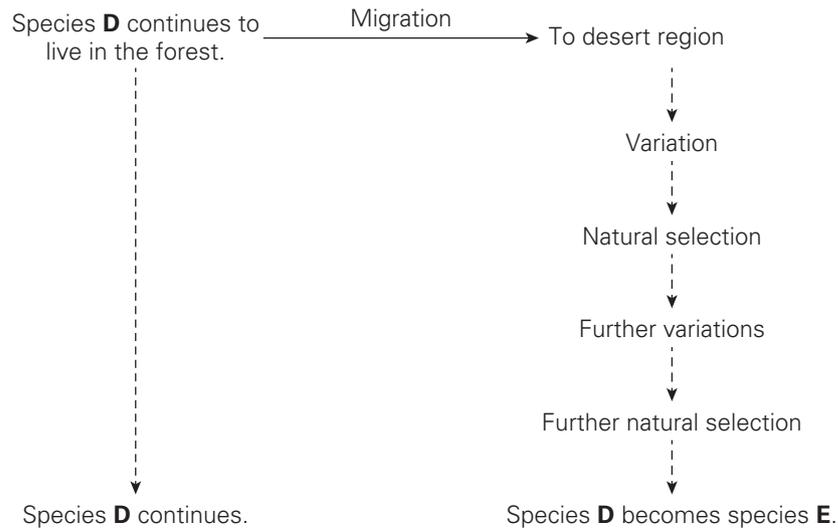
### Understanding

- 3 **Recall** the main causes of variation among organisms.
- 4 **Explain** why 'survival of the fittest' does not necessarily mean survival of the biggest and strongest.
- 5 **Explain** how amino acid sequences can provide evidence for evolution.



**Applying**

- 6 The following diagram represents the process known as speciation.

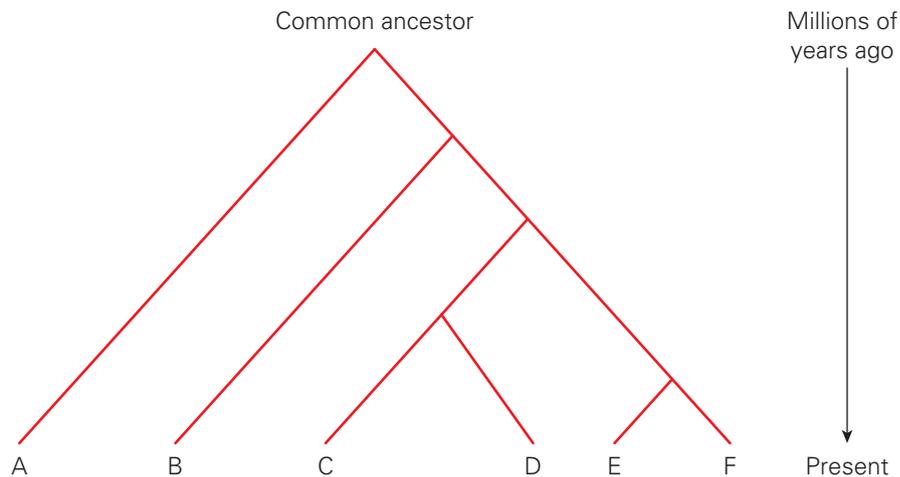


**Explain**, using the information from the diagram, the key forces behind the creation of the new species E in the desert.

- 7 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. **Recall** how the quantity of carbon-14 in a fossil can be used to accurately date a fossil.
- 8 **Explain** how mutations contribute to the process of evolution.

**Analysing**

- 9 The following figure shows the evolutionary tree for six organisms from a common ancestor.



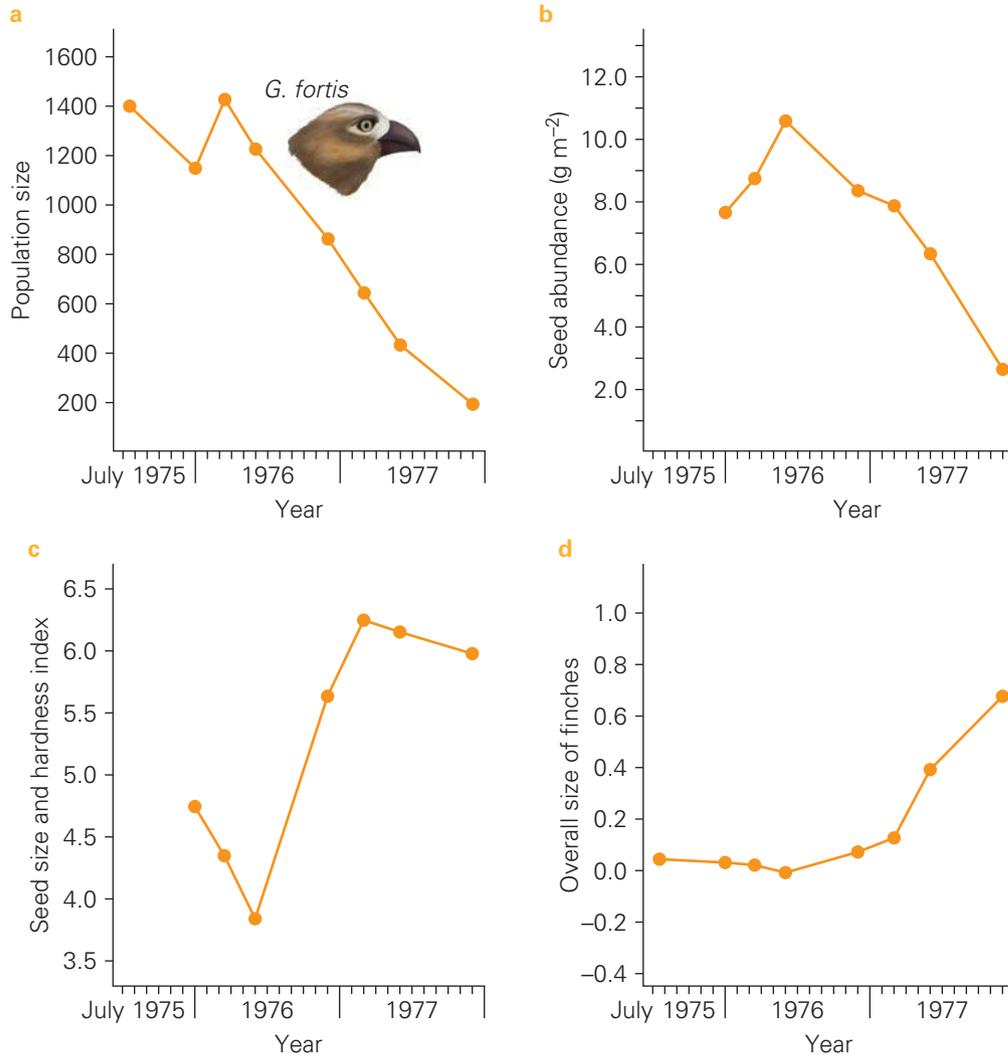
- a According to the diagram, **identify** the present-day organism that is least closely related to the others. Justify your response.
- b **Infer** which two organisms have the most recent common ancestor and justify your response.

### Evaluating

- 10 Using diagrams or symbols, **discuss** how rabbits may have become resistant to the deadly virus *Myxomatosis*, which was released in Australia to try to control the rabbit plagues.
- 11 Use an example to **demonstrate** the advantages and disadvantages of artificial selection.
- 12 **Discuss** how humans might have affected the biodiversity in Western Australia.

### Data questions

*Geospiza fortis* is a ground finch that feeds on seeds on Daphne Major, one of the Galapagos Islands. From 1975 to 1977, the island experienced a severe drought. The graphs below show the population size of *G. fortis* and the island's seed abundance during these years.



- 1 **Calculate** the percentage decrease in population size between July 1975 and December 1977.
- 2 **Identify** any relationships you can find in the graphs.
- 3 **Infer** why the size of the finches increased as the drought continued.

## STEM activity: Designing a wheelchair to aid dogs with genetic problems

### 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, if the individuals within a species are too similar genetically, this 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 19th and 20th centuries because of arranged marriages among the related royal families.

Humans have bred dogs for thousands of years, originally to serve a specific purpose or job like herding and hunting. All modern dog breeds exist as a result of human selective breeding. Unfortunately, many purebred 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



**Figure 3.55** Dachshunds are prone to numerous genetic diseases because of their typical long bodies and tiny legs.

have hip dysplasia and spinal problems because of their long bodies, and eye problems like cataracts.

While dog owners can take preventive measures to reduce the effects of these disorders, often reactive treatment is the method used to give affected dogs a good quality of life. Wheelchairs are a potential solution to help with mobility for dachshunds that have hip and knee problems.

**Design brief:** Design a wheelchair to aid dachshunds with genetic knee and hip problems.

### 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
- icy-pole craft sticks
- elastic bands
- straws
- sticky tape

### Research and feasibility

- 1 Research and list all the features that make a wheelchair comfortable and functional.

Feature	Functionality
e.g. padded seat	Comfortable to use for long amounts of time

- 2 Research current dog wheelchairs available and how they are used for dogs with hip and knee problems. List all the problems that exist with the current model and solutions that could be included.
- 3 Research the dog breed, dachshunds, and make note of the size of the dog breed and the common hip and knee problems that exist.

### Design and sustainability

- 4 Design a prototype of a wheelchair specifically for a dachshund. Annotate your diagram and include all design features and the functionality it provides.
- 5 Reflect on the sustainability of the materials used, and the life cycle of the wheelchair prototype in regard to its durability.

### Create

- 6 Construct the prototype using available materials.

### Evaluate and modify

- 7 Describe any difficulties you came across when constructing your model. Explain how you overcame these difficulties.
- 8 Propose some improvements to the design of your wheelchair to improve comfort and functionality.
- 9 Depending on the size of your model, you may be able to test it by using your wrist or palm as the back of the dog and your index and middle fingers as the front legs to pull it along. Test it with different amounts of downward pressure to represent different dog sizes and weights. Comment on how your wheelchair fared in your tests.



**Figure 3.56** Dachshunds are not the only dog breed that may need the aid of a wheelchair.

# Chapter 4

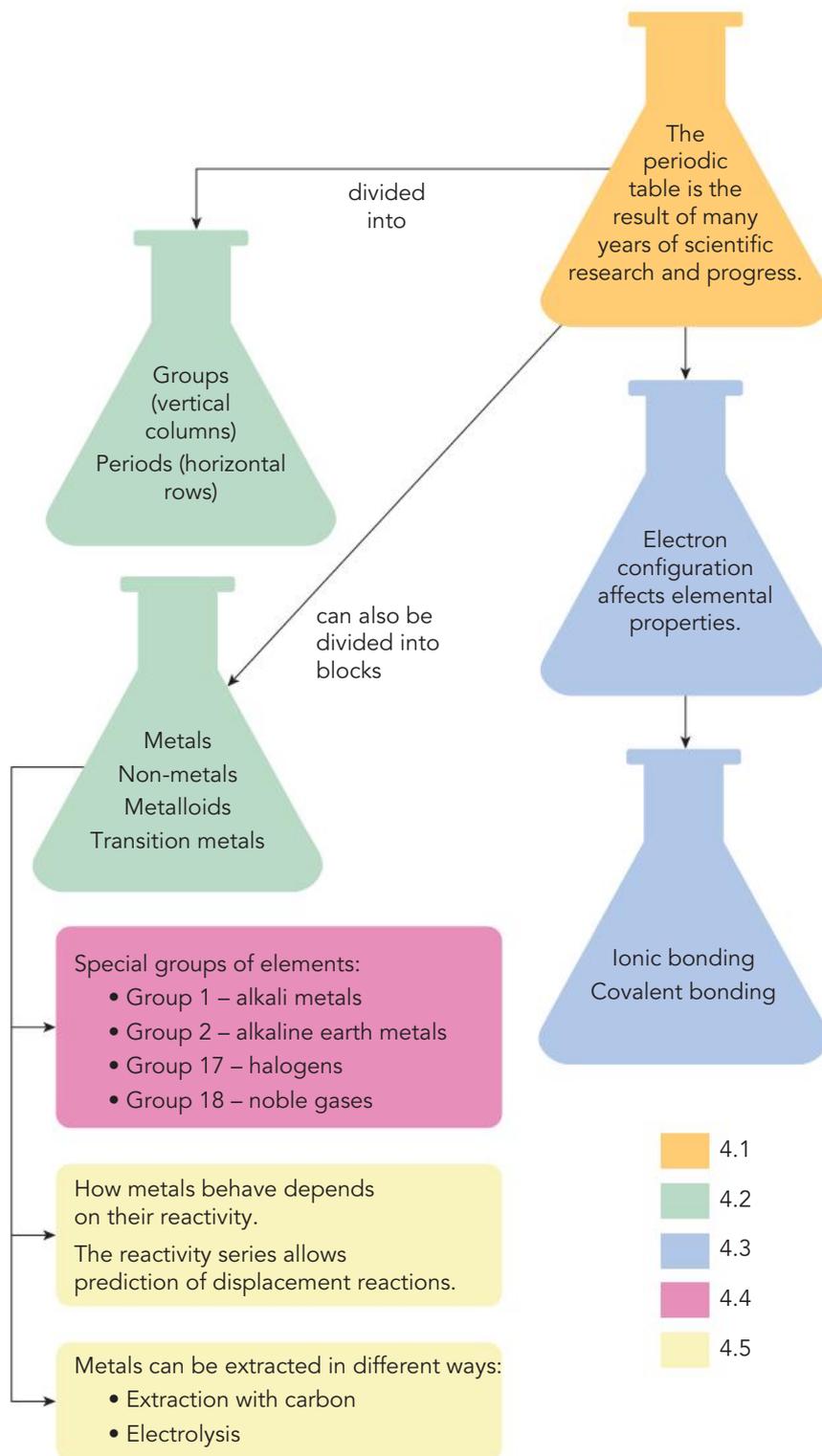
## The periodic table



### 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 available from that arrangement and the properties of particular groups of elements in the periodic table. You will learn about Dmitri Mendeleev, who established the foundation for the modern-day periodic table.

# Chapter map





# 4.1 Development of the periodic table



## Learning goals

- 1 To be able to recall the scientists in the timeline of the periodic table.
- 2 To be able to describe the structure and property trends in Mendeleev's periodic table.

### element

a substance made up of only one type of atom

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.

## 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.

ELEMENTS	
Hydrogen	Stintian
Azote	Barytes
Carbon	Iron
Oxygen	Zinc
Phosphorus	Copper
Sulphur	Lead
Magnesia	Silver
Lime	Gold
Soda	Platina
Potash	Mercury

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 that 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

$$((39 + 7) \div 2 = 23)$$

Salt formers	
Cl	35.5
Br	80
I	127

$$((127 + 35.5) \div 2 = 81)$$

Figure 4.2 Two Döbereiner triads

1863

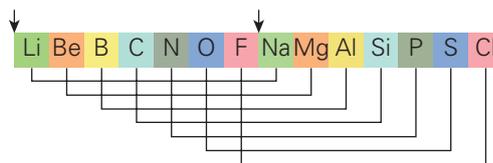
**Alexandre-Émile Béguyer de Chancourtois**

- 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

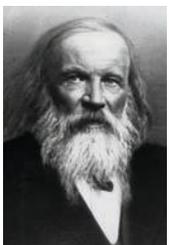
**John Newlands**

- 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 a 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 <sup>0</sup>	Gruppe II. R <sup>0</sup>	Gruppe III. R <sup>0'</sup>	Gruppe IV. R <sup>H</sup> R <sup>0'</sup>	Gruppe V. R <sup>H</sup> R <sup>0'</sup>	Gruppe VI. R <sup>H</sup> R <sup>0'</sup>	Gruppe VII. R <sup>H</sup> R <sup>0'</sup>	Gruppe VIII. R <sup>0'</sup>
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

## Quick check 4.1

- 1 Work out the atomic mass of element Y using Döbereiner's method if X, Y and Z form a triad.

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 4.5 that he drew lines to show where he thought a discovery would be made. This was important, but what makes many people consider him as the father of modern chemistry was that he predicted the properties of these unknown elements years before they were even discovered.

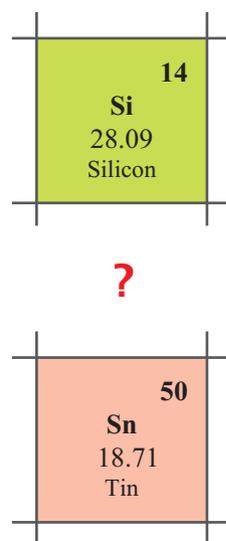


Figure 4.5 Mendeleev predicted that there would be an element between silicon and tin.

To explain how Mendeleev made his predictions, we will look at an example: he left a gap between silicon (Si) and tin (Sn). 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 ( $\text{g cm}^{-3}$ )	Density of its chloride ( $\text{g cm}^{-3}$ )	Boiling point of its chloride ( $^{\circ}\text{C}$ )
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 ( $\text{g cm}^{-3}$ )	Density of its chloride ( $\text{g cm}^{-3}$ )	Boiling point of its chloride ( $^{\circ}\text{C}$ )
Germanium	73	5.3	1.88	86

Table 4.2 The chemical properties of germanium

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 The discovery of what element supported Mendeleev's predictions?

### Explore! 4.1

#### Breaking his own rule

We have already discussed that Mendeleev arranged the elements in order of their atomic mass, and that elements with similar properties were placed in the same groups. However, this did not work in all cases. For example, the elements tellurium (Te) and iodine (I), when arranged in order of mass, are in group 17 and group 16 respectively.

- 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 for 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?



Figure 4.7 Pure iodine exists in both solid and gaseous forms. Shown here is a solution of povidone-iodine and other components in purified water, commonly used as a disinfectant.

53	52
<b>I</b>	<b>Te</b>
126.90	127.60
Iodine	Tellurium

Figure 4.8 Iodine and tellurium when arranged by atomic mass

**Practical 4.1: Investigation****Predicting properties of elements****Aim**

To investigate the relationship between the position of an element in the periodic table and its density.

**Useful formulas**

$$\text{Density (g cm}^{-3}\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

$$\text{Percentage difference} = \frac{(\text{actual value} - \text{predicted value})}{\text{actual value}} \times 100$$

**Materials**

- sample elements
  - carbon rod
  - silicon
  - tin
- 50 mL measuring cylinder
- graph paper
- balance
- ruler
- weigh boats (small container to hold sample elements)

**Method****Part 1: Prepare the results table**

- 1 Draw the table shown in the results section into your science journal.
- 2 Identify and label the independent variable and its independent variable groups in the table in terms of the position of each element on the periodic table. You will need to refer to the periodic table (or an online version like ptable.com).
- 3 Identify and label the dependent variable in the table. (Hint: which property are you investigating?)

**Part 2: Measure the mass of each sample element**

- 1 Place a weigh boat onto the balance and zero the balance by pressing 'tare'.
- 2 Place the first sample element on the empty weigh boat and record the mass in the table.
- 3 Remove the sample element.
- 4 Repeat steps 1–3 with the other sample elements.

**Part 3: Measure the volume of each sample element**

- 1 Half fill a 50 mL measuring cylinder with water and record the initial volume in cm<sup>3</sup> (1 mL = 1 cm<sup>3</sup>).
- 2 Gently place the first sample element into the measuring cylinder and record the new volume in the table.
- 3 Remove the sample element by tipping the water out of the measuring cylinder.
- 4 Repeat steps 1–3 with the other sample elements.

**Results****Calculate and graph the densities**

- 1 Calculate the volume of each sample element in cm<sup>3</sup> and record it in the results table.
- 2 Calculate the density of each sample element using the formula above and record it in the results table.
- 3 Draw a scatterplot to analyse the relationship between the period number of each metal and its density.

*continued...*

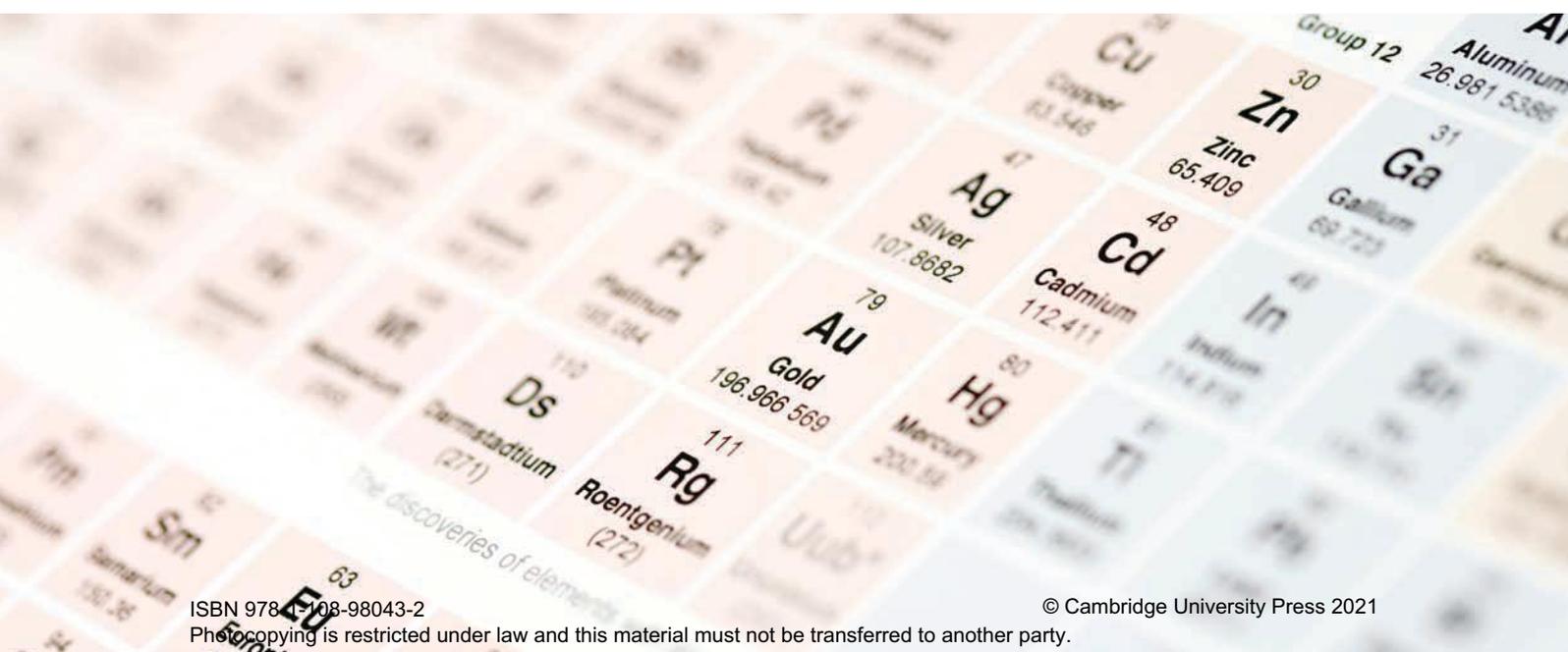
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- 4 Add a line of best fit to the graph, if possible. Note the type of line that fits best to reflect the relationship between the two variables.

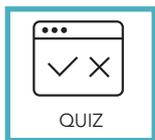
Independent variable		Dependent variable						
Element sample	Position in periodic table (group, period)	Mass (g)	Initial volume in measuring cylinder (cm <sup>3</sup> )	Final volume in measuring cylinder (cm <sup>3</sup> )	Volume of element (cm <sup>3</sup> )	Calculated density (g cm <sup>-3</sup> )	Actual density (g cm <sup>-3</sup> ) (secondary data source)	Percentage difference (%)
Carbon								
Silicon								
Tin								

### Discussion

- Describe the trend or pattern that is found when the line of best fit was applied to the graph. What type of relationship was found?
- Predict the density of germanium (row 4 in the periodic table) and lead (row 6) using your graph. Record your results in your science journal.
- Compare the actual densities for each element with its calculated densities.
- Compare the actual densities for carbon, silicon and tin to the densities calculated mathematically by calculating the percentage difference using the formula above.
- Was the calculated density data reliable enough to base predictions on? Justify your response with data.
- Research online to find the actual densities of germanium and lead (the 'Properties' tab at ptable.com is a good resource to use). Record the actual densities for each in your science journal.
- Compare the actual densities for germanium and lead to the densities predicted mathematically by calculating the percentage difference using the formula above.
- Can reliable conclusions and predictions be drawn from the results? Justify your response with data.
- Can you identify possible limitations of this method? Justify your answer using data if possible.
- Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.



## Section 4.1 questions



## Remembering

- 1 **Recall** the names of three scientists who attempted to organise elements.
- 2 **Recall** who created the first version of the modern periodic table.
- 3 **Recall** the method that most scientists used to arrange chemical elements.

## Understanding

- 4 **State** the modern-day arrangement of elements for which Döbereiner's triads were the forerunner.
- 5 **State** which group of elements is missing from Mendeleev's periodic table.
- 6 Using Döbereiner's law of triads, **calculate** the mass of the element B.

Element	Mass
A	12
B	
C	34

## Applying

- 7 **Explain** why de Chancourtois's arrangement was superior to Döbereiner's.
- 8 **Summarise** how Mendeleev made his predictions surrounding the properties of elements that had yet to be discovered.

## Analysing

- 9 **Compare** Newlands's and Mendeleev's arrangements.
- 10 **Critique** the earlier arrangements of the chemical elements.

## Evaluating

- 11 **Propose** the reasons why Mendeleev's periodic table was accepted.
- 12 **Discuss** the reasons why there were multiple ways proposed throughout history to arrange chemical elements.
- 13 **Determine** the properties of the middle element in the tables below using Döbereiner's law of triads.

a

	Lithium	Sodium	Potassium
Atomic mass	7		39
Melting point (°C)	180		63

b

	Silicon	Germanium	Tin
Atomic mass	28		119
Melting point (°C)	1414		232

c

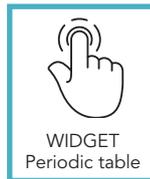
	Chlorine	Bromine	Iodine
Atomic mass	35.5		127
Melting point (°C)	-101		114

- 14 **Determine** why the modern periodic table has remained relatively unchanged since it was reordered by atomic number instead of atomic mass.

# 4.2 Structure of the periodic table

## Learning goals

- 1 To be able to distinguish the groups and periods in the periodic table.
- 2 To be able to differentiate between metals, non-metals and metalloids by their position on the periodic table.
- 3 To describe the position of transition metals, lanthanoids and actinoids on the periodic table.



The modern periodic table is a list of all the known elements in order of their atomic number. The atomic number of an element is equal to the number of protons in the nucleus of an atom of that element. 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.



Figure 4.9 Oganesson is currently the last element on the periodic table, with an atomic number of 118.

## Explore! 4.2

### Naming the elements

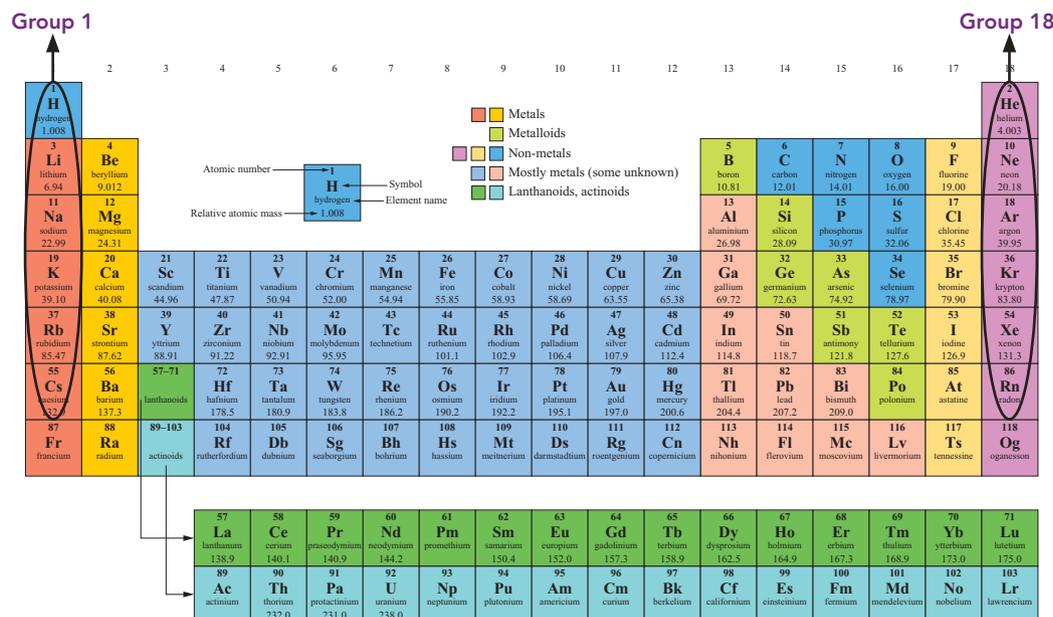
Many elements on the periodic table have symbols that do not match their name. There are also elements named after scientists. For the following elements, research why they have that name or symbol:

- Sodium (Na)
- Iron (Fe)
- Lead (Pb)
- Mendeleevium (Md)
- Curium (Cm)

group  
a vertical column in the periodic table

## Groups of the periodic table

The periodic table is arranged into vertical columns called **groups**. There are 18 groups.



3 <b>Li</b> lithium 6.94
11 <b>Na</b> sodium 22.99
19 <b>K</b> potassium 39.10
37 <b>Rb</b> rubidium 85.47
55 <b>Cs</b> caesium 132.9
87 <b>Fr</b> francium

**Figure 4.11**  
The group 1 metals all have similar properties so behave in similar ways.

Elements in the same group all have similar, observable 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 this chapter, you will be able to explain how and why these elements are grouped together.

### Quick check 4.3

- Decide whether the following statements are true or false. If false, give a reason why.
  - Groups are the vertical rows in the periodic table.
  - Oxygen (O) is in group 5.
  - As strontium (Sr) is in the same group as silicon (Si), it will have similar properties.
- 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 (X) was reacted with oxygen. The product was a metal oxide with the formula XO. In which group would you place the unknown element? Explain why.

## Periods of the periodic table

If groups are the vertical columns, then **periods** are the horizontal rows. There are seven periods.

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**.

**period**  
a the horizontal row in the periodic table

**electron**  
the smallest subatomic particle in an atom arranged around the nucleus in shells

1 <b>H</b> hydrogen 1.008																		2 <b>He</b> helium 4.003
3 <b>Li</b> lithium 6.94	4 <b>Be</b> beryllium 9.012											5 <b>B</b> boron 10.81	6 <b>C</b> carbon 12.01	7 <b>N</b> nitrogen 14.01	8 <b>O</b> oxygen 16.00	9 <b>F</b> fluorine 19.00	10 <b>Ne</b> neon 20.18	
11 <b>Na</b> sodium 22.99	12 <b>Mg</b> magnesium 24.31											13 <b>Al</b> aluminium 26.98	14 <b>Si</b> silicon 28.09	15 <b>P</b> phosphorus 30.97	16 <b>S</b> sulfur 32.06	17 <b>Cl</b> chlorine 35.45	18 <b>Ar</b> argon 39.95	
19 <b>K</b> potassium 39.10	20 <b>Ca</b> calcium 40.08	21 <b>Sc</b> scandium 44.96	22 <b>Ti</b> titanium 47.87	23 <b>V</b> vanadium 50.94	24 <b>Cr</b> chromium 52.00	25 <b>Mn</b> manganese 54.94	26 <b>Fe</b> iron 55.85	27 <b>Co</b> cobalt 58.93	28 <b>Ni</b> nickel 58.69	29 <b>Cu</b> copper 63.55	30 <b>Zn</b> zinc 65.38	31 <b>Ga</b> gallium 69.72	32 <b>Ge</b> germanium 72.63	33 <b>As</b> arsenic 74.92	34 <b>Se</b> selenium 78.97	35 <b>Br</b> bromine 79.90	36 <b>Kr</b> krypton 83.80	
37 <b>Rb</b> rubidium 85.47	38 <b>Sr</b> strontium 87.62	39 <b>Y</b> yttrium 88.91	40 <b>Zr</b> zirconium 91.22	41 <b>Nb</b> niobium 92.91	42 <b>Mo</b> molybdenum 95.95	43 <b>Tc</b> technetium	44 <b>Ru</b> ruthenium 101.1	45 <b>Rh</b> rhodium 102.9	46 <b>Pd</b> palladium 106.4	47 <b>Ag</b> silver 107.9	48 <b>Cd</b> cadmium 112.4	49 <b>In</b> indium 114.8	50 <b>Sn</b> tin 118.7	51 <b>Sb</b> antimony 121.8	52 <b>Te</b> tellurium 127.6	53 <b>I</b> iodine 126.9	54 <b>Xe</b> xenon 131.3	
55 <b>Cs</b> caesium 132.9	56 <b>Ba</b> barium 137.3	57–71 lanthanoids	72 <b>Hf</b> hafnium 178.5	73 <b>Ta</b> tantalum 180.9	74 <b>W</b> tungsten 183.8	75 <b>Re</b> rhenium 186.2	76 <b>Os</b> osmium 190.2	77 <b>Ir</b> iridium 192.2	78 <b>Pt</b> platinum 195.1	79 <b>Au</b> gold 197.0	80 <b>Hg</b> mercury 200.6	81 <b>Tl</b> thallium 204.4	82 <b>Pb</b> lead 207.2	83 <b>Bi</b> bismuth 209.0	84 <b>Po</b> polonium	85 <b>At</b> astatine	86 <b>Rn</b> radon	
87 <b>Fr</b> francium	88 <b>Ra</b> radium	89–103 actinoids	104 <b>Rf</b> rutherfordium	105 <b>Db</b> dubnium	106 <b>Sg</b> seaborgium	107 <b>Bh</b> bohrium	108 <b>Hs</b> hassium	109 <b>Mt</b> meitnerium	110 <b>Ds</b> darmstadtium	111 <b>Rg</b> roentgenium	112 <b>Cn</b> copernicium	113 <b>Nh</b> nihonium	114 <b>Fl</b> flerovium	115 <b>Mc</b> moscovium	116 <b>Lv</b> livermorium	117 <b>Ts</b> tennessine	118 <b>Og</b> oganesson	
			57 <b>La</b> lanthanum 138.9	58 <b>Ce</b> cerium 140.1	59 <b>Pr</b> praseodymium 140.9	60 <b>Nd</b> neodymium 144.2	61 <b>Pm</b> promethium	62 <b>Sm</b> samarium 150.4	63 <b>Eu</b> europium 152.0	64 <b>Gd</b> gadolinium 157.3	65 <b>Tb</b> terbium 158.9	66 <b>Dy</b> dysprosium 162.5	67 <b>Ho</b> holmium 164.9	68 <b>Er</b> erbium 167.3	69 <b>Tm</b> thulium 168.9	70 <b>Yb</b> ytterbium 173.0	71 <b>Lu</b> lutetium 175.0	
			89 <b>Ac</b> actinium	90 <b>Th</b> thorium 232.0	91 <b>Pa</b> protactinium 231.0	92 <b>U</b> uranium 238.0	93 <b>Np</b> neptunium	94 <b>Pu</b> plutonium	95 <b>Am</b> americium	96 <b>Cm</b> curium	97 <b>Bk</b> berkelium	98 <b>Cf</b> californium	99 <b>Es</b> einsteinium	100 <b>Fm</b> fermium	101 <b>Md</b> mendelevium	102 <b>No</b> nobelium	103 <b>Lr</b> lawrencium	

**Figure 4.12** Periods are the horizontal rows in the periodic table.

This arrangement into groups and periods means elements have specific positions on the periodic table. For example, carbon (C) is 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

- Decide whether the following statements are true or false. If false, give a reason why.
  - Periods are the horizontal rows in the periodic table.
  - Lithium is in period 1.
- State the position (group and period) of the following elements in the periodic table.
  - Copper (Cu)
  - Calcium (Ca)
  - Neon (Ne)
  - Aluminium (Al)

## Blocks of the periodic table

The periodic table can be further split up into different blocks.

Metals    Metalloids    Non-metals

‘Step ladder’ separating the metals from the metalloids and non-metals

1 H 1.01 Hydrogen																	2 He 4.00 Helium				
3 Li 6.94 Lithium	4 Be 9.01 Beryllium															5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium															13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.06 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.63 Germanium	33 As 74.92 Arsenic	34 Se 78.97 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton				
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.95 Molybdenum	43 Tc (98.91) Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.29 Xenon				
55 Cs 132.91 Caesium	56 Ba 137.33 Barium	57–71 Lanthanoids	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Tl 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po (210.0) Polonium	85 At (210.0) Astatine	86 Rn (222.0) Radon				
87 Fr (223.0) Francium	88 Ra (226.1) Radium	89–103 Actinoids	104 Rf (261.1) Rutherfordium	105 Db (262.1) Dubnium	106 Sg (263.1) Seaborgium	107 Bh (264.1) Bohrium	108 Hs (265.1) Hassium	109 Mt (268) Meitnerium	110 Ds (281) Darmstadtium	111 Rg (272) Roentgenium	112 Cn (285) Copernicium	113 Nh (284) Nihonium	114 Fl (289) Flerovium	115 Mc (288) Moscovium	116 Lv (293) Livermorium	117 Ts (294) Tennessine	118 Og (294) Oganesson				
		*Lanthanoids	57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (146.9) Promethium	62 Sm 150.36 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.93 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thulium	70 Yb 173.05 Ytterbium	71 Lu 174.97 Lutetium				
		**Actinoids	89 Ac (227.0) Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np (237.0) Neptunium	94 Pu (239.1) Plutonium	95 Am (241.1) Americium	96 Cm (244.1) Curium	97 Bk (249.1) Berkelium	98 Cf (252.1) Californium	99 Es (252.1) Einsteinium	100 Fm (257.1) Fermium	101 Md (288.1) Mendelevium	102 No (289.1) Nobelium	103 Lr (262.1) Lawrencium				

Figure 4.13 Three colours show the elements classified as metals, non-metals and metalloids.



VIDEO  
Name a  
reactive group  
of metals

## Metals, non-metals and metalloids

The elements can be classified as metals, non-metals or metalloids (which have some properties of both metals and non-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 generally:

- are shiny
- have high melting and boiling points
- are malleable, meaning they can be beaten into shapes



**Figure 4.14** Tiny droplets of liquid mercury, the only liquid metal at room temperature.

- are ductile, meaning they can be drawn out into long, thin wires
- are good conductors of heat and electricity.

### 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.

## Science as a human endeavour 4.1

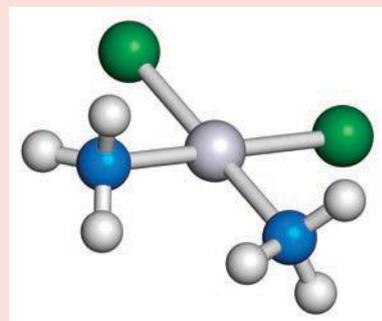
### Killer asteroid killing cancer?

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. 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.

Iridium is the world's second densest metal. It is rarely found on Earth, but has been brought to us from space via asteroids, including the giant asteroid whose impact is thought to have led to the extinction of the dinosaurs.

### Destroying cancer cells using iridium

Iridium can be used to kill cancer cells by filling them with a deadly 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 kill cells. This can be used to treat cancer without harming healthy cells. The process works by giving patients a drug that contains iridium. Trials on a model tumour found that the iridium drug had infused into every layer of the tumour. A visible laser is shone through 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.



**Figure 4.15** Platinum is used in the anti-cancer drug cisplatin,  $Pt(NH_3)_2Cl_2$ .



**Figure 4.16** Dopamine is a chemical transmitter in the nervous system.

*continued...*

...continued

### 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 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. Therefore, these probes have the potential to be used as a diagnostic tool for early screening of some cancers.

### Lanthanoids and actinoids

The lanthanoids and actinoids 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.

Lanthanoids are all silvery white metals. They include elements with atomic numbers from 57 to 71.

The actinoids contain elements with atomic numbers from 89 to 103 and are primarily synthetic elements with a few exceptions, such as uranium. Uranium is a naturally radioactive metal that is best known for its use in nuclear power plants and nuclear weapons.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen 1.008																	2 He helium 4.003
3 Li lithium 6.94	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31											13 Al aluminium 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.06	17 Cl chlorine 35.45	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.87	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.38	31 Ga gallium 69.72	32 Ge germanium 72.63	33 As arsenic 74.92	34 Se selenium 78.97	35 Br bromine 79.90	36 Kr krypton 83.80
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.95	43 Tc technetium	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57-71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson
			57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0	71 Lu lutetium 175.0
			89 Ac actinium	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

Figure 4.17 Location of the transition metals, lanthanoids and actinoids

### Quick check 4.5

- 1 Identify what the block of elements in the middle of the periodic table, containing groups 3 to 12 is called.
- 2 Identify which of the following is a transition metal.  
sodium (Na), tungsten (W), europium (Eu), aluminium (Al)
- 3 State if the following statement is true or false.  
Lanthanoids are part of the sixth period on the periodic table.

## 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 at room temperature – bromine (Br) – five solids and 11 gases.



Figure 4.18 A bottle of liquid bromine, the only liquid non-metal

### metalloids

elements in the periodic table that are situated close to the border between metals and non-metals; metalloids share properties and appearance characteristics with both metals and non-metals

In general, non-metals have particular properties; they generally:

- are dull
- are brittle, meaning they will shatter when bent or struck with something hard

- 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). These elements 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.



Figure 4.19 Arsenic, found in rock, is a metalloid.

### Quick check 4.6

- 1 Recall the side of the periodic table where metals are located.
- 2 Identify the name given to elements that behave like metals and non-metals.
- 3 Decide whether the following statements are true or false. If false, provide reasons why.
  - a Metals have high melting points.
  - b Almost all metals are liquids at room temperature.
  - c There are more non-metals than metals on the periodic table.
  - d There are only two liquid elements on the periodic table at room temperature.
  - e Lead (Pb) is the only metal that is liquid at room temperature.

Table 4.3 summarises the properties of metals and non-metals.

Metals	Non-metals
Shiny	Dull
High density	Low density
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

---

### Remembering

- 1 **State** the number of groups on the periodic table.
- 2 **Name:**
  - a an element in period 3
  - b an element in group 15
  - c a transition metal
  - d a lanthanoid.
- 3 **State** the period that hydrogen and helium are in.
- 4 **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.



### Understanding

- 5 **Explain** why elements close to the 'step ladder' separating metals from non-metals are classified as metalloids.

### Applying

- 6 **Classify** the following elements as either metals or non-metals.
  - Oxygen (O)
  - Boron (B)
  - Aluminium (Al)
  - Iodine (I)
  - Nickel (Ni)
- 7 **Compare** metals and non-metals.
- 8 **Categorise** the following elements as transition metals, lanthanoids, actinoids, metals, metalloids or non-metals.
  - Promethium (Pm)
  - Rubidium (Rb)
  - Arsenic (As)
  - Thorium (Th)
  - Vanadium (V)
- 9 **Decide** what happens to the number of protons as you move from left to right across a period.

### Evaluating

- 10 A new element is discovered that:
  - is shiny
  - conducts electricity
  - is malleable
  - sinks when placed in water.

**Determine** from these properties whether it will be categorised as a metal or a non-metal.

---

## 4.3 Electron configurations of the elements



### Learning goals

- 1 To be able to write an electron configuration for the first 20 elements.
- 2 To be able to describe how electrons are responsible for light emission from some elements.
- 3 To differentiate between the sharing of electrons in an ionic bond and in a covalent bond.

### Where are the electrons?

In Year 9, you learned about the atomic model, and you might recall that electrons are located in shells that 'orbit' the centre of the atom, known as the nucleus, which is made up of protons and neutrons. You can work out how many electrons an element has by finding its atomic number or its position on the periodic table.

**electron shell**  
houses the electrons that orbit the nucleus of an atom

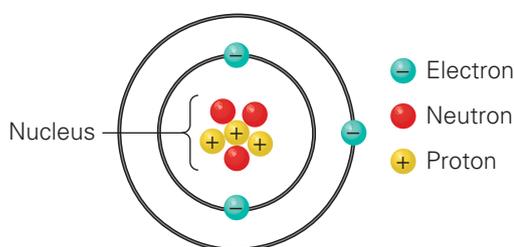


Figure 4.20 An atomic model for lithium

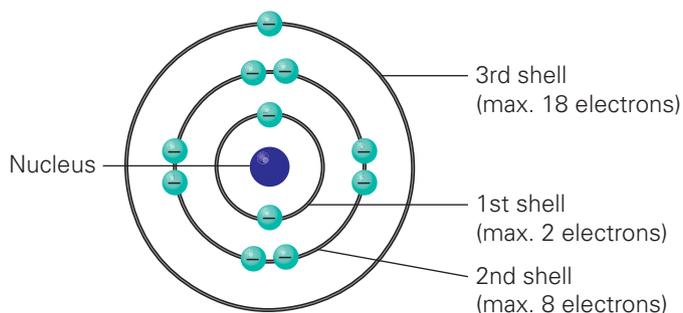


Figure 4.21 Diagram of how electrons arrange themselves in shells around the nucleus

The way electrons arrange themselves around the nucleus of an atom is not random; they arrange themselves in a very organised manner 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. This shell can consist of a maximum of two electrons. The second shell away from the nucleus can hold a maximum of eight electrons, the third shell a maximum of 18 electrons, and the fourth can hold a maximum of 32 electrons. Electrons situated in shells furthest away from the nucleus are at higher energy levels than electrons in closer shells.

Table 4.4 summarises how many electrons can be held in each electron shell.

Shell	Maximum number of electrons in shell
1st (lowest energy level)	2
2nd	8
3rd	18
4th (higher energy level)	32

Table 4.4 The maximum number of electrons in each shell

### Quick check 4.7

- 1 How are electrons arranged in an atom?
- 2 Copy and 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 in the following shells?
 

a First shell	c Third shell
b Second shell	d Fourth shell

## Electron configurations of the elements

The **electron 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**.

Magnesium (Mg) has an atomic number of 12, so it has 12 electrons. It has an electron configuration of 2,8,2. This shows that there are two electrons in the first shell, eight in the second and two in the third. Figure 4.22 shows the electron arrangement of a magnesium atom. As you can see from the diagram, shell 4 is empty, as magnesium does not have enough electrons for this shell to be occupied.

The sum of all the numbers in the electron configuration should equal the total number of electrons in that atom.

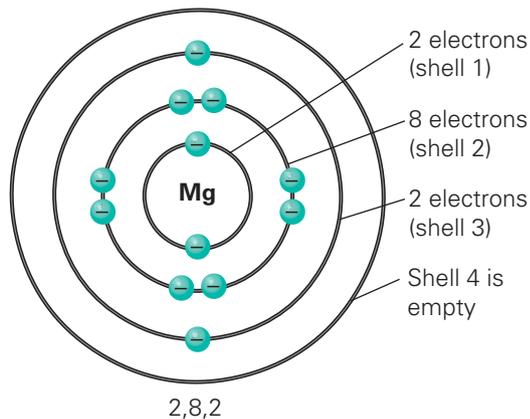


Figure 4.22 The electron configuration of magnesium

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 eight electrons in a shell is considered to be stable (called the **octet rule**), so the remaining two electrons actually occupy the fourth shell. Potassium (K) also does this, and has an electron configuration of 2,8,8,1.

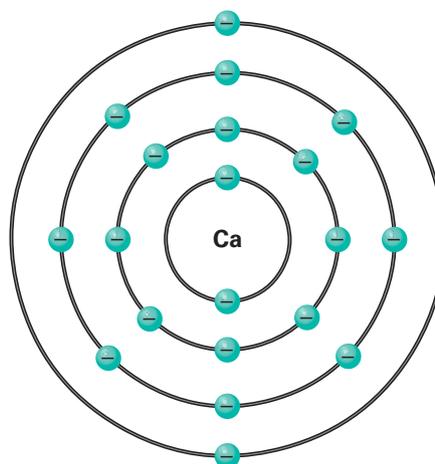


Figure 4.23 The electron configuration of calcium (2,8,8,2)

**electron configuration**  
the arrangement of an atom's electrons in the shells around the nucleus

**ground state**  
the lowest energy level of an atom

**octet rule**  
atoms tend to lose, gain or share valence electrons to achieve eight electrons in their outer shell

**valence electrons**  
the electrons in the outer shell of an element

### Quick check 4.8

- 1 State the name given to atoms when they are at their lowest energy level.
- 2 State the number of electrons in an element with an electron configuration of 2,8,3.
- 3 State the atomic number of an element that has 18 electrons.
- 4 State the electron configuration of oxygen (8 electrons).

## Electron 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.

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.

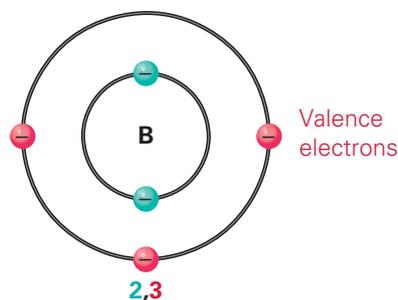
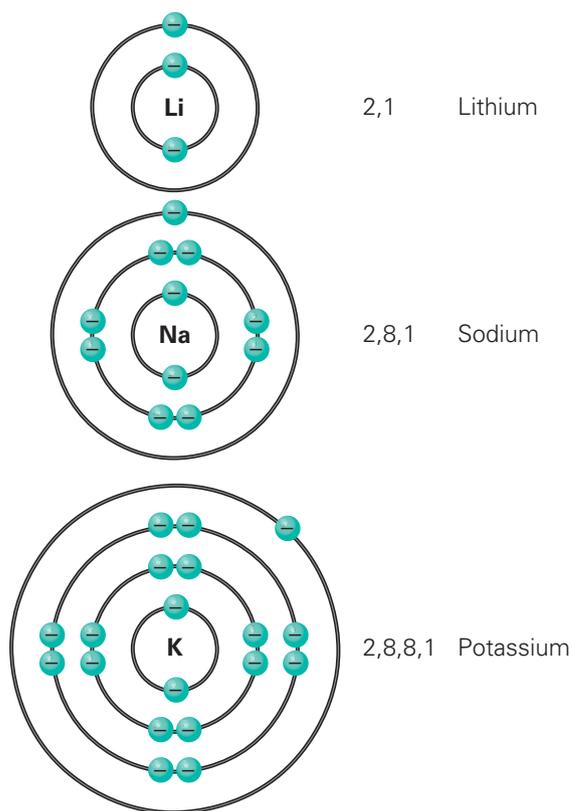


Figure 4.24 Boron (B) has an electron configuration of 2,3. It therefore has three valence electrons (red).

The number of electrons in the outermost shell of an atom influences an element's chemical and physical properties. 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 electron configurations all end in the number one. The last digit of group 17 tells us that elements in this group have seven valence electrons. This handy trick works for all the elements up to calcium (Ca).



**Figure 4.25** These elements in group 1 have one valence electron.

#### Quick check 4.9

- 1 Recall what valence electrons are.
- 2 Recall what the reactivity of a chemical element is determined by.
- 3 State the group that the element with the electron configuration 2,8 belongs to, and why.
- 4 State the period that the element with the electron configuration 2,8,4 belongs to, and why.

We can also determine the period an element is in from its electron configuration. For example, if an electron configuration contains two numbers (as for lithium), then it is in period 2.

### 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?

Electrons gain energy when atoms absorb light photons or heat. For example, absorbing waves of electromagnetic radiation or heat energy can cause electrons to jump to higher energy levels, such as to the next electron shell. When electrons fall back to lower energy levels of their ground state, this energy is lost as light energy.

**Figure 4.26** Copper compounds burn with a characteristic green coloured flame. When an excited copper electron returns back to a lower energy state, it emits green light.



The difference in energy between shells determines 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.

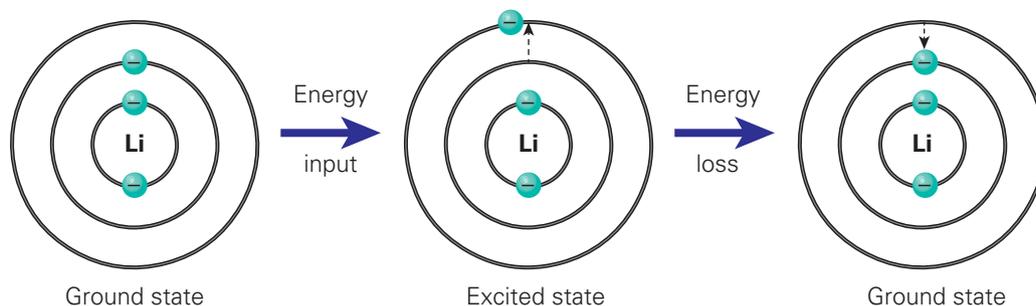
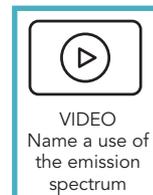


Figure 4.27 What happens to atoms when electrons gain energy?



### Explore! 4.3

#### Spectroscopes

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!



Figure 4.28 White light passes through a prism and is split into a continuous (visible) spectrum.

#### Absorption spectrum



#### Emission spectrum



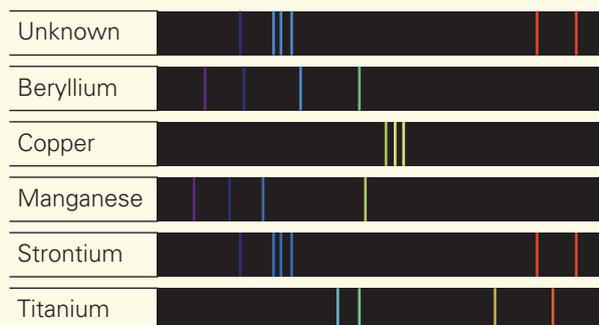
Figure 4.29 The absorption spectrum (top) and emission spectrum (bottom) of a particular element

*continued...*

...continued

(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 Using the information in Figure 4.30, deduce what is present in the unknown emission spectrum in Figure 4.29.



**Figure 4.30** We can compare emission spectra to find out the identity of an unknown element.

### Did you know? 4.1

#### Fireworks

The colours created by fireworks are formed when excited electrons drop back to the ground state. The energy they emit corresponds to a particular colour of light. In the fireworks image in Figure 4.31, 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.



**Figure 4.31** Fireworks rely on the energy emitted from excited electrons dropping back to ground state.

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!

### Quick check 4.10

- 1 Recall what causes electrons to become excited and move up energy levels.
- 2 State the type of energy that is emitted when electrons return to the ground state.
- 3 Recall how we can identify the type of element present when electrons are excited.

## Practical 4.2

### Flame tests using metal salts

#### Aim

To observe the flame colours of different salt solutions.

#### Materials

- solutions of copper chloride, potassium chloride, sodium chloride, lithium chloride and strontium chloride
- beakers
- boiling tubes
- distilled water
- wooden splints
- Bunsen burner
- bench mat
- matches

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Prior to the lesson, thoroughly soak a supply of wooden splints in a beaker of distilled water.
- 3 Sets of boiling tubes should be up to half-filled with the salt solution, and the splints then need to be immersed in these.
- 4 Hold a soaked splint in a blue Bunsen flame to reveal the flame colour, being careful not to let the splint burn too vigorously.
- 5 Dispose of used splints in a beaker of water.

#### Results

Metal compound	Colour in flame
Copper chloride	
Lithium chloride	
Strontium chloride	
Sodium chloride	
Potassium chloride	

#### Discussion

- 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 Explain why different colours of light were observed for compounds containing different metallic elements.

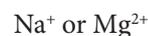
#### Be careful

Ensure appropriate personal protective equipment is worn.

## Valency and bonding

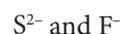
The number of valence (outer shell) electrons an atom possesses can be used to predict how it will bond with other atoms. Neutral atoms contain the same number of positively charged protons in the nucleus and negatively charged electrons orbiting the nucleus. A loss or gain of valence electrons in an atom therefore changes the overall charge of an atom. A charged version of an atom is called an **ion**. Metals, located on the left-hand side of the periodic table, have fewer than four electrons in their outer shell. Metals tend 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:



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:



#### ion

a charged version of an atom, formed from the loss or gain of electrons

#### cation

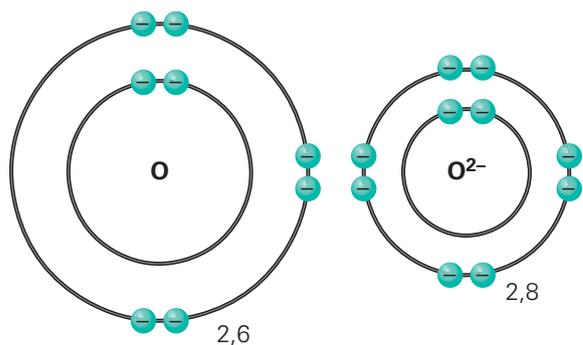
a positively charged ion formed from the loss of electrons

#### anion

a negatively charged ion formed from the gain of electrons

A single  $-$  sign indicates the atom has gained one electron, while a number before the  $-$  sign indicates how many electrons were gained.

An atom's tendency to lose or gain electrons is an indicator of its chemical reactivity. This concept will be further explored in Section 4.5.



**Figure 4.32** An oxygen atom has an electron configuration of 2,6. It tends to gain two electrons to achieve a stable outer shell, giving it an electron configuration of 2,8. It now has a net negative charge and is represented as  $O^{2-}$ .

#### Explore! 4.4

##### The Large Hadron Collider

The Large Hadron Collider (LHC) is used for much international scientific research and is based at CERN on the border of Switzerland and France. The LHC is a particle accelerator that can make particles, like protons and ions, collide at close to the speed of light!

Use your preferred search engine to find the Large Hadron Collider page on the CERN website. Explore the facts and figures for answers to the following questions.

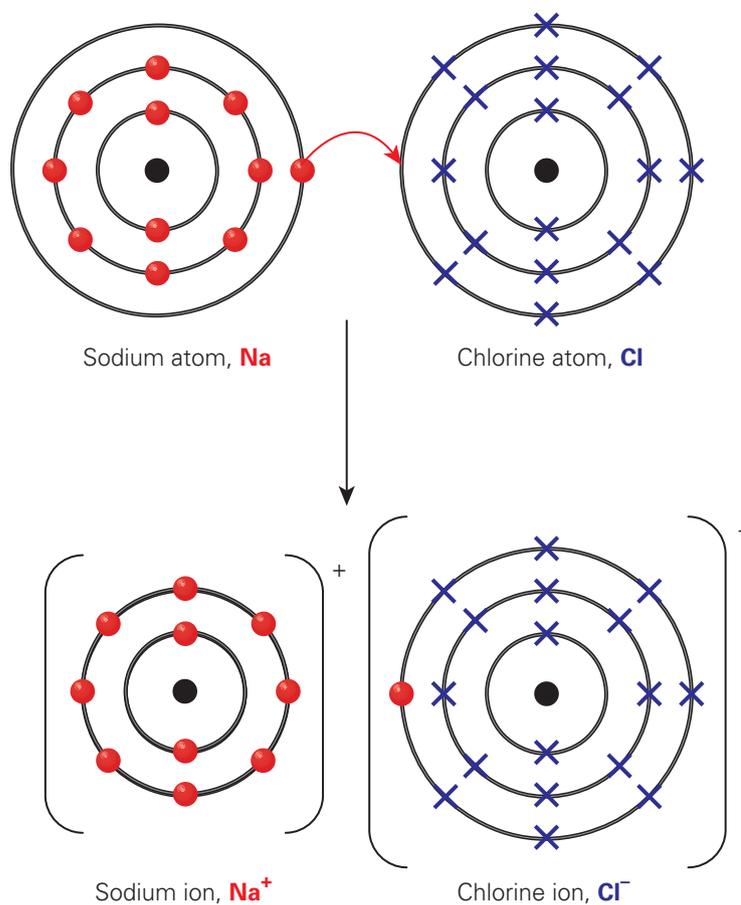
- 1 How long is the ring that particles are accelerated around at the LHC?
- 2 What is a hadron?
- 3 What is one of the main goals of the LHC?

##### electrostatic attraction

an attraction between oppositely charged particles

##### ionic bond

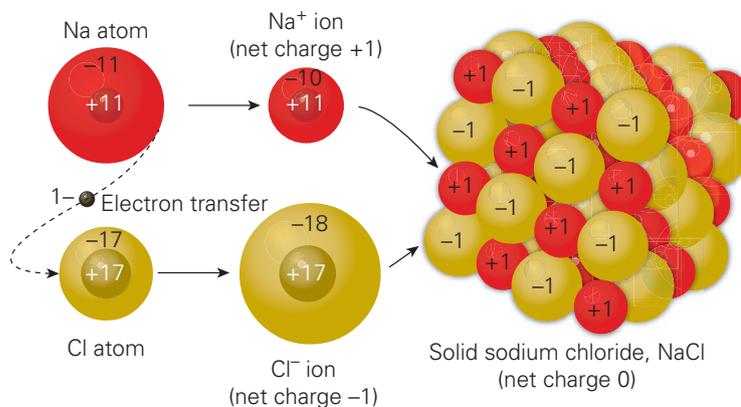
a strong bond between an anion and a cation, formed via electron donation



**Figure 4.33** Ionic bonding in sodium chloride

#### Ionic bonding

Positively charged cations are attracted to negatively charged anions, and this **electrostatic attraction** is known as an **ionic bond**. Strong electrostatic forces bond the ions together into an ionic compound, which tend to take on a lattice structure. The structure of a sodium chloride lattice is shown in Figure 4.34. Because the bond is strong, ionic compounds tend to have high melting temperatures. For example, table salt ( $NaCl$ ) has a melting point of  $801^{\circ}C$ .



**Figure 4.34** A sodium atom donates an electron to a chlorine atom (left). The sodium atom now forms a positively charged cation and the chlorine atom forms a negatively charged anion. These ions are attracted and bond into an ionic compound (right). A crystal lattice configuration is a common way in which ionic compounds are organised.

## Covalent bonding

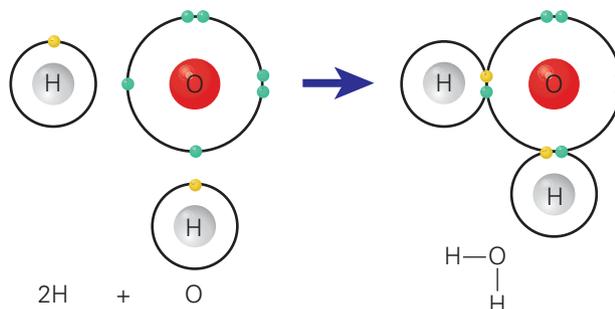
When two non-metals bond together, they both require some electrons to complete their outer shell but neither is 'prepared' to lose theirs! Instead, these two atoms can share electrons, forming a molecule that is held together by a strong **covalent bond**.

An oxygen (O) atom has an electron configuration of 2,6. As we have seen previously, oxygen 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 atoms to have a stable outer shell. Refer to the water

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.

### covalent bond

a strong bond almost always between two non-metals that share electrons, forming a molecule



**Figure 4.35** Two hydrogen atoms and an oxygen atom covalently bond to form a water molecule. The lines between the atoms represent covalent bonds.

### Quick check 4.11

- Define these terms:
  - ion
  - cation
  - anion.
- Explain why certain elements are likely to form cations whereas others tend to form anions.
- Describe a covalent bond.

## Section 4.3 questions

### Remembering

- Select the correct numbers to complete the following table.

Electron shell	Maximum number of electrons housed
1st	
	32
3rd	
	8

- Recall why the shell closest to the nucleus fills with electrons first.
- For each of the following electron configurations **state** the:
  - name of the element
  - number of valence electrons
  - period the element is in
  - group the element is in.

a 2, 8, 1      b 1      c 2, 7      d 2, 8, 8

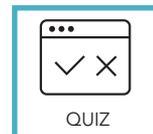
### Understanding

- State** the electron configurations for the following elements.
 

a Helium (He)      b Beryllium (Be)      c Phosphorus (P)      d Potassium (K)
- The electron configuration of carbon is 2,4. **Summarise** all the information you can determine from this.

### Applying

- Describe** the order in which electrons fill shells around the nucleus.
- Explain** why atoms in the same group have similar properties.



- 8 Chlorine has the electron configuration 2,8,7. **Represent** the arrangement of the electrons within a chlorine atom in a diagram.
- 9 Use your knowledge of electron arrangement to **explain** what is significant about the electron configurations of group 18 elements.

#### Analysing

- 10 **Compare** the number of protons and electrons in an uncharged atom with those in an ion.
- 11 **Distinguish** between valence electrons and other electrons of an atom.
- 12 **Compare** how an oxygen atom would participate in an ionic bond versus a covalent bond.

#### Evaluating

- 13 Helium, a group 18 element, has the electron configuration 2, meaning that it has two valence electrons. **Discuss** why helium is not located next to hydrogen with the other group 2 elements, which also have two valence electrons.
- 14 **Construct** a diagram that shows an example of what happens when electrons are excited from ground state.
- 15 A student was instructed to conduct a flame test using copper chloride and strontium chloride. **Discuss** the results they would obtain.

## 4.4 Special groups of elements



### Learning goals

- 1 To be able to recall the physical properties and reactivity trends in group 1 and 2 metals.
- 2 To be able to recall the physical properties and reactivity trends in group 17 and 18 non-metals.

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).

You have already read about the different 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 usually 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 explore four particular groups in the periodic table.



Carbon (C)



Silicon (Si)



Germanium (Ge)



Tin (Sn)



Lead (Pb)

Figure 4.36 Group 14 elements

## The alkali metals (group 1)

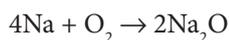
The **alkali metals** (group 1) make up the first group of the periodic table. The elements lithium (Li), sodium (Na), potassium (K), rubidium (Rb), caesium (Cs) and francium (Fr) all belong to the alkali metals. We will focus on the first three elements of this group as these are the elements that you 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 chemical equations.

sodium + oxygen → sodium oxide



**Figure 4.38** A piece of sodium metal that has been cut by a knife. It is shiny on the inside and dull on the outside.

3	<b>Li</b> lithium 6.94
11	<b>Na</b> sodium 22.99
19	<b>K</b> potassium 39.10
37	<b>Rb</b> rubidium 85.47
55	<b>Cs</b> caesium 132.9
87	<b>Fr</b> francium

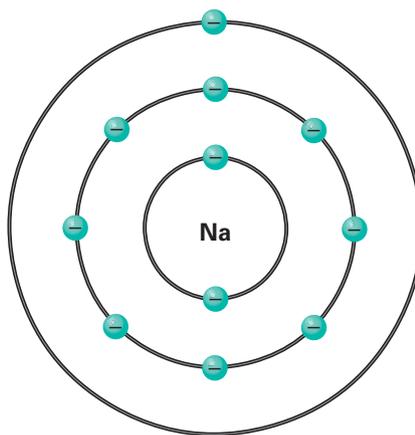
**Figure 4.37** The elements in group 1 are also known as the alkali metals.

When placed in water, lithium, sodium and potassium will float as they are less dense than water (although they are also highly reactive and produce gas upon contact with water). Again, this is unlike most other metals you may have encountered.

**alkali metals**  
the group 1 metals, which form an alkaline solution when they react with water

### Reactivity

The group 1 metals are all highly reactive. This is because they all have one valence electron. Elements are stable when they have a full outer shell of electrons, so group 1 metals 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 requires less energy to remove the outer electron as the atom gets bigger and the outer shell gets further away from the positively charged nucleus.

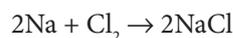
Group 1 elements readily react with group 17 elements, forming white salts – one of these salts being table salt that you put on your chips!



**Figure 4.40** Table salt is formed when sodium reacts with chlorine to form sodium chloride.

The following word and balanced chemical equations show how sodium (Na) reacts with chlorine (Cl) to form table salt (sodium chloride, NaCl).

sodium + chlorine → sodium chloride



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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.

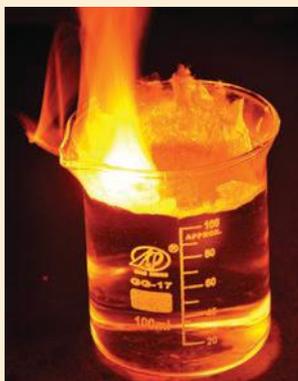
Alkali metals have a memorable reaction with water and this is where they get their name. All group 1 metals react violently with water, producing hydrogen gas and an alkaline solution.

### Did you know? 4.2

#### Do not touch group 1!

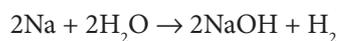
At school, all the group 1 metals will be stored in bottles of oil and your teacher will never touch them with their hands. They are so reactive that even coming into contact with water vapour in the air and sweat on your hands, can cause them to react violently! Always follow the handling precautions and wear the appropriate personal protective equipment when working with those elements.

**Figure 4.41** What happens when sodium reacts with water? Here, the hydrogen gas produced has ignited.



The word and balanced chemical equations show what happens when sodium reacts with water.

sodium + water → sodium hydroxide + hydrogen



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? If false, give a reason why.
  - 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 4.3: Teacher demonstration

### Investigating the reactivity of group 1 metals

#### Aim

To determine the order of reactivity of two group 1 metals.

#### Materials

- lithium and sodium metals
- universal indicator
- large, thick-walled glass bowl
- scalpel
- white tile
- blotting paper
- tweezers
- safety screen
- disposable gloves

#### Method

- 1 Write a prediction in their books stating which they think will be the most reactive metal out of lithium and sodium.
- 2 Copy the results table below.

*continued...*

...continued

- Half fill the large glass bowl with water and add a few drops of universal indicator until the colour can be seen throughout the liquid.
- Using the tweezers, take a piece of lithium from its bottle and place it on the white tile.
- 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.
- Making sure that all students are behind the safety screen, add the small piece of metal to the water and record your observations.
- Repeat for sodium.

### Results

	Hard or soft	Appearance when cut	More or less dense than water	Observations during reaction
Lithium				
Sodium				

### Discussion

- Explain the decision to use tweezers rather than hands to pick up the metals.
- Why was a safety screen necessary when conducting this experiment?
- Describe the purpose of the universal indicator.
- Describe any patterns, trends or relationships in your results.
- Describe how you determined the reactivity of each of the metals investigated.
- How did you determine whether the metals were more or less dense than water?
- Explain how the reactivity of the metals changes as you go down group 1.

### Conclusion

- Propose a conclusion about the different reactivities of the group 1 metals based on this experiment.
- Support your statement by using the data you gathered.

## 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).

### Physical properties

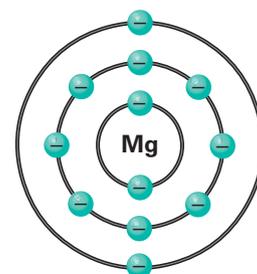
The naturally occurring alkaline earth metals tend to be shiny and silvery white, and they have low melting and boiling points. Magnesium and calcium are abundant in Earth's crust and are considered essential to all living organisms.

## Reactivity

All group 2 elements are reactive, but not as reactive as group 1 elements. This observed behaviour can be explained by them having 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.

Just like group 1 metals, alkaline earth metals 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.

**alkaline earth metals**  
the group 2 metals, which form an alkaline solution when they react with water



**Figure 4.42** Group 2 elements have two valence electrons.

Element	Product formed when reacting with oxygen	Product formed from reacting with chlorine
Beryllium (Be)	Beryllium oxide BeO	Beryllium chloride BeCl <sub>2</sub>
Magnesium (Mg)	Magnesium oxide MgO	Magnesium chloride MgCl <sub>2</sub>
Calcium (Ca)	Calcium oxide CaO	Calcium chloride CaCl <sub>2</sub>

**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 State the charge that alkaline earth metals tend to form when they react.

## Practical 4.4: Investigation

### Investigating the reactivity of group 2 metals

#### Aim

To investigate the relationship between the position of a group 2 element in the periodic table and its reactivity with acid.

#### Prior understanding

Metals in group 2 of the periodic table are less reactive than those in group 1. This investigation will determine the order of reactivity within group 2.

**Recommended:** Use a spreadsheet to analyse the data for this experiment and calculate uncertainty.

#### Useful formula

Change in volume (mL) = final volume (mL) – initial volume (mL)

$$\text{Rate of gas produced (mL min}^{-1}\text{)} = \frac{\text{mean change in volume (mL)}}{\text{mean reaction time (min)}}$$

#### Materials

- 3 similarly sized samples of calcium (approximately 5 mm in diameter)
- 3 similarly sized samples of magnesium (approximately 5 mm in diameter)
- 30 mL hydrochloric acid (1 mol L<sup>-1</sup>)
- 6 test tubes
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- test tube holder
- rubber stopper with glass tubing inserted through to fit the test tube
- rubber stopper to fit the 100 mL measuring cylinder
- 4 mm plastic tubing (minimum 30 cm)

#### Be careful

To reduce risk of skin burn from acid:

- ensure appropriate personal protective equipment is worn
- wear safety glasses at all times
- wash hands after practical.

*continued...*

...continued

- 1 large bowl
- retort stand, bosshead and clamp
- stopwatch
- tweezers

### Planning

- 1 Develop a hypothesis by predicting the position of a group 2 metal on the periodic table will affect its reactivity.
- 2 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
- 3 Complete a risk assessment for this investigation, describing how any risks will be controlled.

### Method

#### Part 1: Prepare the results table

Draw the table shown in the results section into your science journal.

#### Part 2: Measure the reactivity of the first metal sample

- 1 Fill the large bowl with tap water.
- 2 Fill the 100 mL measuring cylinder with tap water.
- 3 Stopper the measuring cylinder using the rubber stopper (a complete seal will not be possible).
- 4 Invert the measuring cylinder into the large bowl (your teacher will show you how to do this if you are not sure) and clamp it in place with the stopper below the water line, as shown in Figure 4.43.
- 5 Remove the stopper from the measuring cylinder.
- 6 Attach the plastic tubing to the glass tubing on the rubber stopper. Place beside the measuring cylinder for easy access later.
- 7 Measure 5 mL of 1 mol L<sup>-1</sup> hydrochloric acid and pour into a test tube.
- 8 Using tweezers, add a piece of the first metal sample into the acid in the test tube. Be careful not to splash the acid.
- 9 Attach the rubber stopper with the plastic tubing to the test tube and position the end of the plastic tubing underneath the measuring cylinder so the gas can be collected.
- 10 Measure the initial volume of the gas in the inverted measuring cylinder and record it in your table. Start the stopwatch.

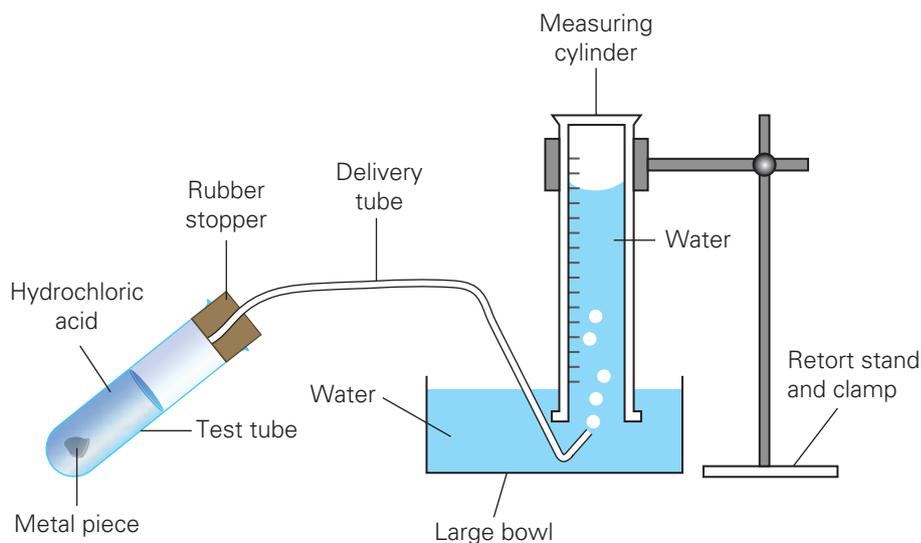


Figure 4.43 Diagram of experimental set-up

continued...

...continued

- 11 After five minutes, record the final volume of the gas in the inverted measuring cylinder in your table.
- 12 Remove the rubber stopper and tubing from the test tube. Store the test tube and contents in the test tube holder.
- 13 Repeat steps 7–12 with the other two samples of the first metal.
- 14 Remove the measuring cylinder and refill with tap water.
- 15 Stopper the measuring cylinder using the rubber stopper.
- 16 Invert the measuring cylinder into the large bowl and clamp it in place with the stopper below the water line.
- 17 Remove the stopper from the measuring cylinder.

### Part 3: Measure the reactivity of second metal sample

Repeat steps 7–12 with the other second metal samples.

### Results

#### Calculate the mean reaction rate for each metal sample

- 1 Calculate the change in gas volume for each trial and record it in the results table.
- 2 Calculate the rate of gas production in mL/min for each metal and record it in the results table.
- 3 Draw a scatterplot to analyse the relationship between the period number of each metal and its reaction rate.
- 4 Calculate the uncertainty for each metal.
- 5 Optional: format the graph and insert a copy below the results table into your science journal.

	Measurements	Trial 1	Trial 2	Trial 3	Mean rate of gas production (mL min <sup>-1</sup> )	Uncertainty of rate of gas production: $\frac{\text{max} - \text{min}}{2}$
Period 2 Magnesium	Initial volume (mL)					
	Final volume (mL)					
	Change in volume (mL)					
	Rate of gas production (mL min <sup>-1</sup> )					
Period 3 Calcium	Initial volume (mL)					
	Final volume (mL)					
	Change in volume (mL)					
	Rate of gas production (mL min <sup>-1</sup> )					

### Discussion

- 1 Compare the mean rate of gas production for the different elements.
- 2 Predict the trend in reactivity for group 2 elements that are positioned lower on the periodic table.

continued...

...continued

- 3 Draw a conclusion as to how increasing the period position of different elements might affect the rate of gas production in reactions with acids.
- 4 Critique your management of the controlled variables. Were they managed properly to ensure they did not change and affect the measurements?
- 5 Could these results be used to predict reactivity trends in other groups on the periodic table? Explain your reasoning.
- 6 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

#### Conclusion

- 1 Propose a valid conclusion that can be drawn from these results.
- 2 Justify this conclusion using data from your results.
- 3 Explain your conclusion using your own knowledge and research about group 2 metals.
- 4 State whether or not your hypothesis is supported.

## The halogens (group 17)

Group 17 elements are also known as the **halogens**. This group contains the elements fluorine (F), chlorine (Cl), bromine (Br), and iodine (I). Astatine (At) is a halogen but it is a very rare and radioactive element and it will not be considered here.

### 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 swimming 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  $-1$ .

**halogens**  
the group 17 elements (e.g. chlorine and iodine)

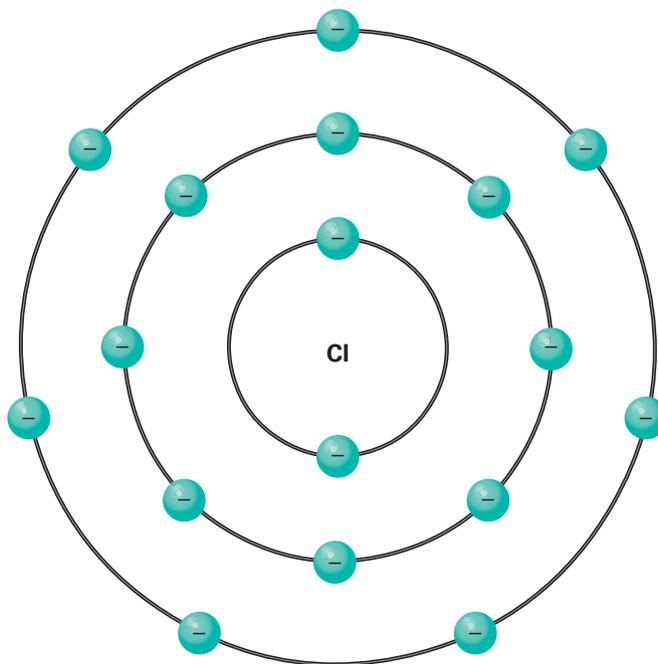


Figure 4.44 Group 17 elements have seven valence electrons.

Halogen	Formula	State	Colour	Melting point (°C)	Boiling point (°C)	Reactivity
Fluorine	F <sub>2</sub>	Gas	Pale yellow	-220	-188	Reactivity increases up the group 
Chlorine	Cl <sub>2</sub>	Gas	Pale green	-101	-35	
Bromine	Br <sub>2</sub>	Liquid	Brown	-7.2	58.8	
Iodine	I <sub>2</sub>	Solid	Purple	114	184	

**Table 4.6** Some properties of the halogens

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.

Going down group 17, the elements have higher melting points and appear darker in colour, 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<sub>2</sub>.

#### Quick check 4.14

- 1 Name three elements in group 17.
- 2 Give the charge of a group 17 ion.
- 3 State one physical or chemical trend that can be observed going down group 17.

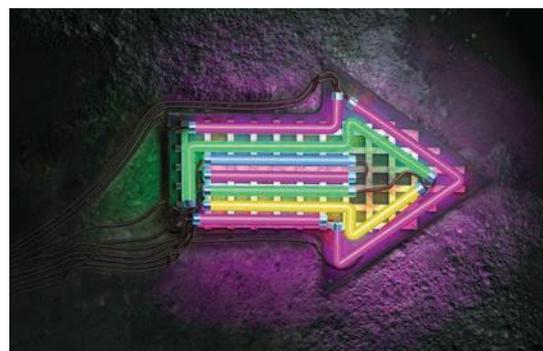
### The noble gases (group 18)

Group 18 elements are also known as the **noble gases**. This group contains the elements helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn).

**noble gases**  
the group 18  
elements (e.g.  
neon and krypton)

#### Physical properties

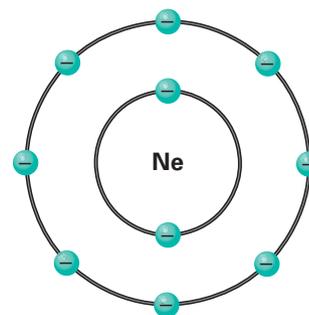
The noble gases tend to be colourless, odourless and non-flammable. Their applications include neon signs, medical imaging and radiotherapy to treat cancer.



**Figure 4.45** The first neon signs used neon, which produces an orange colour. Different elements, such as hydrogen, helium etc., are used to get different colours in modern neon signs.

#### Reactivity

Unlike the other groups we have discussed, noble gases are extremely unreactive. (They were once called inert gases because it was thought that they did not react readily.)



**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?

## Explore! 4.5

**The Hindenburg disaster**

The Hindenburg airship could travel from Europe to North and South America in half the time of the fastest ocean liner. The airship was filled with hydrogen rather than helium due to export restrictions that the United States imposed against Nazi Germany.

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.

- 1 What was the problem with using hydrogen gas in the Hindenburg airship?
- 2 Why would helium have been a safer alternative?
- 3 Why is helium able to be used to fill airships?
- 4 Helium is heavier than hydrogen and therefore provides less lift. Why is this a problem for airship designers?



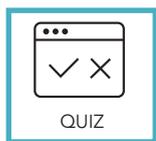
**Figure 4.47** The Hindenburg airship was a revolution in travel.



**Figure 4.48** The Hindenburg bursting into flames on arrival in New Jersey, United States



## Section 4.4 questions

**Remembering**

- 1 State** the group number of the following.
  - Alkaline earth metals
  - Halogens
  - Noble gases
  - Alkali metals
- 2 Recall** what happens to the reactivity as you move down group 1.
- 3 Identify** if the following statements are true or false. If false, give a reason why.
  - All halogens are gases.
  - All alkali metals form hydrogen when they react with water.
  - Noble gases do not form ions.
  - Alkaline earth metals form ions with a +2 charge.
  - The general formula of a halogen molecule is  $X_2$ .
- 4 State** how many valence electrons each of the following groups has.

<b>a</b> Alkali metals	<b>c</b> Halogens
<b>b</b> Alkaline earth metals	<b>d</b> Noble gases

**Understanding**

- 5** A new element is discovered. It is shown to form an ion with a charge of +2. **Identify** which group it could belong to.
- 6 Explain** why group 2 elements are less reactive than group 1.

**Applying**

- 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.

**Analysing**

- 9 Classify** the following elements as alkali metals, alkaline earth metals, halogens or noble gases.

<b>a</b> Magnesium	<b>d</b> Potassium
<b>b</b> Argon	<b>e</b> Iodine
<b>c</b> Sodium	
- 10 Compare** the properties and reactions of group 1 and 2 elements.

**Evaluating**

- 11** Use example provided in the text to **construct** a balanced chemical equation for the reaction between:
  - rubidium and water
  - lithium and oxygen.
- 12** Look at 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.
- 13 Predict** the products of the following reactions.
  - Potassium and water
  - Magnesium and chlorine
  - Calcium and oxygen
  - Sodium and fluorine
- 14 Decide** why group 18 was not present in Mendeleev's periodic table.
- 15 Decide** if you would expect strontium to be chemically more similar to calcium or rubidium, giving reasons for your choice.

# 4.5 Reactivity of metallic elements

## Learning goals

- 1 To be able to use the reactivity series to predict the result of displacement reactions.
- 2 To be able to describe methods of extracting metals including native metals, extraction with carbon and electrolysis.



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. Alkali metals are very reactive, more reactive than the group 2 metals and the transition metals. The more reactive a metal, the more readily it loses an electron from its outer shell (the valence electrons). This is known as the activity of a metal.

## The reactivity series

The **reactivity series** describes the observable reactivity (most likely in terms of rate of reaction) of some common metals with acids and cations. Figure 4.49 shows this order of reactivity of some common metals in the periodic table.

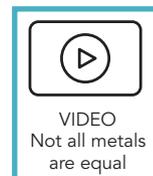
The reactivity series shows that tin is more reactive than lead and that zinc is more reactive

Metal	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)	
Less reactive	

Figure 4.49 The reactivity series

than gold, for example. Potassium is the most reactive metal listed, while gold is the least reactive metal listed.

**reactivity series**  
a series of metals ordered by their reactivity, from highest to lowest



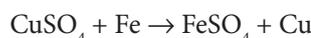
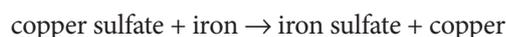
## Quick check 4.16

- 1 Decide whether the following statements are true or false. If false, give a reason why.
  - a Potassium is the most reactive metal in the reactivity series shown in Figure 4.49.
  - b Silver is less reactive than gold.
  - c Group 1 metals are the most reactive in the reactivity series.
- 2 Name the only group 13 element in the reactivity series.

## Displacement reactions

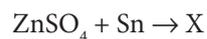
Using the reactivity series, you can predict the outcome of a particular type of reaction involving these metals, called a **displacement reaction**. In a displacement reaction, an ion of a more reactive metal will displace (remove or replace) an ion

of a less reactive metal from a solution of its compound. The following is an example:



**displacement reaction**  
when a more reactive metal removes a less reactive metal from its compound

In this reaction, because iron is more reactive than copper, the iron atom loses two electrons to form an  $\text{Fe}^{2+}$  ion and it has displaced (or removed) the copper ion ( $\text{Cu}^{2+}$ ) from its compound. The iron ion ( $\text{Fe}^{2+}$ ) has joined with the sulfate ion ( $\text{SO}_4^{2-}$ ) and the  $\text{Cu}^{2+}$  ion gains two electrons to form copper metal. So what happens when the metal on its own is less reactive than the metal in the compound?



In this case there is no reaction. Tin is lower in the reactivity series, so it will not remove the zinc from its compound.

### Practical 4.5: Investigation

#### Displacement reactions

##### Aim

To determine the order of reactivity of metals by the outcome of displacement reactions.

##### Prior understanding

The periodic table was originally developed by grouping together elements that have common physical and chemical properties. The periodic table reveals trends and patterns of chemical properties (such as reactivity) that are determined by the underlying structure of each element.

You are going to be investigating the reactivity of metals using displacement reactions. This is a type of reaction involving a metal salt solution (a metal salt is a compound made from a combination of a metal and a non-metal) and a pure metal. Pure metals with a higher reactivity than the metal within the salt solution will react and 'push out' (displace) the metal that is within the salt solution, forcing the less reactive metal into its pure element form.

##### Materials

- 3 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
- dimple tile or spotting tile

##### Planning

- 1 Write a brief rationale that explains the factors that affect a metal's reactivity and the purpose of the reactivity series. You may want to talk about atomic radius or valence electrons.
- 2 Develop a hypothesis using the reactivity series as to how the position of a metal in the reactivity series will affect its reactivity with a metal lower in the series.
- 3 Draw a results table that will allow you to collect sufficient data.

##### Method

- 1 Add 3 drops of copper nitrate to four dimples in a row, as shown in Figure 4.50.
- 2 Add 3 drops of magnesium nitrate to four dimples in a row.

*continued...*

#### Be careful

To avoid risk of contamination from chemicals:

- wear goggles at all times
- wash hands after practical.

...continued

- 3 Add 3 drops of zinc nitrate to four dimples in a row.
- 4 Add a piece of the first test metal to each dimple in the second column and record your observations in the results table.
- 5 Repeat step 4 for each of the other two test metals, place them in the third and fourth column of dimples.

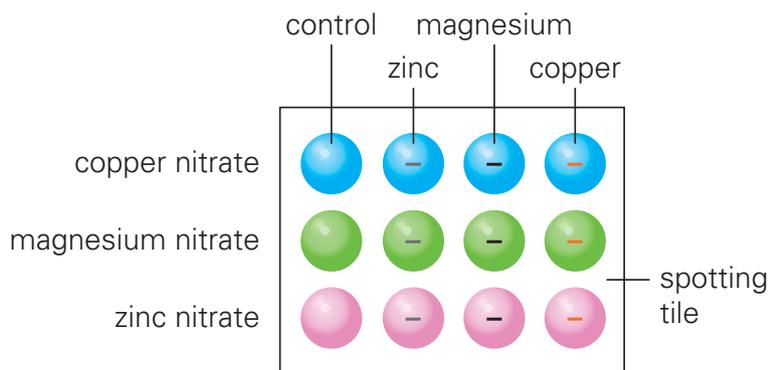


Figure 4.50 Arrangement of solutions on dimple tile

#### Discussion

- 1 Describe the observations you used to determine whether a displacement reaction had taken place.
- 2 Identify the reactions that did not show displacement. What can you conclude from this result?
- 3 Write word equations for each of the successful displacement reactions.

#### Conclusion

Draw a conclusion regarding the order of reactivity of the elements in the investigation. Justify your answer with data.

#### Quick check 4.17

- 1 For the following mixtures of metals and metal compounds, state whether or not a reaction will occur.
  - a Iron chloride + nickel
  - b Copper sulfate + zinc
  - c Iron sulfate + aluminium
  - d Sodium sulfate + gold
- 2 Describe the term 'displacement reaction'.

### Explore! 4.6

#### 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.

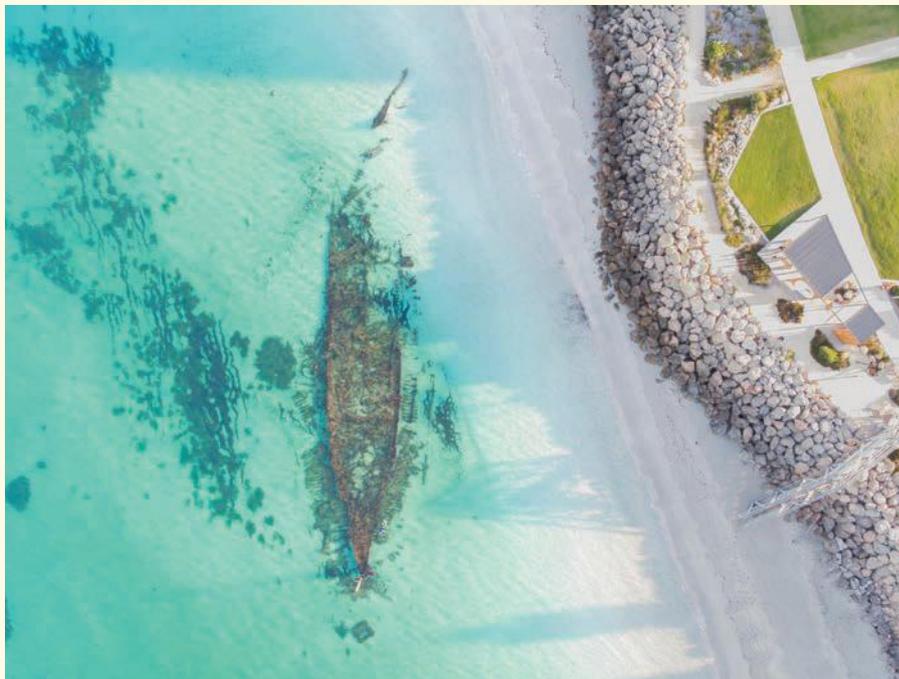


Figure 4.51 Rust coating on the Port Coogee shipwreck at Coogee Beach, Western Australia

What about the metallic pieces shown in Figure 4.52? The plant pot, watering can and spade are 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 reactivity 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.



Figure 4.52 Metallic pot, watering can and spade

## Extracting metals

Most metals in their pure states are reactive, so many of them are found naturally as compounds, known as **ores**. Ores are impure forms of metals, and often form 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

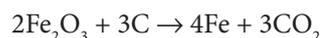
Metals at the bottom of the reactivity series, for example gold and silver, are known as

**native metals**. If the metals do not form ores, they can be extracted in their pure form.

## Extraction with carbon

Metals in the middle of the reactivity 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  $\rightarrow$  iron + carbon dioxide



**ore**  
a substance formed naturally in the ground and from which metal can be obtained

**native metals**  
elements that are found in their pure states in the environment



**Figure 4.53** 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 4.54** Molten iron spews out of a blast furnace where iron ores are reacted with carbon to form pure iron metal.

**Figure 4.55** The Kalgoorlie Super Pit open cut gold mine in Western Australia



## Practical 4.6

### Extracting iron using a matchstick

#### Aim

To extract iron from iron oxide.

Note: The experiment works best with non-safety matches that have a pinkish-red head.

#### Be careful

Ensure appropriate personal protective equipment is worn.

#### Materials

- iron(III) oxide powder
- sodium carbonate powder
- 100 mL beaker filled with water
- watchglasses
- crucible tongs
- weighing boat
- spatula
- Bunsen burner
- bench mat
- magnet
- safety match
- cling wrap

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Run the magnet over the iron(III) oxide powder, sodium carbonate powder and match head. Record whether they are magnetic.
- 3 Moisten the head of the match by dipping it into a beaker of water.
- 4 Place a small amount of sodium carbonate powder in a watchglass. Do the same with the iron(III) oxide powder.
- 5 Roll the head of the match in the sodium carbonate powder and then in the iron(III) oxide powder.
- 6 Using the pair of tongs, hold the head of the match into a blue Bunsen burner flame – only let it burn halfway down the match.
- 7 Allow the match to cool.
- 8 Use the spatula to crush the charred head of the match into the weighing boat.
- 9 Run the magnet underneath the weighing boat and record what you see. If you have wrapped the magnet in cling wrap, then it could be directly dipped into the match remains.

#### Results

Substance	Magnetic?
Iron(III) oxide powder	
Sodium carbonate powder	
Match head (before heating)	
Charred remains (after heating)	

#### Discussion

- 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 Explain why iron can be extracted in this way, including information about the reactivity series.

## Electrolysis

For metals at the top of the reactivity series, reacting with carbon is not an effective method of extraction. To extract these metals, an electrical current is passed through the impure metal, resulting in the extraction of the pure form of the metal. As this process is expensive, it is generally used to extract reactive metals like sodium and potassium.

### Quick check 4.18

- 1 Define the term 'native metals'.
- 2 Define the term 'metal ore'.
- 3 Name a metal that can be extracted by:
  - a reacting with carbon
  - b electrolysis.



**Figure 4.56** (left to right, top to bottom) Potassium, sodium, calcium, magnesium and aluminium can be extracted through the process of electrolysis.

## A summary of extracting metals

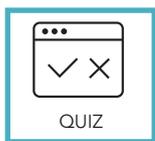
Table 4.7 summarises the primary extraction methods used to obtain pure forms of each metal.

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 reactivity series



## Section 4.5 questions

**Remembering**

- Select** which metals are found as native metals.
  - Least reactive metals
  - Most reactive metals
  - Metals that can be extracted by reacting with carbon
  - All metals
- State** how aluminium is usually extracted from its ore.
- State** why electrolysis is not used to extract all metals in the reactivity series.
- Recall** in what form most metals are found.

**Understanding**

- Select** a metal from the reactivity series in Figure 4.49 that:
  - can be extracted by electrolysis
  - can displace a solution of nickel nitrate
  - loses electrons the easiest
  - is a native metal.

**Applying**

- Explain** why sodium cannot be extracted by reacting with carbon.
- Explain** why it is harder to extract the more reactive metals from their ores.
- Explain** the advantages of some metals being extracted by both electrolysis and reaction with carbon before they are used.

**Analysing**

- Classify** the following metals as more or less reactive than iron.
  - Potassium
  - Gold
  - Copper
  - Zinc
- Analyse** why jewellery is often made from gold and silver.
- Distinguish** between the extraction methods of electrolysis and reaction with carbon.

**Evaluating**

- Predict** the outcome of the following displacement reactions.
  - Iron oxide + carbon
  - Copper nitrate + zinc
  - Magnesium sulfate + zinc
  - Gold + zinc nitrate
- Train track welding is often known as thermite welding. In this reaction, aluminium metal is reacted with iron oxide in a displacement reaction.
  - Construct** a word equation to show the reaction and the products formed.
  - Infer** why this process allows train tracks to be bonded together.

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
4.1 I can describe how Mendeleev arranged elements in his early periodic table.	8	
4.2 I can describe the structure of the periodic table in terms of groups, periods and blocks of metals, metalloids and non-metals.	1, 2	
4.2 I can identify the transition metals, lanthanoids and actinoids on the periodic table.	3	
4.3 I can determine the electron configuration of different elements.	13	
4.3 I can describe how electron configuration is linked to element properties such as emission of light.	12	
4.3 I can describe how valence electrons are shared in ionic bonding and covalent bonding.	16	
4.4 I can recall the physical properties and chemical reactivity elements in groups 1, 2, 17 and 18 in the periodic table.	9	
4.5 I can use the reactivity series to predict the outcome of a displacement reaction.	5	
4.5 I can recall some methods of extracting metals.	10	

## Review questions

### Remembering

- State the group and period of the following elements.
 

a Boron (B)	c Platinum (Pt)
b Titanium (Ti)	d Strontium (Sr)
- State the group number of the following.
 

a An element with the electronic configuration 2,8,1	c The halogens
b An element with 18 electrons	d A noble gas
- Identify each of the following elements as a transition metal, lanthanoid or actinoid.
 

a Europium	b Rhenium	c Uranium
------------	-----------	-----------
- Magnesium and beryllium are in group 2. Recall the other name given to elements in group 2.
- Name a metal that will displace zinc by using the table of reactivity series (Figure 4.49).

### Understanding

- Describe the position of metals and non-metals on the periodic table.
- Explain why elements in the same group have similar properties.
- Explain why Mendeleev left gaps in his periodic table.
- Describe the change in properties of the halogens as you move down group 17.
- Summarise the extraction methods for non-native metals.



**Applying**

**11 Identify** the names and positions of three elements in the transition metals.

**12** A new element has been discovered that:

- reacts violently with water
- is soft
- has an electron configuration of 2,8,8,1.

Given these properties, **determine** the group in which the new element belongs. Give reasons for your choice.

**13 Construct** a diagram to show the electron arrangement of an atom of carbon.

**14** Select the best statement that **describes** why elements are placed together in the same group. Explain why.

- They are placed in the same group because they are in alphabetical order.
- They are placed in the same group because they have the similar chemical and physical properties.
- They are placed in the same group because they behave the same.
- They are placed in the same group because they are metals or non-metals.

**15 Construct** a word equation to show the displacement reaction of iron sulfate with zinc.

**Analysing**

**16 Compare** ionic and covalent bonding. You may choose to do so in a table.

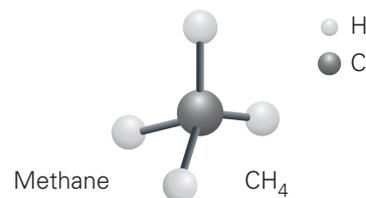
	Ionic bonding	Covalent bonding
Strength of bond		
Bond is between ...		
How is the bond formed?		

**17 Compare** the properties of iron metal and chlorine gas.

**18** Observe the model of the methane molecule shown.

Methane is a gas at room temperature and has a chemical formula of  $\text{CH}_4$ . **Infer** what sort of bond exists between the carbon and hydrogen atoms.

**19 Distinguish** between physical properties and chemical reactivity of elements in group 1 and elements in group 2.

**Evaluating**

**20 Contrast** an atomic absorption spectrum and an atomic emission spectrum.

**21 Critique** Mendeleev's method of predicting the properties of unknown elements.

**22 Justify** the inclusion of helium in the noble gases, even though it does not have eight electrons in the outer shell.



Figure 4.57 Balloons filled with helium

- 23 Use the melting point data below to **predict** the physical states (solid, liquid or gas) of the unknown elements at room temperature (20°C).

Element	Melting point (°C)	Physical state
X	-240	
Y	17	
Z	57	

### Data questions

Magnesium and calcium are group 2 alkaline earth metals and can be taken as general health supplements to aid regulation of bodily functions, including muscle functions and bone development. A scientist is testing the claim from eight different supplement brands that their magnesium and calcium tablets contain 200 mg of each element. Each supplement was analysed and the amount of magnesium or calcium present in each tablet is presented in Figure 4.58.

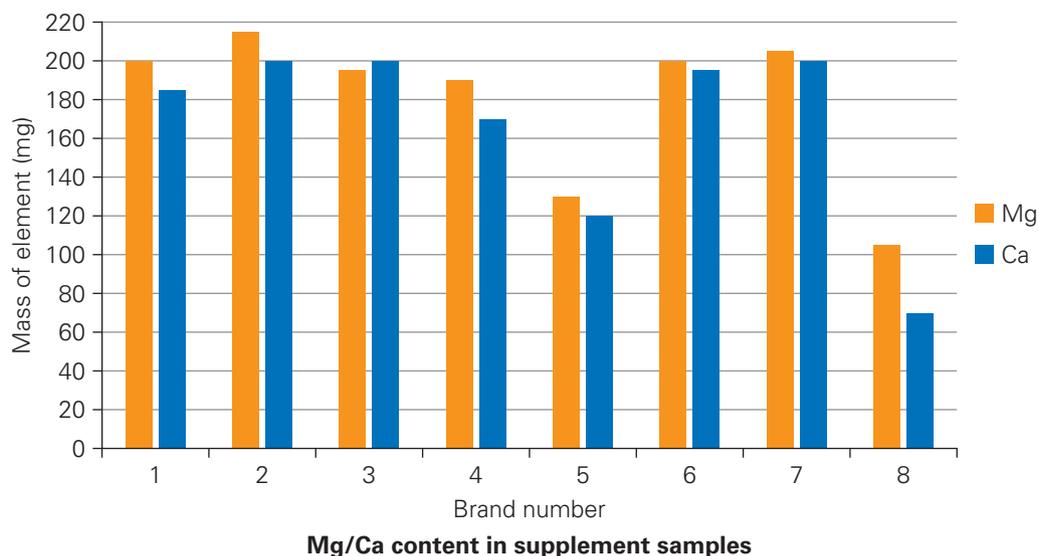


Figure 4.58 Mass of magnesium or calcium in eight commercial supplement samples

- Identify** all samples that had less than the advertised 200 mg of magnesium.
- Brand 3 advertised that the magnesium content was 200 mg  $\pm$ 10%. **Calculate** the minimum amount of magnesium that could be present in this advertised sample.
- Use your answer to Question 2 to **determine** whether the analysed brand 3 has a magnesium content within the advertised range.
- Brand 5 is being investigated for false advertising with its claim that 'we have a more accurate calcium content than (brand 1)'. Explore this statement and **draw conclusions** about its accuracy.
- A spokesperson for brand 6 has stated that 'the calcium content is more difficult to maintain as calcium is a more reactive metal than magnesium'. **Contrast** the magnesium and calcium content in brand 6. Does this explanation match the data presented in Figure 4.58?
- Identify** the general trend between the mass of magnesium and the mass of calcium in a brand's supplements.
- The 200 mg magnesium supplements are deemed to be falsely advertised if the content is found to be below 180 mg. **Compare** the data for the eight samples; which of the brands have falsely advertised?
- A magnesium content of over 220 mg would also be considered misleading advertising. Use the data to **justify** that no brand is providing misleading information in this regard.
- Brand 7 has released a new series of magnesium and calcium supplements containing 250 mg of magnesium or calcium. Use your response to Question 5 to **predict** whether the samples of these products would contain more magnesium or calcium.

## STEM activity: Creating composite materials

### Background information

In this chapter, you learned that the electronic structure of an atom determines its properties and its position 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 and nanomaterials (extremely small substances). Materials engineers 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 glass fibre and a thermosetting plastic.

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 4.59** 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.

**Design brief:** Create a composite material for the purpose of building a specific product.

### Activity instructions

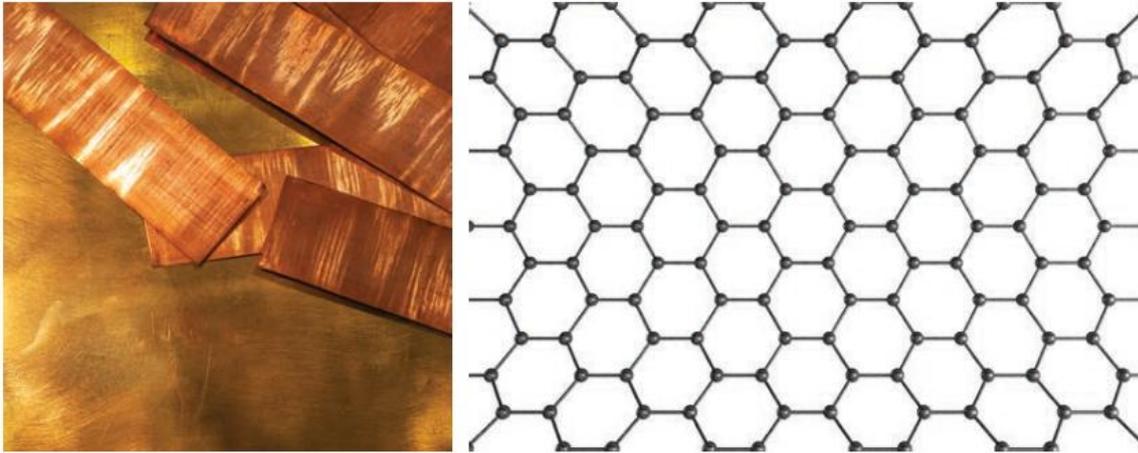
In groups of three or four, decide what kind of structure you would like to build. For example, you could build a beam bridge, an aeroplane, a building or a chair. Then conduct some research and brainstorm what kind of properties you need in the material used to build the product. Think about what kinds 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



**Figure 4.60** 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.

### Research and feasibility

- 1 Research the two composite materials: glass fibre-reinforced concrete (GFRC) and steel-reinforced concrete. Copy and complete the table below and add other properties you believe are important.
  - a What are the differences and what are the benefits of one material over the other?
  - b How would the discovery of each material change the way we use concrete?

	Glass fibre-reinforced concrete (GFRC)	Steel-reinforced concrete
Strength		
Benefits compared to concrete		
Temperature variance		

- 2 As a group, decide on a purpose for creating a new material for manufacture. Research the important properties and features the new composite material will require.

### Design and sustainability

- 3 List the ratios of each material used in the composite, and the method of manufacturing and testing your composite material. (Think about the properties of your materials and which material would be the best.)

- 4 Design the best possible method to create your new composite material.
- 5 Discuss the sustainability of your material, and its environmental impact. Your new material must have a positive environmental impact and be sustainable to manufacture.

### Create

- 6 Manufacture the composite material in the various ratios as set out in the design phase and allow to set if required.
- 7 Test your material by applying forces to your material. Record the type of force (such as gravity).

### Evaluate and modify

- 8 Evaluate the capabilities of the original material compared to those of the new material. Discuss and explain the difference.
- 9 What are the maximum forces that could be applied to each ratio? Explain the effect of the ratios of the single materials when used as a composite material.
- 10 Suggest ways to improve the composite material. Should another material be added? Should the ratios of the component materials be altered?
- 11 Predict how the composite material might behave if it was constructed differently but with the same materials.

# Chapter 5

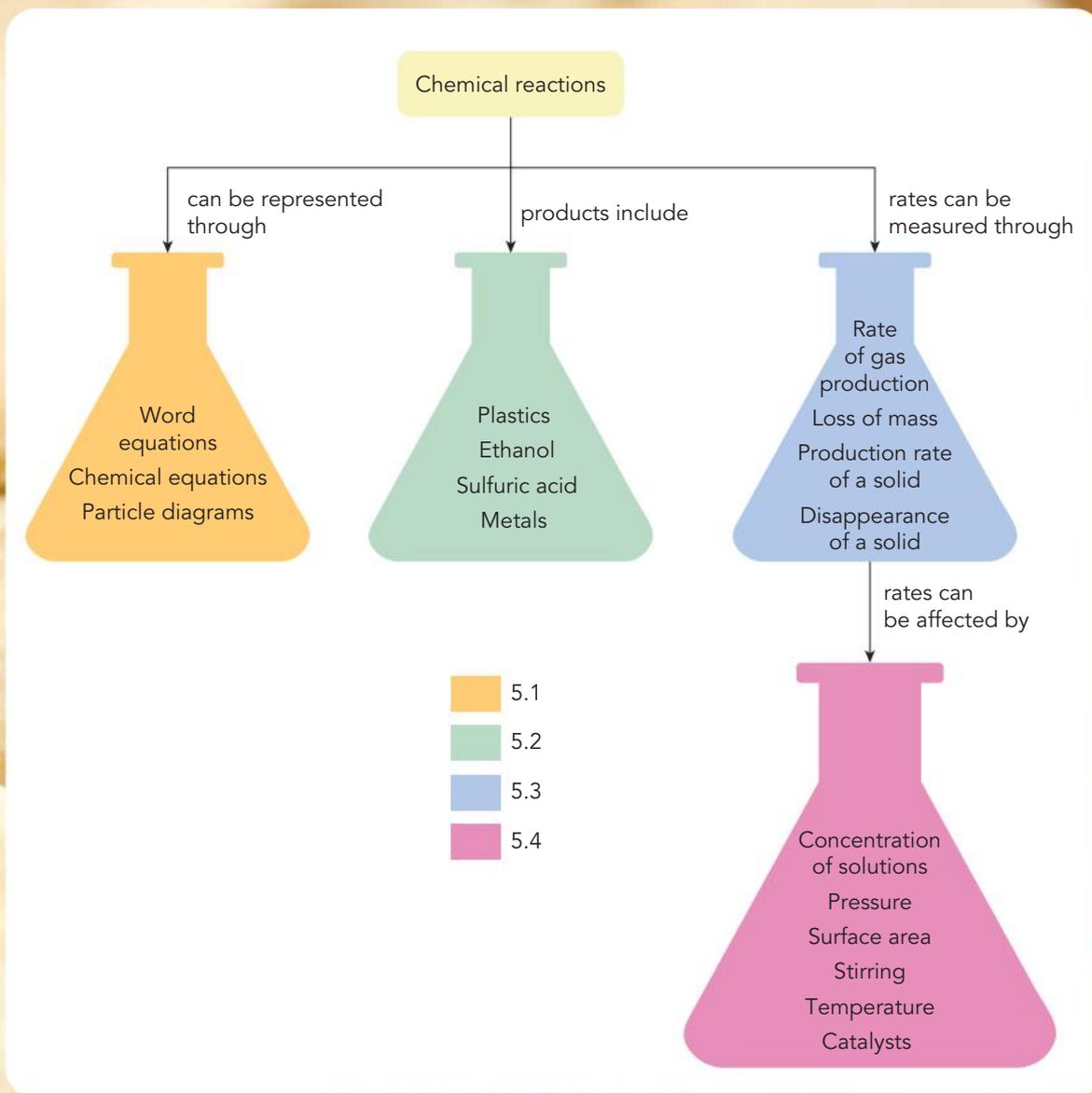
# Chemical reactions



## 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 required to produce these substances quickly and efficiently. In this chapter, you will learn how to represent chemical reactions as word and balanced chemical equations. You will investigate factors that can affect the rates of chemical reactions and how these rates can be monitored.

# Chapter map



# 5.1 Representing chemical reactions



## Learning goals

- 1 To be able to represent a chemical equation using word, formula and particle equations.
- 2 To be able to recall the correct use of state symbols in a formula equation.
- 3 To be able to balance a chemical equation.

### reactants

the chemicals that react together in a reaction

### products

the chemicals produced in a reaction

### word equation

a chemical reaction written using the names of the reactants and products involved

### chemical formula

chemicals written using their elemental symbols

In Year 9 you learned that in a chemical reaction, bonds are broken in **reactants** and new bonds are formed to make the **products**. Reactants are those chemicals that are being made to react and products are the chemicals that are produced in a chemical reaction. In this section, you will learn how to represent chemical reactions as word equations, balanced chemical equations and particle diagrams.

## Word equations

One way to represent a chemical reaction is with a **word equation**. Word equations are written with just the names of the reactants and products in the chemical equation. Below is the word equation for the reaction of two common chemicals you will have already used in your science lessons, an acid and a base. 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, when possible, you should write the reactants on the left and the products 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!

sodium hydroxide + hydrochloric acid → sodium chloride + water

## Quick check 5.1

- 1 What is wrong with the following word equation?  
 $\text{CO}_2 + \text{water} \rightarrow \text{glucose} + \text{oxygen}$
- 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.)
  - Just carry on to the next line, it does not matter where you write the reactants and products.
  - Rewrite the equation so it fits onto the piece of paper.
  - 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.
  - If it is too long, do not bother writing the word equation at all.

## Symbol equations

A second way of representing a chemical reaction is by writing a chemical equation using **chemical formulas**. These equations 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



**Figure 5.1** Iron is one of the elements with two letters in its chemical symbol. One is upper case (capital) the other is lower case. The symbol comes from its Latin name, ferrum.

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.

All the metallic elements on the periodic table exist as individual atoms on their own and are described as being **monatomic**, meaning one atom. However, many non-metallic elements do not exist on their own but instead 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 <sub>2</sub>
Nitrogen	N <sub>2</sub>
Oxygen	O <sub>2</sub>
Fluorine	F <sub>2</sub>
Chlorine	Cl <sub>2</sub>
Bromine	Br <sub>2</sub>
Iodine	I <sub>2</sub>

**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. These non-metal substances

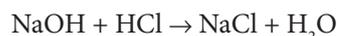
are called molecules. Substances with no subscript number after the chemical symbol have only one atom of that element present; for example, Ca represents just one atom of calcium.

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 the previous page 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<sub>2</sub>O). Using the symbols for these compounds, you can create a chemical equation like the one below.



This chemical equation shows you what is happening when the compounds sodium hydroxide and hydrochloric acid react. The atoms are rearranged to form two new compounds – sodium chloride and water.

**monatomic**  
one atom, sometimes spelled ‘monoatomic’

**diatomic**  
two atoms bonded together

### Quick check 5.2

- 1 What does the formula C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> tell you about one molecule of glucose?
- 2 Chlorine is a diatomic molecule. What does this mean?
- 3 Write a chemical equation with symbols for the reaction between iron (Fe) and chlorine (Cl<sub>2</sub>) to make iron chloride (FeCl<sub>2</sub>).

### State symbols

Chemical equations give you more information than word equations regarding the rearrangement of atoms within compounds. You can add more information to chemical 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.

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.

#### aqueous

a physical state of matter that means dissolved in water (e.g. salt water)

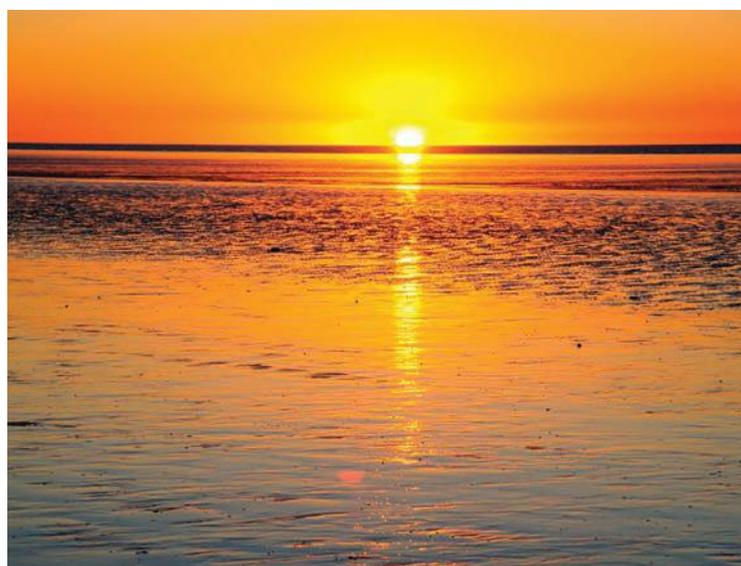
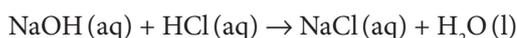
#### particle diagram

a representation of elements and compounds where atoms are drawn as balls or circles

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 solute dissolved in water. An example is salt water.

You can now make the chemical equation even more informative by adding in state symbols for the four substances in the equation.



**Figure 5.2** Seawater is an aqueous solution because salt (sodium chloride) is dissolved in the water.

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.

### Quick check 5.3

- 1 Why is salt water described as an aqueous solution?
- 2 Which two of the following compounds would be given the state symbol (s)?  
hydrogen gas, copper, sugar (glucose), hydrochloric acid

### Particle diagrams

Finally, you can also use **particle diagrams** to represent chemical reactions. Here, particle formula diagrams (pictures showing the arrangement of the atoms) are used. You can convert the chemical equation used previously to a particle diagram.

One of the advantages of using a particle diagram to represent a chemical reaction is that you can see how the atoms are bonded. For example, the formula for water is H<sub>2</sub>O.

This, however, only shows that water contains two hydrogen atoms and one oxygen atom. The particle diagram 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 particle diagram shown in Figure 5.3, the bond between the sodium and oxygen in sodium hydroxide and the bond between hydrogen and chlorine in hydrochloric acid have broken, and these atoms have bonded with other atoms to make different products.



**Figure 5.3** The particle diagram for the reaction between sodium hydroxide and hydrochloric acid

## Quick check 5.4

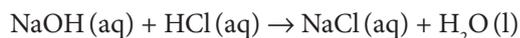
- 1 What are particle diagrams?
- 2 What is the main advantage of a particle diagram to represent chemical reactions?

## Balancing chemical equations

Chemical reactions must observe the law of conservation of mass, which states that mass is neither gained nor lost, but is always conserved. Therefore, the mass of reactants must equal the mass of the products. Atoms from the reactants cannot disappear, and similarly, atoms cannot just appear in the products.

A balanced chemical 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 particles can make it easier to pinpoint when equations are not balanced.

Look at the example equation used throughout this section:



To determine whether this equation is balanced or not, you need to count the number of each

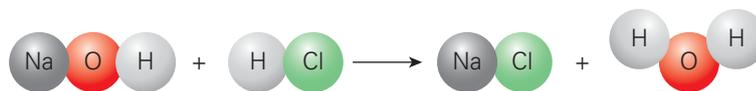


Figure 5.5 Particle diagram

	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.



Figure 5.4 Equations with the same number of reactant atoms as product atoms are said to be balanced.

atom on both sides of the equation. It helps to do this in a table (as shown in Table 5.3) and it can also be easier to use the particle diagram, shown 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.

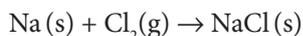


WIDGET  
Balancing  
chemical  
equations



VIDEO  
Indicators  
of chemical  
reactions

In the following example, solid sodium metal (Na) is reacting with chlorine gas (Cl<sub>2</sub>) to make solid sodium chloride (NaCl).



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.

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<sub>2</sub> 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. These cannot be altered.

What you have to do is add more 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 substance.

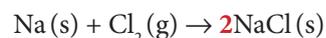
**coefficient**

the number placed before a molecule/formula unit in a chemical equation to ensure that it is balanced

For example, changing O<sub>2</sub>(g) to 2O<sub>2</sub>(g) means there are two molecules of oxygen gas instead of one.

The problem identified in the equation was that there were two atoms of chlorine in the

reactants, but only one in the products. To even out the number of chlorine atoms, you can add another unit of NaCl to the products, as shown here.

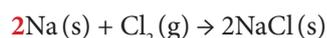


Use Table 5.5 to see if you have solved the problem.

	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 balanced now?

You have solved the original problem of the unbalanced chlorine atoms, but by adding another unit 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.



	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 unit of sodium chloride and a sodium atom, the equation is now balanced. All you have to remember is that the numbers before the chemical symbols (or **coefficients**) indicate the number of compounds/formula units, and the subscript numbers indicate the number of atoms within the compound/formula unit.

## Quick check 5.5

- Determine whether the following chemical reactions are balanced or unbalanced.
  - $\text{Fe} + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$
  - $\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}$
  - $\text{Zn} + \text{CuSO}_4 \rightarrow \text{Cu} + \text{ZnSO}_4$
  - $\text{Be} + \text{Cl}_2 \rightarrow \text{BeCl}_2$
- Describe an equation that is unbalanced.
- Balance these chemical equations. (Draw a particle diagram if you need to. To help you, the first two have spaces to show where you should add coefficients.)
  - $\_\_ \text{H}_2 + \text{O}_2 \rightarrow \_\_ \text{H}_2\text{O}$
  - $\_\_ \text{Mg} + \text{O}_2 \rightarrow \_\_ \text{MgO}$
  - $\text{Fe} + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$
  - $\text{Ca}(\text{OH})_2 + \text{HNO}_3 \rightarrow \text{Ca}(\text{NO}_3)_2 + \text{H}_2\text{O}$  (Hint:  $(\text{OH})_2$  means there are 2 oxygens and 2 hydrogens.)
- Write a chemical equation for the reaction between aluminium (Al) and chlorine ( $\text{Cl}_2$ ) to make aluminium chloride ( $\text{AlCl}_3$ ).

## Explore! 5.1

## The Haber process

The German scientist Fritz Haber and his assistant Robert Le Rossignol developed the Haber process, which was later industrialised by Carl Bosch. Haber was awarded a Nobel Prize for his efforts in 1918. The Haber process enabled the production of ammonia ( $\text{NH}_3$ ) on a large scale by reacting nitrogen ( $\text{N}_2$ ) gas with hydrogen ( $\text{H}_2$ ) gas under optimum conditions.

The largest ammonia plant in Australia is on the Burrup Peninsula in the Pilbara region of Western Australia; it produces around 330 000 tonnes each year. Ammonia is mainly used to make fertiliser.

- Write a word equation for the production of ammonia in the Haber process.
- Write a balanced symbol equation with state symbols.
- The Haber process is actually a reversible reaction. How is this represented in the word and symbol equations?
- Why is the large-scale production of ammonia so beneficial?



VIDEO  
Haber  
process

## Practical 5.1: Investigation

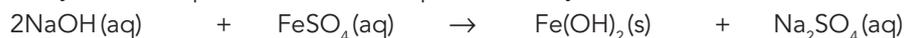
## Comparing theoretical equations with experimental data

## Aim

To consider the accuracy of experimental data compared with the theoretical outcome based on chemical equations.

## Useful formulas

sodium hydroxide(aq) + iron(II) sulfate(aq)  $\rightarrow$  iron(II) hydroxide(s) + sodium sulfate(aq)



calcium carbonate(s) + hydrochloric acid(aq)  $\rightarrow$  calcium chloride(aq) + water(l) + carbon dioxide(g)



## Be careful

Ensure appropriate personal protective equipment is used (safety glasses, disposable gloves, lab coat).

*continued...*

...continued

### Materials

- 4 mL of 1 mol L<sup>-1</sup> iron(II) sulfate solution
- 5 mL of 1 mol L<sup>-1</sup> hydrochloric acid solution
- 8 mL of 1 mol L<sup>-1</sup> sodium hydroxide solution
- small piece of calcium carbonate
- 2 × 10 mL measuring cylinders
- 2 × 50 mL conical flasks
- test tube
- 2 rubber stoppers
- thread
- balance

### Planning

Refer to the chemical reactions above. For each reaction, predict whether the mass will change during the reaction. Justify your reasoning for this based on details from the theoretical equation.

### Method

#### Part 1: Prepare the results table

- 1 Draw the table shown in the results section into your science journal.

#### Part 2: Measure the mass of the reactants and products of the reaction between iron(II) sulfate and sodium hydroxide

- 1 Record the level of uncertainty for the scales you are using in the results table.
- 2 Using a measuring cylinder, measure 8 mL of sodium hydroxide solution.
- 3 Using a second measuring cylinder, measure 4 mL of iron(II) sulfate solution.
- 4 Place the conical flask on the scales and press 'tare' to zero.
- 5 Pour the contents of both measuring cylinders into the conical flask.
- 6 Record the mass of the combined mixture.
- 7 Observe the chemical reaction take place and record observations.
- 8 When the reaction is finished, record the mass of the final products in the flask.

#### Part 3: Measure the mass of the reactants and products of the reaction between calcium carbonate and hydrochloric acid

- 1 Using a measuring cylinder, measure 8 mL of hydrochloric acid solution.
- 2 Place the conical flask on the scales and press 'tare' to zero.
- 3 Pour the hydrochloric acid into the conical flask. Add the calcium carbonate on the plate beside the flask.
- 4 Record the mass of the two reactants.
- 5 Add the calcium carbonate into the conical flask.
- 6 Observe the chemical reaction take place and record observations.
- 7 When the reaction is finished, record the mass of the final products in the flask.

### Results

- 1 Calculate the change in mass for each reaction and record it in the results table.
- 2 Calculate the range of uncertainty and record it in the table.

continued...

...continued

- 3 Calculate the relative uncertainty and record it in the table.

e.g. uncertainty =  $\pm 0.05$  g

$$\text{Relative uncertainty} = \frac{(\text{uncertainty value})}{(\text{average value})} \times 100 = \frac{0.05 \text{ g}}{2.50 \text{ g}} \times 100 = 2\%$$

Independent variable	Dependent variable					
	Initial mass (g)	Final mass (g)	Change in mass (g)	Uncertainty ( $\pm$ ____)	Relative uncertainty	Other observations
Reaction 1						
Reaction 2						

### Discussion

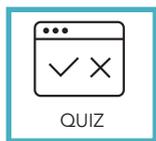
- Describe the change in mass for each of the groups using data.
- Discuss possible reasons for a change in mass in the two groups.
- Relate these results back to the law of conservation of mass and discuss any discrepancies.
- Discuss whether the experimental data supports the predicted outcome as shown in the chemical reactions above.
- Uncertainty is a measure of the variability in data. Describe the relative uncertainty for each of the groups.
- Identify possible limitations of this method.
- Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

## 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 $\rightarrow$ sodium chloride + water
Balanced chemical equation with state symbols	$\text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$
Particle diagram	

Table 5.7 Three ways a chemical equation can be represented



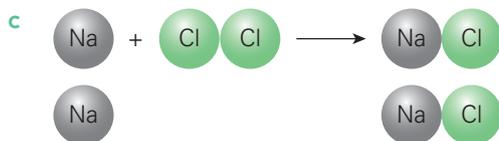
## Section 5.1 questions

## Remembering

1 **Identify** the type of equation shown in the following examples.

a carbon + oxygen  $\rightarrow$  carbon dioxide

b  $2\text{Ca(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{CaO(s)}$



2 **Name** the state symbols that would represent the following substances.

a Sodium chloride (salt)

b Sulfuric acid

c Water

d Nitrogen

3 **Identify** which of the following molecules are diatomic.

a  $\text{H}_2\text{O}$

b  $\text{CO}_2$

c  $\text{N}_2$

d  $\text{F}_2$

## Understanding

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 **State** the reactants in the reaction.

b **State** the products in the reaction.

c **State** the word equation.

5 **Identify** the coefficients in the equations below.

a  $2\text{Ca} + \text{O}_2 \rightarrow 2\text{CaO}$

b  $2\text{Fe} + 3\text{Cl}_2 \rightarrow 2\text{FeCl}_3$

c  $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$

6 **Describe** the composition of copper sulfate ( $\text{CuSO}_4$ ) in terms of the number of each type of atom.

7 **Explain**, using the term 'conservation of mass', why it is important that chemical equations are balanced.

## Applying

8 **Represent** different ways of writing a chemical reaction for the reaction between solid calcium (Ca) with liquid bromine ( $\text{Br}_2$ ) to form solid calcium bromide ( $\text{CaBr}_2$ ).

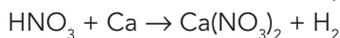
a Word equation

b Balanced chemical equation with state symbols

c Particle diagram

9 **Explain** why it is important that you only change coefficients of formulas of substances in a chemical equation and not the subscripts.

10 **Explain** why this chemical equation is unbalanced.

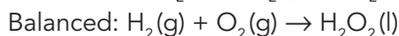
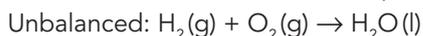
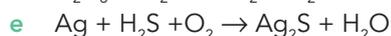
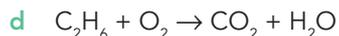
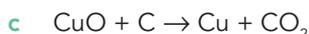
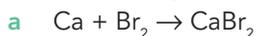


11 **Construct** a balanced symbol equation with state symbols for the reaction of potassium metal with oxygen to form solid potassium oxide ( $\text{K}_2\text{O}$ ).

12 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 than oxygen is produced in this reaction.

**Analysing****13 Compare** structural and chemical equations.**14 Analyse** the way the following equation has been balanced:**Evaluating****15 Decide** whether the following equations are balanced or unbalanced, and then correct the unbalanced equations.**5.2****Chemical reactions that produce useful products****Learning goals**

- 1 To explore useful chemical reactions to produce polymers, ethanol and sulfuric acid.
- 2 To be able to describe the use of chemical reactions in extraction and protection of metals.



In this section, we will discuss some important chemical reactions that produce useful substances.

Chemical reactions produce many 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 medical conditions.

**Explore! 5.2****Taxol: from yew tree to anti-cancer drug**

In 1962, scientists extracted chemicals from the bark of Pacific yew trees and found that the bark was toxic to living cells. They purified the active ingredient in the bark, which was found to be paclitaxel, and began



**Figure 5.6** Felled logs of Pacific yew trees. The bark is the sole source of the breast cancer drug paclitaxel, commonly sold as Taxol.

to test its biological action. It was not until 15 years later, in 1977, that scientists were able to confirm that paclitaxel had anti-tumour activity in mice. And it took another 15 years before the drug, Taxol, was approved for use in treating ovarian cancer and advanced breast cancer.

- 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 in humans.



**Figure 5.7** A Taxol drip is set up for this patient who has breast cancer.



VIDEO  
Fractional  
distillation –  
crude oil

## 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 with in school, to name only two uses. Plastics are incredibly useful, but because they do not biodegrade readily, they are bad for the environment when they are not disposed of correctly.

### monomer

a single unit that when joined together repeatedly make a polymer

### polymer

a long-chain molecule made of repeating subunits called monomers

### catalyst

a chemical that speeds up a chemical reaction by lowering the activation energy, and does not get used up in the process

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, abbreviated PE) is used

to make plastic shopping bags, and is one of the most common plastics used today. It is made by reacting ethene (also known as ethylene) monomers obtained from a chemical reaction of 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 PE.

Many other polymers, such as polyvinyl chloride (PVC) and polystyrene (in bean bags) are formed by similar methods. PVC has many applications, including credit cards, toys, pipes and shower curtains. Notice that the name of a polymer is often the monomer name with a prefix of 'poly'. This system of naming is consistent across a range of addition polymers, so that the polymer name is easy to predict from its monomer.



**Figure 5.8** Plastic packaging in use at a supermarket (top); plastic waste is bad for the environment (bottom).

### 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.

### Quick check 5.6

- 1 What is the name of the monomer that is used to make polyethene?
- 2 What is the name of the polymer made from combining methyl methacrylate monomers?
- 3 Why are plastics called polymers?

## Did you know? 5.1

**Fermentation of cycad seeds**

When James Cook's fleet arrived in Australia in 1770, many of his crew became very ill after consuming the toxic seeds of the cycad plant. Aboriginal and Torres Strait Islander peoples had already mastered the detoxification processes of the seeds. For example, the Noongar people of south-western Australia would soak and bury the fleshy red outer seedcoat (called the sarcotesta) for several weeks. This fermentation process reduces the toxins and enables the end-product (called by-yu) to be eaten.



**Figure 5.9** *Macrozamia fraseri* is a cycad that is native to Western Australia.

**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.

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 microorganism) breaks down glucose (a sugar) in the absence of oxygen to produce ethanol and carbon dioxide, shown in the following reaction.

glucose  $\rightarrow$  ethanol + carbon dioxide



This process is not only used to manufacture biofuels, but is also used in the production of beer and wine.

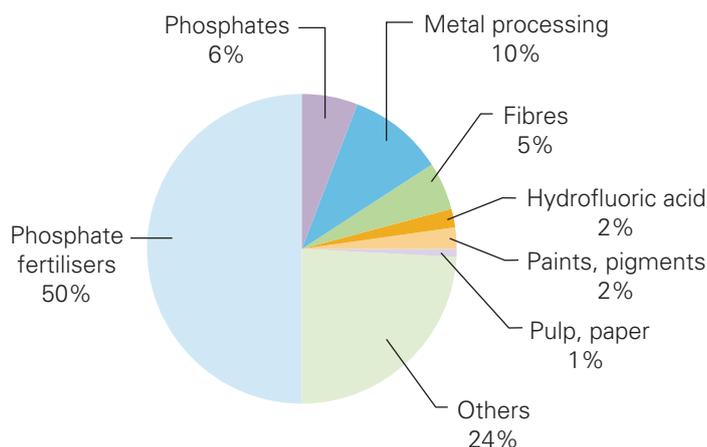
**Quick check 5.7**

- 1 Name the microorganism needed to break down sugars in fermentation.
- 2 What is the name of fuels that are made by fermenting sugars?

**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.

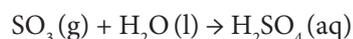
**biofuel**  
a fuel that is derived from living materials



**Figure 5.10** Sulfuric acid is required for the production of many substances.

To make sulfuric acid, sulfur is reacted (burned) with oxygen to make sulfur dioxide. The sulfur dioxide is then further reacted with oxygen, in the presence of a catalyst, to make sulfur trioxide, which is then reacted with water to produce sulfuric acid, as shown by the equation below.

sulfur trioxide + water  $\rightarrow$  sulfuric acid



### Quick check 5.8

- 1 Give two uses for sulfuric acid.
- 2 Name the reactants used in the final reaction that produces sulfuric acid.

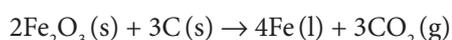
## Making metals

### 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 from iron oxide in a blast furnace. Here, iron oxide (in iron ore) is reacted with carbon to produce iron and carbon dioxide.

**galvanising**  
coating iron or steel with a protective layer of zinc

iron oxide + carbon  $\rightarrow$  iron + carbon dioxide



Of the metal that is refined today, 90 per cent is iron, with most of it being used to manufacture steel. Steel is softer, but stronger and less brittle than iron, and therefore has a wider variety



Figure 5.11 Steel sleeves produced for car suspensions

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.

### Protecting metals

**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 5.2: Investigation

### Investigating the effectiveness of different sacrificial metals to prevent corrosion

#### Aim

To determine how the rate of corrosion on an iron nail is affected when combined with other metals.

#### Prior understanding

When a metal corrodes, atoms at the surface of the metal lose electrons and change to metal ions. As a result, a solid compound

#### Be careful

Ensure appropriate personal protective equipment is worn.  
There is risk of injury from hot agar, chemicals and the Bunsen burner.

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containing metal ions forms on the surface of the metal. The corrosion or rusting of iron occurs when iron is in contact with water and oxygen. Initially, some iron atoms lose electrons to form iron(II) ions,  $\text{Fe}^{2+}$ . Oxygen and water then accept the electrons to form hydroxide ions,  $\text{OH}^-$ . The  $\text{Fe}^{2+}$  and  $\text{OH}^-$  ions will then combine, forming a precipitate of iron(II) hydroxide,  $\text{Fe}(\text{OH})_2$ . This precipitate will further react with more oxygen and water, forming iron(III) hydroxide,  $\text{Fe}(\text{OH})_3$ . This will then change to hydrated iron(III) oxide or rust.

In this investigation, potassium hexacyanoferrate forms a blue colour where the iron is losing electrons, indicating where the rusting of iron is occurring. When iron is in contact with a more reactive metal, this metal will rust instead of the iron, therefore protecting the iron. Metals like this are known as sacrificial metals. Phenolphthalein (an acid–base indicator) turns pink in any region where oxygen is taking electrons, indicating where the corrosion of any metal is taking place.

## Materials

### Part 2: Make up the agar mixture

(Can be prepared beforehand by technicians)

- 2 mL potassium hexacyanoferrate(III) ( $0.1 \text{ mol L}^{-1}$ )
- 2 mL of 0.1% phenolphthalein indicator
- 2 g agar
- 200 mL water
- 10 mL measuring cylinder
- 250 mL measuring cylinder
- 500 mL beaker
- stirring rod
- Bunsen burner
- bench mat
- tripod
- gauze mat
- heat-resistant gloves
- balance
- weighing boat
- disposable gloves

### Part 3: Test the iron nail

- 2 × 6 cm zinc strips
- 2 × 6 cm tin strips
- 2 × 6 cm copper strips or copper wire
- 2 × 6 cm magnesium ribbon
- 10 clean iron nails
- 5 Petri dishes and lids
- emery paper
- pliers
- sticky tape
- black marker pen
- disposable gloves
- 5 mm graph paper with bold lines

## Planning

- 1 Write a rationale that includes information about metal corrosion and sacrificial metals.
- 2 Develop a hypothesis by predicting how a change in the type of sacrificial metal will affect the corrosion of iron.
- 3 Write a risk assessment for this investigation.

## Method

### Part 1: Prepare the results table

- 1 Draw the table shown in the results section into your science journal.
- 2 Identify and label the independent variable and its independent variable groups in the table in terms of the position of each element on the periodic table. You will need to refer to the periodic table (or an online version like [pstable.com](http://pstable.com)).
- 3 Identify and label the dependent variables in the table.
- 4 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.

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### Part 2: Make up the agar mixture

- 1 Measure 200 mL of water in a 250 mL measuring cylinder and pour it into the 500 mL beaker.
- 2 Heat the water on top of the bench mat, Bunsen burner, tripod and gauze mat as shown in Figure 5.12.

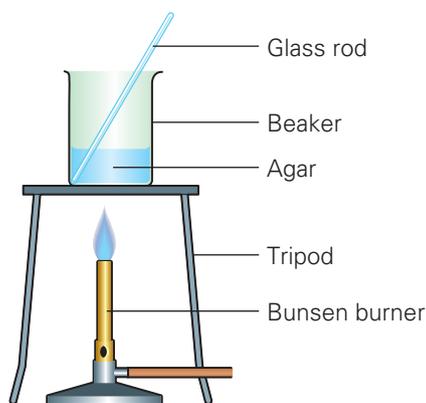


Figure 5.12 Making the agar mixture

- 3 Using the balance, weigh out 2 g of agar into the weighing boat.
- 4 Remove the beaker of water from the heat and stir in the agar using the stirring rod.
- 5 Return the beaker of agar solution to low heat and stir thoroughly to ensure the agar fully dissolves.
- 6 Using the 10 mL measuring cylinder, measure 2 mL of 0.1 mol L<sup>-1</sup> potassium hexacyanoferrate(III) and 2 mL of 0.1% phenolphthalein indicator, and add them to the agar mixture, stirring thoroughly.

### Part 3: Test the iron nail

- 1 While the agar is cooling, clean the iron nails with emery paper and place one of them on one side of one of the Petri dishes. This will be your control.
- 2 Bend another nail with pliers into a right angle. Place this in the other side of your control Petri dish.
- 3 Clean the surface of the zinc strip with the emery paper and wrap it around the other nail tightly so that the zinc is in full contact with the iron. Put this nail on one side of the second Petri dish. Add another zinc-covered nail to the other side.
- 4 Repeat step 3 with the copper, tin and magnesium.
- 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. Label with your group name and the metal being tested.
- 8 Leave the dishes overnight and observe their appearance the next day. Record your observations in the results table.

### Results

#### Calculate the mean area of corrosion for each group.

- 1 Place each Petri dish on top of the 5 mm graph paper and count the number of squares covered in blue and pink for each of the nails. Record in your table. (If purple, count as a half for each colour.)
- 2 Calculate the mean area for each group and record it in the results table.
- 3 Draw **two** graphs to analyse the relationship between the groups and the coloured area. Use a separate spreadsheet for each dependent variable (pink area and blue area).

continued...

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- Calculate the uncertainty for the trials.
- Optional: Format the graph and insert a copy below the results table in your science journal.

### Part 1

Independent variables	Dependent variables									
	Trial 1			Trial 2			Calculations			
	Pink area	Blue area	Other observations	Pink area	Blue area	Other observations	Mean pink area	Uncertainty	Mean blue area	Uncertainty
Group 1 (control)										
Group 2										
Group 3										
Group 4										
Group 5										

### Part 2

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	
Bent nail and agar mixture only	
Iron nail wrapped in zinc and agar mixture	
Iron nail wrapped in tin and agar mixture	
Iron nail wrapped in copper and agar mixture	
Iron nail wrapped in magnesium and agar mixture	

### Discussion

- Discuss the results in the phenolphthalein (pink) variable. This indicates corrosion of ANY metal has occurred. Compare the mean corrosion in each of the different groups. Justify your response with data.
- Discuss the results in the potassium hexacyanoferrate variable. This indicates corrosion of IRON has occurred. Compare the mean corrosion in each of the different groups. Justify your response with data.
- Determine which metal is most effective at protecting iron from corrosion. Justify your response with data.
- Describe the uncertainty for each group. Were they within acceptable levels? Justify your response with data.
- Discuss the limitations of this investigation.
- Were there other variables that may have affected the reliability of these results? Explain your reasoning.
- Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

### Conclusion

- Propose a valid conclusion that can be drawn from these results.
- Justify this conclusion using data from your results.
- State whether or not your hypothesis is supported.
- Explain your findings using your scientific knowledge.

## Science as a human endeavour 5.1

**From tyres to biofuel**

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 an iron compound).

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 is 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.

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. In 2017, a stockpile of 15 000 tyres was found on a property near the Great Barrier Reef. The government only realised this after purchasing the \$7 million cattle station. These tyres were recycled by a company near Ipswich before being reprocessed and converted into fuel.

While it is more expensive to convert the tyres than simply stockpiling them, it is less dangerous and far more environmentally friendly to recycle them. Tyres are highly combustible and once they start to burn, they are incredibly difficult to extinguish. One tyre fire in Wales burned continuously for 15 years! When tyres burn, high levels of chemical toxins such as cyanide, carbon monoxide, sulfur dioxide and heavy metals are released into the environment. Interestingly, stockpiled tyres also provide a breeding ground for mosquitoes that can spread diseases such as dengue fever, Australian encephalitis, Ross River virus disease and Barmah Forest virus.



Figure 5.13 Burning coke in a blast furnace



Figure 5.14 Stage 2 opening of the New Acland Coal Mine in Muldu, Queensland



Figure 5.15 The 15 000 used tyres dumped on a property in Springvale Station, north of Cairns, were converted into fuel.

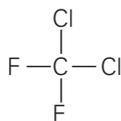
## Manufacturing chlorofluorocarbons

**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.

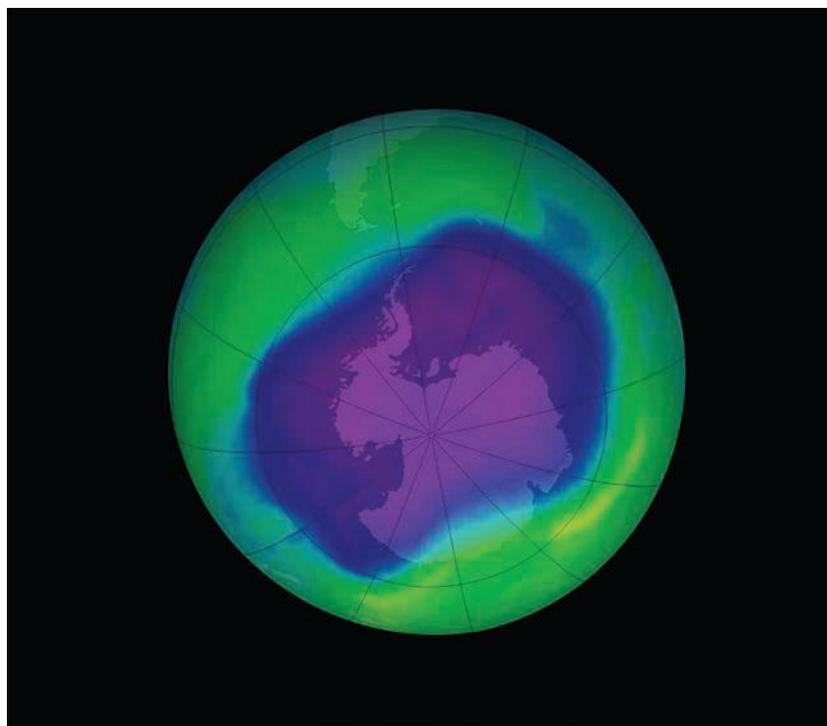
Scientists first thought that CFCs would be harmless to Earth's atmosphere because they are very unreactive and insoluble in water, and so are very stable. However, in the late 1970s, scientists found that higher up in Earth's atmosphere, where the Sun's ultraviolet (UV) light waves are more intense, the CFCs break down into highly reactive chlorine radicals, i.e. single chlorine atoms (Cl not Cl<sub>2</sub>). These radicals can damage Earth's ozone layer, which protects us from cancer-causing UV radiation.

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 restored by the middle of the 21st century.



**Figure 5.16** 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.



**Figure 5.17** The hole in the ozone layer above Antarctica. The blue and purple colours are where there is the least ozone.



**Figure 5.18** The 28th Meeting of the Parties to the Montreal Protocol in Kigali, Rwanda, in 2016

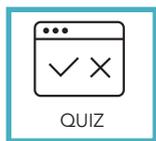
### Quick check 5.10

- 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.

**chlorofluorocarbons**  
chemicals containing atoms of carbon, chlorine and fluorine that are non-toxic and non-flammable

## Section 5.2 questions

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### 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 **Recall** the elements and molecules used to produce sulfuric acid.
- 4 **Recall** the elements present in all alcohols.
- 5 **Name** the layer of Earth's atmosphere that is damaged by CFCs.

### Understanding

- 6 **Explain** the detrimental effect of CFCs on Earth's atmosphere.
- 7 **Summarise** what happens when ethene monomers are reacted under high temperatures and pressures in the presence of a catalyst.
- 8 **Explain** why iron is often coated in a layer of zinc.

### Applying

- 9 **Describe** how you could model polymerisation using paperclips.
- 10 **Construct** a balanced chemical equation to show the reaction of iron oxide with carbon in a blast furnace.

### Analysing

- 11 **Compare** 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 changes in government policies and social behaviour in relation to the use of chlorofluorocarbons (CFCs).

### 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

## Learning goals

- 1 To be able to calculate the reaction rate of a chemical reaction.
- 2 To be able to list methods to measure gas production or loss.
- 3 To be able to list methods to measure solid production or consumption.



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). For example, the units for rate of reaction may be given as  $\text{g s}^{-1}$  or  $\text{mL s}^{-1}$ . The quicker a product forms or a reactant is used up, the greater 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

### 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 5.19 shows the set-up for this method of measuring reaction rates.

In this example, the magnesium reacts with the acid to produce hydrogen gas, which travels through the delivery tube and collects in the

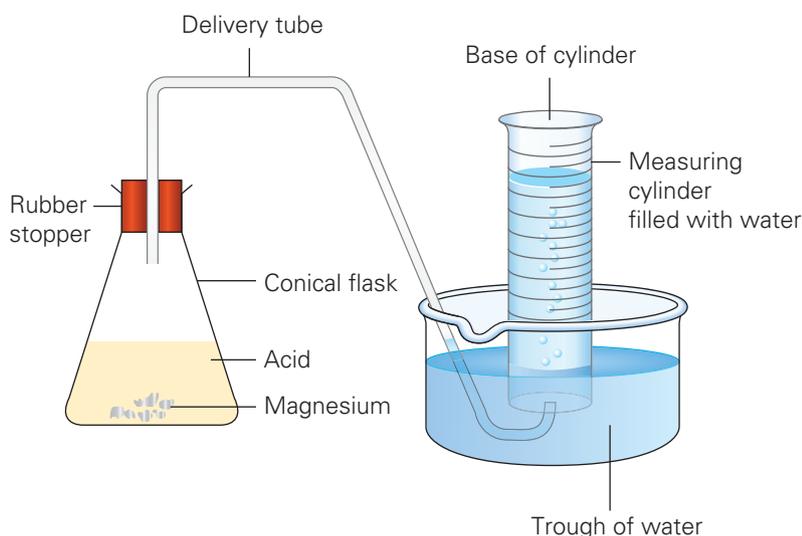


Figure 5.19 Diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

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  $\text{mL s}^{-1}$ .

#### reaction rate

the quantity of reactant used up or product made per unit time; how fast the reaction goes

### Gas syringe

Gas syringes directly collect the volume of gas produced by a reaction. Figure 5.20

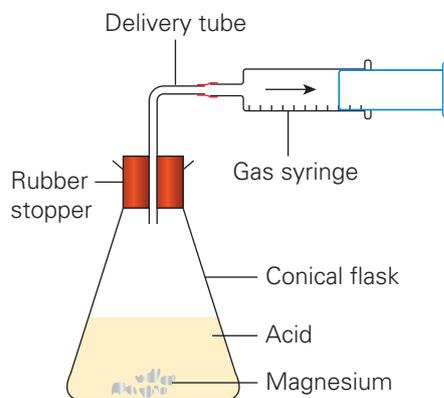


Figure 5.20 Diagram showing how to set up a gas syringe to monitor reaction rate

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  $\text{mL s}^{-1}$ . Gas syringes are more accurate than measuring cylinders, but they may not be as practical depending on the amount and rate of gas produced.

### Quick check 5.11

- Determine which of the following reactions can have their rate monitored using a gas syringe. Give reasons for your choice.
  - $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
  - $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $\text{Zn}(\text{s}) + \text{CuSO}_4(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{ZnSO}_4(\text{aq})$
  - $2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
- Why is a gas syringe better than an upturned measuring cylinder for measuring reaction rate?
- 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  $\text{g s}^{-1}$ . This method relies on gas loss into the atmosphere, so it can only be used for reactions that produce a gas.

Note that hydrogen gas is an asphyxiant and can explosively ignite in the atmosphere, so the use of

a fume hood is required (using or producing any hazardous substance should always be done under a fume hood to reduce exposure).

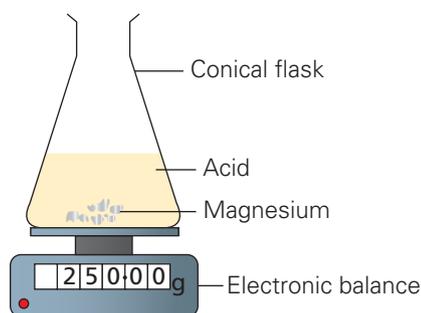


Figure 5.21 A diagram showing how reaction rate can be monitored by measuring loss of mass

### Quick check 5.12

- Determine which of the following reactions can have their rate monitored by measuring the loss of mass. Give reasons for your choice.
  - $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
  - $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $\text{Zn}(\text{s}) + \text{CuSO}_4(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{ZnSO}_4(\text{aq})$
  - $2\text{H}_2\text{O}_2(\text{l}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
- Why is using an electronic balance more accurate than using a gas syringe or upturned measuring cylinder?
- What are the units of rate when measuring the loss of mass in a reaction?

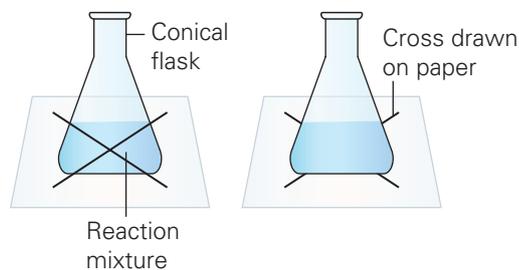
## Measuring the rate of solid production

The rate of the production of a solid in a reaction can be used as a way of monitoring the reaction rate. This can be done by collecting the precipitate and weighing it, and thus producing a reaction rate in grams per second,  $\text{g s}^{-1}$ .

However, in reality, it is not practical to collect a precipitate and weigh it as it is being formed because it forms in solution.

Another way for comparing relative reaction rates can be seen in the set-up in Figure 5.22. 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 5.22** A diagram illustrating how to monitor the relative rate of a reaction in which a solid product is formed

### Quick check 5.13

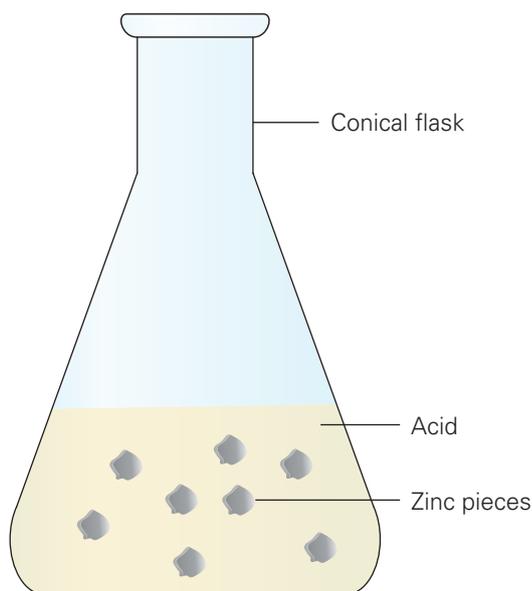
- Determine which one or more of the following reactions can have their relative rate monitored using the time taken for a cross to disappear as shown in Figure 5.22. Give reasons for your choice.
  - $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
  - $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $2\text{HCl}(\text{aq}) + \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) \rightarrow \text{S}(\text{s}) + \text{SO}_2(\text{g}) + 2\text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
- What are the units of relative rate when measuring the production of a solid in a reaction?

## Measuring rate of solid consumption

It is possible to record the time taken for a solid reactant to react with a liquid or solution. The weight of the solid is recorded at the start. Then the solid is placed into the liquid or solution. If the liquid is clear enough for the solid pieces to be observed, then the time taken for the solid to disappear can be recorded. The unit of rate for the consumption of solid is grams per second,  $\text{g s}^{-1}$ .

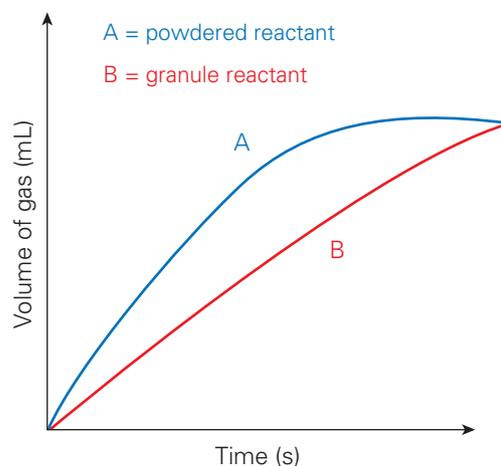
## Graphing experimental data

A number of measurements of mass or volume need to be collected at regular time intervals during the course of the reaction. After collecting data, graphs can be plotted to provide more information on the rate of a chemical reaction. The steeper the gradient of a graph, the faster the rate.



**Figure 5.23** A reaction containing a solid and a liquid reactant can be monitored by eye if the solid pieces are large enough to be observed.

Consider the reaction between solid calcium carbonate and hydrochloric acid. The graph in Figure 5.24 shows that using powdered calcium carbonate produces a greater rate of reaction as it has a steeper gradient than when the calcium carbonate is in granule form.



**Figure 5.24** A graph showing the effect of surface area on the volume of gas produced over time

### Practical 5.3: Teacher demonstration

#### Monitoring reaction rates

##### Aim

To determine how the surface area of zinc affects the rate of reaction with nitric acid, by using the upturned measuring cylinder technique.

##### Prior understanding

Although you are changing the mass of zinc in this experiment, you are actually changing the surface area of the metal. In this experiment, the nitric acid is in excess to each of the masses of zinc, so by increasing the mass, you are actually increasing the surface area. By measuring the volume of gas produced after one minute, the effect of increasing the surface area of the zinc on the reaction rate can be determined.

##### Materials

- zinc powder
- nitric acid (2 mol L<sup>-1</sup>)
- 25 mL measuring cylinder
- 50 mL measuring cylinder
- 250 mL conical flask
- large bowl
- 1 rubber stopper and delivery tube
- weighing boat
- bosshead and clamp
- electronic balance
- stopwatch

##### Planning

Write a hypothesis for your investigation regarding the effect that the mass of zinc will have on the rate of the reaction.

##### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Half fill the large bowl with water.
- 3 Fill a 50 mL measuring cylinder with water and carefully invert it in the large bowl of water. Do not lose any water out of the measuring cylinder.
- 4 Clamp the measuring cylinder in place using a bosshead and clamp.
- 5 Using the 25 mL measuring cylinder, measure 20 mL of 2 mol L<sup>-1</sup> nitric acid and pour the acid into the conical flask.
- 6 Using the electronic balance, measure 0.5 g of zinc powder into a weighing boat.

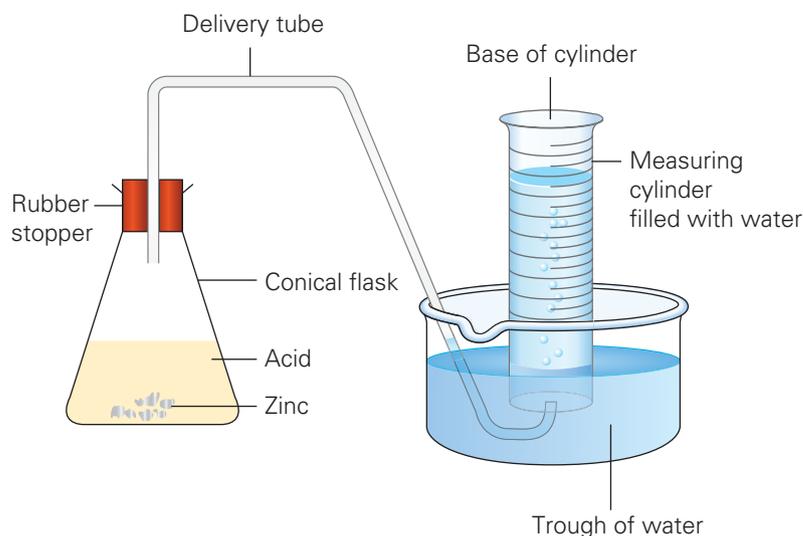
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#### Be careful

Ensure appropriate personal protective equipment is worn.

...continued

- 7 Set up the delivery tube so the end without the bung runs underneath and into the upturned measuring cylinder (see Figure 5.25 to help you).



**Figure 5.25** A diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

- 8 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.
- 9 After one minute, record the volume of water displaced from the measuring cylinder. This is the same as the volume of gas produced.
- 10 Repeat once more with the same mass of zinc powder.
- 11 Repeat the steps for the other masses of zinc powder.

### Results

Mass of zinc (g)	Volume of gas collected after 1 minute (mL)		
	1	2	Mean
0.50			
1.00			
1.50			
2.00			

### Discussion

- 1 Calculate the mean 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 (that is, surface area) of zinc and reaction rate?
- 6 Write a balanced chemical equation with state symbols for the reaction between zinc metal (Zn) and nitric acid (HNO<sub>3</sub>) to form zinc nitrate (Zn(NO<sub>3</sub>)<sub>2</sub>) and hydrogen (H<sub>2</sub>).
- 7 List other methods you could have used to monitor the rate of this reaction.

continued...

...continued

### Conclusion

- 1 Make a claim about the effect of the surface area 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.

## Explore! 5.3

### Using colorimetry to monitor reaction rates

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.

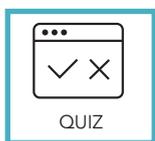
propanone + iodine  $\rightarrow$  iodopropanone + hydrogen iodide

- 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).



Figure 5.26 A scientist placing a sample for testing in a colorimeter

## Section 5.3 questions



### Remembering

- 1 **Name** two ways of monitoring the production of a gas from a chemical reaction.
- 2 **State** the units of rate for the following methods of measuring reaction rates.
  - a Loss of mass
  - b Production of a solid
  - c Gas syringe

### Understanding

- 3 **Identify** the correct word to complete the following sentences.
  - a The greater the rate of reaction, the \_\_\_\_\_ the reactants are used up.
  - b The steeper the gradient on a volume versus time graph, the \_\_\_\_\_ the rate of reaction.

- 4 **Identify** the time period during the experiment shown in Figure 5.27 that shows the fastest rate of reaction. Justify your choice.

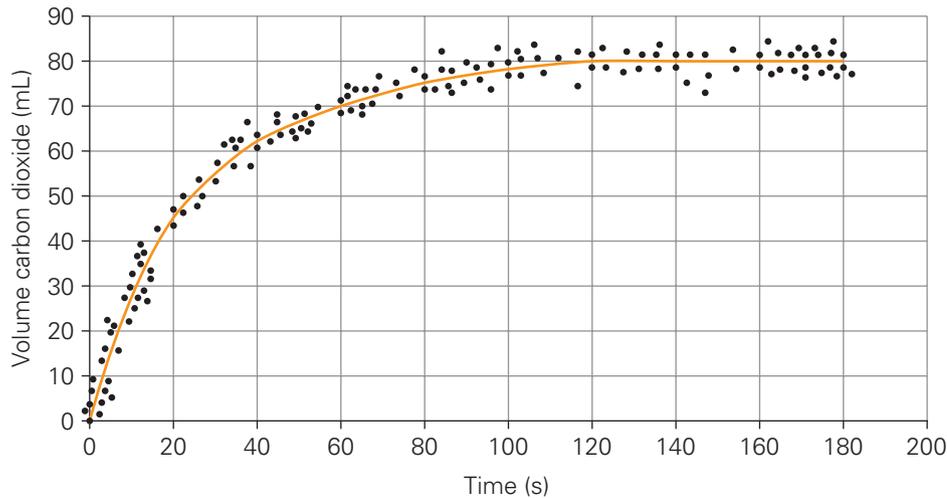


Figure 5.27 Graph of experiment

- 5 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.

#### Applying

- 6 **Describe** what is meant by the term 'rate of reaction'.
- 7 **Explain** why the rate of reaction is greatest at the beginning.
- 8 **Illustrate** the rest of the diagram in Figure 5.28 to show how a gas can be collected, and, therefore, the rate of reaction measured. Label the equipment in the diagram.

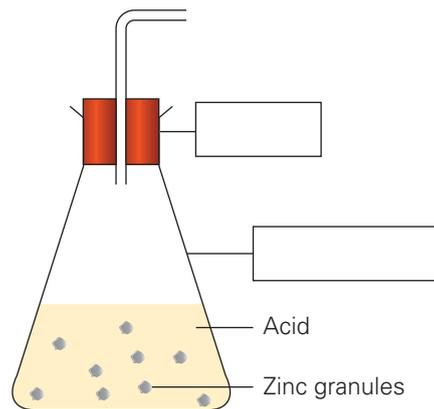


Figure 5.28 Diagram of gas collection

#### Analysing

- 9 **Contrast** the rates of reaction for the three experiments shown in Figure 5.29.

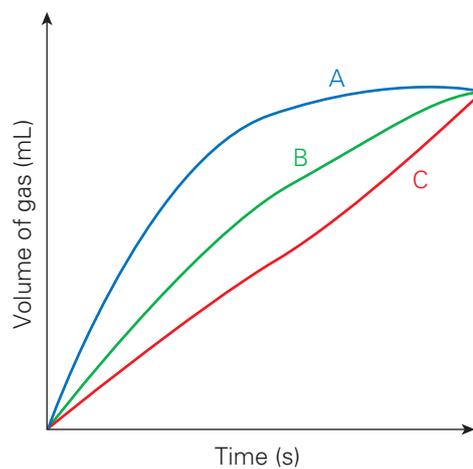


Figure 5.29 Rates of reaction graph

- 10 **Analyse** how stirring the reaction mixture affected the rate of the chemical reaction shown in Figure 5.30.

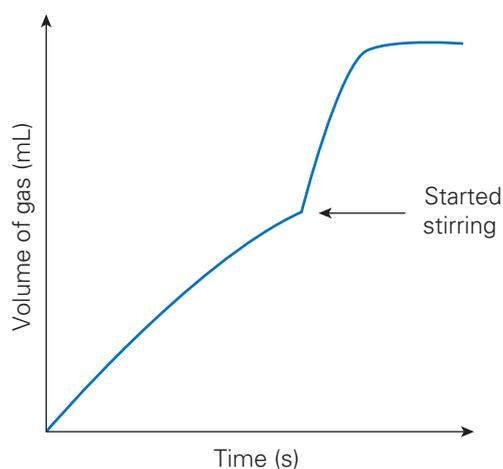
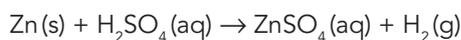


Figure 5.30 Rates of reaction graph before and after stirring

### Evaluating

- 11 **Determine** the most accurate technique to monitor the rate of this chemical reaction, giving reasons for your choice.



- 12 The volume of carbon dioxide produced in an experiment was graphed, as shown in Figure 5.31.
- Deduce**, using your knowledge of chemical reactions, why between 120 and 180 seconds the volume of carbon dioxide stays the same in this experiment.
  - Decide** the value for the rate of the reaction during the time period between 120 and 180 seconds.

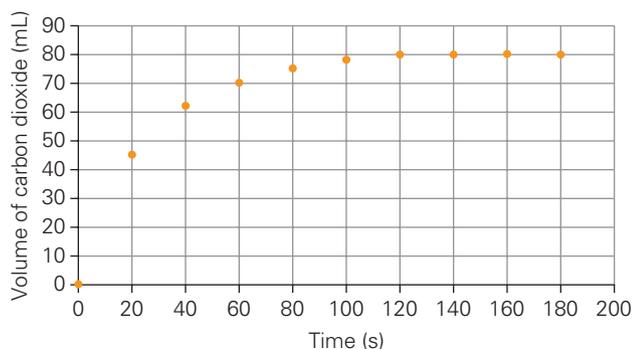


Figure 5.31 Graph of the volume of carbon dioxide produced in experiment

## 5.4

## Factors affecting reaction rates

## Learning goals

- 1 To be able to describe how six factors affect the frequency of collisions between reacting particles.
- 2 To be able to describe how six factors affect the rate of a chemical reaction.
- 3 To be able to define the role of a catalyst in a chemical reaction.



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 per unit of time) 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 State two requirements for a successful chemical reaction.
- 2 Define the term 'activation energy'.

**Figure 5.32** Industrial chemical plants rely on knowledge of reaction rates to produce maximum amounts of product in minimal amounts of time.



## Concentration

The **concentration** of a solution is a measure of the number of particles per unit volume. It is measured as moles per litre ( $\text{mol L}^{-1}$ ) where moles is related to the amount of solute. (You may also see the units written as a capital M, it is the same as  $\text{mol L}^{-1}$ .)

A solution that contains a relatively large number of solute particles within a given volume of solvent is called a

**concentrated solution**. Likewise, a solution that contains a relatively small number of solute particles within a given volume of solvent is called a **dilute solution**. Increasing the concentration of a solution means that you are putting more particles into the same volume.

### concentration

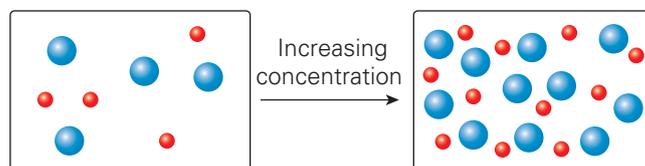
the amount of substance in a given volume

### concentrated solution

a solution that contains a large amount of solute compared to solvent

### dilute solution

a solution that contains a small amount of solute compared to solvent



**Figure 5.33** Increasing the concentration of a solution increases the number of particles within 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.

## Quick check 5.15

- 1 Decide whether the following statements are true or false. If false, give a reason why.
  - 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 5.4

### Concentration and reaction rate

#### Aim

To determine how changing the concentration of sodium thiosulfate affects the rate of reaction with hydrochloric acid.

#### Materials

- hydrochloric acid ( $2 \text{ mol L}^{-1}$ )
- sodium thiosulfate solution ( $0.15 \text{ mol L}^{-1}$ )
- 250 mL conical flask
- 10 mL measuring cylinder
- 50 mL measuring cylinder
- stirring rod
- 1 piece of white paper
- black marker pen
- stopwatch

#### Be careful

Ensure appropriate personal protective equipment is worn. This experiment must be performed in a fume hood. Do not breathe in fumes when making observations.

*continued...*

...continued

### Planning

Construct a hypothesis regarding how the sodium thiosulfate concentration will affect the reaction rate.

### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Using the black marker, draw a large 'X' on the paper.
- 3 Using a 50 mL measuring cylinder, measure 50 mL of sodium thiosulfate and pour it into the 250 mL conical flask. In the fume hood, centre the conical flask on the black cross (Figure 5.34).
- 4 Using the 10 mL measuring cylinder, measure 5 mL of hydrochloric acid.
- 5 Pour the acid into the conical flask, stir with a stirring rod and start the stopwatch.
- 6 Stop timing when the cross is no longer visible and record the time in your results table.
- 7 If available, dispose of the reaction mixture in a fume hood, otherwise pour it down the sink, rinsing with lots of cold water (taking care not to splash).
- 8 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  $0.15 \text{ mol L}^{-1}$ ); however, adding water dilutes the solution.

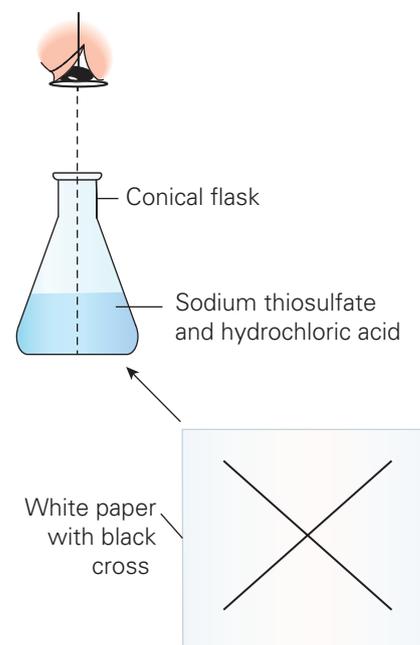


Figure 5.34 Diagram of centring the 'X' under the conical flask

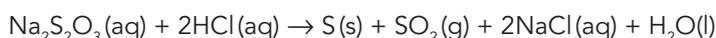
### Results

Concentration of sodium thiosulfate ( $\text{mol L}^{-1}$ )	Volume of sodium thiosulfate (mL)	Volume of water (mL)	Time taken for cross to disappear (s)	Reaction rate $\frac{1}{\text{time}}$ ( $\text{s}^{-1}$ )
0.15	50	0		
0.12	40	10		
0.09	30	20		
0.06	20	30		
0.03	10	40		

- 1 Work out the relative rate of the reaction by calculating:  $\frac{1}{\text{reaction time}}$ .
- 2 Plot a graph of concentration (x-axis) versus rate (y-axis).

### Discussion

- 1 Using your graph, describe how increasing the concentration of sodium thiosulfate affects the rate of this chemical reaction.
- 2 Explain why increasing the concentration of a reactant normally increases the rate of reaction.
- 3 Explain why the disappearing cross method was suitable for this reaction, using the equation below:

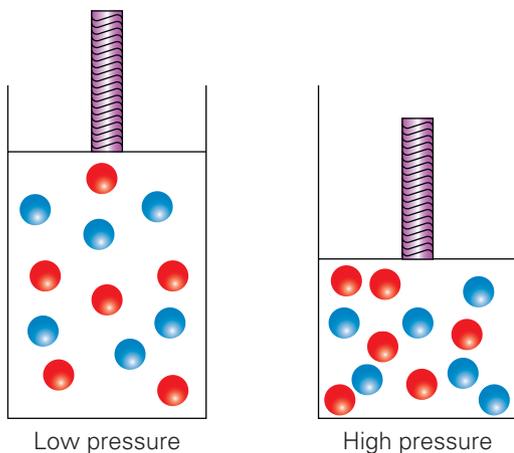


### Conclusion

- 1 State a conclusion regarding the concentration of sodium thiosulfate and the effect this has on the rate of reaction.
- 2 Support your statement by using the data you gathered.

## Pressure

To increase the **pressure** of gaseous molecules, you can increase the number of particles and/or decrease the volume of the container.



**Figure 5.35** 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.

**pressure**  
the force produced by collisions of gas particles per unit area of the container walls

**surface area**  
the area of the outer part or surface of an object

### Quick check 5.16

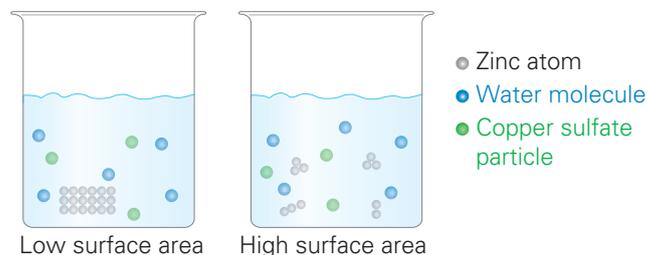
- 1 Describe why increasing the pressure of solid and liquid reactants does not affect reaction rate.
- 2 Describe how the pressure of a gas can be increased.

## 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 it into pieces or grinding it into a powder, then the **surface area** is increased and more particles are exposed. Imagine a cake: when its surface area is increased by cutting into smaller pieces, there is a greater area of the cake exposed to the air; and therefore, it will dry out more quickly.



**Figure 5.36** Cutting a cake into pieces increases its surface area.



**Figure 5.37** 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 affected.

### Did you know? 5.2

#### Swallow, don't crush

The pharmaceutical industry manufactures a wide variety of specific medicines through chemical reactions to help an immune response or reduce pain. Often pharmaceutical medicines are sold in tablet form and are meant to be swallowed in that form – not crushed. The chemicals in the tablet can react with stomach acid to release the active ingredients into the bloodstream in a controlled fashion. However, if the tablet is crushed, the surface area of the reactant is increased and this reaction in the stomach becomes much faster and less controlled. Therefore, there is a possibility of overdosing, or other side effects may occur, as the medicine may be released into the body too quickly. Moreover, it might also render the medicine less effective. Pharmaceuticals in tablet form are designed, not only to provide you relief from illness, but also to provide the medicine in the right amount of time.



**Figure 5.38** If swallowing tablets is difficult, it may be worthwhile asking a pharmacist whether the medicine comes in other forms.

### Quick check 5.17

- 1 List two ways that the surface area of a solid can be increased.
- 2 A chemical reaction contains two different gaseous reactants. Justify whether increasing their surface area will increase the reaction rate.
- 3 Explain why increasing the surface area of a solid reactant increases the reaction rate.

### Try this 5.2

Make three cups of hot weak tea (so you can still see the bottom of the cup), filled to the same height. Place a sugar cube in cup 1, a level teaspoon of granulated sugar in cup 2 and a level teaspoon of icing sugar in cup 3. Time how long it takes for the sugar in each cup to dissolve. After reading this section, you should be able to make a prediction about surface area and rate at which sugar dissolves.



**Figure 5.39** Sugar comes in various forms for various uses.

**Practical 5.5: Investigation****Surface area and reaction rate****Aim**

To investigate how changing the surface area affects reaction rate.

**Prior understanding**

Rhubarb contains oxalic acid (toxic in large doses) which will react with pink-coloured acidified potassium permanganate to form colourless manganese(II) ions. This provides an ideal end point for measuring the rate of reaction.

**Materials**

- measuring cylinder
- beakers
- potassium permanganate crystals
- 1 mol L<sup>-1</sup> sulfuric acid
- white tile
- rhubarb stalks with leaves removed (Note: there is variation in the oxalic acid found in different stalks. Check if the stalks produce a result with the concentration of acidified potassium permanganate. Radish could be used as a replacement.)
- cutting tile
- knife
- stopwatch
- tweezers

**Planning**

- 1 Identify the independent variable from the clue in the aim and describe the different groups that will be set up for the experiment.
- 2 Define the dependent variables and how they will be measured.
- 3 Identify and list the controlled variables to be monitored. For each variable, you must define the property that will be measured (numerically if possible) to ensure it is not changing throughout the experiment, e.g. temperature (to be maintained at 25°C).
- 4 Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.
- 5 Write a risk assessment for this investigation.
- 6 Create a results table that will allow you to collect sufficient and relevant raw data, in addition to calculating the mean and uncertainty.

**Method****Part 1: Prepare the potassium permanganate solution**

Add two potassium permanganate crystals to 150 mL of 1 mol L<sup>-1</sup> sulfuric acid and stir well. Add another 150 mL of 1 mol L<sup>-1</sup> sulfuric acid to this solution, resulting in a light purple colour.

**Part 2: Prepare the rhubarb**

- 1 Cut nine identical lengths of rhubarb, ensuring they are as uniform as possible. You may need to use your knife to create straight edges and remove any excess.
- 2 Take three of the lengths and calculate the approximate surface area of one of these lengths by using the following calculation. These will be your 'low' surface area rhubarb.

**Be careful**

There is a risk of acid burns.

Ensure appropriate personal protective equipment is worn.

Wear safety glasses at all times.

Do not consume food items.

*continued...*

...continued



$$SA = 2lw + 2lh + 2wh$$

**Figure 5.40** Calculating the surface area of a rectangular prism

- 3 Take another three of the lengths and cut them in half. Calculate the total surface area for the two halves. This will be your 'medium' surface area rhubarb.
- 4 Take another three of the lengths and cut them into four even pieces. Again, calculate the total surface area for the four quarters. This will be your 'high' surface area rhubarb.

### Part 3: Measure the reaction time

- 1 Add 30 mL of acidified potassium permanganate to a beaker and place the beaker on a white tile.
- 2 Using tweezers, add a piece of the low surface area rhubarb to the beaker. Be careful not to splash the acid.
- 3 Immediately start the stopwatch. Stir the solution until the purple colour disappears, then stop the timer. You may want to have a beaker of water next to the reaction beaker for a comparison.
- 4 Empty, wash and dry the reaction beaker.
- 5 Complete **Part 3** steps 1–3 twice more with another piece of low surface area rhubarb.
- 6 Repeat **Part 3** steps 1–4 with the other samples.

### Results

- 1 Calculate the mean reaction rate for each rhubarb sample.
- 2 Draw a scatterplot to analyse the relationship between the numerical independent variable and its dependent variable.
- 3 Draw a graph and insert a copy below the results table in your science journal.

### Discussion

- 1 Describe any trends, patterns or relationships in your results.
- 2 Use your graph to predict the value of the dependent variable if you were given rhubarb pieces that were halfway between the sizes of the medium and high surface area groups.
- 3 Extrapolate your data to predict the value of the dependent variable if you were given rhubarb pieces that had been cut into eight pieces.
- 4 How much variation was observed between the measurements between different student groups within the class?
- 5 Were other variables that could affect the validity of the results successfully controlled during the experiment?
- 6 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

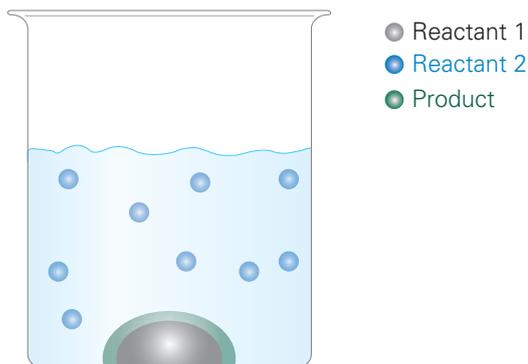
### Conclusion

- 1 Propose a conclusion regarding the type of relationship between the surface area of the rhubarb and reaction rate. Justify your answer with data.
- 2 Use your own knowledge and scientific research to explain the theory behind your conclusion.

## Stirring (agitation)

**agitating**  
stirring or shaking

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 5.41), 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.



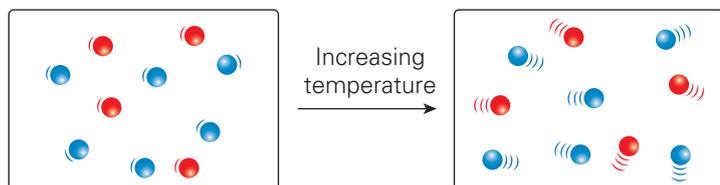
**Figure 5.41** Stirring this reaction mixture would allow all of reactant 1 to come into contact with reactant 2.

### Quick check 5.18

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 5.42** Increasing the temperature of a reaction increases the 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

- When heat is applied to a chemical reaction, the particles convert into which one of the following types of energy?
  - chemical energy
  - gravitational potential energy
  - kinetic energy
  - light energy
- Describe why increasing the temperature of a chemical reaction increases the frequency of successful collisions.

### Try this 5.3



**Figure 5.43** A chemical reaction causes glow sticks to release light.

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.

## Practical 5.6

### Temperature and reaction rate

#### Aim

To determine the effect of temperature on reaction rate.

#### Materials

- 3 pieces of magnesium ribbon (3 cm in length)
- 2 mol L<sup>-1</sup> hydrochloric acid, initially at room temperature
- 10 mL measuring cylinder
- beaker
- 3 boiling tubes
- ice
- stopwatch
- thermometer
- Bunsen burner
- gauze
- tripod
- bench mat
- matches

Note that water baths or a hotplate may be used if available.

#### Planning

- 1 Create a research question that can be easily and safely investigated.
- 2 Write a hypothesis for your investigation regarding the effect of temperature on reaction rates.
- 3 Identify the independent and dependent variables in this investigation.
- 4 Give two controlled variables and why they needed to be controlled.

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Using the 10 mL measuring cylinder, measure 10 mL of the room temperature 2 mol L<sup>-1</sup> hydrochloric acid and pour it into the boiling tube.
- 3 Add one piece of magnesium ribbon to the acid and start timing immediately.
- 4 Time how long it takes for the magnesium to disappear.
- 5 Repeat steps 2–4 another two times.
- 6 Using either a Bunsen burner, water bath or hotplate, heat a beaker of water to 40°C. This will be your water bath.
- 7 Once your water bath has reached 40°C, reduce the heat to maintain the temperature, but do not allow it to increase.
- 8 Measure another 10 mL of 2 mol L<sup>-1</sup> hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your water bath and wait for it to reach the same temperature as the water. Switch off the hotplate or Bunsen.
- 9 Repeat steps 3–5.
- 10 Finally, create a cold ice bath by placing ice in a beaker of water.
- 11 Measure another 10 mL of 2 mol L<sup>-1</sup> hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your cold ice bath and wait for it to reach the same temperature as the water.
- 12 Repeat steps 3–5.

#### Be careful

Hydrochloric acid is corrosive.

Heat the hydrochloric acid using a water bath only. Do not heat the acid directly with the Bunsen or hotplate.

Do not seal the boiling tube while reacting the acid and magnesium.

Wear safety glasses. Work under a fume hood.

*continued...*

...continued

**Results**

Temperature (°C)	Time taken for magnesium to disappear (s)				Uncertainty
	Trial 1	Trial 2	Trial 3	Mean	

- 1 Calculate the mean time taken for the magnesium to disappear at each temperature.
- 2 Calculate the uncertainty for each set of trials at each temperature.
- 3 Plot a graph of your results, including a line of best fit.
- 4 Extrapolate your graph to predict the time it would take for the magnesium to disappear at 50°C and 60°C.

**Discussion**

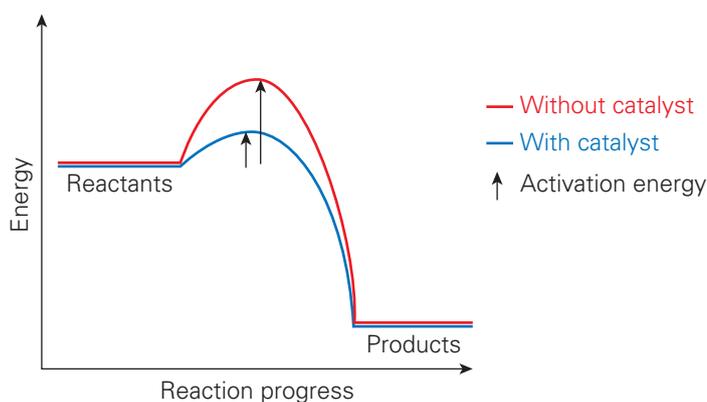
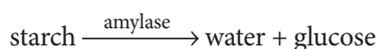
- 1 Identify any patterns, trends or relationships in your results.
- 2 Write word and balanced chemical equations with state symbols for the reaction of magnesium (Mg) with hydrochloric acid (HCl) to form magnesium chloride (MgCl<sub>2</sub>) and hydrogen gas (H<sub>2</sub>).

**Conclusion**

- 1 State a conclusion regarding the effect of temperature on reaction rate based on this experiment.
- 2 Support your statement by using the data you gathered.
- 3 Explain how the data support your statement.

**Catalysts**

A catalyst is a substance that can be added to a chemical reaction to increase the reaction rate. During the reaction, there is no net consumption of the catalyst, and therefore it 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.



**Figure 5.44** Adding a catalyst to a chemical reaction decreases the activation energy and therefore increases the number of successful collisions and reaction rate.

When you eat carbohydrate-rich foods, the starch molecules react 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). But, 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 Define the term 'catalyst'.
- 2 Describe how a catalyst speeds up a chemical reaction.

## Practical 5.7

### Catalysts and reaction rate

#### Aim

To determine the most effective catalyst to decompose hydrogen peroxide.

#### Materials

- 0.5 g manganese(IV) oxide
- 0.5 g iron(III) oxide
- 50 vol hydrogen peroxide solution
- 1 cm<sup>3</sup> piece of potato
- 1 cm<sup>3</sup> piece of liver
- 1 cm<sup>3</sup> piece of celery
- dishwashing detergent
- 5 × 250 mL measuring cylinders
- plastic tray

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Line up the five measuring cylinders into the tray and add about 1 mL of dishwashing detergent to each measuring cylinder.
- 3 Add 25 mL of the 50 vol hydrogen peroxide to each measuring cylinder.
- 4 Add the manganese oxide to one of the measuring cylinders and start the stopwatch.
- 5 Measure the height of the foam when it stops rising.
- 6 Repeat steps 4 and 5 in a clean measuring cylinder for two more trials.
- 7 Repeat steps 2–6 for each of the catalysts.

#### Results

Catalyst	Height of foam (cm)				Uncertainty of foam height $\frac{\text{max} - \text{min}}{2}$
	Trial 1	Trial 2	Trial 3	Mean	
Manganese oxide					
Iron oxide					
Potato					
Liver					
Celery					

- 1 Calculate the mean height of foam for each catalyst.
- 2 Calculate the uncertainty in your results.

#### Discussion

- 1 Identify the catalyst that was the *most* effective at decomposing the hydrogen peroxide. How did you know?
- 2 Identify the catalyst that was the *least* effective at decomposing the hydrogen peroxide. How did you know?
- 3 Write a balanced chemical equation including state symbols for the decomposition of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) into water (H<sub>2</sub>O) and oxygen (O<sub>2</sub>).
- 4 One of the products produced relights a glowing splint. Identify this product.
- 5 Identify any limitations to your experiment.
- 6 Describe any improvements you could make that would improve the reliability of your results.

#### Be careful

Ensure appropriate personal protective equipment is worn.

## Explore! 5.4

**Catalytic converters**

Catalytic converters have been key components 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 converter is to speed up a chemical reaction that converts harmful emissions produced by burning petrol and diesel into less harmful emissions. Catalytic converters play such an important part in reducing harmful exhaust emissions that you can be given a heavy fine if your car does not have one.



Figure 5.45 A catalytic converter used in a car's exhaust system

- 1 Research and give the name of some harmful gases produced by burning petrol and diesel and describe how they could affect the environment.
- 2 Give the name of the gases produced by the catalytic converter and describe how they affect the environment.
- 3 Give the balanced chemical equation for the conversion 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 chemical equation for the oxidation of carbon monoxide (CO) into carbon dioxide ( $CO_2$ ) by reacting it with oxygen ( $O_2$ ) that occurs in a catalytic converter. 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.

## A summary of changing reaction rates

Table 5.8 summarises how each factor discussed in this section influences the rate of a chemical reaction.

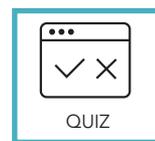
Factor affecting reaction rate	Effect on the frequency of collisions	Effect on number of successful collisions	Effect on rate
Increasing concentration of reactants	Increases	Not affected	Increased
Increasing pressure of gaseous reactants			
Increasing agitation (stirring)			
Increasing surface area of solid reactants			
Increasing temperature			
Adding a catalyst	Not affected	Increased	

Table 5.8 A summary of how each factor discussed affects reaction rate

## Section 5.4 questions

## Remembering

- 1 **State** three factors that can affect the rate of a chemical reaction.
- 2 **State** whether the following statements are true or false. If false, give a reason why.
  - 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 **Recall** the name of chemicals that are added to a chemical reaction to reduce the activation energy.



## Understanding

- 5 Your fire is not hot enough, so you add more fuel. **Identify** which factor you have changed to increase the reaction rate.
- 6 **a Identify** the solutions in the Figure 5.46 that have the same concentration.  
**b Identify** if the solution in other beaker is more concentrated or more dilute, giving reasons for your choice.
- 7 **Recall** the relationship between surface area and reaction rate.

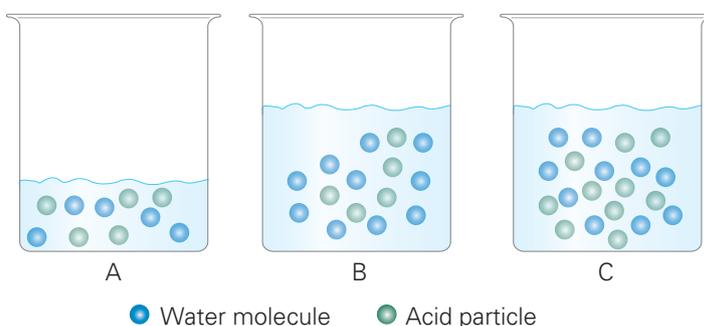


Figure 5.46 Solution concentrations

## Applying

- 8 **Summarise** the requirements for a chemical reaction.
- 9 **Summarise** the relationship between temperature and reaction rate.
- 10 Custard powder can explode when thrown into the air in the presence of a spark, but not when it is tightly packed in a container. **Explain** why.
- 11 Scientists often use magnetic stirrers to stir chemical reactions. **Explain** why this continuous stirring increases the rate of reaction.

## Analysing

- 12 **Contrast** dilute solutions and concentrated solutions.
- 13 Children are advised to take fewer tablets than adults. **Decide** the factor affecting reaction rate that is influencing this advice.

## Evaluating

- 14 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?
- 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 in Figure 5.47. **Discuss** what can be concluded about the effect of increasing the concentration of acid in this reaction, giving detailed reasoning why this may be the case.

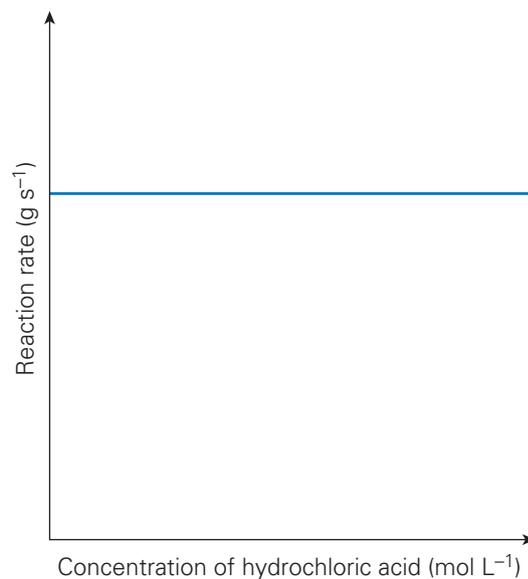


Figure 5.47 Graph of experiment

- 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 both have 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, giving reasons for your choice.

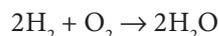
## 5.5 Extension: Chemistry calculations



### Learning goals

- 1 To be able to define the Avagadro constant.
- 2 To be able to calculate the molar mass for an atom or compound.
- 3 To be able to use the mole equation to solve problems including moles and mass.

In order to measure the efficiency of chemical reactions, scientists need to know how many particles are colliding and reacting in the chemical reaction. Take the following chemical reaction for example:



By analysing the coefficients of the chemical species, we know that *two* hydrogen molecules will react with *one* oxygen molecule to produce *two* water molecules. However, it will be very difficult to measure exactly two hydrogen molecules and one oxygen molecule to complete this reaction!

In fact, it will also be difficult on a larger scale to measure out 2 million hydrogen molecules and 1 million oxygen molecules. Scientists need an easier way to measure specific quantities of reacting particles.

### The mole

To make this next concept simpler, imagine that you have a bag of rice grains and you measure *one* cup of rice grains in a measuring cup. A measuring cup might contain 8612 rice grains; however, a recipe will not tell you to measure 8612 rice grains, but instead to measure *one* cup of rice. This makes measuring rice a lot easier than counting individual rice grains 8612 times!



**Figure 5.48** Imagine if recipes required you to count individual grains of rice!

Now let us treat **elementary entities** as rice grains and one cup as a **mole** ( $n$ ). Elementary entities can include small particles such as atoms, molecules and ions. One mole contains  $6.022 \times 10^{23}$  of these elementary entities,

### Did you know? 5.3

The number of elementary entities in a mole,  $6.022 \times 10^{23}$ , is also known as the Avagadro constant,  $N_A$ , after the Italian scientist, Amadeo Avagadro. His work in the early 1800s on the number of atoms in a given volume of gas was an important foundation to the mole concept, which would be defined later that century. Another scientist, Jean Perrin, then named the constant after Avagadro in the early 1900s to celebrate his early influence on this field of chemistry. In 2019, the Avagadro constant was updated to be exactly  $6.022\,140\,76 \times 10^{23}$  elementary entities. However, for simplicity we will use the number  $6.022 \times 10^{23}$  in our calculations.



**Figure 5.49** Amadeo Avagadro was born in 1776 in Turin, Italy.

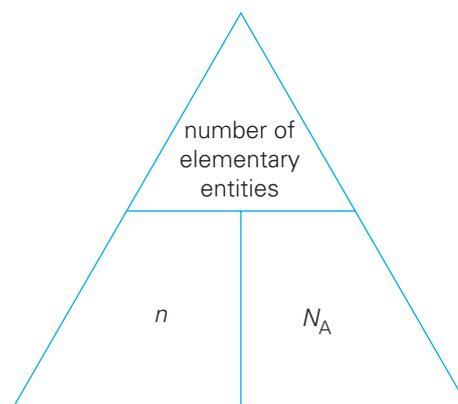
also known as the Avagadro constant ( $N_A$ ). Therefore, if a scientist were to now measure one mole of oxygen gas ( $O_2$ ), they would have  $6.022 \times 10^{23}$  molecules to be exact, just as one cup of rice would contain 8612 rice grains in the previous example.

This relationship between the mole and the Avagadro constant can be expressed mathematically:

$$\text{Number of moles} = \frac{\text{number of elementary entities}}{\text{Avagadro constant}}$$

Or

$$n \text{ (mol)} = \frac{\text{number of elementary entities}}{N_A \text{ (mol}^{-1}\text{)}}$$



**Figure 5.50** The formula triangle for the number of elementary entities

**elementary entity**  
a small particle such as an atom, molecule or ion

**mole**  
 $6.022 \times 10^{23}$  elementary entities

### Worked example 5.1

- 1 Calculate the number of moles of gold atoms if there are  $3.011 \times 10^{24}$  atoms.
- 2 Calculate the number of molecules of hydrogen gas,  $H_2$ , in 0.5 moles.

Working	Explanation
1 Substitute values into the equation and solve.	
$n = \frac{\text{number of elementary entities}}{N_A}$ $\frac{3.011 \times 10^{24} \text{ atoms}}{6.022 \times 10^{23} \text{ atoms mol}^{-1}} = 5 \text{ mol}$	To solve for the number of moles, substitute the number of atoms as the number of elementary entities and the Avagadro constant, $6.022 \times 10^{23}$ , for $N_A$ .
2 Rearrange the equation to solve for number of molecules.	
$\text{number of elementary entities} = n \times N_A$ $= 0.5 \text{ mol} \times 6.022 \times 10^{23} \text{ mol}^{-1}$ $= 3.011 \times 10^{23} \text{ entities or molecules}$	Rearrange the equation to solve for number of molecules (elementary entities). Substitute the number of moles and the Avagadro constant to solve.

## Quick check 5.21

- 1 Identify the number of hydrogen molecules in one mole.
- 2 Identify the number of hydrogen molecules in two moles.
- 3 Calculate the number of water molecules in 3.5 moles.
- 4 Identify the number of moles of sodium in  $1.8066 \times 10^{23}$  atoms.

The mole is a useful concept; however, we still have not answered the question of how we can measure a mole of a chemical species. How can we measure  $6.022 \times 10^{23}$  molecules, and where did the Avagadro constant come from?

### Molar mass

In the early 1900s, a scientist, Jean Perrin, set out to answer the question of how many molecules of oxygen gas,  $O_2$ , were in exactly 32 grams of the gas. From the periodic table, we can see that the atomic number of oxygen is 8 – that is also the number of protons in

the nucleus of an oxygen atom. The periodic table also shows a number of **relative atomic mass**, which is the number of protons plus the average number of neutrons in the nucleus. Many periodic tables will show this

**relative atomic mass**

the sum of the number of protons and average number of neutrons in an atom

**molar mass**

the mass of one mole of an elementary entity

number to be 15.9994 for oxygen and in this example, we will round that number to 16.00.

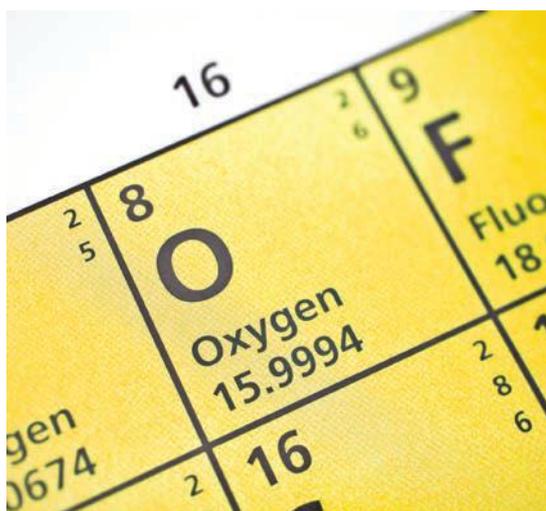
A molecule of oxygen gas,  $O_2$ , has two oxygen atoms and therefore the overall relative atomic mass of this molecule can be calculated as:  $16 + 16 = 32$ . Thus, Perrin wanted to know how many molecules were present in a measurable mass of 32 grams; a number similar to the relative atomic mass of oxygen gas of 32. This number of molecules was found to be  $6.022 \times 10^{23}$  molecules. Perrin then named it the Avagadro constant, the number of elementary entities in a mole.

Therefore, if 32 grams of oxygen gas contains  $6.022 \times 10^{23}$  molecules, and one mole of oxygen gas contains  $6.022 \times 10^{23}$  molecules, then 32 grams of oxygen gas should contain one mole of oxygen gas. This concept is known as the **molar mass** ( $M$ ) and the molar mass of a molecule of oxygen gas can be determined from the relative atomic mass provided on the periodic table.

For example:  $M(O_2) = 32 \text{ g mol}^{-1}$

In other words, there are 32 grams per mol of oxygen gas.

Even more amazing than this conversion is that this relationship between moles, the Avagadro constant and molar mass can be used for any atom, molecule or compound using the relative atomic masses shown on the periodic table.



**Figure 5.51** The relative atomic mass of oxygen on the periodic table

### Worked example 5.2

- 1 Calculate the molar mass of carbon.
- 2 Calculate the molar mass of water.
- 3 Calculate the molar mass of sodium chloride.

Working	Explanation
<b>1</b> Molar mass of a single atom Relative atomic mass of C = $12.01 \text{ g mol}^{-1}$ $M(\text{C}) = 12.01 \text{ g mol}^{-1}$	For a single atom, the molar mass is the same as the relative atomic mass shown on the periodic table with units of $\text{g mol}^{-1}$ .
<b>2</b> Molar mass of a molecule Relative atomic mass of O = $16.00 \text{ g mol}^{-1}$ Relative atomic mass of H = $1.01 \text{ g mol}^{-1}$ $M(\text{H}_2\text{O}) = 1.01 + 1.01 + 16.00 = 18.02 \text{ g mol}^{-1}$	For a molecule, add all relative atomic masses from the periodic table with units of $\text{g mol}^{-1}$ . Remember, there are 2 hydrogen atoms per $\text{H}_2\text{O}$ molecule.
<b>3</b> Molar mass of a compound Relative atomic mass of Na = $22.99 \text{ g mol}^{-1}$ Relative atomic mass of Cl = $35.45 \text{ g mol}^{-1}$ $M(\text{NaCl}) = 22.99 + 35.45 = 58.44 \text{ g mol}^{-1}$	For a compound, add all relative atomic masses from the periodic table with units of $\text{g mol}^{-1}$ .

### Quick check 5.22

- 1 Calculate the molar mass of nitrogen gas,  $\text{N}_2$ .
- 2 Calculate the molar mass of elemental gold, Au.
- 3 Calculate the molar mass of ammonia,  $\text{NH}_3$ .
- 4 Calculate the molar mass of calcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$ .

## The mole equation

The mole, the Avagadro constant and the molar mass can now be brought together to create an equation relating the measurable mass of a substance to the number of moles or even elementary entities. This is known as the mole equation:

$$\text{Number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

Or

$$n \text{ (mol)} = \frac{m \text{ (g)}}{M \text{ (g mol}^{-1}\text{)}}$$

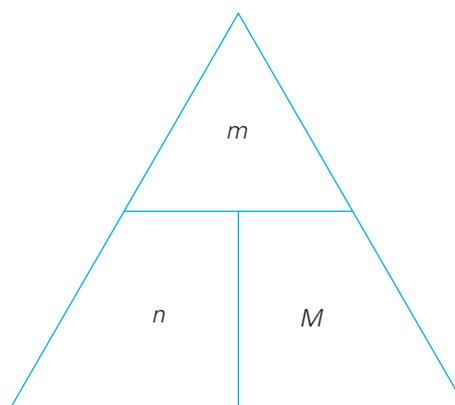


Figure 5.52 The formula triangle for molar mass

Using this equation, scientists can calculate a measurable mass of chemical substance for a given number of moles of that substance.

## Worked example 5.3

- 1 Calculate the number of moles of silver (Ag) in 0.25 g of metallic silver.
- 2 Calculate the number of moles of water (H<sub>2</sub>O) in 5 g of the liquid.
- 3 Calculate the mass of 1.35 mol of barium bromide, BaBr<sub>2</sub>.

Working	Explanation
<b>1</b> Number of moles of Ag	
$m = 0.25 \text{ g}$ $M(\text{Ag}) = 107.87 \text{ g mol}^{-1}$	Identify the mass and molar mass of atomic silver. You need to refer to the periodic table for the molar masses.
$n = \frac{m}{M} = \frac{0.25 \text{ g}}{107.87 \text{ g mol}^{-1}} = 0.0023 \text{ mol}$	Substitute known values of mass and molar mass (from periodic table) and solve for moles.
<b>2</b> Number of moles of H <sub>2</sub> O	
$m = 5 \text{ g}$ $M(\text{O}) = 16.00 \text{ g mol}^{-1}$ $M(\text{H}) = 1.008 \text{ g mol}^{-1}$ $M(\text{H}_2\text{O}) = 2 \times 1.008 + 16.00 = 18.016 \text{ g mol}^{-1}$	Identify the mass and molar mass of H <sub>2</sub> O. (Add values of oxygen and 2 hydrogen from periodic table.)
$n = \frac{m}{M} = \frac{5 \text{ g}}{18.016 \text{ g mol}^{-1}} = 0.0023 \text{ mol}$	Substitute known values of mass and molar mass and solve for the number of moles.
<b>3</b> Mass of BaBr <sub>2</sub>	
$n = 1.35 \text{ mol}$ $M(\text{Ba}) = 137.33 \text{ g mol}^{-1}$ $M(\text{Br}) = 79.90 \text{ g mol}^{-1}$ $M(\text{BaBr}_2) = 137.33 + 2 \times 79.90 = 297.13 \text{ g mol}^{-1}$	Identify the number of moles $n$ and molar mass $M$ of BaBr <sub>2</sub> . (Add values of barium and 2 bromine from periodic table.)
$m = n \times M$ $= 1.35 \text{ mol} \times 297.13 \text{ g mol}^{-1}$ $= 401.13 \text{ g}$	Rearrange equation to solve for mass. Substitute known values of moles and molar mass.

## Quick check 5.23

- 1 Calculate the number of moles of 1 g of hydrogen gas, H<sub>2</sub>.
- 2 Calculate the mass of 15 mol of lithium metal, Li.
- 3 Calculate the molar mass of an unknown compound that has 2 mol of particles in 72.9 g.

## Bringing it all together

As we know, a given number of moles of a substance is directly related to the Avagadro constant of elementary entities and also the mass, we can therefore relate a mass to number of elementary entities.

See the two equations used in this chapter once more:

$$n \text{ (mol)} = \frac{\text{number of elementary entities}}{N_{\text{A}} \text{ (mol}^{-1}\text{)}}$$

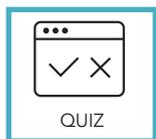
$$n \text{ (mol)} = \frac{m \text{ (g)}}{M \text{ (g mol}^{-1}\text{)}}$$

## Worked example 5.4

- 1 Calculate the number of water molecules in 0.65 g of the liquid.
- 2 Calculate the mass of  $1.138 \times 10^{24}$  molecules of methane,  $\text{CH}_4$ .

Working	Explanation
<b>1</b> Finding the number of molecules, given the mass	
$m = 0.65 \text{ g}$ $M = 18.02 \text{ g mol}^{-1}$ (see Worked example 5.2)	Identify the mass and molar mass.
$n = \frac{m}{M}$ $= \frac{0.65 \text{ g}}{18.02 \text{ g mol}^{-1}}$ $= 0.0361 \text{ mol}$	Use the molar mass triangle. Substitute known values of mass and molar mass and solve for moles.
number of molecules = $n \times N_A$ $= 0.0361 \text{ mol} \times 6.022 \times 10^{23} \text{ mol}^{-1}$ $= 2.17 \times 10^{22}$ elementary entities There are $2.17 \times 10^{22}$ molecules of water in 0.65 g.	Use the moles and the Avagadro constant triangle to solve for the number of molecules.
<b>2</b> Finding the mass, given the number of molecules	
number of molecules = $1.138 \times 10^{24}$ molecules $N_A = 6.022 \times 10^{23} \text{ molecules mol}^{-1}$	Identify the number of molecules and the Avagadro constant.
$n = \frac{\text{number of molecules}}{N_A}$ $= \frac{1.138 \times 10^{24} \text{ molecules}}{6.022 \times 10^{23} \text{ molecules mol}^{-1}}$ $= 1.89 \text{ mol}$	Use the moles and Avagadro constant triangle.  Substitute known values of molecules and the Avagadro constant and solve for moles.
$M(\text{C}) = 12.01 \text{ g mol}^{-1}$ $M(\text{H}) = 1.01 \text{ g mol}^{-1}$ $M(\text{CH}_4) = 12.01 + 4 \times 1.01 = 16.05 \text{ g mol}^{-1}$	Calculate the molar mass.
$m = n \times M$ $= 1.89 \text{ mol} \times 16.05 \text{ g mol}^{-1}$ $= 30.33 \text{ g}$	Use the moles and the molar mass triangle to solve for the mass.

## Section 5.5 questions

**Remembering**

- 1 **State** the number and units of the Avagadro constant.
- 2 **Define** the mole in relation to Chemistry.

**Understanding**

- 3 **Describe** why the units of molar mass are  $\text{g mol}^{-1}$ . In your response, refer to the Avagadro constant.
- 4 **Determine** the molar mass of carbon dioxide,  $\text{CO}_2$ .
- 5 **Determine** the molar mass of ammonium sulfate,  $(\text{NH}_4)_2\text{SO}_4$ .
- 6 **Determine** the molar mass of tryptophan,  $\text{C}_{11}\text{H}_{12}\text{N}_2\text{O}_2$ .

**Applying**

- 7 **Calculate** the number of moles of carbon monoxide,  $\text{CO}$ , present in 90.25 g.
- 8 **Calculate** the number of moles of  $6.022 \times 10^{22}$  atoms of platinum, Pt.
- 9 **Calculate** the mass of 3.41 mol of ozone,  $\text{O}_3$ .
- 10 **Calculate** the mass of 0.999 mol of uranium oxide,  $\text{UO}_2$ .

**Analysing**

- 11 An unknown compound of 1.5 g was analysed to contain  $1.048 \times 10^{22}$  particles. Use this information to **explain** how one could find the molar mass of the unknown compound and determine this value.
- 12 The unknown compound in question 11 was identified as hexane,  $\text{C}_6\text{H}_{14}$ . **Confirm** that the molar mass that was determined in question 11 matches that of this compound.

**Evaluating**

- 13 A sample of water,  $\text{H}_2\text{O}$ , was weighed and a mass of 5.00 g was recorded. **Justify** that from this measurement, the number of water molecules in the sample *can* be determined.
- 14 For the same sample in question 13, **justify** that the number of hydrogen atoms present in the sample *can* be determined.

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
5.1 I can represent chemical reactions in word and balanced chemical equations.	9	
5.1 I can use appropriate notation to show chemical species as gas, liquid, solid or aqueous.	9	
5.2 I can describe how chemical reactions can be used to create useful products such as polymers, ethanol, sulfuric acid or extract metals.	10	
5.3 I can determine the rate of reaction through experimental procedures and calculations.	16	
5.4 I can name and explain the factors that affect rates of reaction.	20	

## Review questions

### Remembering

- 1 **Name** three diatomic elements on the periodic table.
- 2 **Define** the meaning of the term 'monomer'.
- 3 **Recall** one method of monitoring reaction rates.
- 4 **Recall** one factor that 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 Using a labelled diagram, **illustrate** how one 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. **Write** 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 in the following balanced formula equation.



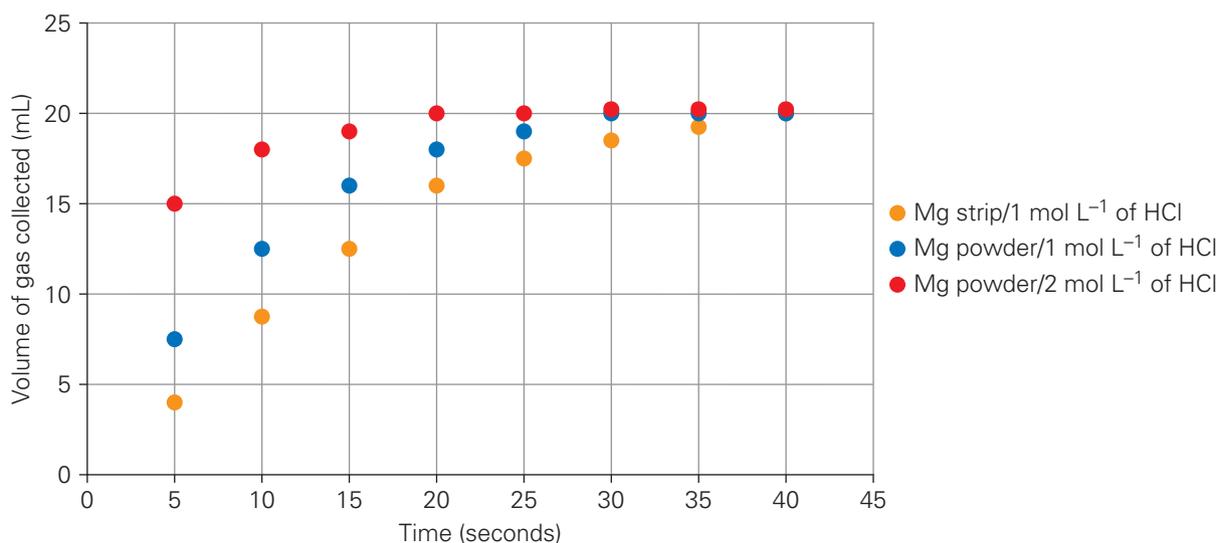
- 14 Analyse** the use of a less reactive metal, like copper, in preventing the corrosion of iron.
- 15** Using your knowledge of rate graphs, **distinguish** between the start and end of a reaction.
- 16 Describe** how the reaction rate relates to the time taken for a reaction to reach completion.

### 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** The reaction of hydrogen gas and ethene ( $C_2H_4$ ) produces ethane ( $C_2H_6$ ) in the presence of a palladium (Pd) catalyst. **Discuss** the role a catalyst plays in this chemical reaction.
- 20 Discuss** the importance of the understanding of reaction rates on the chemical industry. Include in your discussion, a description of the factors that affect reaction rate.

### Data questions

A group of Chemistry students is measuring the rate of a reaction of magnesium metal and hydrochloric acid under different conditions. The students added a strip of magnesium to  $1 \text{ mol L}^{-1}$  of HCl, some powdered magnesium to  $1 \text{ mol L}^{-1}$  of HCl, or some powdered magnesium in  $2 \text{ mol L}^{-1}$  of HCl to each of three test tubes. The results are presented in Figure 5.53. Note that the same mass of magnesium was used for each reaction.



**Figure 5.53** Volume of gas collected over time from reactions of magnesium metal and hydrochloric acid

- 1 Identify** the conditions under which the reaction went to completion fastest.
- 2 Calculate** the rate of the reaction (in  $\text{mL s}^{-1}$ ) for magnesium strip/ $1 \text{ mol L}^{-1}$  of HCl from the time 0 to 40 seconds.
- The rate of the reaction for the Mg powder/ $1 \text{ mol L}^{-1}$  of HCl is  $0.67 \text{ mL s}^{-1}$ . Use this information and your answer to questions **1** and **2** to **determine** which reaction has the lowest reaction rate.
- 4 Identify** the trend in the plot that is similar for all three experiments.
- 5 Contrast** the effect of the magnesium surface area on the volume of gas produced and the rate of the reaction.

- 6 **Analyse** the data presented in Figure 5.53 for the three experiments. What would be the volume of gas collected for each experiment at 0 seconds (before reactants were mixed)?
- 7 A student has stated that when all magnesium and hydrochloric acid has reacted, the volume of gas produced will be 20 mL. **Justify** this conclusion with reference to the data in Figure 5.53.
- 8 **Extrapolate** the data for the Mg strip/1 mol L<sup>-1</sup> of HCl experiment and estimate the volume of gas produced after 120 seconds.
- 9 The students would like to run another experiment with the same mass of magnesium powder and 5 mol L<sup>-1</sup> of HCl. **Predict** (using Figure 5.53 as a template) how the data might be different in this experiment.

## STEM activity: Designing airbags

### Background information

Airbags work on the principle of increasing the time of impact between two objects. In a car this could be the difference between life and death. A sensor is connected to an electrical circuit and once activated will send a signal that ignites the extremely toxic chemical sodium azide ( $\text{NaN}_3$ ) and releases nitrogen at high speed.

Airbags are not without risk though and have failed, causing burns and injury due to the chemical reaction and projectile velocity of the bag itself, which can reach velocities up to  $330 \text{ km h}^{-1}$ . Sodium azide undergoes an initial reaction where it produces nitrogen gas and sodium metal. Sodium metal is highly reactive and if left would explode with the surrounding oxygen. Potassium nitrate is then used to react with the sodium, and after this

reaction, silicon dioxide is used to produce the final product silicate which is both harmless and stable.

**Design brief:** Design and create an airbag prototype that uses environmentally friendly chemicals and materials of manufacture. The airbag will need to create gas rapidly to work effectively.

### Activity instructions

In groups you will design an airbag that uses a chemical reaction to produce a safe gas that fills the airbag space. Your design will incorporate features that would make your airbag safe through the whole chemical reaction, and environmentally friendly for disposal. If you cannot source the materials you need, you can produce a model and state the chemical reaction.



Figure 5.54 An airbag that has been activated

### Suggested materials

- various types of acid (e.g. vinegar)
- various types of bases (e.g. baking soda)
- beakers of various size
- measuring cylinder
- rubber tubing
- thermometer
- plastic bags
- stopwatch
- balloons
- various building materials

### Research and feasibility

- 1 Research how airbags work at present and how the chemicals are reacted in a safe way in the bag.
- 2 Research safe chemical reactions and different catalysts that could be used.
- 3 Discuss in your group the available materials you have and research the environmental concerns of the disposal of these materials.

### Design and sustainability

- 4 Decide as a group the chemical reaction you will use and how you will increase the rate of reaction of gas produced.
- 5 Design how your airbag will work, and sketch ideas before deciding on the final design. Remember, you will need to capture the gas. You may want to think about how you will test the effectiveness of your chemical reaction that is occurring within the bag.
- 6 Complete a risk management table for the chemicals you are using. Make a note of any special disposal conditions the chemicals may have.

Material	Hazard	Risk management
e.g. 2 mol L <sup>-1</sup> hydrochloric acid	Burning skin/clothing	Use gloves and wear aprons, be careful when handling

### Create

- 7 Create your prototype airbag and test the effectiveness of your design.

### Evaluate and modify

- 8 Discuss the positives and negatives about your design. You may use a PNI table, as shown below, to present your findings to the class.

Positives	Negatives	Interesting

- 9 Evaluate the effectiveness of your chemical reaction at producing gas, reaction time for gas to be produced, the completion of the reaction, and how safe the chemical reaction was.
- 10 Recommend changes you would make in your design of the airbag, and the chemical reaction choice.

# Chapter 6

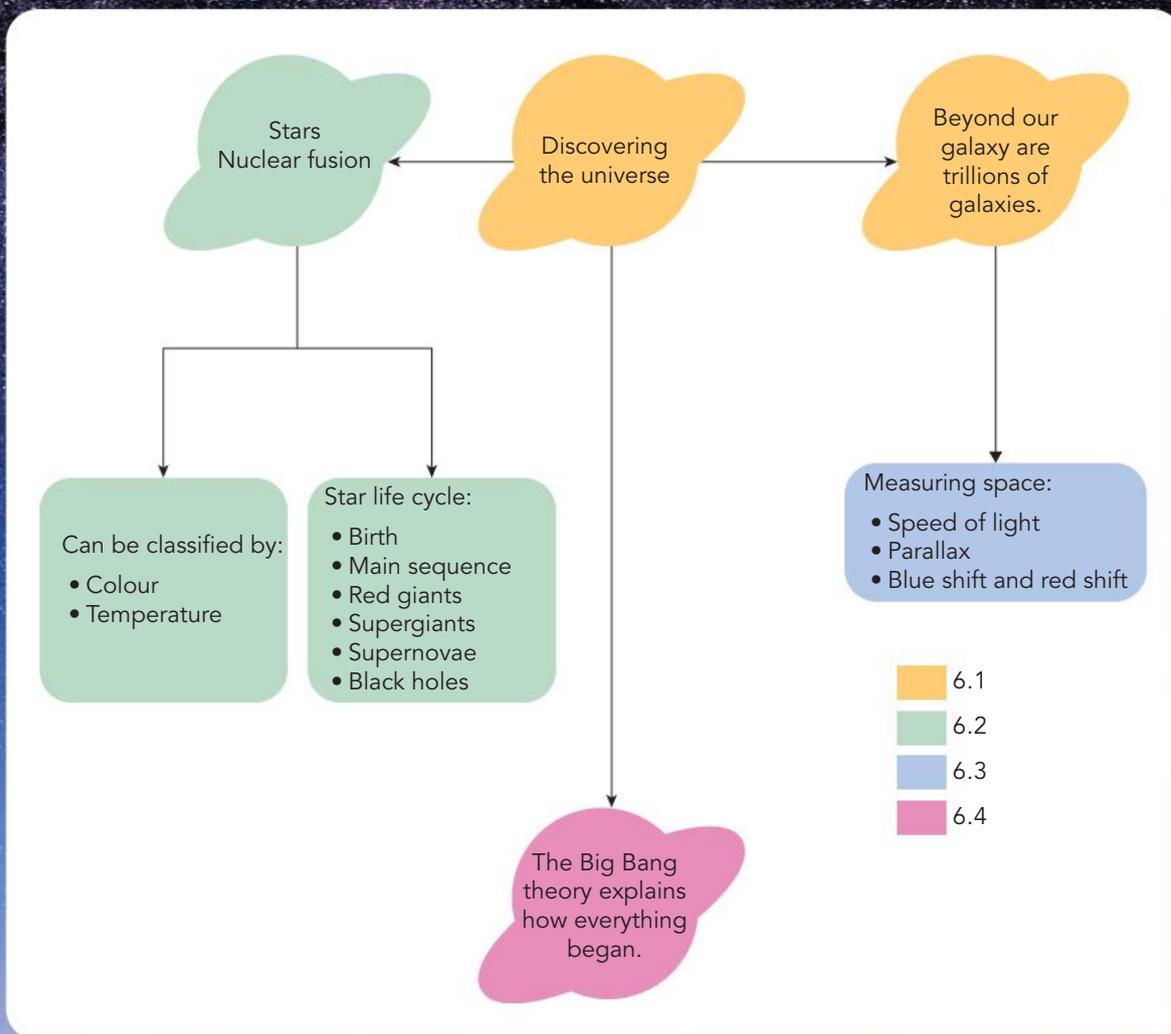
## The universe



### 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 can be a certain feeling of insignificance as well as awe 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.

# Chapter map



# 6.1 Discovering the universe



## Learning goals

- 1 To be able to distinguish between the geocentric and heliocentric models of the universe.
- 2 To be able to explain the use of optical and radio telescopes in modern day astronomy.

Aboriginal and Torres Strait Islander peoples observe the night sky and document it to pass on knowledge through generations. Well before European settlement in 1788, they had a deep understanding of the movements of celestial bodies and are sometimes called the ‘world’s first astronomers.’

Many **constellations** are associated with stories, and many communities have unique stories. Aboriginal and Torres Strait Islander astronomy identifies stars and constellations not only by their brightness, but also from patterns originating from the dark clouds.

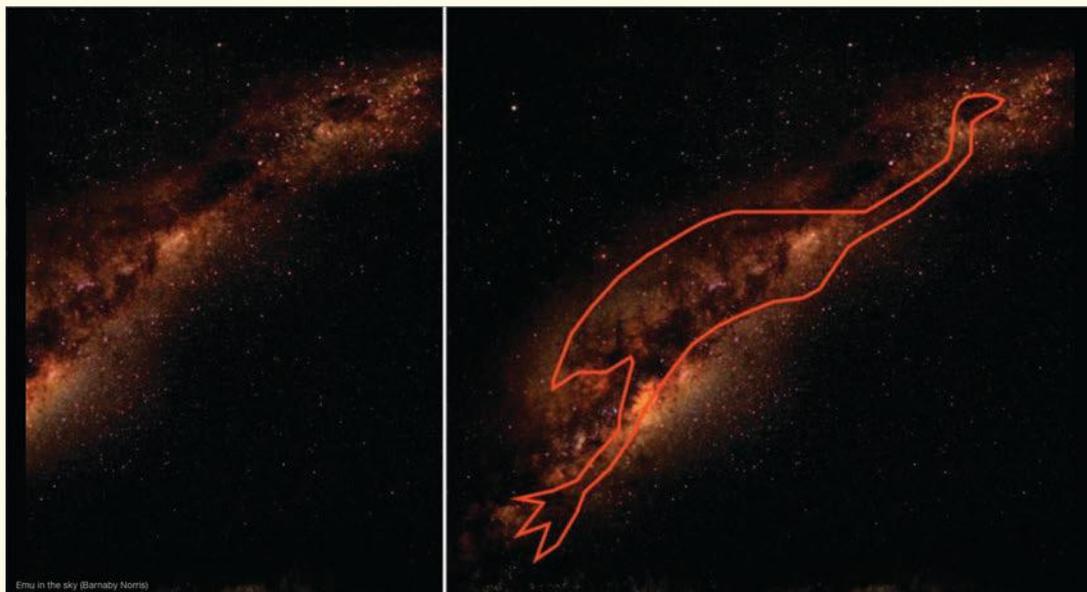
**constellation**  
a group of stars as seen from Earth that appear to form a familiar shape



## Explore! 6.1

### Constellations

The story of the Emu in the Sky is a common one. However, many Aboriginal and Torres Strait Islander communities have different stories or images associated with the part of the Milky Way shown in Figure 6.1. The emu is known as *weijtj* in Noongar language, and it is a male *weijtj* guarding eggs. Use your preferred search engine to find out some of the other names and stories from different communities and what significance each plays in indicating changing seasons or the community’s practices throughout the year.



**Figure 6.1** The dark patches in the Milky Way make up the body of the Emu in the Sky, a story common to many Aboriginal groups. The orientation of the emu, sitting or running, indicates the start of different seasons, timing of ceremonies and even when it is time to hunt emus or collect emu eggs.

Constellations were important in early human migration and thereby shaped the modern world. Today, astronomers and astrophysicists use advanced technology to make their observations. However, astronomy is a field of science where you do not have to be a professional to take part. An Australian amateur astronomer from Perth 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', in other words, able to support life.

### 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 2nd 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.

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

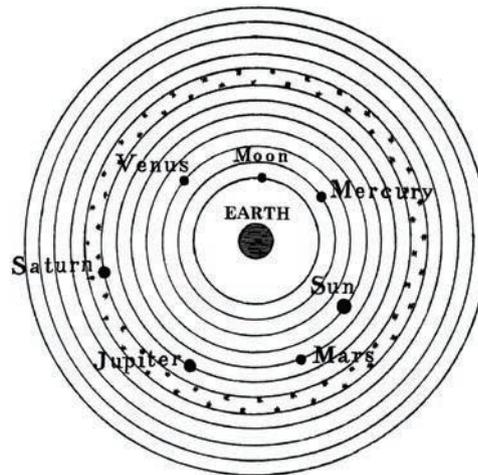
**retrograde motion** and supports the heliocentric model.

In the early 1500s, Nicolaus Copernicus proposed a **heliocentric** model of the solar system, in which the planets revolved around the Sun. This could

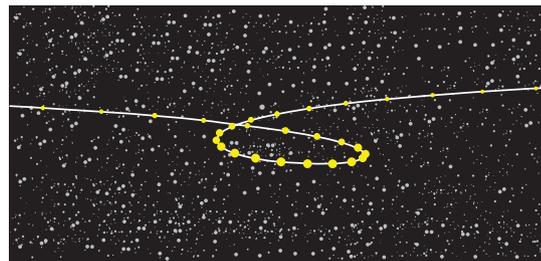
**geocentric**  
a model of the solar system with Earth at the centre

**retrograde motion**  
apparent backwards motion of a planet as seen from Earth

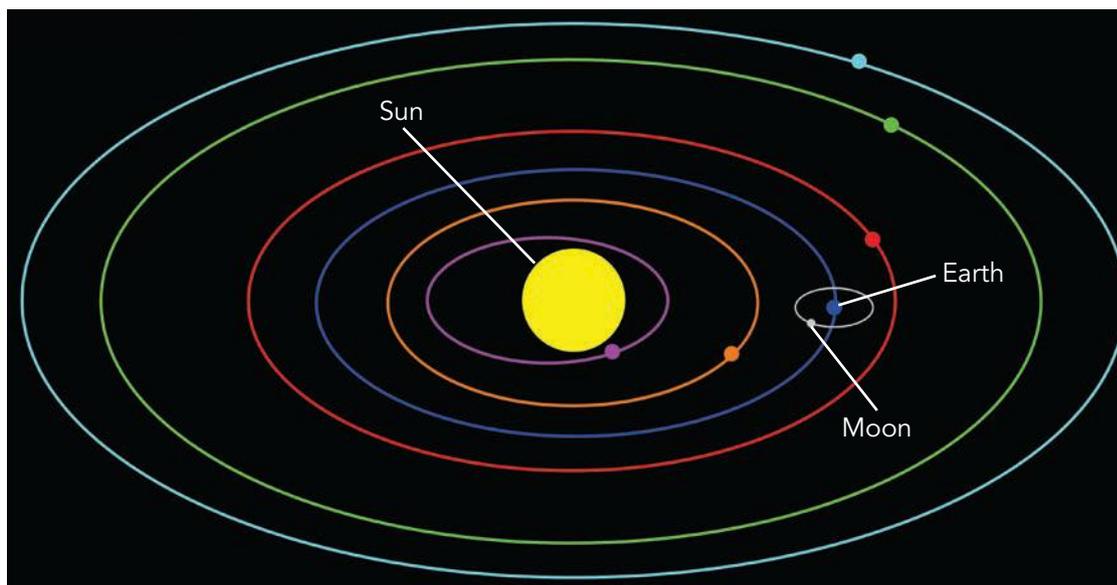
**heliocentric**  
a model of the solar system with the Sun at the centre



**Figure 6.2** The geocentric model proposed that Earth was the centre of the universe, with the planets and stars orbiting around it.



**Figure 6.3** Retrograde motion of Mars across the sky as seen from Earth.



**Figure 6.4** The heliocentric model proposes that planets revolve around the Sun, rather than Earth.

explain the retrograde motion of the planets, occurring when a faster moving planet catches up with a slower moving planet and then passes it.

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 that planet.

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.

### Quick check 6.1

- 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 Describe the main flaw in the geocentric model.

## Modern day astronomy

Modern day astronomers have access to amazing technologies. Telescopes have become larger and larger to allow scientists 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

**optical telescope**  
a device that collects and focuses light from the visible spectrum to form an image

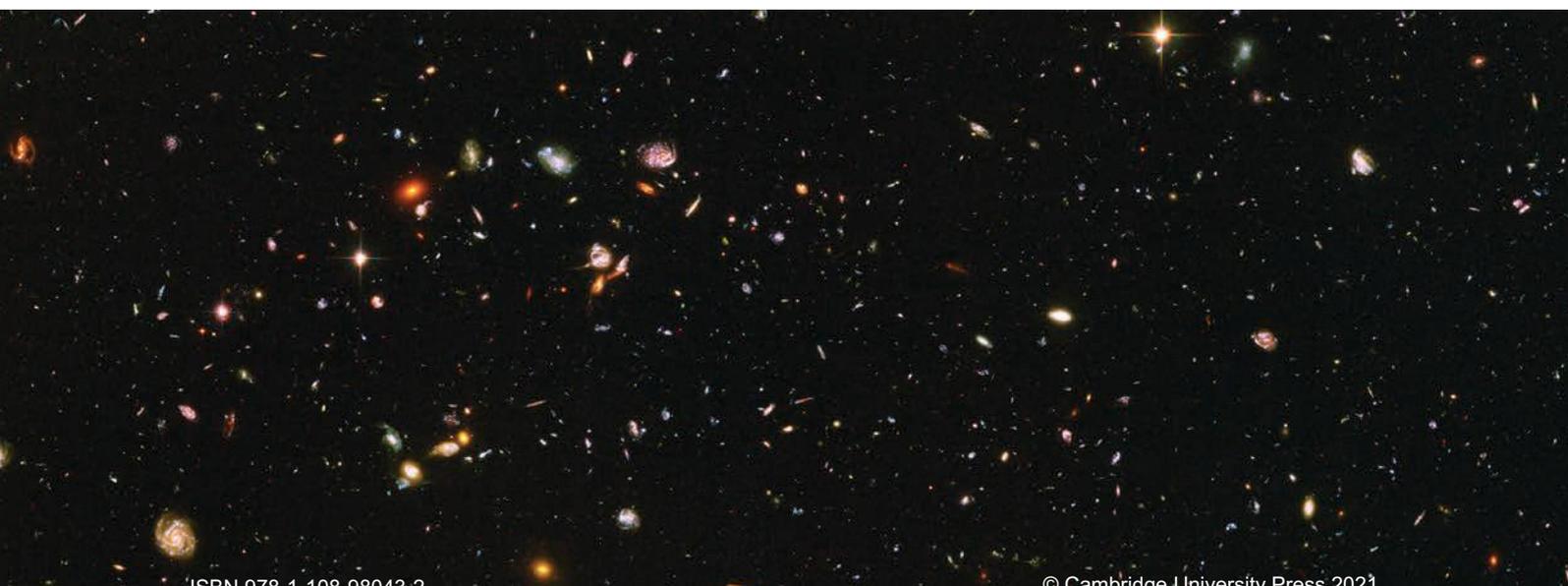
multitudes of galaxies that had never been observed before. It further demonstrated the enormous size of the universe.

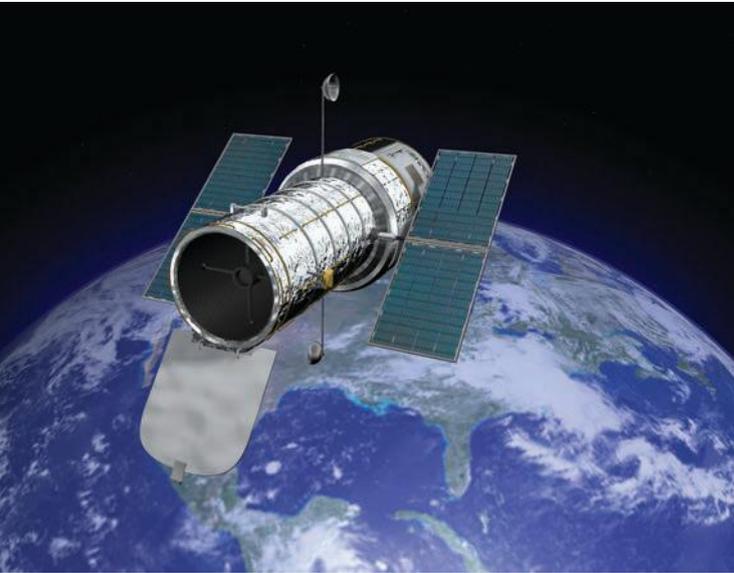
To minimise the effects of light pollution and the distorting effects of the atmosphere completely, the Hubble Space Telescope was launched into Earth's orbit and is controlled remotely from the ground. It has been instrumental in developing our understanding of the universe and the Big Bang theory.

## 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 glass lenses became 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.

**Figure 6.5** This figure shows a portion of the Hubble Ultra Deep Field image, taken over a period of months in 2003–04. More detailed than the original Deep Field from 1995, the full image covers only a tiny portion of the sky and yet shows approximately 10 000 galaxies, many of which contain billions of stars each. The full-sized image can be viewed online.





**Figure 6.6** The Hubble Space Telescope can observe the light from distant galaxies without the dimming 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 is expected to be completed in



**Figure 6.7** An artist's impression of the Square Kilometre Array in Western Australia, which will have the potential to look further into space than has ever been possible before

Western Australia in 2028, 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 6.7.

**radio telescope**  
a device that receives radio waves emitted by stars and other celestial objects

### Quick check 6.2

- 1 Name the two main types of telescopes and recall which part of the electromagnetic spectrum they detect.
- 2 Recall where the best telescopes are located.

### Did you know? 6.1

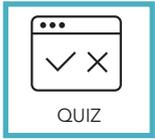
#### The Parkes radio telescope

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 6.8** The Parkes radio telescope in New South Wales

## Section 6.1 questions

**Remembering**

1 **Recall** the reason that most observatories are located in remote areas and at high altitudes.

**Understanding**

2 **Explain** why the Sun and stars follow a circular path across the sky each day.

**Applying**

3 A radio telescope, like the Parkes telescope, focuses light in the same way as a concave mirror. **Illustrate** how radio waves are focused on the large dish on the Parkes radio telescope.

**Analysing**

4 **Contrast** the geocentric and heliocentric models and state why the motion of the planets as observed on Earth supports the heliocentric model.

**Evaluating**

5 **Discuss** the improvements in technology since early astronomers that have allowed us to look further and further into space.

6 **Discuss** the advantages and disadvantages of having a telescope in space.

## 6.2 Stars

**Learning goals**

- 1 To be able to determine a star's spectral class from its colour and temperature.
- 2 To be able to compare the luminosity value of a star to that of the Sun.
- 3 To be able to list the different stages in a star's life cycle.



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 the Earth, the Sun and our solar system even existed.

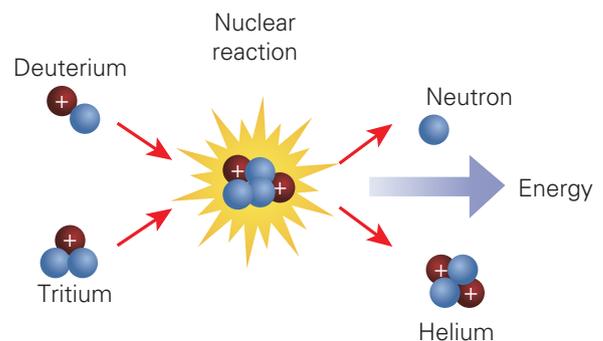
**Nuclear fusion**

The Sun and other stars are often considered as big balls 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

**spectral class**  
a group into which stars are classified based on their spectra/colour

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 6.9** 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).

**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

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 6.1** Temperatures and spectral classes of the star colours

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 is a G-type star.

### B-V colour index

Most stars look white, but a few, such as Betelgeuse (642.5 light years from Earth), 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 6.3

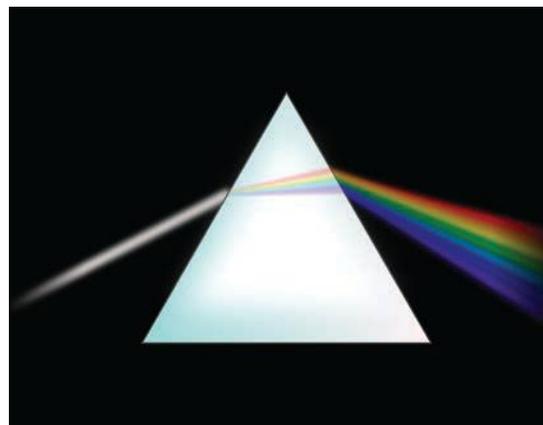
- 1 What is the name of the process that occurs inside stars?
- 2 Recall what the colour of a star tells us.

### Explore! 6.2

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).

### 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.



**Figure 6.10** White light consists of the full range of wavelengths (colours) from the visible spectrum.

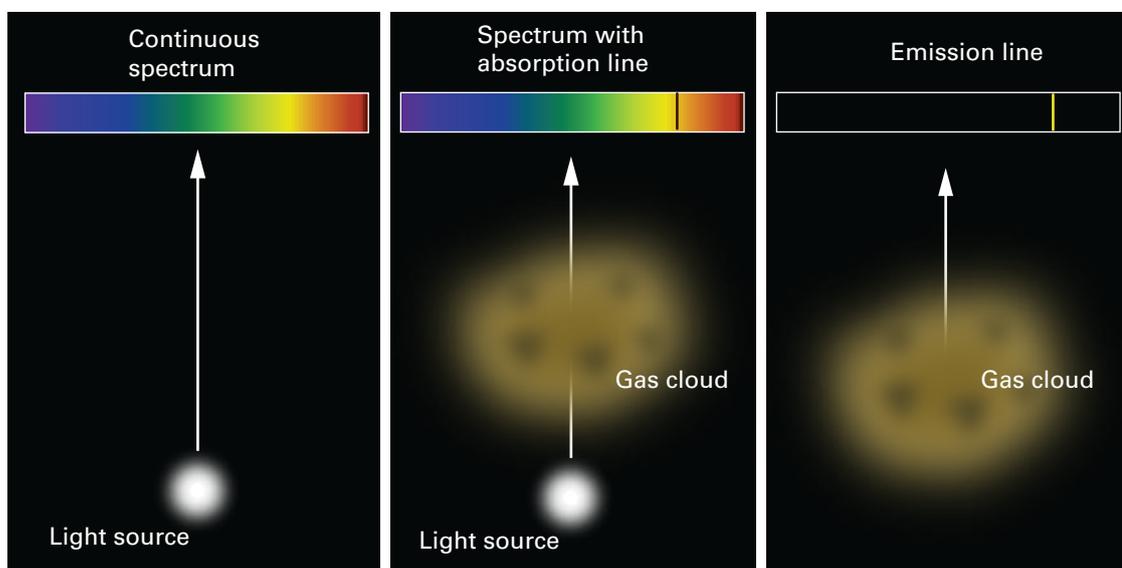


Figure 6.11 A demonstration of how the three types of spectra are produced

#### 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

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 at the wavelengths of light that are no longer detected. 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 6.11 shows the differences between each of these spectra.

## Practical 6.1

### Flame tests and observing emission spectra

#### Aim

To investigate how emission spectra can be used to determine the metal in unknown substances.

#### 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

##### Part 1: Prepare the results table

Draw the table shown in the results section into your science journal.

#### Be careful

Ensure appropriate personal  
protective equipment is  
worn. Wear safety glasses.  
Wash hands after practical.

*continued...*

...continued

### Part 2: Test the known solutions

- 1 Set up the Bunsen burner with bench mat and connect the Bunsen burner to the gas.
- 2 Turn on the Bunsen burner and adjust to a blue flame.
- 3 Dip the wooden splint into the first solution and place in the flame.
- 4 Observe the colour and record.
- 5 Dip the same splint into the same solution and have your partner observe the flame through the emission spectrometer.
- 6 Draw lines on the results table to match the spectral lines shown through the emission spectrometer. Take note of the very faint dark lines, the most notable being at wavelengths of 4.9 and 5.2 (in hundreds of nanometres).
- 7 Repeat steps 4–6 with the other known solutions using a new wooden splint for each solution.

### Part 3: Test the unknown solutions

Repeat steps 4–6 and record the colour and emission spectra for the unknown solutions.

### Results

Determine the metal present in the unknown solutions A, B and C and record this in the table by drawing lines that match the colours you see. The first row has been completed as an example.

Solution	Flame test	Emission spectrometer						
	Colour in flame	Colours (wavelength in hundreds of nm)						
		4	4.5	5	5.5	6	6.5	7
Known solution								
Copper chloride	Blue or bluish-green							
Lithium chloride								
Strontium chloride								
Sodium chloride								
Potassium chloride								
Unknown solution								
A								
B								
C								

### Discussion

- 1 Determine the identity of the three unknown solutions. Justify your statements with data.
- 2 At which wavelengths would 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.
- 3 Suggest why spectra are referred to as 'fingerprints' of the stars. Explain how the data supports the statement, with reference to Chapter 4 and electron configurations and light emission.

## 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

## 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.

### main sequence

the phase during which stars convert hydrogen into helium at their cores

### red giant

a very large, bright, cool star that has run out of hydrogen at its core

### white dwarf

a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

## Birth of stars

Stars form inside clouds of dust and gas called molecular clouds. The dust and gas collapse under their own gravity and form 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.

## 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 begin in roughly 5 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 will then begin to fuse helium into heavier elements.

When a red giant runs out of fuel, its outer layers drift off in a planetary nebula and its core 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!

## 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 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.

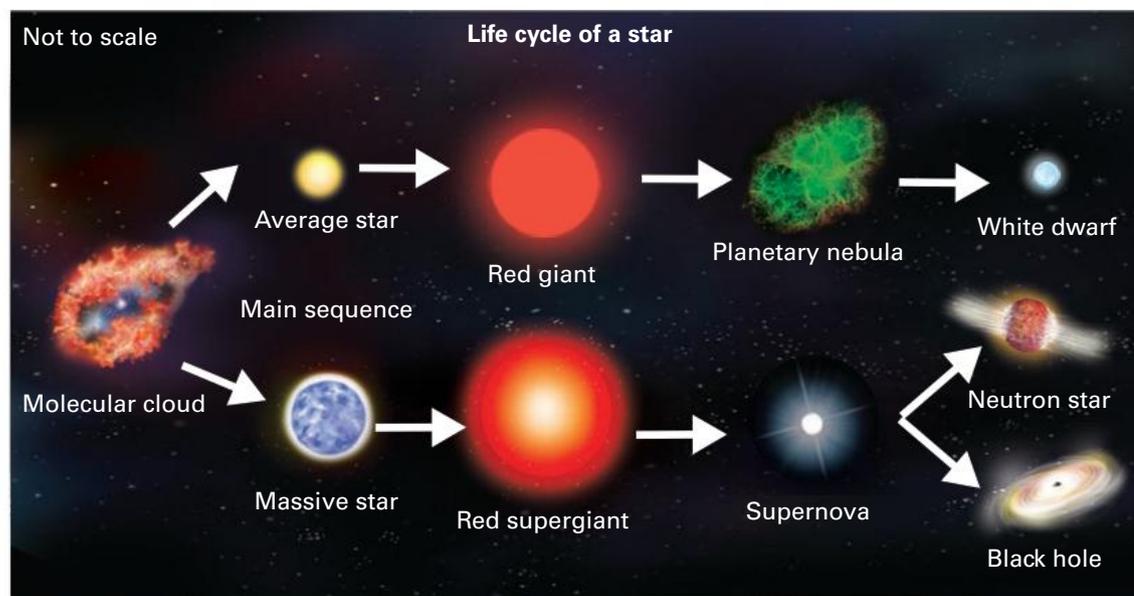


Figure 6.12 How stars change over time depends on their size.

## Supernovae

When a supergiant runs out of fuel, it collapses under its own gravity and produces an enormous explosion called a **supernova** (plural *supernovae*). All of the elements heavier than iron, such as uranium and gold, are theorised to have been created during these spectacular explosions. Generally speaking, if a star is less than 40 times the mass of our Sun, it collapses into a neutron star, while a star that has a mass greater than 40 times the mass of our Sun will become a black hole.

## Black holes

If the mass of a star prior to the supernova explosion is great enough, the amount of gravity can be so enormous that the core of the remaining star collapses 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.

### Quick check 6.4

- 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! 6.3

#### Spaghettification and worm holes

Black holes have captured the imagination of astronomy enthusiasts, science fiction writers and astrophysicists alike since their existence was hypothesised 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.

#### supernova

the explosion of a massive star

#### 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

a gravitationally bound system of gas, dust and millions or billions of stars and solar systems

## Science as a human endeavour 6.1

### The first image of a black hole

Figure 6.13 shows the first 'image' of a black hole, released on 10 April 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 collected data of a black hole in a supergiant elliptical galaxy for 10 days in order to capture the image. Scientist Dr Katie Bouman developed an algorithm called CHIRP to sift through the enormous amount of data gathered by the EHT project. The algorithm created an image using the data.

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! 6.3).



**Figure 6.13** The black hole at the centre of galaxy Messier 87

## Hertzsprung–Russell diagrams

A Hertzsprung–Russell or **H–R diagram** is a plot of star brightness (measured as luminosity) against star temperature/colour. In Figure 6.14, you can see a diagonal band of coloured dots that represent stars in the main sequence. Red giants, supergiants and white dwarfs make up their own section of the graph.

### H–R diagram

a graph of star luminosity against spectral type/temperature (Hertzsprung–Russell diagram)

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.

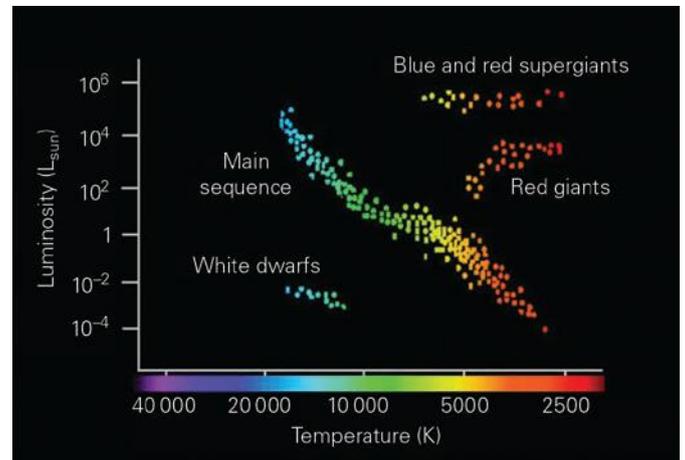
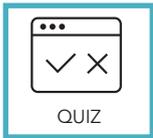


Figure 6.14 A Hertzsprung–Russell diagram plots star brightness (luminosity) against surface temperature.

## Section 6.2 questions



### Remembering

- 1 **Recall** the temperature and luminosity of our Sun.

### Understanding

- 2 **Describe** the process by which a star forms.

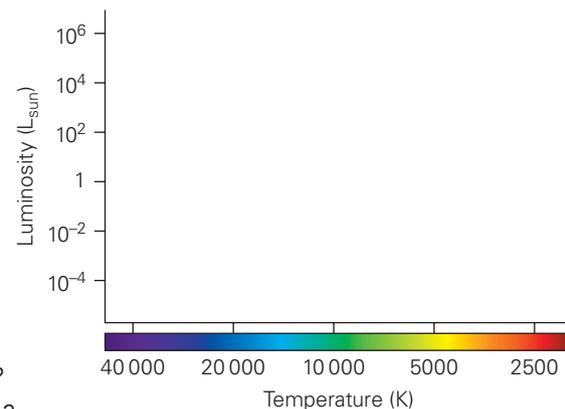
### Applying

- 3 **Explain** the two factors that determine how bright a star appears from Earth.

### Analysing

- 4 Copy and use the H–R diagram below to plot the following stars on it. **Examine** the graph to answer the following questions.

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.

### Evaluating

- 5 **Propose** a reason why nobody has ever seen a black hole. How do we know that they are there?
- 6 **Create** a summary of the observable features of stars and how they relate to each other.

# 6.3 Beyond the Milky Way



### Learning goals

- 1 To be able to define a light year.
- 2 To describe how the distance of a distant star is determined using parallax.
- 3 To describe how the Doppler effect provides evidence that the universe is expanding.

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 8 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 it. 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)! In 1936, the astronomer Edwin Hubble classified the Local Group as a group of 12 galaxies, which includes the Milky Way and the Andromeda Galaxy. Since then, as we learn more, the Local Group has grown to 36.

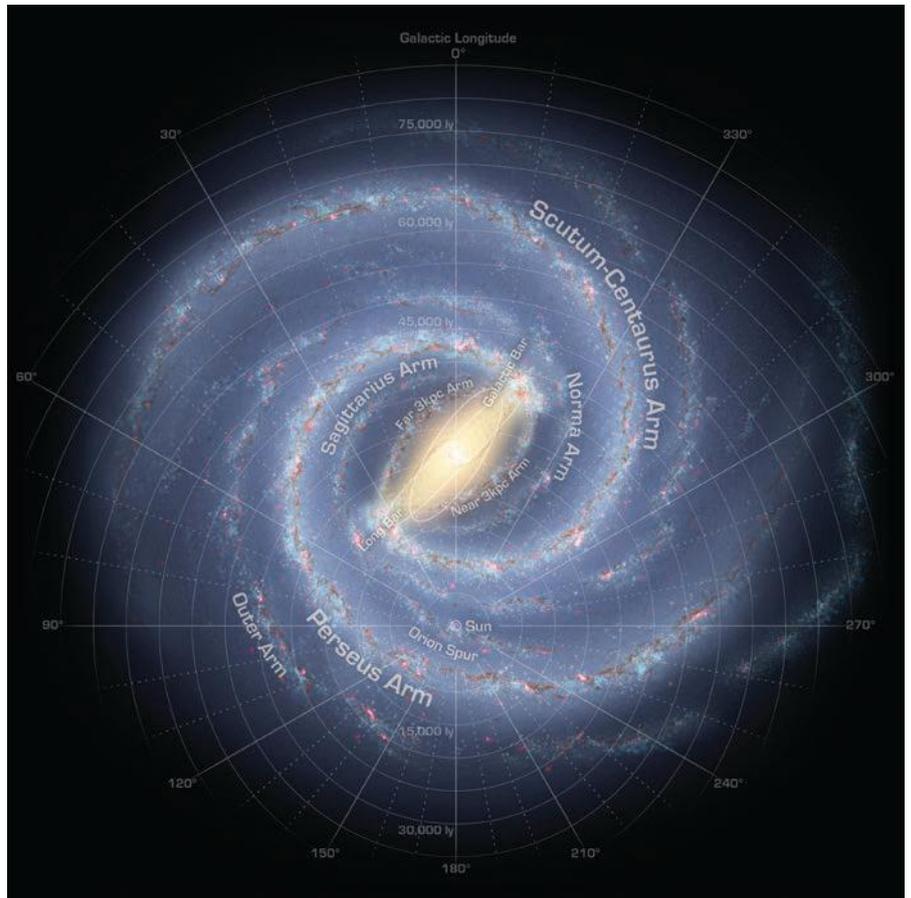


Figure 6.15 Our solar system sits on the Orion-Cygnus Arm (also known as the Orion Arm or Orion Spur) of the Milky Way.

### Galaxies

Galaxies are classified by their shape, according to the Hubble galaxy classification scheme. Galaxies can be classified as elliptical, lenticular, spiral or irregular.

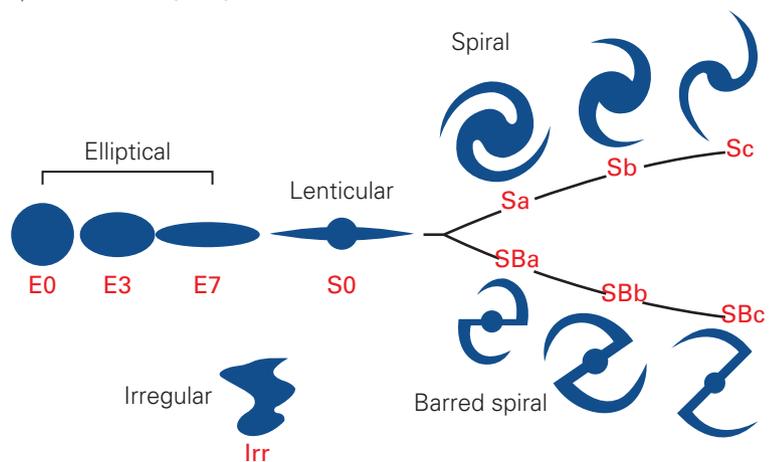


Figure 6.16 Hubble's galaxy classification scheme

## Quick check 6.5

1 Classify the following galaxies using Hubble's classification scheme.



## Try this 6.1

## 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 crowd-sourced astronomy project called 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 year**  
the distance that light travels in one year (about 10 trillion kilometres)

Light travels at a speed of 300 million metres every second, or  $3 \times 10^8 \text{ m s}^{-1}$ . 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.

## Try this 6.2

## Cheese and light

Use your microwave to calculate the speed of light!

- 1 Open 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  $\text{m s}^{-1}$ ,  $f$  is the frequency in Hz and  $\lambda$  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.

## Be careful

Handle with care as cheese may be extremely hot.

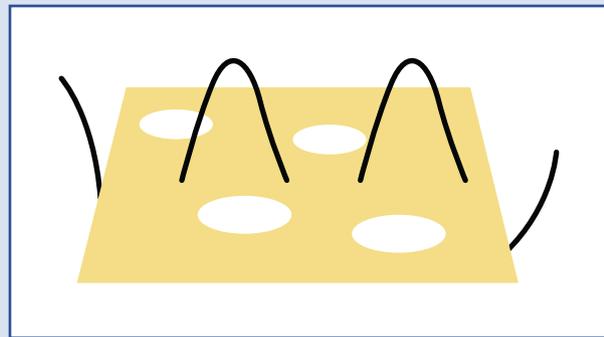


Figure 6.17 A microwave wave heating up a slice of cheese

## Explore! 6.4

### The kilogram

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.

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 Planck'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 their old definitions were and explain how they are related to mass.



Figure 6.18 A replica of Big K, the global standard for a kilogram

## 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 open that eye 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.

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 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).

### 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)

### parsec

the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion kilometres)

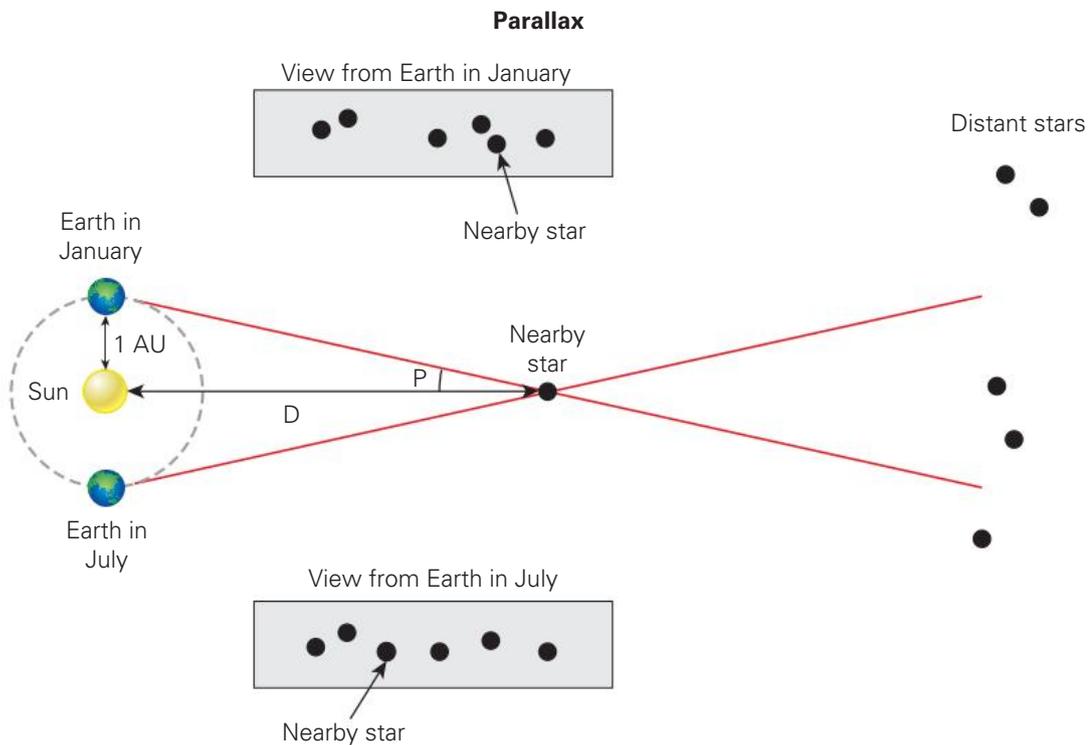
### arcsecond

1/3600th of a degree

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 by 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 parsecs.



**Figure 6.19** 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 6.6

- 1 Does a light year measure time or distance?
- 2 What is the limit out to which star distance can be measured by the parallax method?
- 3 Will a closer star have a larger or smaller parallax angle?



## Practical 6.2: Investigation

### Parallax

#### Aim

To investigate the use of parallax angles to reliably 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

##### Part 1: Prepare the results table

Draw the table shown in the results section into your science journal. You will be collating your results with the class to analyse the reliability of this method.

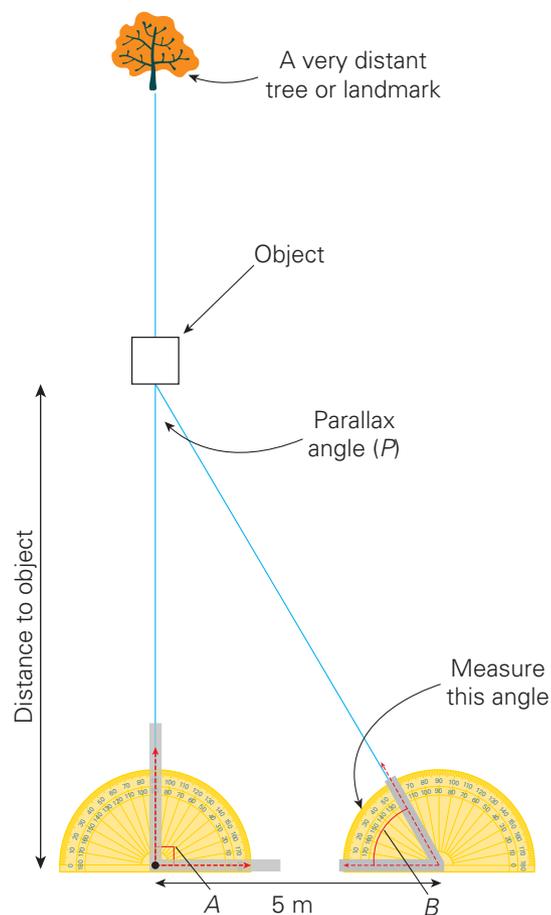
##### Part 2: Set up the distances

- 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, angle (A) perpendicular to the line going through the object and the landmark, as shown in the diagram.
- 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 angle (B) (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.)

#### Results

- 1 Calculate the parallax angle ( $P$ ) by subtracting the angle ( $B$ ) from  $90^\circ$ .
- 2 Use trigonometry  $D = \frac{5}{\tan(P)}$  to calculate the distance ( $D$ ) to the object.
- 3 Use the trundle wheel to measure the actual distance to the object.
- 4 Calculate the relative error.
- 5 Combine data on a class board or spreadsheet.
- 6 Draw a scatterplot to analyse the relationship between the distance to the object and its parallax angle.

*continued...*



...continued

- 7 Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

	Baseline distance (m)	Angle B (°)	Angle P = 90 - Angle B (°)	Calculated distance to the object (m)	Measured distance to the object (m)	Relative error $\frac{\text{Measured distance} - \text{Calculated distance}}{\text{Measured distance}} \times 100$
Group 1	5					
Group 2	5					
Group 3	5					
Group 4	5					
Group 5	5					
Group 6	5					
Mean	5					

**Discussion**

- 1 Describe the relationship between the parallax angle and the calculated distance.
- 2 Describe the amount of relative error for your own calculations and the mean relative error for the class group.
- 3 Instrument error is one factor that could affect the precision of the experiment. Were other factors that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning.
- 4 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

**Doppler effect**

a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

**blue shift**

a spectrum shifted towards shorter wavelengths

**red shift**

a spectrum shifted towards longer wavelengths

**The Doppler effect**

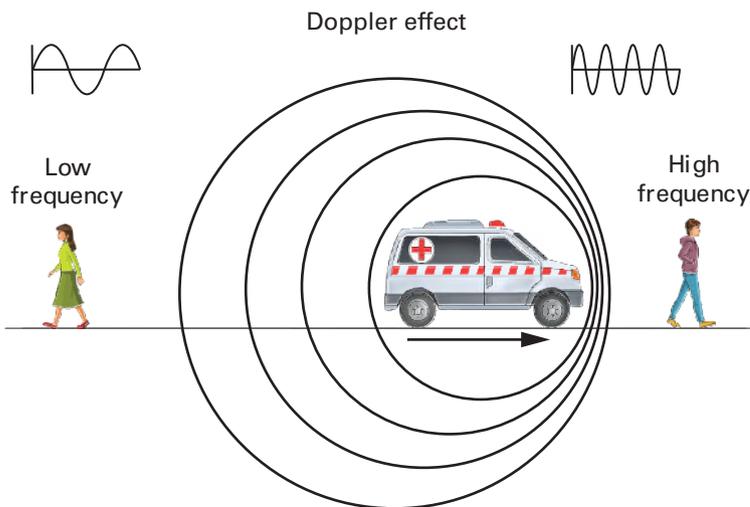
When you hear an ambulance travelling past you, the pitch of the siren changes as it passes. When the ambulance is travelling towards you, the sound wave is a little more squashed than usual and results in a higher frequency wave. You hear it as a higher pitch. When

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**.

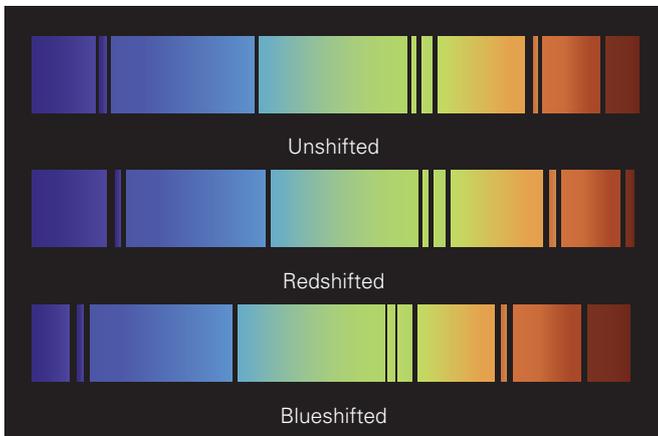


The same phenomenon happens with light waves if an object is travelling fast enough. When the object is travelling towards you, the light it emits is of a higher frequency, which translates to the light appearing more blue. This is called **blue shift**. When the object is travelling away from you, the light it emits is of a lower frequency, which translates to the light appearing more red. This is called **red shift**.

When astronomers look at light 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.



**Figure 6.20** 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 6.21** 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.

## Travelling large distances

Earth as we know it is not going to be around forever, as it will become enveloped by our Sun expanding into a red giant in 5 billion years. 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) presents 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 spaceship leaving Earth to 99% of the speed of light, but an equally enormous amount of energy to decelerate at journey's end.

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 indirectly, such as 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 could breathe, 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, in order for water to exist in liquid form. 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.

### exoplanet

a planet outside our solar system, orbiting a star other than our Sun

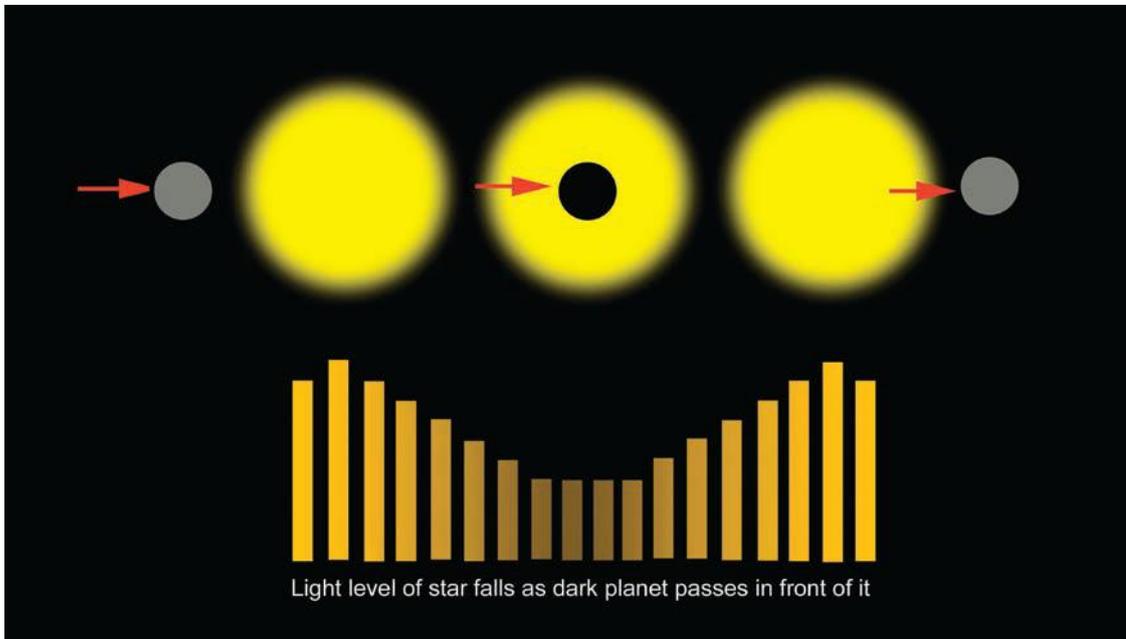
### Goldilocks zone

the habitable zone around a star where it is not too hot and not too cold in order for water to exist in liquid form

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 several 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!



**Figure 6.22** Astronomers use transit photometry to detect exoplanets.

## Science as a human endeavour 6.2

### 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).



**Figure 6.23** Professor Penny Sackett, Chief Scientist of Australia (2008–11)

### Science as a human endeavour 6.3

#### Dr Abigail Allwood

Dr Abigail Allwood is the first female and first Australian principal investigator on a NASA Mars Rover mission searching for evidence of life on Mars. She grew up in Brisbane and studied stromatolites, detection of life on other planets and evolution of life on early Earth at Queensland University of Technology and Macquarie University in Sydney.

### Section 6.3 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 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.

#### Applying

- 4 **Explain** why an ambulance siren changes to a slightly lower pitch as it drives past you.
- 5 **Describe** what is meant by the term 'Goldilocks zone'. How does it apply to humans being able to live outside our solar system?
- 6 **Explain** how astronomers determined that the majority of galaxies we can observe are travelling away from us.

#### Analysing

- 7 **Contrast** red shift and blue shift.

#### Evaluating

- 8 **Evaluate** the potential of humans finding a way to leave our solar system.

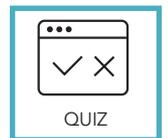
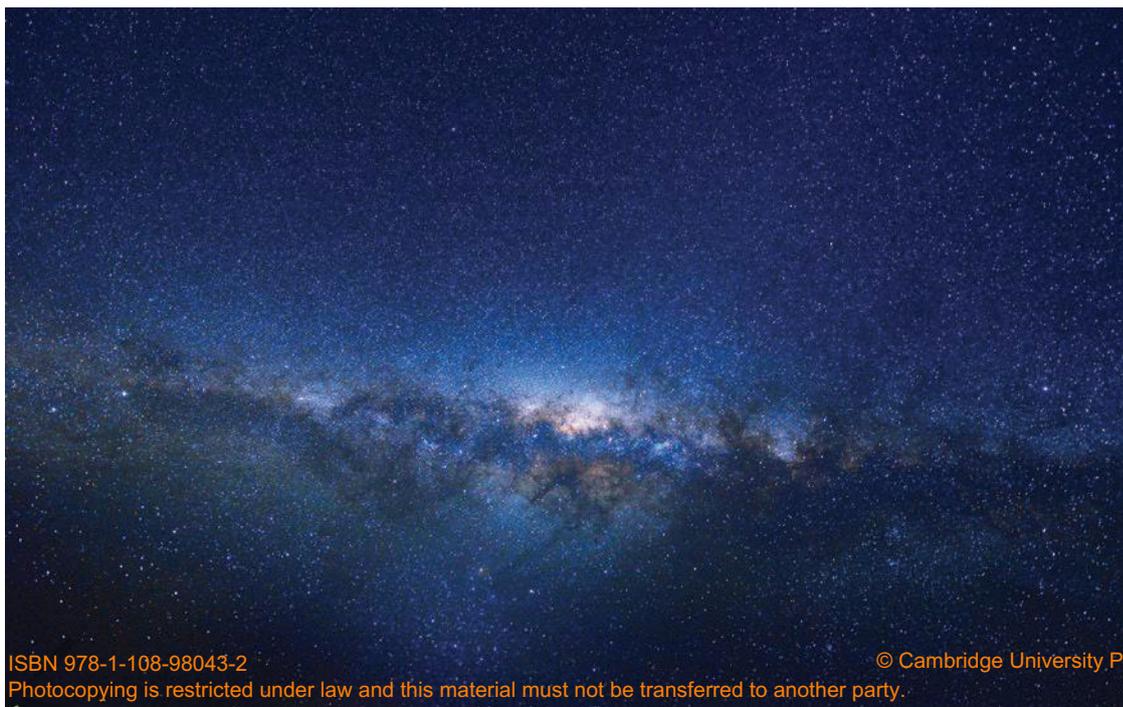


Figure 6.24 The Milky Way seen from the Southern Hemisphere



## 6.4 The Big Bang



### Learning goals

- 1 To appreciate how scientific thinking is refined over time.
- 2 To be able to recall the three main pieces of evidence that support the Big Bang theory.
- 3 To be able to define the cosmic microwave background.
- 4 To be able to define Hubble's law.



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?

### The beginnings of a theory

Albert Einstein, a theoretical physicist, developed the theory of relativity between 1907 and 1915. He assumed the universe was confined to the Milky Way, and that it was static or non-evolving, which means its structure does not change, and it did not have a beginning.

In 1927, Georges Lemaître, a Catholic priest, astronomer, mathematician and cosmologist, published a model of the universe using Einstein's theory. Lemaître's model allowed for the universe to evolve by expanding. Hubble discovered many more galaxies like the Milky Way, and they all appeared to be moving away from us. Lemaître's theory gained ground due to Hubble's findings, but it still had much opposition. Einstein initially continued to support the steady state universe even though he was very impressed by Lemaître's work.

**Big Bang**  
the large explosion that scientists believe created the universe

**cosmic microwave background**  
electromagnetic radiation left over from the early stages of the universe

Lemaître further explored the consequences of the expanding universe when he found out about Hubble's discovery. He proposed that the universe started from a single point he called the 'primeval atom'.

It was a bold proposal, and the scientific community met it with scepticism. The term 'big bang' was first used by steady state astronomer



Figure 6.25 Georges Lemaître

Fred Hoyle, while he was on a radio talk for the BBC in 1949. The term stuck. However, it took another 30 years for the expanding universe to be generally accepted. It was the discovery of the **cosmic microwave background** in 1964, by Arno Penzias and Robert Wilson, both radio astronomers, that proved conclusive. Lemaître died in 1966 and lived just long enough to see his theory finally accepted.

Our present theories about the origin of the universe continue to evolve. The inflationary model, dark energy and dark matter are all currently being investigated, and a new generation of telescopes (for example, the James Webb Space Telescope) are being built.

Over the last 100 years, the scientific community has been constantly reviewing and refining theories about the origin of the universe in accordance with new discoveries.

### Quick check 6.7

What discoveries supported Lemaître's model of the expanding universe?

### Explore! 6.5

#### Contributions of countless many

It would be impossible to name every single person involved in shaping our understanding of the universe to what it is today. Conduct some research on Jocelyn Bell Burnell and Alan Guth and summarise their contributions. How does their work link directly or indirectly to the Big Bang theory?



Figure 6.26 Jocelyn Bell Burnell (left) and Alan Guth (right) are two of the countless great minds in the modern era.

### Evidence for the Big Bang

The Big Bang theory suggests that the universe was created 13.8 billion years ago from a very small, yet very dense **singularity**. Three main pieces of evidence support the Big Bang theory:

- Almost all galaxies are red shifted, which 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 some of 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.

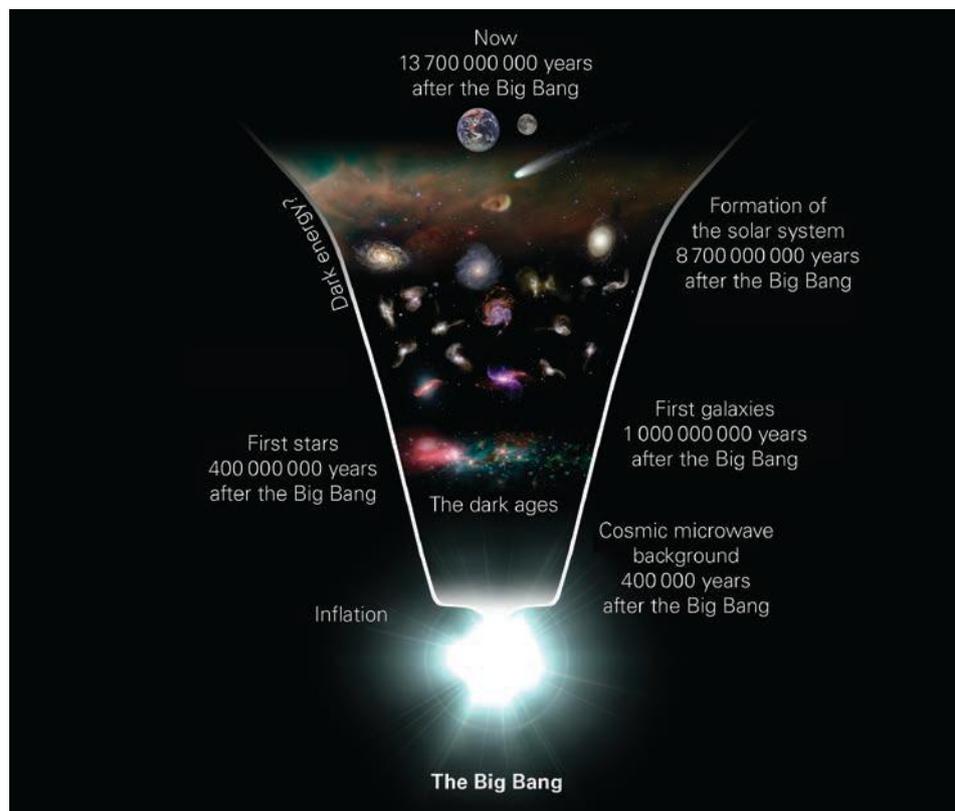


Figure 6.27 The history of the universe

**singularity**  
a point at which infinitely dense matter occupies an infinitely small space

### In the beginning

The Big Bang theory suggests that before the universe was created 13.8 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 high 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

**epoch of recombination**  
the point in time where  
electrons and ions could  
combine to form atoms

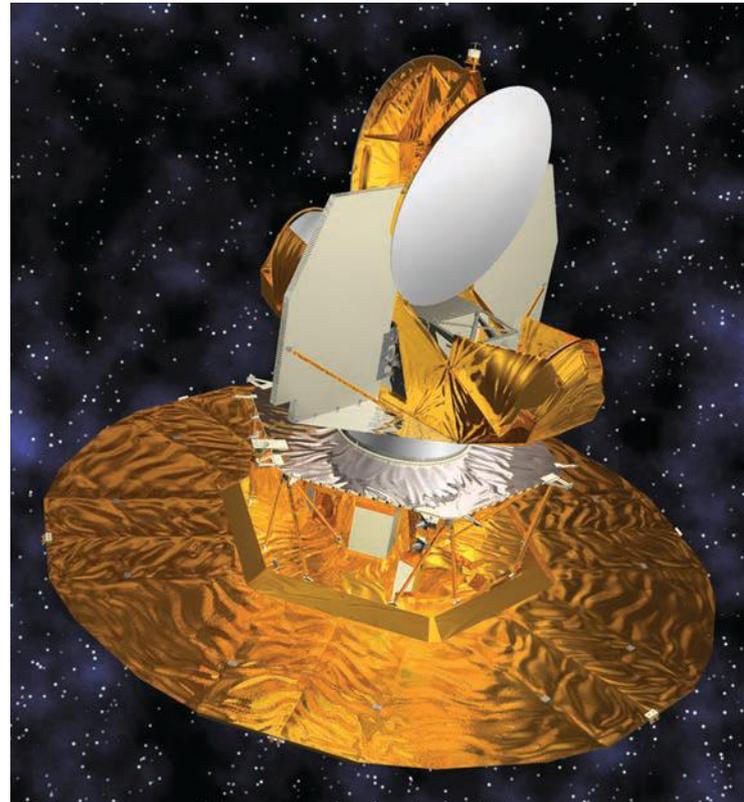
ions and electrons could bond together is called the **epoch of recombination**. The term 'recombination' can be misleading as it does not mean that protons and electrons were combined before, but rather it is a historical convention as the term came about before the Big Bang model became the primary theory for the origins of the universe.

### Cosmic microwave background

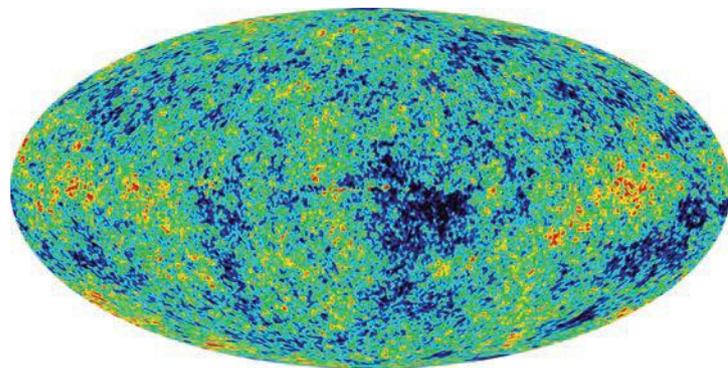
Radiation is the name that we give to all frequencies of the electromagnetic spectrum, including gamma rays, X-rays, microwaves, ultraviolet waves, visible spectrum light, infrared waves and radio waves. Radiation was emitted from the Big Bang, and we can still observe that radiation today. It exists 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 (see Chapter 9). For

example, when we look at the light from Alpha Centauri, 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 13.8 billion years ago!



**Figure 6.28** The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft operated in the early 2000s to collect temperature data from the cosmic microwave background.



**Figure 6.29** Data collected from WMAP was used to give a temperature map of what the universe looked like shortly after the Big Bang.

**Quick check 6.8**

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 13.8 billion years that the universe has existed. The distance out to which we can observe is actually well beyond 13.8 billion light years. This is because of the expansion of the universe. In the last 13.8 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.

**Dark matter and dark energy**

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. Astronomers theorised that there must be some other type of matter causing this extra gravity, calling it **dark matter**. In 1965, Vera Rubin provided evidence that dark matter existed when she observed a difference in the predicted and observed motion of galaxies. She concluded that invisible gravity sources were pulling planets and stars in certain directions.

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!

**observable universe**  
the spherical region of the universe that can be observed from Earth because light has had time to reach Earth

**dark matter**  
matter that does not emit light and is responsible for unidentified gravity in the universe

**dark energy**  
a theoretical force responsible for accelerating the expansion of the universe

**Science as a human endeavour 6.4****Professor Brian Schmidt**

Professor Brian Schmidt, from the 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 6.30** Nobel Prize laureate, Professor Brian Schmidt

## 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.

### 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 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. Hubble found that the further a galaxy is from



**Figure 6.31** Edwin Hubble, one of the most important astronomers of all time

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  $v = H_0 D$ , 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  $500 \text{ km s}^{-1} \text{ Mpc}^{-1}$  (Mpc is megaparsec), or  $160 \text{ km/s/million-light-years}$ . However, over time, the constant has been measured more and more accurately, and the current value is  $73.8 \text{ km s}^{-1} \text{ Mpc}^{-1}$ .

Hubble's law demonstrates two points.

- 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.
- 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’.

## Practical 6.3: Investigation

### 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
- a permanent marker
- piece of string around 40 cm long
- ruler
- paperclip
- stopwatch

#### Method

##### Part 1: Prepare the results table

Draw the table shown in the results section into your science journal.

##### Part 2: Set up the model

- 1 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).
- 2 Stick six dots on the balloon at random points and label one H (for home) and the others 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.

##### Part 3: Measure the variables

- 1 Use the string and ruler to measure the distances HA, HB, HC, HD and HE, and record them in the results table under  $D_1$ .
- 2 Remove the paperclip, then fully inflate the balloon, timing how long it takes you to do this with the stopwatch. Tie the balloon off.
- 3 Measure the five distances again and record them in the results table under  $D_2$ .

#### Results

Position on balloon	$D_1$ (cm)	$D_2$ (cm)	Mean speed ( $\text{cm s}^{-1}$ ) $= \frac{(D_2 - D_1)}{t}$
HA			
HB			
HC			
HD			
HE			

- 1 Calculate the mean speed that each dot was moving away from the home dot in the time ( $t$ ) it took you to blow up the balloon, by using mean speed  $= \frac{(D_2 - D_1)}{t}$ .
- 2 Draw a scatterplot to analyse the relationship between mean speed (on the y-axis) and the  $D_2$  (on the x-axis).
- 3 Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

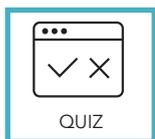
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### Discussion

- 1 Describe the trend or pattern that is found when the line of best fit was applied to the graph. What type of relationship was found?
- 2 Suggest how you apply this relationship to understanding the movement of galaxies and expansion of the universe.
- 3 Predict the misconception that might arise if you drew the galaxies on with the permanent marker rather than using stickers. You can try this out and describe what happens.
- 4 Evaluate the limitations of using a balloon as a model for 3D space and suggest a better model.
- 5 Can a valid conclusion regarding the expansion of the universe be drawn from modelled experiments such as this one? Support your statement using data and limitations of the model.
- 6 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the reliability or validity of the data.

## Section 6.4 questions



### Remembering

- 1 **Recall** the age of the universe.
- 2 **State** the assumption that Hubble made about galaxies and what he concluded about galaxies that appeared smaller than others.

### Understanding

- 3 An astronomer observed a distant galaxy to be travelling at a recessional velocity of  $370 \text{ km s}^{-1}$ . Use the current value of Hubble's constant ( $73.8 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ) to **calculate** its distance from us. Give your answer in both megaparsecs and light years.

### Applying

- 4 **Explain** the concept of the observable universe.

### Analysing

- 5 **Organise** the following parts of the electromagnetic spectrum from lowest frequency to highest: infrared, gamma, radio, X-ray, microwave, visible, ultraviolet.

### Evaluating

- 6 **Create** a drawing with labels to demonstrate the enormous size of the universe. Alternatively, describe how you would demonstrate it using everyday objects.
- 7 **Propose** how theories and discoveries work together to refine scientific thinking. Use how we think about the origin of the universe as an example.



**Figure 6.32** The Orion Nebula in a composite image of visible light and infrared, taken by the Hubble Space Telescope.

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
6.1 I can summarise the changes in the model of the universe that have been proposed over time.	1	
6.1 I can distinguish between modern usage of optical and radio telescopes.	6	
6.2 I can describe the formation, luminosity and life cycle of different stars.	7	
6.3 I can describe the parallax method to determine the distance that stars and galaxies are from Earth.	2	
6.3 I can define a light year.	8	
6.3 I can describe the Doppler effect.	5	
6.4 I can describe the Big Bang theory.	3	
6.4 I can explore the evidence for the Big Bang theory including cosmic microwave background and Hubble's law.	10	

## Review questions

### Remembering

- 1 **Describe** the evidence that Ptolemy used to explain his geocentric model.
- 2 **Describe** how the distance that stars are from Earth can be calculated.
- 3 **List** the evidence that supports the Big Bang theory.

### Understanding

- 4 **Describe** the relationship between star brightness, size and length of lifetime.
- 5 An astronomer finds that the spectral lines from a distant galaxy are shifted towards the red part of the spectrum. **Explain** what this evidence suggests about the galaxy and universe.

### Applying

- 6 **Contrast** optical and radio telescopes.
- 7 Use your knowledge of a star's lifecycle to **distinguish** between a red giant and a white dwarf.

### 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.

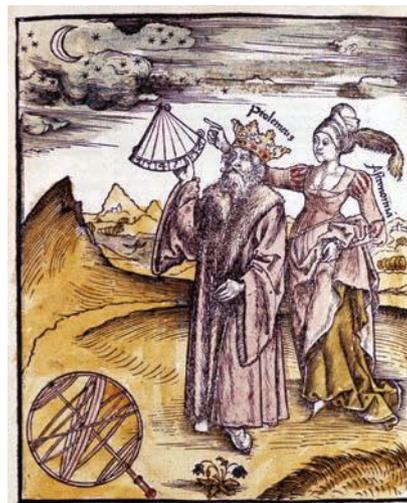


Figure 6.33 An artist's engraving of Ptolemy looking to the sky

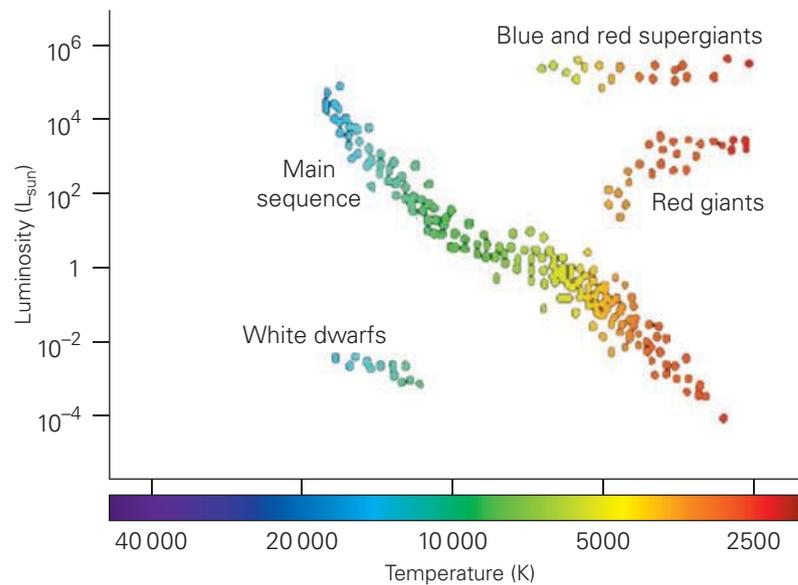


### Evaluating

- 9 **Discuss** the chances of finding intelligent life elsewhere in the universe. Use evidence to justify your answer.
- 10 **Evaluate** Hubble's law as evidence for the Big Bang theory.

### Data questions

The universe is home to billions of stars, many much larger and much brighter than the star we call 'the Sun'. Figure 6.34 presents a selection of stars in our universe and shows their surface temperature and luminosity. As a reference, the Sun has a luminosity of 1 and a surface temperature of approximately 5800 K. The stars in Figure 6.34 belong to four different categories depending on their properties: the main sequence, white dwarves, red giants, and blue/red supergiants.



**Figure 6.34** A Hertzsprung–Russell diagram illustrating the surface temperature and luminosity of various stars in the universe

- 1 **Identify** the category of star to which our Sun would belong.
- 2 **Determine** which category of star is most luminous.
- 3 The x-axis provides the star surface temperature in units of kelvin ( $^{\circ}\text{C} = \text{K} - 273$ ). Given the surface temperature of the Sun is 5800 K, **calculate** the surface temperature in  $^{\circ}\text{C}$ .
- 4 **Identify** the trend of surface temperature and luminosity of stars in the main sequence.
- 5 **Contrast** the properties of white dwarves and red giants.
- 6 **Identify** any patterns occurring in the properties of blue and red supergiants.
- 7 A large star has been discovered and classified as a main sequence star with a surface temperature of 15 000 K. **Deduce** the luminosity of this star compared to the Sun.
- 8 New data has suggested that the new star from Question 7 is almost 100 000 years old, its surface is cooling and it is becoming slightly more luminous. **Predict** the category this star will belong to as it changes properties from the main sequence.
- 9 **Compare** the properties of all four categories of star. Do you think the size of a main sequence star will ultimately determine whether it becomes a supergiant, giant or dwarf?

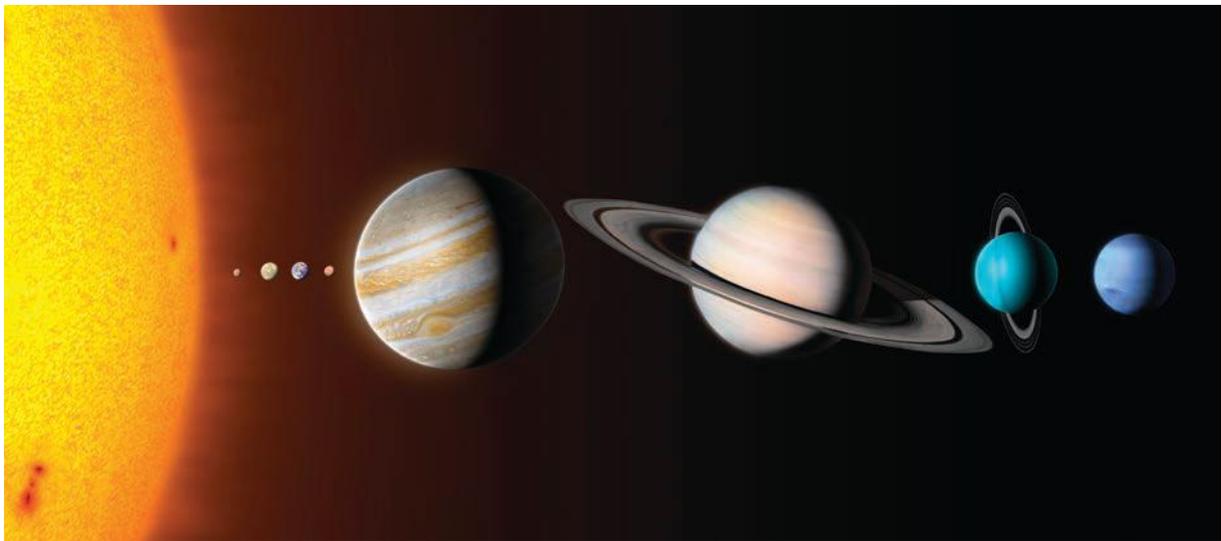
## STEM activity: Creating a representation of our solar system to scale

### Background information

How do you create an image that shows, as accurately as possible, the distance between our Sun and Earth (150 million kilometres)? 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 will create a representation of our solar system to scale to gain a better understanding of its size.



**Figure 6.35** A representation of our solar system where the distances are not to scale, but the sizes are to scale.

**Design brief:** Design a scale model of the universe and present this information in the form of a vlog (video blog or video log).

### Activity instructions

The scale of the universe is immense. In this activity you will collaborate in groups to create a representation of our planetary system to scale, using hands-on materials while recording your progress. The scale model must include all the planets and known dwarf planets. You will need

to make sure that your scale model helps others gain a better idea of the vastness/true size of our solar system. To do this you will need to find a way (for example, a formula) to convert distances and diameters of planets into something humans can comprehend. 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 kilometres to 2 metres. Can you see how much easier it is to visualise and comprehend the 'metre' than the 'millions of kilometres'? Now you can repeat this conversion for all planets in 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 (12756 km) to a more manageable number. What about 10 cm? Then convert the diameters of the other bodies in our solar system.

Use your new measurements to create a 2D version of the solar system, showing Earth and all other planets and dwarf planets. Record a vlog of all the stages of your 2D solar system and edit this video to be used as an educational resource.

## Suggested materials

### Model

- a basketball or soccer ball (the Sun)
- large reel of measuring tape
- colouring pencils, cardboard and paper to create your planets
- protractor
- scissors
- movie maker software and recording device

Note: You may need to use the school oval to really represent the distances involved.

## Research and feasibility

- 1 Using the information in Table 6.2 on the following page, research how you could create a formula to assist you to convert all values from millions of kilometres to more manageable units (metres or centimetres). What skills do you need to perform that task? Record all information on your vlog.
- 2 Discuss in your group the feasibility of presenting the scale model within the restrictions of school. List your ideas of how to demonstrate the vast size of the solar system.
- 3 Record your research and results as the Research and feasibility section of your vlog.

## Design and sustainability

- 4 Analyse Table 6.2 and make a statement about how the orbital period of a celestial body is affected by its distance from the Sun. Explain your reasoning.
- 5 The dwarf planet Haumea has been described as 'eccentric' by its discoverers. Analyse the table and determine which data shows how this dwarf planet is very different from other dwarf planets.
- 6 Planets orbit around the Sun on elliptic orbits.
  - a Compare and contrast the average distance from the 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? You can draw or sketch your answer if you like.
- 7 Record your analysis as a Design and sustainability section of your vlog.

Name of planet	Average distance from Sun (km)	Diameter (km)	Time for a single spin on axis	Time for a single orbit around Sun	Distance scale (m)	Diameter scale (cm)
Mercury	57 900 000	4 878	59 days	88 days		
Venus	108 160 000	12 104	243 days	224 days		
Earth	149 600 000	12 756	23 hours, 56 minutes	365.25 days	2	10
Mars	227 936 640	6 794	24 hours, 37 minutes	687 days		
Jupiter	778 369 000	142 984	9 hours, 55 minutes	11.86 years		
Saturn	1 427 034 000	120 536	10 hours, 39 minutes	29 years		
Uranus	2 870 658 186	51 118	17 hours, 14 minutes	84 years		
Neptune	4 496 976 000	49 532	16 hours, 7 minutes	164.8 years		
<b>Dwarf planets</b>						
Ceres	413 900 000	950	9 hours, 5 minutes	4 years, 220 days		
Pluto	4 436 820 000 to 7 375 930 000	2 370	6 days, 9 hours	248 years		
Haumea	5 260 000 000 to 7 708 000 000	1 960 × 1 518 × 996	4 hours	258 years		
Eris	5 665 500 000 to 14 634 000 000	2 326	7 hours, 46 minutes	557 years		

**Table 6.2** Some information about planets and dwarf planets within our solar system

## Create

- 8 Create your 2D solar system model. Make sure to include your scale.
- 9 Record the whole creation of your 2D model in the Create section of your vlog.

## Evaluate and modify

- 10 Edit your vlog into a video file that can be shared.
- 11 Reflect on how effective your vlog is in demonstrating the vastness of our solar system.
- 12 Present your vlog to the class and discuss the use of vlogs to share information, and the effectiveness of its use.

# Chapter 7

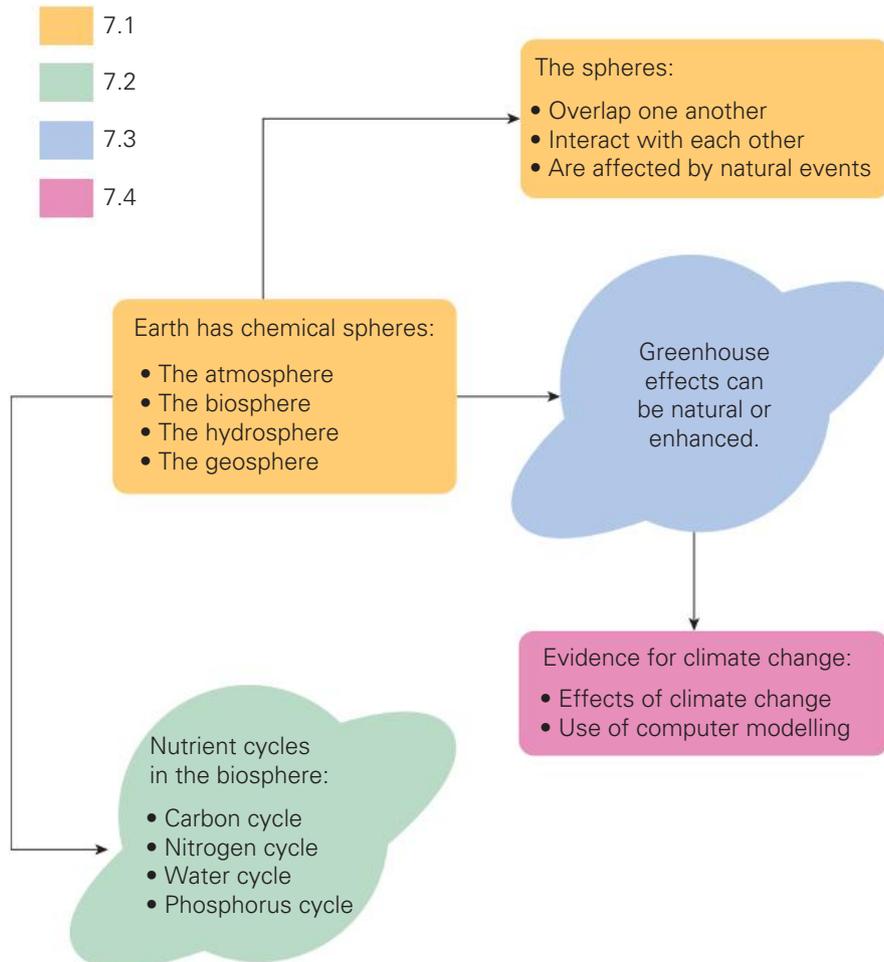
## Global systems

### Chapter introduction

The first time people had a glimpse of Earth from space was in October 1946, when a film camera set to take photos every 1.5 seconds was launched on a rocket. Earth was photographed in greater detail in December 1968 by Apollo 8 astronauts on their trip to orbit the Moon. This encouraged 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 future.

# Chapter map



# 7.1 Earth's interacting spheres



## Learning goals

- 1 To be able to distinguish between Earth's chemical spheres: atmosphere, biosphere, geosphere and hydrosphere.
- 2 To be able to list the five layers of the atmosphere.
- 3 To describe the effect of natural events such as earthquakes, volcanos and cyclones on the chemical spheres.

In your 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; it is constantly changing, unlike the Moon, which remains relatively unchanged.

## 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.

### atmosphere

the mixture of gases mainly above the surface of Earth

### troposphere

a layer of Earth's atmosphere that 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

## 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.



**Figure 7.1** The Moon is not dynamic, unlike matter on Earth which is constantly on the move. Notice how the Moon is marked by millions of craters from being struck by meteorites, most of which would burn up in the Earth's atmosphere.

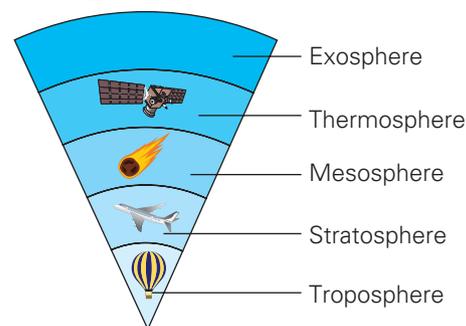
Atmospheric gas	Percentage composition (%)
Nitrogen	78
Oxygen	21
Argon	1
Trace gases (e.g. carbon dioxide, neon, methane, water vapour)	<1

**Table 7.1** The composition of gases in Earth's atmosphere

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 (UV) radiation
- protect us from bombardment by all but the largest meteorites (contrast with the surface of the Moon; without an atmosphere it has millions of craters)
- keep the surface temperature of Earth more or less constant.

The layers of most importance to us and other life on Earth are the troposphere and the stratosphere.



**Figure 7.2** The five layers of Earth's atmosphere

## Quick check 7.1

- 1 Name the gas that is the most abundant in Earth's atmosphere.
- 2 Recall the functions of Earth's atmosphere.

### The troposphere

The troposphere is the layer closest to the surface of Earth and averages between 8 and 15 km thick. It contains about 75% of the mass of gas of the entire atmosphere. It is in the troposphere that most of the weather occurs as a result of hot air rising and cold air sinking within this layer. Greenhouse gases, carbon dioxide, methane and water vapour are found in the troposphere; you will read more on this later in the chapter.



**Figure 7.3** Most of Earth's weather is found in the troposphere.

### The stratosphere

The stratosphere lies directly above the troposphere and is about 35 km thick. 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. Most jet aircraft fly in the lower part of the stratosphere.



**Figure 7.4** Jet aircraft often fly in the lower stratosphere to avoid turbulence.

#### Quick check 7.2

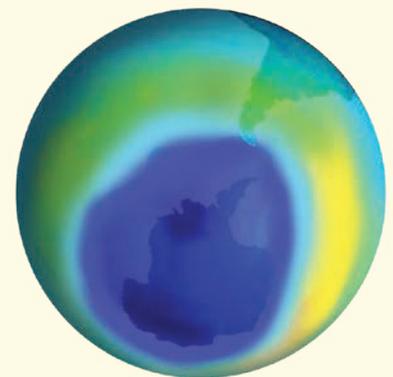
- 1 List some features of the troposphere.
- 2 Describe the function of the ozone layer in the stratosphere.

#### Explore! 7.1

##### The Antarctic hole in the ozone layer

In 1985 scientists found that parts of the ozone layer above the continent of Antarctica had broken down. They also noticed that similar thinning of the ozone layer was happening over parts of Australia, and that this correlated with an increase in cases of skin cancer. They needed to find out why this had happened and if it could be reversed. Do some research and answer the following.

- 1 Compare the molecular structures of oxygen gas ( $O_2$ ) and ozone gas ( $O_3$ ).
- 2 Identify the main function of the ozone layer in more detail to explain the impact of ozone thinning.
- 3 Research the causes of ozone thinning.
- 4 Describe the purpose of the Montreal Protocol.
- 5 Discuss whether the process of ozone thinning can be reversed. Provide evidence to support your discussion.



**Figure 7.5** The hole in the ozone layer above Antarctica. The bluish purple areas show the least amount of ozone.

## Science as a human endeavour 7.1

**Felix Baumgartner: the fastest skydiver on Earth**

On 14 October 2012, Austria's Felix Baumgartner rose nearly 39 km to the stratosphere in a helium-filled balloon. He then jumped into thin air, freefalling for 4 minutes and 22 seconds before opening his parachute. The entire journey back to the ground lasted just under 10 minutes. Baumgartner reached an estimated speed of  $1342 \text{ km h}^{-1}$ , which makes him the first man to break the speed of sound in freefall, and he broke the record for the world's highest ever freefall.

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. Early in the dive, there was concern that he could not get into the correct position for freefall (head down, arms swept back). Instead, he found himself tumbling over and over. However, due to his extensive freefalling experience, Baumgartner was able to correct his fall and get into a stable position.



Figure 7.6 Felix Baumgartner

**biosphere**

all the parts on Earth and in its atmosphere that contain life

**hydrosphere**

all of the water found on Earth (e.g. lakes and rivers)

**The biosphere**

The **biosphere** consists of all parts 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 such as bacteria.

**The hydrosphere**

The **hydrosphere** is made up of all the water on Earth. This includes the oceans, rivers, lakes, glaciers, ice, clouds rain, water vapour, underwater basins and even puddles.

**Quick check 7.3**

- 1 Define the term 'biosphere'.
- 2 Justify whether flying birds are part of the atmosphere.

**Quick check 7.4**

- 1 Define the term 'hydrosphere'.
- 2 State an example of something that is part of the hydrosphere.



Figure 7.7 Little penguins (*Eudyptula minor*), as living organisms, are part of the biosphere. The Indian Ocean is part of the hydrosphere.

## The geosphere

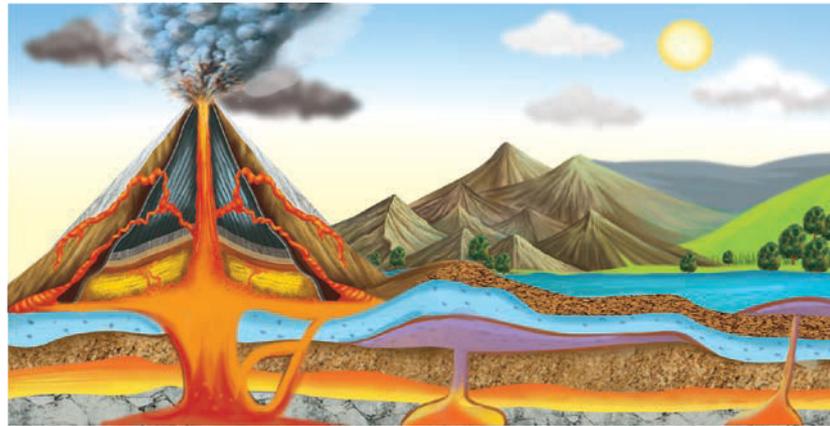
The **geosphere** consists of the Earth's geological material, such as magma, lava, rocks and minerals, located on the Earth's surface and below. This includes all the rocks and sand from dry land to the bottom of the ocean, plus minerals, lava and magma below Earth's crust, dust in the atmosphere and sediment in water.



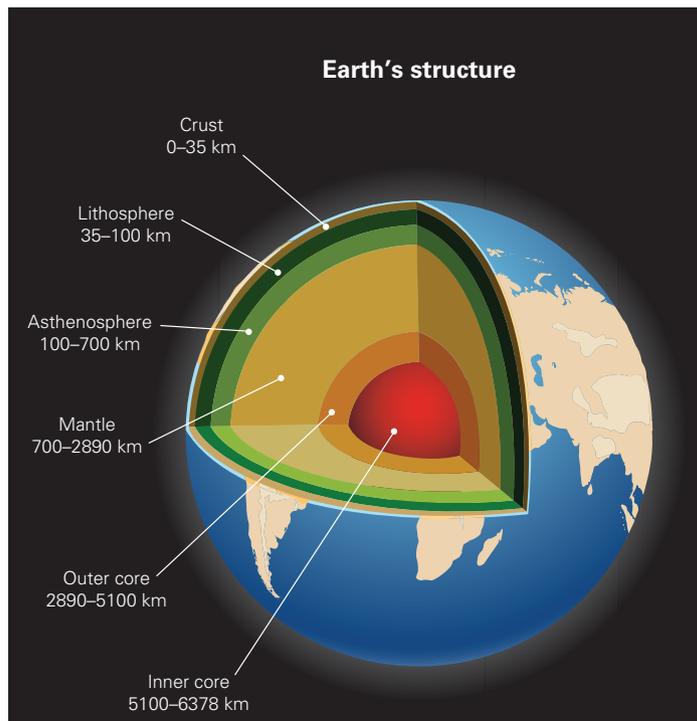
**Figure 7.8** The Bungle Bungle Range in the Kimberley region of Western Australia is part of the geosphere.

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.

**geosphere**  
includes the Earth's magma, lava, rocks and minerals



**Figure 7.9** The geosphere is constantly in motion due to the many processes involved in the rock cycle.



**Figure 7.10** The structure of Earth's geosphere, measured from Earth's surface

You may also hear the **lithosphere** mentioned as part of Earth's global systems. 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.

**lithosphere**  
the geological parts of Earth's crust and upper mantle only

### Quick check 7.5

- 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 productive 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 organisms from the biosphere.

## Sphere interactions

The chemical spheres on Earth interact and affect each other, maintaining a natural balance. 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 7.2.

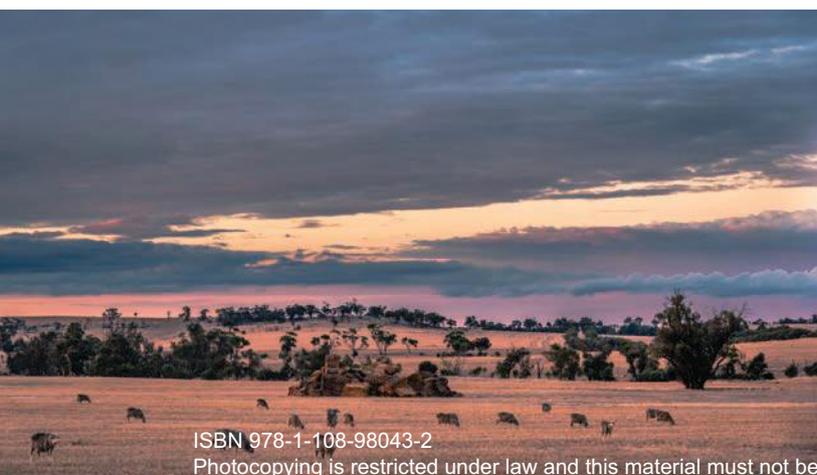
	Gain	Loss
Energy	Radiation from the Sun (mostly infrared, visible and UV wavelengths)	Heat loss into space
Mass	Cosmic dust and meteorites; comets (in the distant past)	Escape of gases into space

**Table 7.2** A summary of Earth's gains and losses of mass and energy

### Quick check 7.6

- 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 one way it can gain and lose energy.
- 3 The rate that matter moves around Earth varies, from very slow to incredibly fast. Decide whether this statement is true or false. Give a reason why.
- 4 Provide an example of a transfer of matter from the biosphere to the atmosphere.

**Figure 7.12** Farmland is one place where multiple spheres interact.



**Figure 7.11** Productive soil belongs to all four chemical spheres.

The lithosphere, the upper part of the geosphere, comes into contact with the other spheres. Let's take Figure 7.12 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.

**Figure 7.13** Plants interact with multiple chemical spheres.



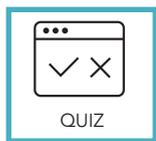
## Natural events affecting chemical spheres

Natural events such as earthquakes and volcanoes influence the interactions between the chemical spheres. Table 7.3 summarises how natural events cause sphere interactions.

Natural event	Effect on the lithosphere	Effect on the biosphere	Effect on the atmosphere	Effect on the hydrosphere
Earthquake	Blocks of land move apart, together or slide past each other Land rises or sinks Landslides Mudslides 	Changes the mineral environment and hydrosphere, damages ecosystems 	Toxic gases emitted from the ground 	Tsunamis Changes the course of rivers Destroys dams and raises or lowers lakes 
Volcano	Can form land (e.g. islands) and destroy land (volcanic explosions) while the dust and acid gases change soil minerals and conditions 	Lava burns plants and animals New land becomes habitats for ecosystems Volcanic dust changes soil and water chemistry, occasionally benefitting the biosphere, and also reduces sunlight and lowering temperatures 	Large ash clouds reduce sunlight, lowering temperatures and releasing 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 	Uproots trees and plants, destroying ecosystems 	High wind speeds 	Produces very heavy rain, causing floods Storm surges 

Table 7.3 How natural events influence the interaction between spheres

## Section 7.1 questions

**Remembering**

- 1 **Recall** the correct definition for each chemical sphere.
  - a Atmosphere
  - b Biosphere
  - c Lithosphere
  - d Hydrosphere
- 2 **Identify** the sphere where each of the following is found.
  - a Glacier
  - b Tectonic plate
  - c Earthworm
  - d Ozone
- 3 **Recall** the layer of the atmosphere where most of the weather occurs.
- 4 **Recall** 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 **Identify** which of Earth's spheres would contain matter that has arrived from space.
- 7 **Explain** why you cannot describe Earth as a closed system (one where the total mass does not change).
- 8 **Explain** the problems associated with a hole in the ozone layer.

**Applying**

- 9 **Describe** the role of Earth's atmosphere in terms of sustaining life on Earth.
- 10 **Compare** the geosphere with the lithosphere.

**Analysing**

- 11 **Identify** examples of the chemical spheres in Figure 7.14.
- 12 **Identify** the sphere interactions taking place in Figure 7.15.
- 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 spheres clouds belong to and then justify your answer.
- 16 **Discuss** how a natural disaster, such as an earthquake, can affect chemical spheres. Try to include all the spheres in your answer.



Figure 7.14 Chemical spheres



Figure 7.15 Sphere interactions

## 7.2 Nutrient cycles in the biosphere

### Learning goals

- 1 To be able to recall the seven processes of the carbon cycle.
- 2 To be able to recall the six processes of the nitrogen cycle.



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.

### The carbon cycle

The carbon cycle describes the movement of carbon through all four spheres. Carbon is one of the most important elements for life on Earth because of the almost infinite variety, complexity and size of the molecules it can form. The carbon cycle occurs in many stages, but it is important to note that carbon can stay at one particular stage for thousands of years before moving on to the next stage.

**sustainable ecosystem**  
a biological environment that is able to support itself without outside assistance

Table 7.4 summarises the forms of carbon in each of the chemical spheres.

Chemical sphere	Carbon content
Atmosphere	Carbon dioxide (CO <sub>2</sub> ), methane (CH <sub>4</sub> )
Biosphere	Carbohydrates (such as glucose, C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> ), fats, proteins and the nucleic acids of all living things
Hydrosphere	CO <sub>2</sub> dissolved in rivers, lakes and the ocean, forming carbonic acid, H <sub>2</sub> CO <sub>3</sub>
Lithosphere	Decomposing organic matter in soils Fossil fuels (coal, oil and gas) Limestone (calcium carbonate, CaCO <sub>3</sub> )

Table 7.4 A summary of the carbon content in each chemical sphere

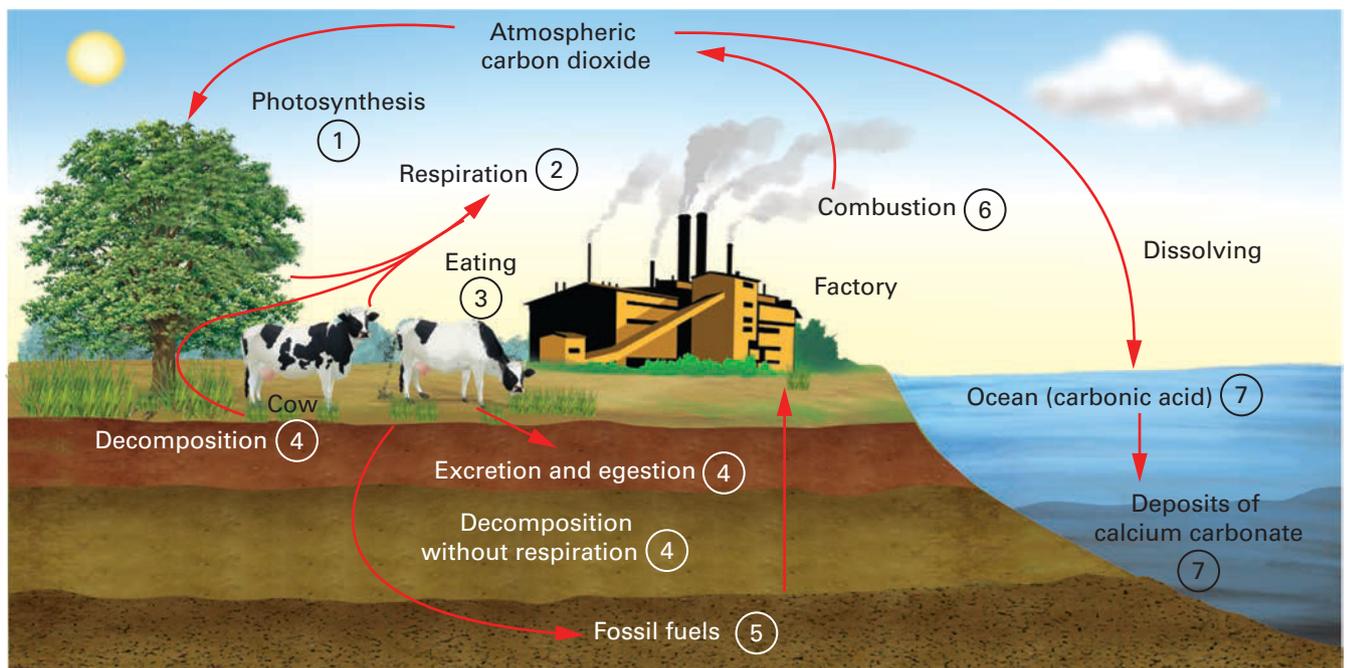


Figure 7.16 The main stages and processes in the carbon cycle (numbers refer to points in the text)  
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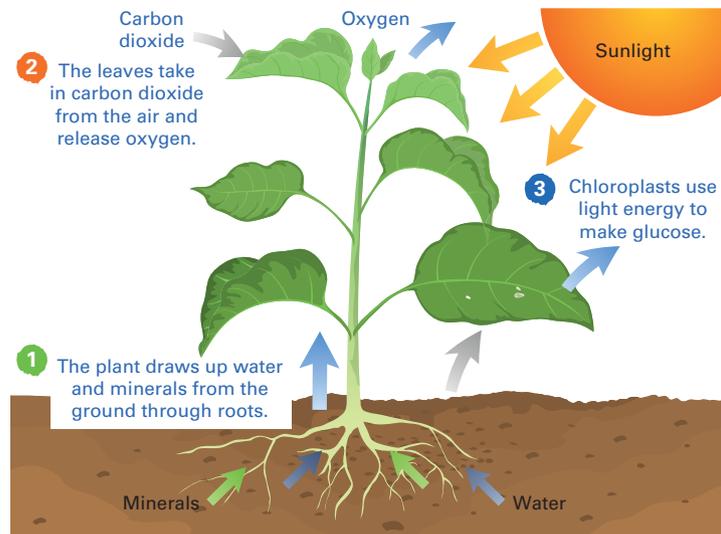
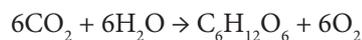
The carbon cycle can be summarised in seven processes, which either increase or decrease the amount of carbon dioxide in the atmosphere.

### 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 for plants:

carbon dioxide + water → glucose + oxygen



**Figure 7.17** Plants remove carbon dioxide from the atmosphere during photosynthesis.

#### Quick check 7.7

- 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 What form of carbon is carbon dioxide converted into during 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 7.18** The carbon content of the cricket is now being consumed by the leopard gecko.

### 3. Respiration

Plants and animals break down glucose in a reaction with oxygen to form carbon dioxide and water. This process is called respiration. The carbon dioxide is added to the atmosphere when organisms breathe out.



**Figure 7.19** Carbon dioxide is produced during respiration and breathed out by humans, along with water vapour that condenses on cold days.

The following equation summarises respiration:  
glucose + oxygen → carbon dioxide + water + ATP



#### 4. Excretion, egestion, death and decomposition

Some of the carbon content of animals and plants enters the soil as waste such as urine and faeces.



**Figure 7.20** Egestion increases the carbon content of the soil, as with these kangaroo faeces.

Dead animals and plants (organic matter) also contribute to the carbon content of the soil. Waste material and dead organic matter is broken down by **decomposers**, which respire, releasing carbon dioxide back into the atmosphere.

#### Quick check 7.8

- 1 How do animals obtain their carbon in the carbon cycle?
- 2 Apart from carbon dioxide, what other product is released during the breakdown of glucose in respiration?
- 3 Name ways that animals can increase the carbon content of soil.

#### 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.

##### ATP

a chemical (adenosine triphosphate) in living organisms that stores energy and releases it when needed

##### egestion

the process of removing undigested waste material from the body in the form of faeces



**Figure 7.21** 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.

##### decomposer

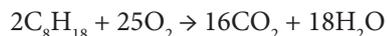
a living organism, such as bacteria and fungi, that breaks down dead organic matter

**Figure 7.22** The combustion of coal in furnace produces large amounts of carbon dioxide gas.



The following equation shows the combustion of octane, a component of oil, which is used in car petrol:

octane + oxygen  $\rightarrow$  carbon dioxide + water



## 7. Formation of limestone

Carbon dioxide gas in the atmosphere can dissolve in the oceans, forming carbonic acid. The carbon dioxide also provides the carbon that combines with dissolved calcium ions to make calcium carbonate,  $\text{CaCO}_3$ , which is 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. Related rocks that are mainly calcium carbonate include marble and chalk. The carbon stored in limestone can remain there for millions of years before it re-enters the carbon cycle.



Figure 7.23 Fossilised shells in limestone

### Quick check 7.9

- 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 the main compound in 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 7.5 A summary of the gains and losses of atmospheric carbon within the carbon cycle

## Practical 7.1

### The oceans and carbon dioxide

#### Aim

To determine what happens when carbon dioxide dissolves in water.

#### Be careful

Ensure appropriate personal protective equipment is worn.  
Wear safety glasses.  
Use the correct method for blowing into the test tube.

#### Materials

- bottle of universal indicator and pH scale
- water
- test tube
- test-tube rack
- straw

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 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.

*continued...*

...continued

### Results

	Colour	pH
Before blowing		
After blowing		

### Discussion

- 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.
- 6 Determine the ability of carbon dioxide to dissolve in water, based on this experiment.
- 7 Discuss the global issues behind carbon dioxide dissolving in water.

### Conclusion

Explain how your observations support your claim.

## Practical 7.2

### Limestone and carbon dioxide

#### Aim

To determine whether limestone is a store of carbon dioxide.

#### Materials

- calcium carbonate chips (often called marble chips)
- hydrochloric acid (1 mol L<sup>-1</sup>)
- limewater
- 2 × 10 mL measuring cylinders
- 2 test tubes
- delivery tube
- 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 of the tube in the limewater solution.
- 4 Observe what happens to the limewater.

#### Results

Record your observations from the experiment in your science journal.

#### Discussion

- 1 Describe what happened to the limewater solution.
- 2 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.
- 3 Identify the part of the carbon cycle represented by this investigation.

#### Be careful

Ensure appropriate personal protective equipment is worn. Wear safety glasses.



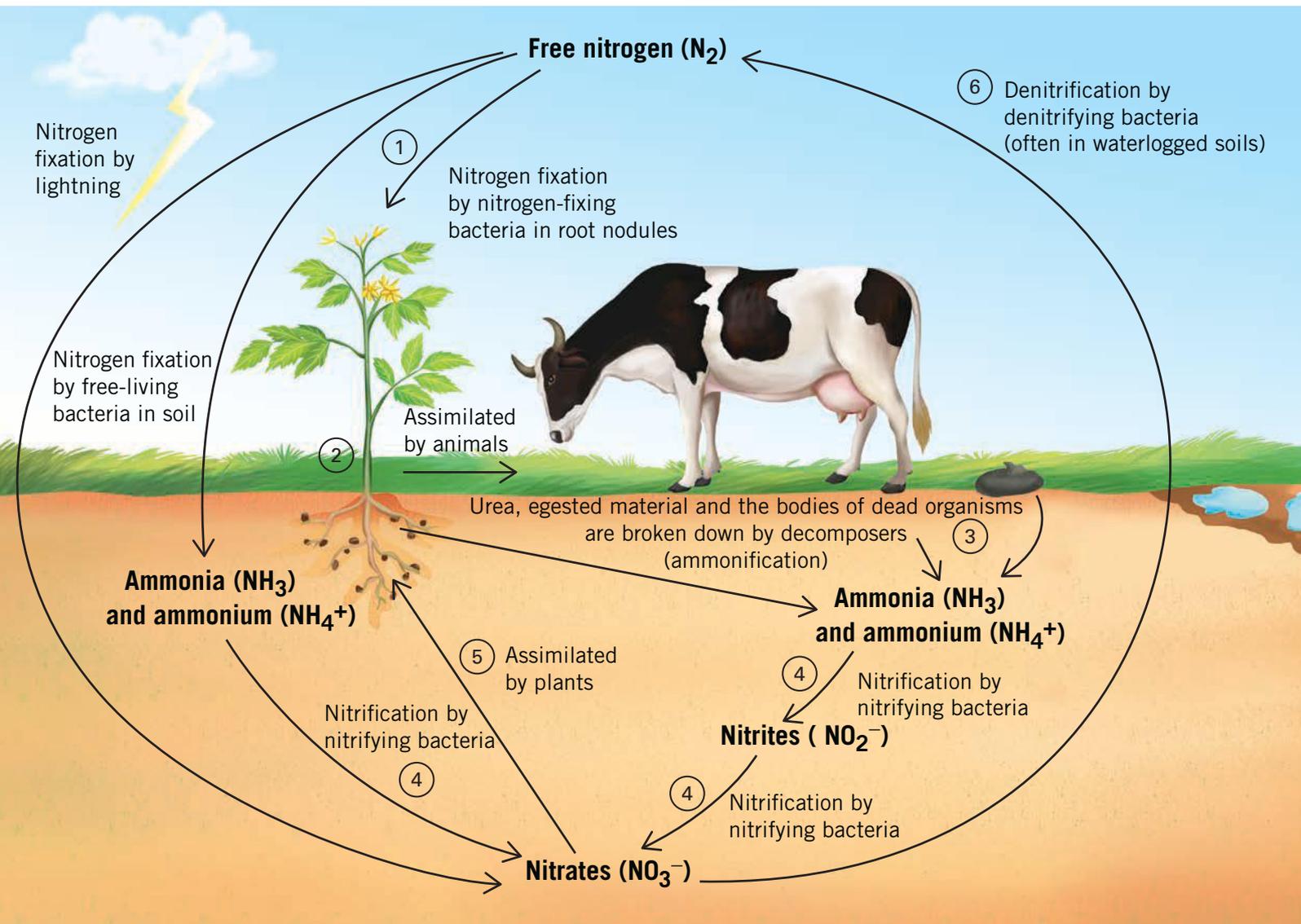
## The nitrogen cycle

Nitrogen in its elemental form has the formula  $N_2$ . Nitrogen is important for all living things as it is an important component of nucleic acids and amino acids, the subunits of proteins. It is the fourth most abundant element in living things after oxygen, carbon and hydrogen. The majority of gas found in the atmosphere is  $N_2$  (78%). However, a large proportion of organisms cannot access this form of nitrogen.

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. Table 7.6 shows the main forms of nitrogen in each of the chemical spheres.

Chemical sphere	Nitrogen content
Atmosphere	Nitrogen ( $N_2$ ) gas
Biosphere	Amino acids (the building blocks of proteins) and the DNA and RNA of all living things
Hydrosphere	Nitrates ( $NO_3^-$ ) from soil runoff and the marine nitrogen cycle
Lithosphere	Nitrates ( $NO_3^-$ ) from the decomposition of organic matter and nitrification

**Table 7.6** A summary of the nitrogen content in each chemical sphere



**Figure 7.24** The main stages and processes in the nitrogen cycle on land (a similar process takes place in the oceans). Numbers refer to points in the text.

## 1. Nitrogen fixation

**Nitrogen fixation** makes nitrogen in the atmosphere accessible to the majority of organisms.

Lightning converts nitrogen gas in the air ( $N_2$ ) by bonding it with oxygen to form nitrates ( $NO_3^-$ ), which then dissolves in rain. Plants can use nitrates directly.

Nitrogen gas ( $N_2$ ) is also converted to ammonia ( $NH_3$ ) or ammonium ions ( $NH_4^+$ ) by nitrogen-fixing bacteria that are free living in soil or living in root nodules of plants (mostly legumes such as peas, beans, lentils and clover).



**Figure 7.25** Nitrogen-fixing bacteria live in root nodules of certain plants.

### Quick check 7.10

- 1 Identify where the majority of nitrogen is found in the nitrogen cycle.
- 2 Name the process and organisms involved in converting nitrogen gas into useful nitrogen-containing compounds.

## 2. Transfer through the food chain

Plants absorb nitrates ( $NO_3^-$ ) from the soil (or root nodules in some plants) and use these to build up proteins. Animals then obtain their nitrogen through eating plants or other animals. Nitrogen-containing compounds are therefore transferred through the food chain.

**nitrogen fixation**  
the conversion of atmospheric nitrogen into ammonia or other related nitrogenous compounds by nitrogen-fixing bacteria or lightning



**Figure 7.26** Animals obtain their nitrogen by eating other animals or plants.

**ammonification**

the process in which decomposers in the soil convert dead plant and animal material into ammonia

**nitrification**

the conversion of ammonia into useful nitrates by nitrifying bacteria

**denitrification**

the process of converting nitrates into nitrogen gas to be released back into the atmosphere

### 3. Ammonification

Urea and excreted waste material, as well as dead organisms, are broken down by decomposers (bacteria and fungi).

This results in nitrogen being returned to the soil as ammonia ( $\text{NH}_3$ ) or ammonium ions ( $\text{NH}_4^+$ ). This is **ammonification**.

### 4. Nitrification

Ammonia ( $\text{NH}_3$ ) and ammonium ions ( $\text{NH}_4^+$ ) are converted to nitrites ( $\text{NO}_2^-$ ) by nitrifying bacteria in the soil, which is then oxidised into nitrates ( $\text{NO}_3^-$ ), also by nitrifying bacteria. This is called **nitrification**.

### 5. Uptake by plants

The nitrates formed during nitrification are taken up by plants and used to make nucleic acids (DNA and RNA) and amino acids, the building blocks of proteins.

### 6. Denitrification

The process of **denitrification** also involves bacteria, in this case, denitrifying bacteria. Denitrification is the conversion of nitrates into nitrogen gas, which is released back into the atmosphere. This often takes place in waterlogged soils.



**Figure 7.27** Decomposing organic matter and animal excretions are part of both the ammonification and nitrification processes.

#### Quick check 7.11

- 1 Identify where animals obtain their nitrogen from in the nitrogen cycle.
- 2 Name the organisms that are responsible for breaking down dead organic matter into ammonia.
- 3 Name the process and organisms involved in converting ammonia into nitrates.

Table 7.7 summarises the gains and losses from the soil of nitrogen in the form of nitrates in the nitrogen cycle.

Soil nitrate gains	Soil nitrate losses
Nitrification	Denitrification
Nitrogen fixation	Uptake by plants

**Table 7.7** A summary of the gains and losses of nitrates in the soil in the nitrogen cycle

#### Quick check 7.12

- 1 Name the process and organisms involved in converting nitrates into nitrogen gas.
- 2 Explain the importance of nitrogen for living organisms.

**Explore! 7.2****The phosphorus cycle**

Phosphorus in its elemental form is highly reactive; however, animals and plants rely on more stable forms compounds of phosphorus (such as phosphate) to survive. Like carbon and nitrogen, different forms of phosphorus are recycled through the phosphorus cycle.

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 expect to find no phosphorus 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 had
- 5 Compare the phosphorus cycle to the other nutrient cycles discussed in this section.

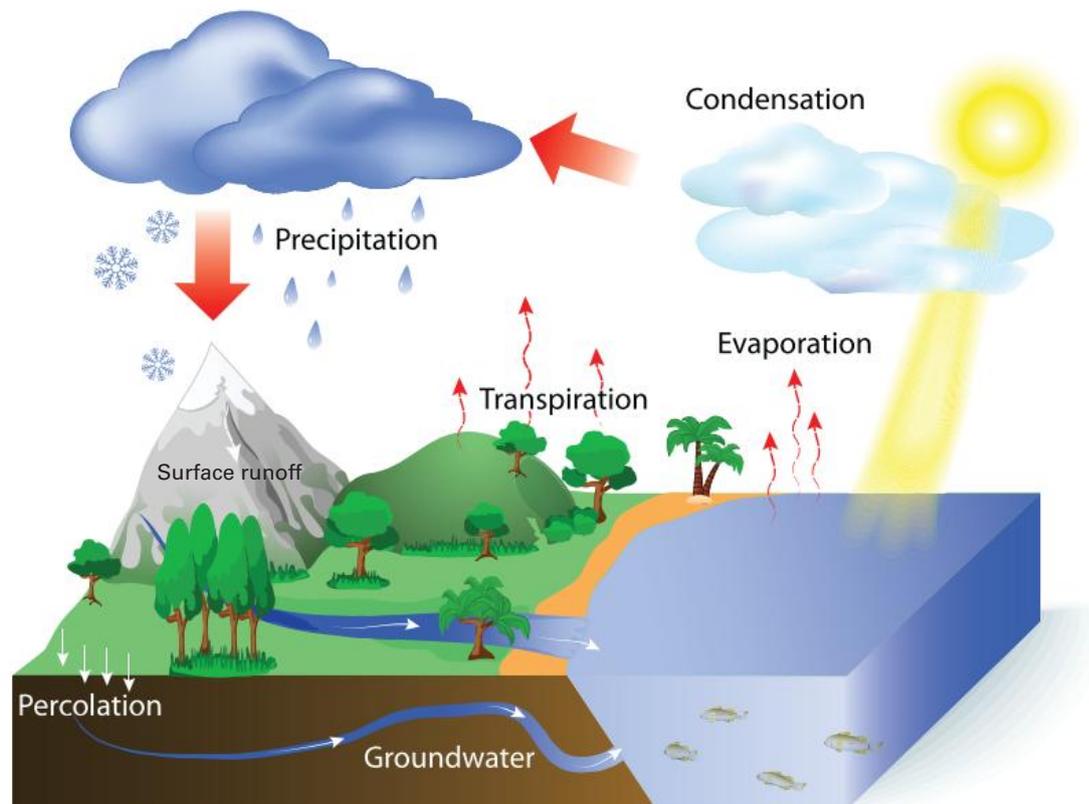


**Figure 7.28** A phosphate mine on Christmas Island, an Australian territory in the Indian Ocean, lying south of Java, Indonesia. Phosphates (and nitrates) are important fertilisers.

**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 to the atmosphere as water vapour through the process of evaporation.



**Figure 7.29** The main stages in the water cycle

## Section 7.2 questions

**Remembering**

- 1 **Identify** the cycle (carbon, nitrogen or water) that includes the following processes.
  - a Denitrification
  - b Respiration
  - c Decomposition
  - d Transpiration
  - e Combustion
- 2 **State** the name and formula of a 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 **Recall** the reason why living organisms require nitrogen.
- 5 Bacteria can take nitrogen from the atmosphere and convert it into nitrogen compounds. **State** another way in which this can happen.

**Understanding**

- 6 **Identify** which of the following processes involve bacteria.
  - Nitrification
  - Decomposition
  - Evaporation
  - Percolation
- 7 **Select** the best definition for a sustainable ecosystem and justify your choice.
  - An environment that requires intervention to continue
  - A biological environment that is self-sustaining
  - A system that is a mixture of biotic and abiotic factors
- 8 **Recall** the types of plant that have nitrogen-fixing bacteria in their root nodules.

**Applying**

- 9 **Explain**, with the use of a word equation, why respiration is part of the carbon cycle.
- 10 **Describe** the process of photosynthesis to show how carbon dioxide from the atmosphere is transferred to plants.
- 11 **Explain** why the water cycle involves all four chemical spheres.
- 12 **Summarise** the role of decomposers in both the carbon and nitrogen cycles.
- 13 **Explain** where the carbon in coal, oil and gas originally came from.
- 14 **Explain** why plants can suffer from a lack of nitrogen when they are surrounded by a plentiful supply of nitrogen in the atmosphere.

**Analysing**

- 15 **Contrast** the processes of nitrogen fixation and denitrification in the nitrogen cycle.
- 16 **Compare** the carbon and nitrogen cycles. What processes are similar?

**Evaluating**

- 17 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.
- 18 **Deduce** what would happen if the nitrogen cycle stopped.
- 19 **Deduce** why insectivorous plants, such as Venus flytraps, are often found in waterlogged soils.

## 7.3

# The greenhouse effect in the atmosphere

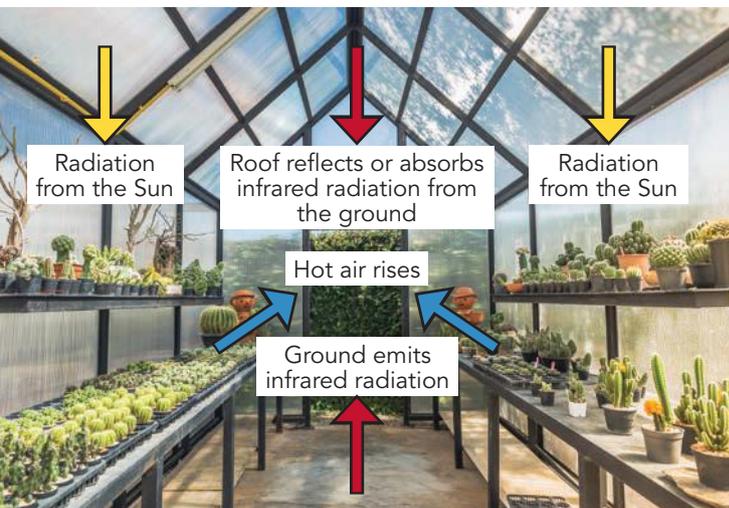
## Learning goals

- 1 To be able to recall four different greenhouse gases.
- 2 To be able to compare the natural greenhouse effect and the enhanced greenhouse effect.



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-sensitive or temperature-sensitive plants, or those that are out of season. They protect plants from cold and adverse weather conditions. The advantage of using a greenhouse is that growers have more control over the conditions under which the plants grow.

Greenhouses are made from glass and plastic. When the Sun's radiation passes through these materials, it heats the ground and air inside 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 because 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 7.30** Greenhouses protect plants from cold and adverse weather conditions by keeping in the thermal energy.

## Quick check 7.13

- 1 Name a type of radiation emitted from the ground and air.
- 2 Explain why greenhouses are made of glass or plastic.

## 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 infrared radiation back towards the atmosphere. 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 ( $\text{H}_2\text{O}$ ) is the most abundant (95%) greenhouse gas. Methane ( $\text{CH}_4$ ), carbon dioxide ( $\text{CO}_2$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ) are three of the other most common greenhouse gases.

**greenhouse gases**  
gases that contribute to the greenhouse effect

**Figure 7.31** The Sun emits radiation, which passes through our atmosphere.



The following table compares the effectiveness in trapping heat of the three most common greenhouse gases after water vapour.

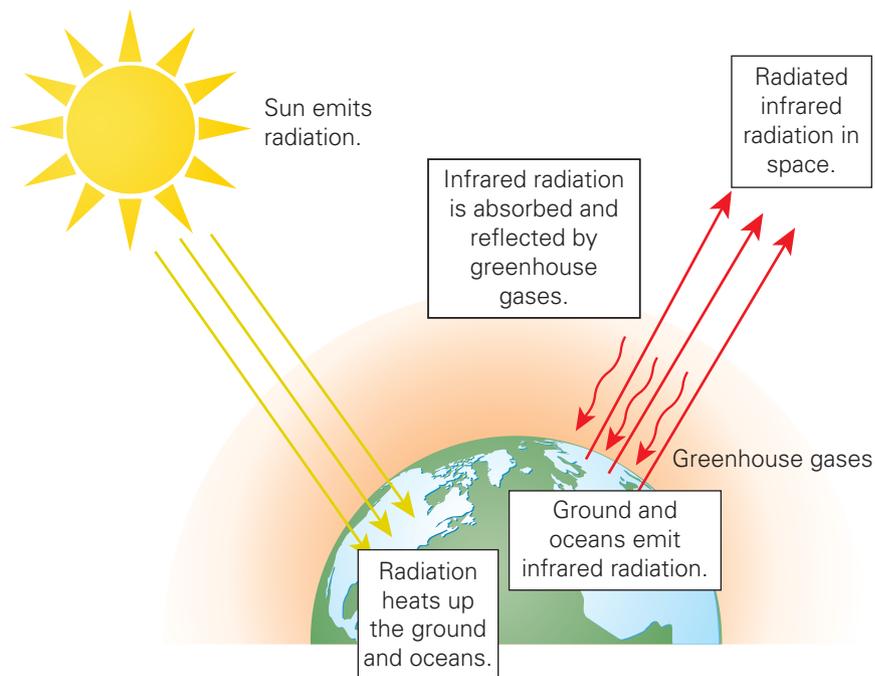
	Carbon dioxide (CO <sub>2</sub> )	Methane (CH <sub>4</sub> )	Nitrous oxide (N <sub>2</sub> O)
% of the total number of greenhouse gases	84	9	5
Persistence in the atmosphere (years)	100	10	100
Effectiveness of trapping heat compared to carbon dioxide		30 times more effective	300 times more effective

**Table 7.8** A summary of the three most common greenhouse gases, excluding water vapour

The process of trapping the Sun's solar energy in Earth's atmosphere is called the **greenhouse effect**. The radiation from the Sun is most powerful in the visible light and ultraviolet (UV) light wavelengths. This type of radiation is able to pass directly through the atmosphere. The infrared radiation emitted from the ground and the oceans is of longer wavelengths, which are absorbed by

the greenhouse gases, keeping Earth warm. If the Sun's UV and visible radiation was not converted into infrared, we would lose much of the thermal energy back into space, and Earth would be colder and much less habitable. Plants, animals and humans would struggle to survive on Earth without the greenhouse effect's role in maintaining a comfortable consistent average temperature.

**greenhouse effect**  
the trapping of the Sun's warmth by a layer of gases in the lower atmosphere



**Figure 7.32** A summary of the greenhouse effect

#### Quick check 7.14

- 1 State 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?

## Did you know? 7.1

**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 7.33** Earth would freeze without the greenhouse effect.

## Explore! 7.3

**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.

- 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?



**Figure 7.34** The average surface temperature of Venus would melt lead.

Table 7.9 summarises the features of radiation emitted by the Sun and Earth.

Solar radiation	Radiation emitted by Earth
Emitted by the Sun	Emitted by the ground and oceans
Most powerful in UV and visible light	Infrared
Mostly passes through the atmosphere	Trapped by greenhouse gases in the atmosphere

**Table 7.9** Features of solar radiation and radiation emitted by Earth

## Quick check 7.15

- 1 Name a source of UV and visible radiation.
- 2 Name the radiation that is absorbed by greenhouse gases in the atmosphere.

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 7.10 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 fossil fuels such as coal, oil and gas. In 2020, 70% of Australia's electricity was produced by burning coal.	
Methane	Farming cattle (which produce methane when they digest grass) and growing rice in paddies. Increased temperatures lead to the melting of permafrost in the Arctic. Permafrost is frozen soil that contains trapped methane produced from the decomposition of plants and animals.	
Nitrous oxide	Using fertilisers increases the amount of nitrogen in the nitrogen cycle, which increases 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 increase 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 7.10** How humans have increased the concentration of greenhouse gases in the atmosphere

### Explore! 7.4

#### Your environmental footprint

An environmental footprint is the effect that an individual has on the environment and can include greenhouse gas contribution and pollution of non-biodegradable materials. Use your preferred search engine to research how you can calculate your own environmental footprint. Construct a list of the things that make up your environmental footprint.

**Quick check 7.16**

- 1 State one way in which we have increased the concentration of carbon dioxide in the atmosphere.
- 2 Provide one example of how humans have increased the concentration of nitrous oxide in the atmosphere.
- 3 State the composition of permafrost.

**Practical 7.3: Investigation****Comparing the natural and enhanced greenhouse effects****Aim**

To compare the impacts of the natural and enhanced greenhouse effects.

**Materials**

- baking soda
- water
- vinegar
- 2 × 500 mL beakers
- 100 mL measuring cylinder
- cling wrap
- 2 elastic bands
- 2 weighing boats
- balance
- marker pen
- sticky tape
- stopwatch
- 2 thermometers
- high-intensity lamp
- heat-resistant gloves

**Method****Part 1: Prepare the results table**

- 1 Read the rest of the steps in the method and make a prediction on what will happen.
- 2 Create an appropriate results table for this experiment.

**Part 2: Prepare the equipment**

- 1 With the marker pen, label one of the 500 mL beakers 'Control'.
- 2 Using the sticky tape, tape one of the thermometers to the inside of this beaker. It must be about 5 cm above the bottom of the beaker.
- 3 With the marker pen, label the second beaker 'CO<sub>2</sub>'.
- 4 Tape the thermometer to the inside of this beaker, again making sure it is 5 cm from the bottom.
- 5 Prepare the cling wrap and elastic bands for sealing; you will cover each beaker immediately after you have poured in the liquid.

**Part 3: Collect the data**

- 1 Using the balance, weigh out 35 g of baking soda into each weighing boat and pour it into each beaker.
- 2 Using the 100 mL measuring cylinder, measure 65 mL of water and pour it into the control beaker. Immediately cover the beaker with the cling wrap and seal with it the elastic band.
- 3 Using the same 100 mL measuring cylinder, measure 65 mL of vinegar and pour it into the CO<sub>2</sub> beaker. Immediately cover the beaker with the cling wrap and seal it with the elastic band.
- 4 Swirl the contents of each beaker to make sure that the baking soda has fully dissolved and the temperatures have adjusted back to room temperature.
- 5 Place both beakers underneath the lamp.
- 6 Record the starting temperature of each atmosphere before the lamp is turned on.
- 7 Turn on the lamp and start the stopwatch.
- 8 Measure the temperature in each beaker every 2 minutes for 8 minutes, recording the temperature in your results table.
- 9 At 8 minutes, measure the temperature and then turn off the light.
- 10 Record the final temperature 2 minutes later.

**Be careful**

Care should be taken when handling the lamp as it can become hot with prolonged use. Ensure heat-resistant gloves are worn.

*continued...*

...continued

### Results

- 1 Calculate the increase in temperature in each container by the difference between the temperature at 8 minutes and the starting temperature.
- 2 Calculate the thermal energy retention by the difference in the temperature at 8 minutes and at 10 minutes.

### Discussion

- 1 State the container that had the greatest increase in temperature. Did this match your prediction?
- 2 State the container that retained the most thermal energy in the final 2 minutes.
- 3 Explain these results, using your own knowledge and scientific research.

### Conclusion

- 1 State a conclusion about the enhanced greenhouse effect based on this experiment.
- 2 Support the statement by using your data.



VIDEO  
Name some effects of climate change

**carbon sources**  
processes or areas that release carbon

**carbon sinks**  
areas where carbon is stored (e.g. fossil fuels)



WIDGET  
Greenhouse effect

## 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 large amounts of fossil fuels for energy. This means we have been moving stored carbon from the lithosphere into the atmosphere, directly affecting the balance of the carbon cycle.

As part of the carbon cycle, Earth has **carbon sources**, processes or areas that release carbon (such as the atmosphere) and **carbon sinks**, areas where carbon is stored (such as the oceans or fossil fuels).

The problem with burning fossil 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.

### Quick check 7.17

- 1 State the definition of carbon sources and give an example.
- 2 State the definition of carbon sinks and give an example.



**Figure 7.35** Carbon moves from the atmosphere to the lithosphere via the hydrosphere during rainfall.



**Figure 7.36** Carbon moves from the hydrosphere to the lithosphere via the biosphere when shellfish convert carbonic acid to carbonates in the oceans' carbon sink.

## Section 7.3 questions

**Remembering**

- 1 **Name** three gases in the atmosphere that are responsible for the greenhouse effect.
- 2 **Define** the term 'enhanced greenhouse effect'.
- 3 **State** the types of radiation important in the greenhouse effect emitted from the:
  - a Sun
  - b ground and oceans.
- 4 **Recall** the sources of methane in the atmosphere.

**Understanding**

- 5 **Explain** the differences between the natural and enhanced greenhouse effects.
- 6 **Explain** why the following statement is incorrect: 'The greenhouse effect is caused by humans.'
- 7 **Explain** how a greenhouse mimics the greenhouse effect.

**Applying**

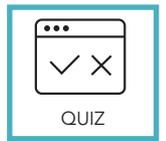
- 8 **Explain** the origin of the heat that burns your bare feet on the sand on a sunny day, and what happens to that heat in the greenhouse effect.
- 9 **Illustrate** a diagram to show how the greenhouse effect keeps Earth warm.
- 10 **Compare** solar radiation and radiation emitted by the Earth.

**Analysing**

- 11 **Distinguish** between greenhouse gases and other gases in the atmosphere, such as nitrogen and oxygen.
- 12 **Contrast** carbon sinks and carbon sources by giving examples.

**Evaluating**

- 13 **Predict** what the conditions on Earth would be like without greenhouse gases and the greenhouse effect.
- 14 **Decide** 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 **Discuss** the reasons why the carbon cycle is altered by the release of carbon emissions from burning fossil fuels.



## 7.4 Changing climates



### Learning goals

- 1 To be able to recall the difference between weather and climate.
- 2 To explore the human influences on climate change.

### Climate versus weather

#### 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

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

more than 30 years. Different areas can have different climates; for example, the climate in Western Australia is very different from the climate in Russia.

energy, so temperatures over land rise more in the daytime and fall more during the night than they do over water

- features of the land, such as mountains
- type of soil or plant life.

### Quick check 7.18

- 1 Define the term 'weather'.
- 2 Provide one reason for the different climates on Earth.

### Did you know? 7.2

#### How China used rockets to control the weather

China used rockets before and during the 2008 Beijing Olympics opening ceremony to control the weather. China 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. However, this practice, known as cloud-seeding, is controversial, as not all attempts to use it to control the weather are successful.



**Figure 7.38** The opening ceremony of the Beijing Olympics in 2008



VIDEO  
El Nino and  
La Nina

Areas of the world have different climates due to the:

- uneven distribution of the Sun's rays because of the shape of Earth
- tilt of Earth's axis, which causes seasons
- pattern of atmospheric circulation caused by convection and Earth's rotation
- ocean convection currents
- land (or sea) surface; land gets warmer than water given the same amount of thermal



**Figure 7.37** Frozen ships on Lake Baikal in Siberia, Russia. The climate there is described as sub-Arctic with annual average temperatures of about  $-5^{\circ}\text{C}$ .

## 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.

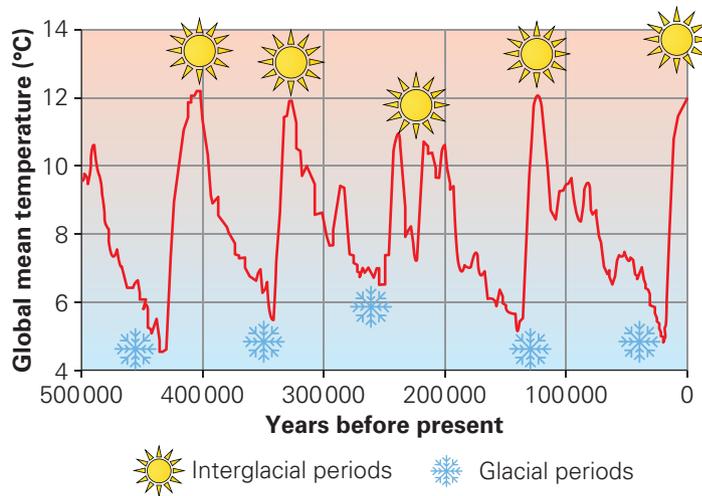


Figure 7.39 Earth has undergone natural cycles of warming and cooling.

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 because sea levels were much lower, since more of the land was covered in ice sheets, as Antarctica is today. For example, parts of Tasmania were covered by glaciers.

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**.



Figure 7.40 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.

**glacial period**  
a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

**interglacial period**  
a period in Earth's history when an increase in global temperatures is sustained for a long period of time

### Quick check 7.19

- 1 Define 'climate change'.
- 2 State the name of the term for when Earth is cooler than the very long-term mean.
- 3 State the name of the term for when Earth is warmer than the very long-term mean.

## 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 7.41 Franz Josef Glacier on the South Island of New Zealand

### Ice cores

Scientists take cores (vertical samples) 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 about the temperature and carbon dioxide levels in that time period.



Figure 7.42 An ice core taken from Antarctica

## Pollen

Pollen that 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.



**Figure 7.43**  
Fossilised pollen can indicate the number and species of plants around in a particular time period.

## 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 7.44** Fossilised remains of sea creatures

### Quick check 7.20

- 1 Provide 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.

## Human influences on climate change

The concentration of carbon dioxide in the atmosphere has increased from 280 parts per million (ppm) before the year 1800 to over 416 ppm in 2021. Table 7.11 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	<p>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.</p> <p>Trees release large amounts of water vapour during transpiration. Fewer trees means less water vapour in the atmosphere and less rain. In 2017–19, parts of Queensland experienced the lowest ever rainfall on record.</p>
Agriculture	Carbon cycle	<p>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.</p>
Fertilisers	Nitrogen cycle	<p>Adding fertilisers containing nitrates to the soil speeds up their conversion into nitrous oxide, another greenhouse gas.</p>
Burning fossil fuels	Carbon and nitrogen cycle	<p>Burning fossil fuels produces carbon emissions, which alters the carbon cycle. Nitrogen oxides (<math>\text{NO}_x</math>) are also produced when fossil fuels burn, causing smog and acid rain.</p>

Table 7.11 A summary of some human influences on climate change

### Quick check 7.21

- 1 State one way humans have affected the nitrogen cycle.
- 2 Explain how deforestation affects the water cycle.

### Explore! 7.5

#### Diesel: dream fuel or nightmare fuel?

A decade ago, many governments and the car industry were promoting diesel as a dream fuel and a cheaper way to 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.

- 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 ( $\text{NO}_x$ ) and carbon particulates, pollutants that 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.



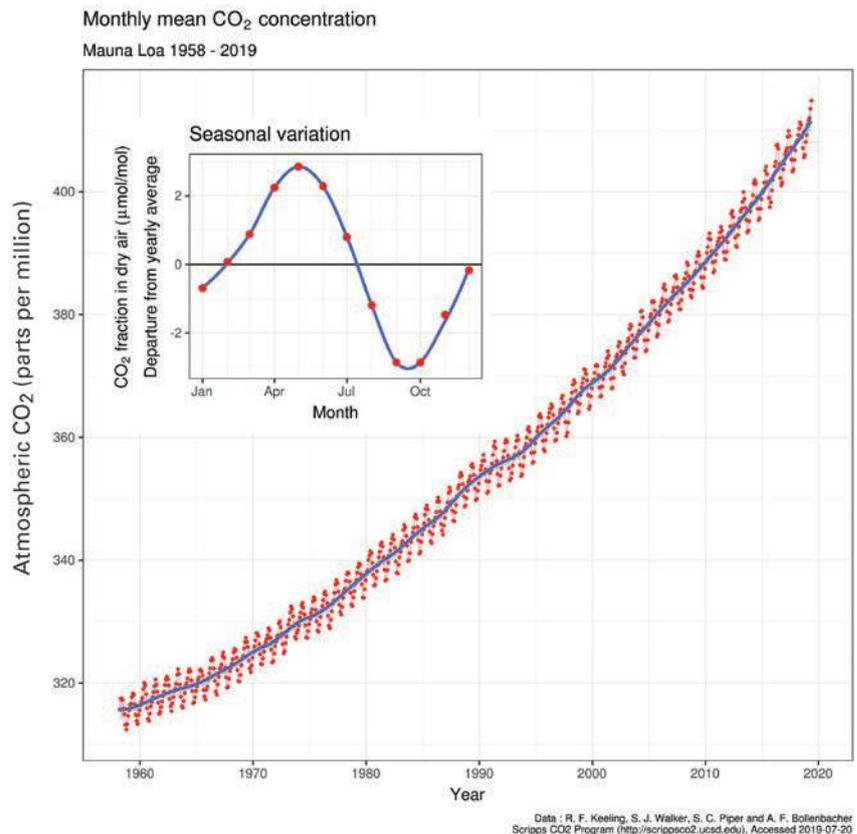
Figure 7.45 Diesel is an alternative fuel to petrol.

### Effects of climate change

As carbon dioxide concentrations rise, Earth continues to warm.

Over the past 100 years, Earth's average temperature has risen between 0.4 and 0.8°C; 2016 was the hottest year and 2019 was the second hottest 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 7.46** The Keeling curve shows the concentration of carbon dioxide in parts per million from 1959 to 2019 using measurements taken from an observatory in Hawaii. This positive gradient shows that carbon dioxide levels are continuing to increase.



## 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 a 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.

### 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, which results in an increase in global temperatures.

### Ocean density driving currents

When seawater freezes in winter, only the water freezes – the salt stays in the unfrozen seawater below. Waters with higher concentrations of salt are denser and are the main cause of ocean currents, circulating seawater from the sea floor to the surface and all around the globe, along with thermal energy, organic matter 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. As seawater becomes stagnant, organic matter and nutrients are not circulated and would impact on the survival of marine life.



Figure 7.47 Melting ice in Eqa Glacier, Greenland

### Quick check 7.22

- 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 winter.



Figure 7.48 Sun shining on ice in Antarctica

## Practical 7.4

### Salinity and density

#### Aim

To determine how the concentration of salt in water (salinity) affects its density.

#### Materials

- 10 mL measuring cylinder
- 100 mL measuring cylinder
- 5 × 100 mL beakers
- 5 pipettes
- food colouring (blue, green, yellow and red)
- salt
- water
- weighing boats
- balance

#### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Using a 100 mL measuring cylinder, measure 60 mL of water and pour it into one of the 100 mL beakers. Repeat four more times.

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 boats 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 5 and add to the 10 mL measuring cylinder.
- 7 Using a pipette, draw up 2 mL of solution 4. Place the pipette along the inside of the measuring cylinder, near the solution added previously. Drop solution 4 drop by drop, allowing it to roll down the side of the measuring cylinder.
- 8 Repeat step 7 for solutions 3, 2 and 1, adding each in turn to the 10 mL measuring cylinder.

#### Results

- 1 Complete the results table.

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 <sup>-1</sup> ) (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...*

...continued

- 2 Sketch a coloured diagram of the measuring cylinder you created.
- 3 Plot a graph of mass of salt on the x-axis and density on the y-axis.

#### Discussion

- 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

State a conclusion about how water salinity affects water density. Support your statement by using your experimental data.

#### biodiversity

the variety of species, ecosystems and genes that exist in a particular area

#### keystone species

a species that has a dramatically large impact on a particular ecosystem relative to its population

## Biodiversity

**Biodiversity** is a measure of the variety of environments, species and genes in an area. There are three types of biodiversity, which are summarised in Table 7.12.

The more biodiverse an environment, the more resistant that environment is to change (it is more stable). An environment that 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.

Type of biodiversity	Description
Ecosystem	The variety of different types of habitats or ecosystems available
Species	The number of different species in an ecosystem
Genetic	A variation of genetic types within a species

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 that affect an ecosystem the most, for instance by providing food and shelter to numerous other species.

Table 7.12 The three types of biodiversity

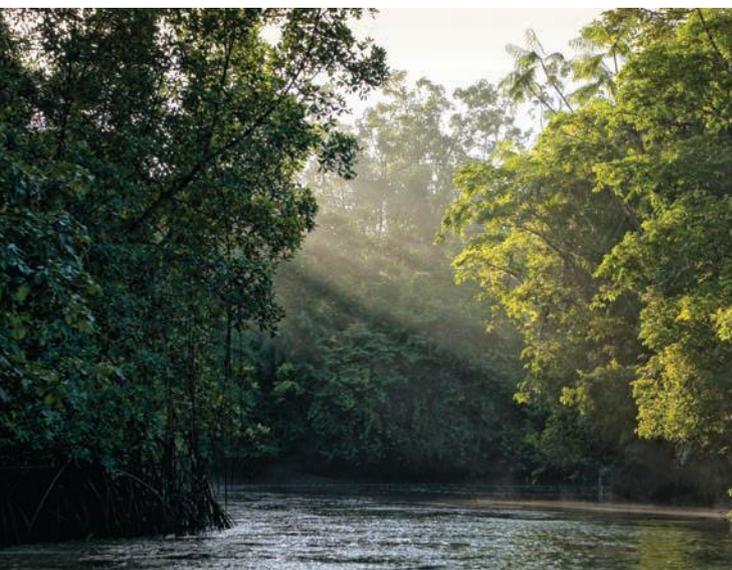


Figure 7.49 The Amazon rainforest is one of the most biodiverse ecosystems in the world.



Figure 7.50 Corals are keystone species in the Ningaloo Reef.

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 7.51 Bleached branching coral

### Explore! 7.6

#### Climate change effects on Earth

Climate change is a cause of changing global temperatures and, in particular, melting of polar sea ice. Investigate and summarise the long-term effects of melting sea ice on:

- a ocean water levels
- b deep ocean currents
- c marine biodiversity.

### Quick check 7.23

- 1 Define the term 'biodiversity'.
- 2 State the name of the term given to coral in a coral reef ecosystem, signifying its relative importance.
- 3 Describe the cause of coral bleaching in oceans.

## Computer modelling and its applications

Computer modelling is the use of computer simulations to make accurate predictions, for instance about Earth's climate thousands and millions of years into the future. With their high processing power, computers are able to run numerous simulations over and over again in a short period of time, something that could take a human over a lifetime to complete. By running numerous simulations, predictions made by computer modelling are much more accurate than those made manually by humans.



Figure 7.52 A supercomputer at the German Climate Computing Centre processes data about Earth's climate to predict the future effects of climate change.

Table 7.13 summarises the applications of computer modelling.

Application of computer modelling	Description
Predicting the weather 	You will see this used every day if you watch the news. Multiple simulations are run by computers. Meteorologists (scientists who study the weather) use these simulations to predict the weather conditions for that week.
Predicting climate change 	Models predicting climate change are based on observational data and fundamental numerical laws 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 7.13** A summary of some of the applications of computer modelling

#### Quick check 7.24

- 1 Why do scientists use computer modelling to predict phenomena?
- 2 Give one application of computer modelling.

Computer models rely on accurate data being fed into the simulation. An example of high-quality data is that obtained at the International Space Station by the cloud-aerosol transport system, which can accurately measure atmospheric clouds and aerosols (extremely small particles in the air) all over the world. This data is used in computer modelling to predict what Earth will be like in years to come.

**Figure 7.53** The ice on Lake Baikal in Siberia, Russia



**Explore! 7.7****Reducing the impact of climate change**

Human influences on climate change are not always negative, and there are many technologies being used in Australia and internationally to reduce the impacts of climate change. Examples of alternatives to fossil fuels that are used throughout Australia include solar cells and wind turbines which reduce greenhouse gas emissions. Many new technologies require government financial support for implementation on a large scale.

Write a paragraph summarising each of these technologies.

- Solar cells
- Wind turbines
- Aboriginal and Torres Strait Islander firestick farming
- Carbon capture

For each technology:

- 1 describe what they are
- 2 explain how the technology works
- 3 reflect on how they contribute to the effects of climate change.

**Section 7.4 questions****Remembering**

- 1 **Name** the models used to make predictions about climate change.
- 2 **Define** the term 'climate'.
- 3 **Identify** the correct word or words to 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 **Recall** a property of ice that allows it to have a cooling effect on Earth.

**Understanding**

- 6 **Identify** the reasons why coral bleaching is disastrous for an environment.
- 7 **Identify** the uses of atmospheric dispersion modelling.

**Applying**

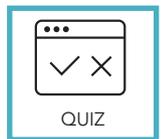
- 8 **Explain** why computer models are useful in predicting future events.
- 9 **Describe** some differences in climate between Central Australia and Siberia.
- 10 **Explain** why it is important to maintain the biodiversity of an environment.
- 11 **Describe** the relationship between global temperatures and the glacial and interglacial periods.

**Analysing**

- 12 **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
- 13 **Compare** global warming and climate change.

**Evaluating**

- 14 **Discuss** how global warming could cause sea levels to rise.
- 15 **Discuss** why less seawater freezing in winter affects ocean currents.
- 16 **Evaluate** the effect of an unexpected volcanic eruption on climate change predictions.



# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
7.1 I can identify and describe Earth's chemical spheres and its five layers of atmosphere.	1	
7.2 I can describe the seven processes in the carbon cycle.	17	
7.2 I can describe the six processes in the nitrogen cycle.	6	
7.2 I can describe the water cycle.	13	
7.3 I can explain the natural and enhanced greenhouse effect.	8	
7.4 I can describe the human influence on climate change.	16	

## Review questions



### Remembering

- List** the five layers of the atmosphere.
- Recall** the name and formula of the form of elemental nitrogen in the atmosphere.
- 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.
- State** one reason why different areas on Earth have different climates.

### Understanding

- Describe** the effects of cyclones on each of Earth's chemical spheres.
- Explain** the role of nitrifying bacteria in the nitrogen cycle.
- Outline** the journey of UV solar radiation emitted from the Sun.
- Describe** how greenhouse gases contribute to the natural greenhouse effect.

### Applying

- Contrast** the ozone layer and greenhouse gases by copying and completing the following table.

	Ozone layer	Greenhouse gases
Composition		
Most important effect		
Location		

- Construct** a word equation to show how the process of respiration leads to an increase in atmospheric carbon dioxide.
- Construct** a graph to show how carbon dioxide concentrations in the atmosphere have changed over the last two decades.

### Analysing

**12 Analyse** the sphere interactions that are taking place in Figure 7.54.



**Figure 7.54** Possible sphere interactions

- 13 List** the main processes involved in the water cycle.
- 14 Analyse** the changes in carbon dioxide concentration in the atmosphere since the Industrial Revolution.
- 15 Examine** the reasons why low-lying areas are most at risk from climate change.

### Evaluating

- 16 Discuss** the human effects on the enhanced greenhouse effect and climate change.
- 17 Explain** how excretion, death and decomposition influence both the carbon and nitrogen cycles.
- 18** Using the summary of greenhouse gases in Table 7.8 on page 290, **justify** why humans should focus on reducing nitrous oxide emissions as well as those from carbon dioxide.
- 19** There is debate as to whether climate change is a significant risk to life on Earth. **Decide** whether you agree, based on what you have learned in this chapter. **Justify** your opinion with facts and evidence.

### Data questions

The Keeling curve in Figure 7.55 illustrates the change in atmospheric carbon dioxide concentration from 1960 to 2005 as measured from the atmosphere above Hawaii, United States. A media outlet is using this data as evidence to suggest that 'climate is changing as there is increasing atmospheric carbon dioxide'.

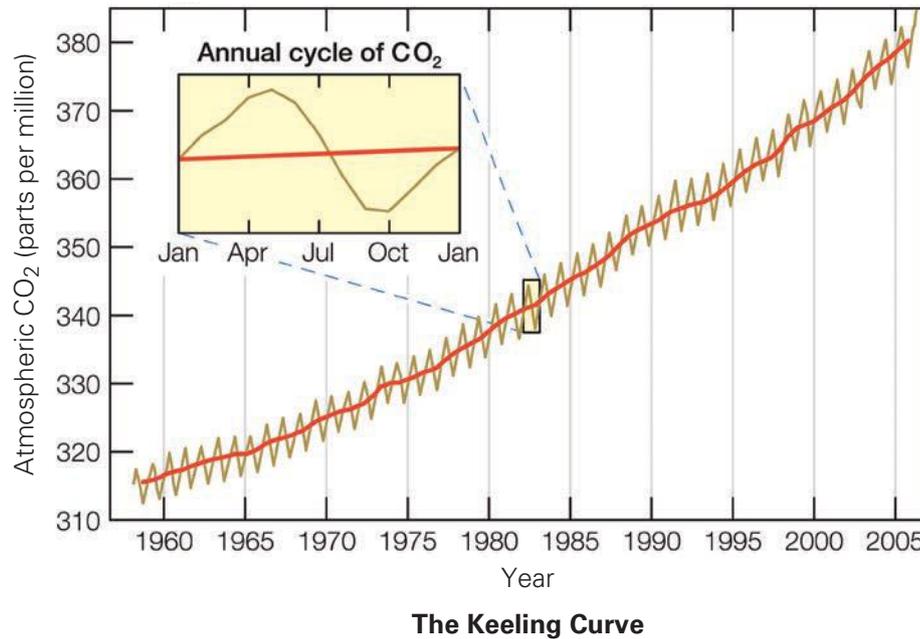


Figure 7.55 Keeling curve showing the atmospheric carbon dioxide concentration over time

- 1 **Identify** the year that had the lowest average atmospheric CO<sub>2</sub>.
- 2 Use the red line to **determine** the concentration of atmospheric CO<sub>2</sub> in 1965.
- 3 **Determine** the annual cycles observed for the brown line.
- 4 **Distinguish** the difference between the brown line and the red line.
- 5 **Identify** the general trend of carbon dioxide concentration as time increases.
- 6 **Identify** the pattern(s) occurring in the brown line.
- 7 Can the data in Figure 7.55 be used to **justify** the statement: 'There is increasing atmospheric carbon dioxide'?
- 8 Can the data in Figure 7.55 be used to **justify** the statement: 'Climate is changing'?
- 9 **Infer** the atmospheric concentration of CO<sub>2</sub> in 2030, using the trend you have observed in Question 5.

## STEM activity: Using aerial imagery to track environmental change

### Background information

Aerial photographs were pioneered by the French photographer and balloonist Gaspard-Félix Tournachon in 1858, four decades after the invention of the camera. Soon, governments over the world realised the potential of aerial imagery in gathering information for military use and monitoring territories. Early military aerial photographers fixed small adjustable cameras on the 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 other high-quality data from our ever-changing world. For example, you probably use a mobile device with an in-built GPS module, capable of giving you directions to anywhere on Earth. Importantly, we can now use this amazing technology to help us monitor our impact on 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 idyllic 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 18 people and covered an entire sub-district with toxic mud from an upstream mine. Studies that will assist with recovering the area and the affected rivers are underway. Satellite imagery will play a pivotal role in the recovery of the area 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.

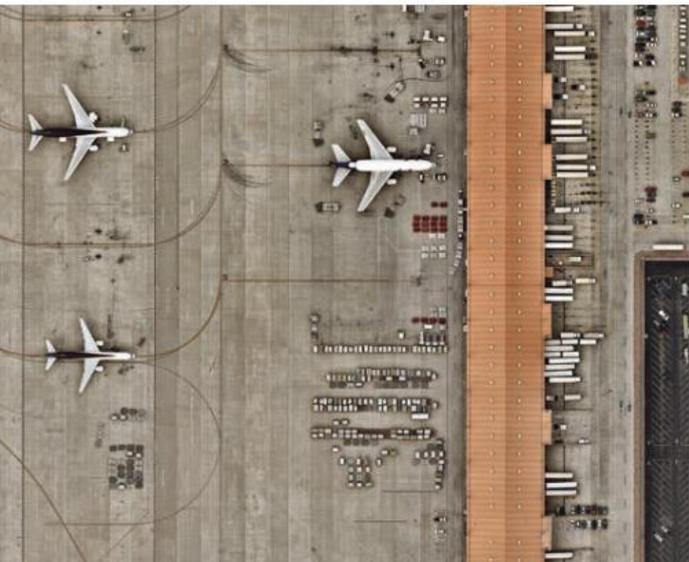


Figure 7.56 An aerial image of a modern airport



Figure 7.57 An aerial image of a river meandering through the landscape

**Design brief:** Design a method to use aerial imagery to track environmental change and make environmental impact predictions.

### 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)

### Research and feasibility

- 1 Outline the advantages and disadvantages of using satellite imagery to assess environmental change within your region. Describe the expertise (skills) needed to gather and decode these images and the potential benefits to the local economy (for example, possible jobs created or improvement to traffic conditions) of using them.

Advantages	Disadvantages
e.g. Economy – predict areas for growth	e.g. Environmental – incorrect use of images without considerations



**Figure 7.58** An aerial image of rice terraces in Bali



**Figure 7.59** An aerial image of a quarry

- 2 Discuss and reflect on the knowledge needed to make predictions on the environmental impact of development.
- 3 Research and decide on a local area that has a river/creek, and a combination of natural/built environment or natural environment that could have development proposed.

### Design and sustainability

- 4 List all the environmental issues currently faced by the chosen area, and future predicted issues based on current and future infrastructure.
- 5 Discuss as a group future development that could be completed in the chosen area. Make a sketch of the future development and annotate the changes, make a list of environmental impacts of the development.
- 6 Decide on the best possible technology to use to create a time-lapse sequence.

### Create

- 7 Create a time-lapse sequence of the area 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?
- 8 Add your future development diagram to your time lapse and show the environmental impact of your development ideas.

### Evaluate and modify

- 9 In your own words, explain how you could use the skills gained in this activity to enhance environmental conservation in your region.
- 10 As a class, evaluate the time-lapse sequences created by your peers and reflect on the challenges associated with anonymous aerial image gathering. In your opinion, are there any privacy concerns or implications associated with this technology? What measures are taken to improve privacy for people in relation to aerial image gathering?



Figure 7.60 An aerial image of farmland



Figure 7.61 Suburban houses viewed from above

# 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.

# Chapter map



# 8.1 Forms of energy



## Learning goals

- 1 To be able to define energy.
- 2 To be able to recall the forms of potential and kinetic 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 powered 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. 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. 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**  
the amount of energy transferred when an applied force causes an object to move some distance

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.

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.



## Worked example 8.1

**Work**

A weightlifter applies a force of 300 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.

Working	Explanation
$F = 300 \text{ N}$ , $s = 1.5 \text{ m}$	List the relevant data that has been provided.
$W = Fs$	Recall the definition of work and the equation.
$W = 300 \text{ N} \times 1.5 \text{ m}$	Substitute the relevant data into the equation.
$W = 450 \text{ J}$	Solve the problem, giving an answer with appropriate units.

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. Worked example 8.1 shows that 450 J of work was done, which means that 450 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 two types: kinetic energy or potential energy.

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)	Electrical (current)
	
Electric (charge)	
	
Mechanical energy	
Mechanical vibrational waves (sound, water waves)	
	
<p>Note that mechanical energy is defined as the sum of the kinetic energy and the potential energy. Therefore, sound energy (that is, mechanical vibrational waves passing through an elastic medium) is a combination of kinetic and potential energies.</p>	

**Table 8.1** The different forms of energy grouped into the two types of energy – potential energy and kinetic energy and a mixture of the two

**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.



WIDGET  
Energy  
conversion  
flow diagrams

**Quick check 8.1**

- 1 Explain what it means 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 How much work is being done by the weightlifter during the 10 seconds of holding the barbell at 1.2 m above the ground?

**Kinetic energy**

Kinetic energy is one of the two main types of energy. **Kinetic energy** ( $E_k$ ) 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. And the more mass an object has, the more kinetic energy it has.

To calculate how much kinetic energy an object has, we use the following equation:

$$E_k = \frac{1}{2}mv^2$$

Here,  $E_k$  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 ( $\text{m s}^{-1}$ ).

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.

**kinetic energy**  
energy possessed by an  
object due to its motion

Speed is often calculated in fast moving objects, such as motor vehicles and projectiles, in  $\text{km h}^{-1}$ . In order to convert to  $\text{m s}^{-1}$  so as to use the given equation, divide the  $\text{km h}^{-1}$  value by 3.6. This conversion will be explained in more depth in the next chapter.

**Figure 8.3** All objects in motion have kinetic energy. The amount of kinetic energy depends on how fast an object is moving as well as its mass.



## Worked example 8.2

**Kinetic energy**

A motorcycle has a mass of 120 kg and is travelling at 150 km h<sup>-1</sup>. How much kinetic energy does the motorcycle have?



Figure 8.4 A motorcycle in motion possesses kinetic energy.

Working	Explanation
$m = 120 \text{ kg}, v = 150 \text{ km h}^{-1}$	List the relevant data that has been provided.
$150 \text{ km h}^{-1} \div 3.6$ $v = 41.67 \text{ m s}^{-1}$	Convert units to the SI base units (Standard International units) used in the equation. (Note that in this conversion the calculation has been rounded to 4 significant figures.)
$E_k = \frac{1}{2}mv^2$	Recall the definition of kinetic energy and the equation.
$E_k = \frac{1}{2} \times (120 \text{ kg}) \times (41.67 \text{ m s}^{-1})^2$	Substitute the relevant data into the equation.
$E_k = 104\,183.33 \text{ J}$ $= 104.2 \text{ kJ}$	Solve the problem, giving an answer with appropriate units. (Note that if the conversion to m s <sup>-1</sup> is done as part of the substitution, the calculation will give 104 166.67 J. Rounding it to 4 significant figures gives 104.2 kJ.)

## Quick check 8.2

- 1 Identify two factors that affect the amount of kinetic energy an object has and the effect they have.
- 2 A cricket player bowls a 160 g cricket ball at a speed of 150 km h<sup>-1</sup>. Calculate how much kinetic energy is transferred to the ball.

**Potential energy**

We now know that the man flying through the air in Figure 8.5 on the next page 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 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



**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 than the other man. Both men still have chemical energy and thermal energy; however, they aren't as relevant in this example.

### Gravitational potential energy

**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.

To calculate how much gravitational potential energy an object has, we use the following equation:

$$E_p = mgh$$

where  $E_p$  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 ( $9.8 \text{ m s}^{-2}$ ); and  $h$  is the height of the object above the surface of Earth, measured in metres (m).



**Figure 8.6** As you ride on a roller-coaster, the amount of gravitational potential energy that you have is constantly changing, as is your kinetic energy.

From this equation, the amount of gravitational potential energy an object has depends on its mass and height above the ground. Say you wanted to lift an object from height A to height B, what would be the difference between the GPE ( $\Delta E_p$ ) at both heights? The change in GPE ( $\Delta E_p$ ) would equal the GPE at height B ( $E_{pB}$ ) minus the GPE at height A ( $E_{pA}$ ):

$$\Delta E_p = E_{pB} - E_{pA}$$

**gravitational potential energy**  
energy stored in an object due to its position above the surface of Earth

Substituting in the formula for GPE, we can see:

$$\Delta E_p = mgh_B - mgh_A$$

Remember that  $F = ma$ , and in this case the acceleration of the force is due to gravity, so we can say  $F = mg$ . Substituting this into our equation, we get:

$$\Delta E_p = Fh_B - Fh_A$$

Or:

$$\Delta E_p = F(h_B - h_A)$$

Moving the object from height A to height B is the same as moving an object a certain distance vertically, so  $h_B - h_A = s$ , and so:

$$\Delta E_p = Fs$$

We know that  $W = Fs$ , so:

$$\Delta E_p = W$$

Therefore, the change in GPE between two heights is equal to the amount of work done to move an object vertically.

### Worked example 8.3

#### Gravitational potential energy

A diver on the diving board has a mass of 60 kg.

- If the diving board is 10 m above the ground, what is the diver's gravitational potential energy?
- When the diver is 0 m above the ground, what is his gravitational potential energy?
- What does this mean in terms of work done  $W = \Delta E_p$  if the diver wants to go from 0 m back to the diving board 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.

Working	Explanation
<b>a</b> GPE at 10 m above ground $m = 60 \text{ kg}$ , $h = 10 \text{ m}$ , $g = 9.8 \text{ m s}^{-2}$ $E_p = mgh$ $E_p = 60 \text{ kg} \times 9.8 \text{ m s}^{-2} \times 10 \text{ m}$ $E_p = 5880 \text{ J}$ $= 5.88 \text{ kJ}$	List the relevant data that has been provided. Recall the definition of gravitational potential energy and the equation. Substitute the relevant data into the equation. Solve the problem, giving an answer with appropriate units.
<b>b</b> GPE at 0 m above ground GPE at ground level = ? GPE at ground level = 0 J	At $h = 0 \text{ m}$ , the gravitational potential energy is 0 J.
<b>c</b> Work done Work done to climb back up to the board = ? Work done to climb back up to the board = 5.88 kJ	This means that if he wants to climb back up from the ground to a height of 10 m, there will have to be of 5.88 kJ of work done, as that is the difference in gravitational potential energy, $\Delta E_p$ .

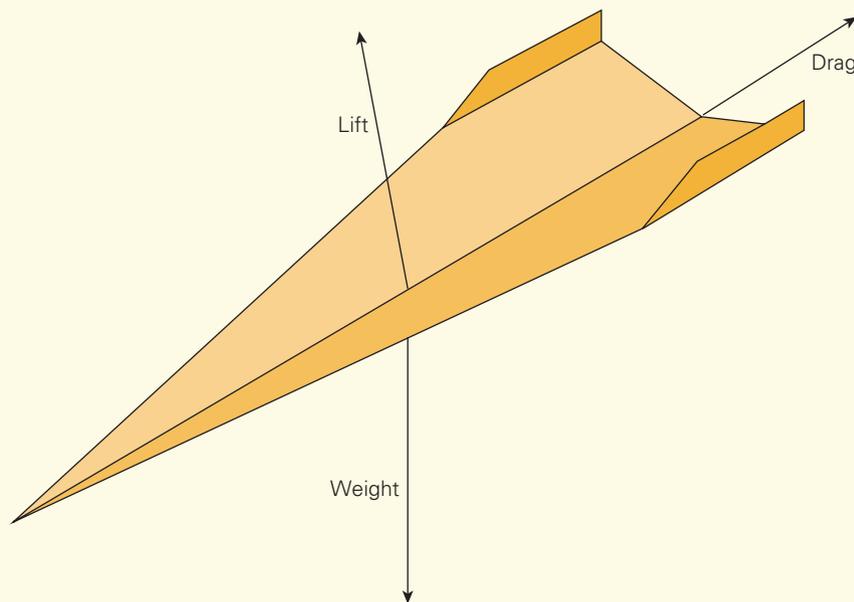
## Explore! 8.1

### Engine-less planes?!

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 (air resistance) 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?



**Figure 8.8** A glider is an aircraft that does not have an engine, yet can stay airborne for hours at a time.



**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.

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.

### 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:

$$E_e = \frac{1}{2}kx^2$$

where  $E_e$  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 is measured in  $\text{N m}^{-1}$ ; and  $x$  is the linear length that it has been expanded or compressed relative to its equilibrium position, measured in metres (m).

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



**Figure 8.10** A stretched slinky has elastic potential energy. When released, the slinky will return to its original position.

compression or stretching. Again, some force ( $F$ ) 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  $W = \Delta E_e$ .

### Worked example 8.4

#### Elastic potential energy

A bow has an elasticity constant of  $2000 \text{ N m}^{-1}$ . It is stretched by  $30 \text{ cm}$ . How much elastic potential energy does the bow store?

Working	Explanation
$k = 2000 \text{ N m}^{-1}$ , $x = 0.30 \text{ m}$	List the relevant data that has been provided.
$E_e = \frac{1}{2}kx^2$	Recall the definition of elastic potential energy and the equation.
$E_e = \frac{1}{2} \times (2000 \text{ N m}^{-1}) \times (0.30 \text{ m})^2$	Substitute the relevant data into the equation.
$E_e = 90 \text{ J}$	Solve the problem, giving an answer with appropriate units.



**Figure 8.11** A stretched bow stores elastic potential energy.

**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 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.

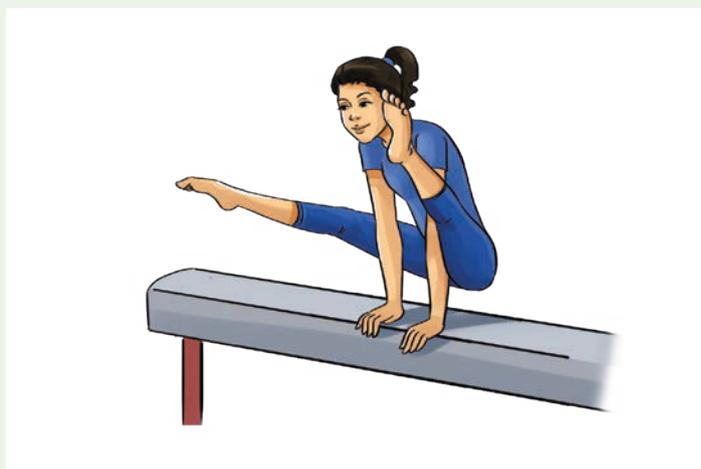


**Figure 8.12** A paper spinner or 'woer woer' is a toy from the 1980s that uses elastic potential energy to create motion and sound.

- 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, state 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?

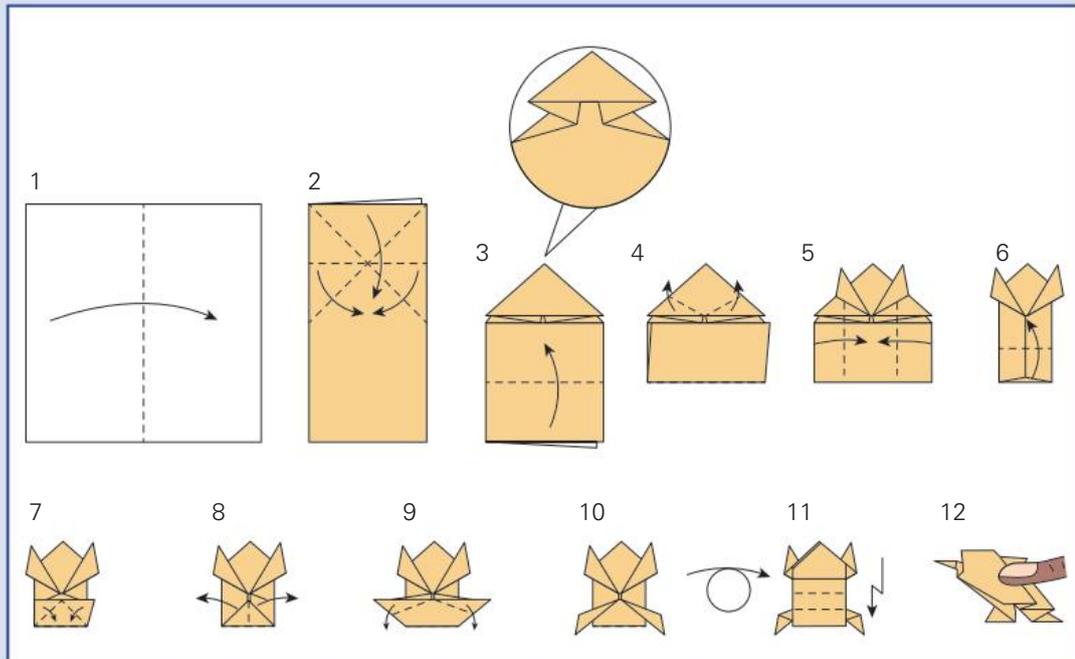
### Try this 8.3

#### Jumping paper frogs

Create an origami frog to demonstrate the conversion of elastic potential energy to kinetic energy and gravitational potential energy. You will need origami paper and optionally a ruler.

#### Instructions

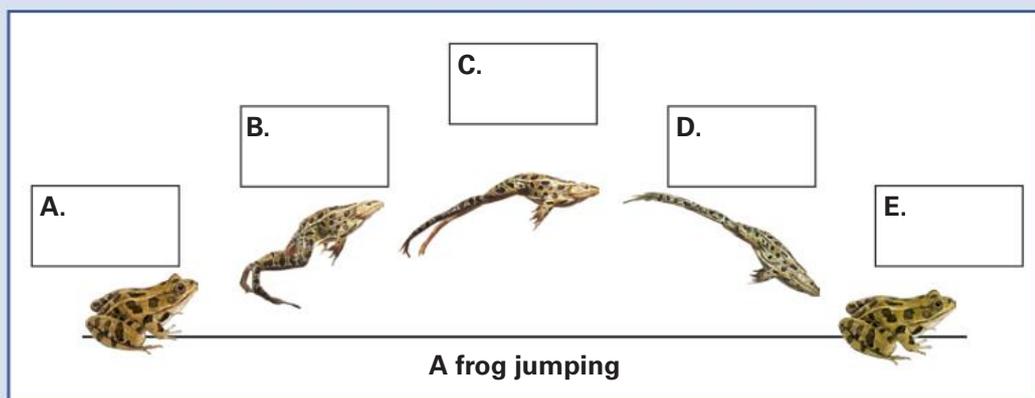
- 1 Use the following steps to create your own jumping frog.



- 2 Press down on your frog to make it jump and record both the height and distance it jumped.
- 3 Explore ways to change the amount of energy your frog has so it can jump different heights and/or distances.

#### Questions

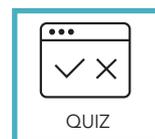
- 1 Where does the energy that enables your frog to move come from?
- 2 Complete the illustration below by indicating the form of energy (kinetic, gravitational potential or elastic potential) possessed by the frog at different stages of its jump.



## Section 8.1 questions

## Remembering

- 1 **Define** the term 'energy'.
- 2 **Recall** what kinetic energy is.
- 3 **Name** three everyday objects that have elastic potential energy.

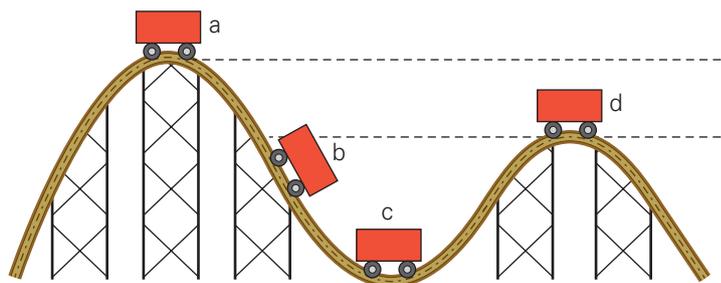


## Understanding

- 4 **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.
- 5 **Explain** how work done relates to lifting an object against gravity using the formula  $W = \Delta E_p$ .

## Applying

- 6 **Describe** the energy changes in the roller-coaster below at points a, b, c and d.



- 7 **Classify** the following as possessing either kinetic energy or potential energy.
  - a The moving (or spinning) blades in a blender
  - b Books sitting on a bookshelf
  - c Hot water in a kettle
  - d The sound coming from a radio
  - e A cheeseburger

## Analysing

- 8 **Compare** gravitational and elastic potential energy.
- 9 **Organise** the following items from having the most to the least amount of gravitational energy.
  - An apple hanging in a tall tree
  - An apple lying under a tree
  - An apple in a fruit bowl on a table

## Evaluating

- 10 In the case of a person pushing against a rock wall, **justify** why no work is being done.

## 8.2 Thermal energy



### Learning goals

- 1 To be able to define temperature and the kelvin scale.
- 2 To be able to recall the first law of thermodynamics.
- 3 To describe heat transfer via conduction, convection and radiation.

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, 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 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 temperature. Objects with a higher temperature have more kinetic energy. It is the **internal energy** contained within a system that is responsible for its thermal energy. The internal energy of a substance is the total stored potential energy and the kinetic energy of the particles in a system. The total amount of thermal energy that an object or system has depends on three factors:

- temperature, where objects that have higher temperatures have more thermal energy than identical objects at lower temperatures
- mass, where heavier objects have more thermal energy than lighter ones of the same material and temperature
- material, where some materials can store thermal energy better than others.

As you could work out from the example in Figure 8.14, the amount of motion (and thus kinetic energy) that the atoms have determines the temperature of the quiche. Thermal energy



**Figure 8.14** The atoms in the slice of quiche and 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.

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 and is usually measured with a thermometer. However, the concept of temperature in physics is a rather complicated one.

We define temperature as a measure of the *average* kinetic energy of the particles of matter, whereas internal energy is the *total* kinetic energy of all the particles of matter and the stored potential energy. **Heat** is a transfer of thermal energy between molecules in a system, caused by a difference in temperature. Heat is always transferred from the system with the highest temperature to the system with the lowest temperature.

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.

#### temperature

a measure of the average kinetic energy of all the particles in a substance

#### thermal energy

the internal energy present in a system due to its temperature

#### internal energy

the total potential energy stored in bonds and kinetic energy of the particles in a system

#### heat

the transfer of thermal energy caused by a difference in temperature



VIDEO  
What is temperature?



**Figure 8.15** A metal tap feels colder than a wooden board, despite them both being the same temperature.

Three scales are commonly used to measure and describe temperature. In Australia, we use the Celsius scale ( $^{\circ}\text{C}$ ), which was constructed relative to the freezing and boiling points of water at sea level and at an atmospheric pressure of one atmosphere. On the Celsius scale, the freezing point of pure water is  $0^{\circ}\text{C}$  and the boiling point of pure water is  $100^{\circ}\text{C}$ .

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

### Try this 8.4

Take three large containers and fill one with room temperature water, one with warm water (be careful that it is not too hot) 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?

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  $-273.15^{\circ}\text{C}$ . Scientists have come relatively close to reaching absolute zero, reaching temperatures of less than a billionth of a kelvin.

A third scale, Fahrenheit ( $^{\circ}\text{F}$ ), is commonly used in the United States as a measure of environmental temperature, but is not commonly used in science.

### Did you know? 8.1

#### Kelvin versus Celsius

The kelvin scale defines zero as absolute zero, which means that zero on the Celsius scale ( $0^{\circ}\text{C}$ ) 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  $100^{\circ}\text{C}$ , can now be defined as the equivalent to 373.15 K.

## Explore! 8.2

**How do thermometers work?**

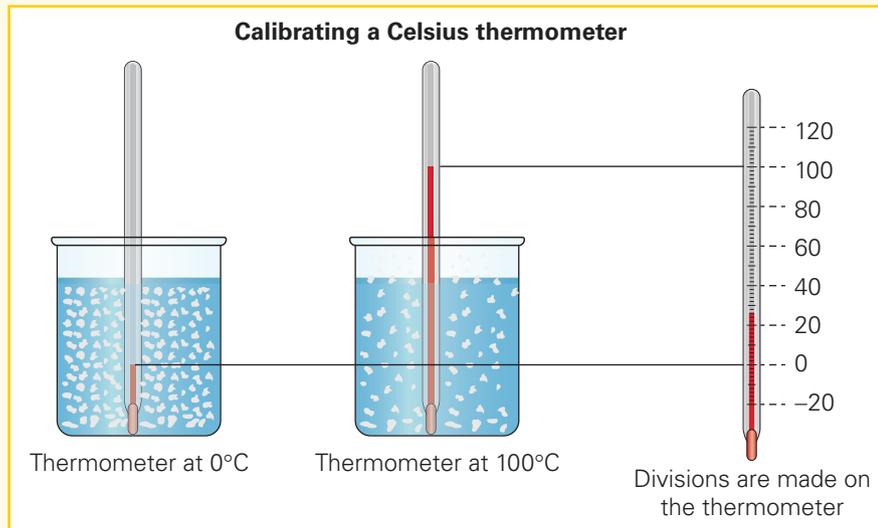
A thermometer is a device that is designed and calibrated to measure the temperature. Common household thermometers consist of a thin glass tube sealed at both ends that is partially filled with a liquid, usually a red-coloured alcohol.

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 vibrate more rapidly and move away from each other, 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 ( $0^{\circ}\text{C}$ ) and the boiling point of pure water at an atmospheric pressure of one atmosphere ( $100^{\circ}\text{C}$ ).

- 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 Figure 8.17.



**Figure 8.16** Calibration of a Celsius thermometer involves using two known temperature points.



**Figure 8.17** 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, thus increasing the temperature.

### 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.

## 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.



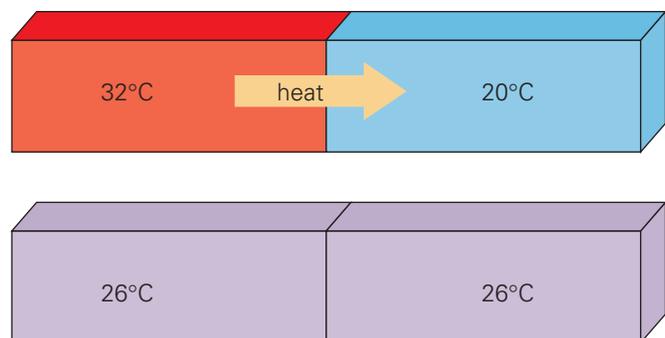
**Figure 8.18** An incandescent light globe that has been burning for some time will be too hot to touch with your bare hands. This can be explained by thermodynamics.

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.

**thermodynamics**  
the branch of physics that relates to the transfer and transformation of energy; in particular, thermal energy

**thermal equilibrium**  
describes two bodies that are at the same temperature and, therefore, have no net thermal energy transfer

The red and blue blocks in Figure 8.19 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.



**Figure 8.19** The top system (red and blue blocks) is not in thermal equilibrium, while the bottom system (purple blocks) is in thermal equilibrium.

## Did you know? 8.2

## The Mpemba effect



**Figure 8.20** The Mpemba effect in action. Hot water freezes instantly when exposed to below freezing conditions.

The Mpemba effect is 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.

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. You may 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 8.18 must get its thermal energy from somewhere. 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 if you were to touch it – so do not touch it! Thermal energy can move from one place to another in three different ways of heat transfer: conduction, convection and radiation.

**first law of thermodynamics**  
energy cannot be created or destroyed; it can only be transformed into other forms of energy or transferred to other objects

**law of conservation of energy**  
the total amount of energy in an isolated system is constant

## 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!

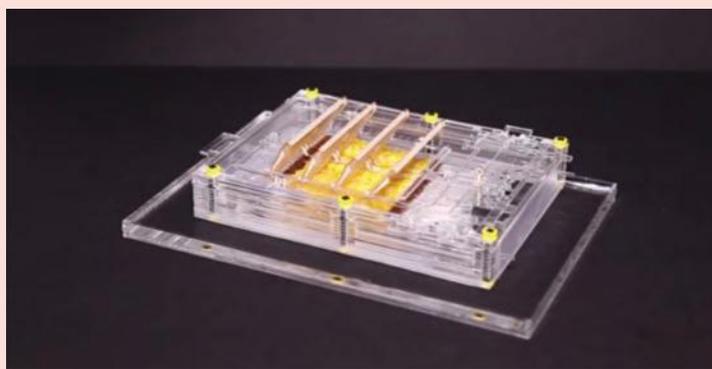
In 2015, the researchers discovered a way to harness the process of evaporation to produce a seemingly endless, controllable, renewable energy resource. The secret to their discovery was the property possessed by bacterial spores whereby they expand when exposed to water and contract as they dry out.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

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.



**Figure 8.21** Evaporation from lakes and oceans is an untapped energy source that could be the solution to our inconsistent power supply.



**Figure 8.22** 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.

## 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. How is this heat transferred to your hands without touching the flames?



**Figure 8.23** Keeping warm around a campfire and roasting marshmallows require the transfer of heat.

Three types of heat transfer are occurring simultaneously in Figure 8.23. 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.

## Conduction

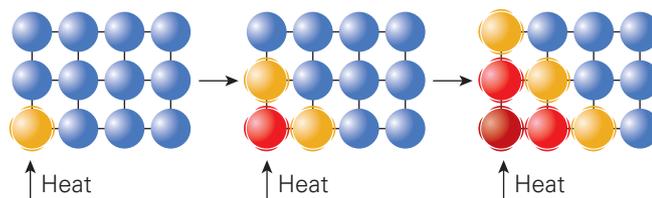
**Conduction** is the transfer of thermal energy through a substance, or between substances, as a result of the collisions between particles. Heat is able to travel by conduction when particles with a large amount of thermal energy (so are vibrating rapidly) pass on that energy as vibrations to adjacent particles, causing them to gain thermal energy and vibrate faster. This can only happen if there is a temperature gradient (rate of change of temperature over a distance), and it will continue to happen as long as there is a temperature gradient and contact between particles.



VIDEO  
Conduction

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 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.

**conduction**  
the transfer of thermal energy through a substance, or between substances, as a result of collisions between particles



**Figure 8.24** 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 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**.

**conductor**  
a material that can transfer heat a via conduction

**insulator**  
a material that is a poor conductor of heat

### Explore! 8.3

#### Radiators keep cars cool

In our homes, radiators radiate heat, keeping us warm. In cars, however, radiators are used to cool the engine, and thus are 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 8.25 Radiators prevent car engines from overheating.

### Practical 8.1

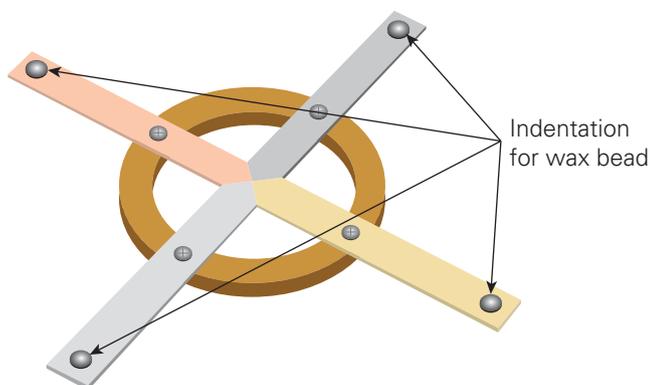
#### Heat transfer by conduction

##### Aim

To determine which material is the better conductor of thermal energy.

##### Materials

- conduction ring with 4 metal arms (e.g. copper, aluminium, brass, steel)
- Bunsen burner
- heat mat
- retort stand
- bosshead and clamp
- 4 wax beads
- stopwatch
- matches



#### Be careful

Ensure all equipment is properly cooled before handling.

continued...

...continued

### Method

- 1 Draw the table shown in the results section into your science journal.
- 2 Set up the Bunsen burner on top of the heat mat.
- 3 Place one wax bead into the small indentation at the end of each arm.
- 4 Set up the conduction ring using the retort stand, bosshead and clamp to suspend the centre over the Bunsen burner.
- 5 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.
- 6 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		

### Discussion

- 1 Identify which arm melted the wax first.
- 2 State which arm melted the wax the slowest.
- 3 Which material was the best conductor? Propose 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.

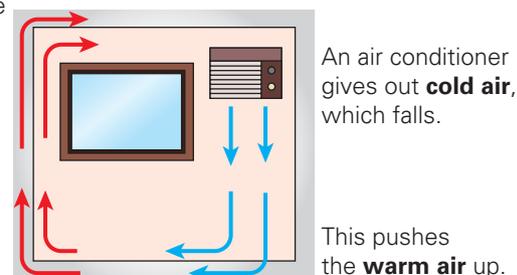
## Convection

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. This occurs because as a region of fluid is heated, the particles gain more kinetic energy and move away from each other. This results in them being less dense and so they rise. They are now away from the heat source, so the particles cool down, move closer together and thus become more dense and sink. You experience convection at school and home. In Figure 8.26, the air conditioning system produces cold air, in which the particles are more tightly packed, and thus denser 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.

**Warm air** is taken in by the air conditioner and cooled.



**Figure 8.26** 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.

**convection**  
the transfer of thermal energy due to the movement of particles in a fluid



## Practical 8.2

### Convection in liquids

#### Aim

To observe convection currents in a beaker of water.

#### Materials

- potassium permanganate crystal (alternative: tea leaves)
- 500 mL beaker
- cold water
- a thick straw
- forceps
- Bunsen burner
- heat mat
- tripod
- gauze mat

#### Method

- 1 Set up the Bunsen burner and tripod on top of the heat mat.
- 2 Pour 400 mL of cold water into the beaker and place onto the gauze mat on top of the tripod stand.
- 3 Place the straw into the cold water so that its base is close to the wall of the beaker. Using the forceps, drop a single potassium permanganate crystal down the straw into the water.
- 4 Carefully remove the straw without disturbing the water in the beaker.
- 5 Record your observations.
- 6 Place the Bunsen burner to one side of the beaker and light it.
- 7 Record your observations.

#### Results

Sketch and label the movement of the coloured water.

#### Discussion

- 1 Use your understanding of convection currents to explain the motion of the water as it was heated.
- 2 Summarise the relationship between the temperature of a fluid and its density.

#### Be careful

Ensure appropriate personal protective equipment is worn. Do not dispose of the potassium permanganate down the sink without neutralising. All materials are to be collected to be disposed safely.

#### radiation

the transfer of thermal energy without the presence of particles of matter



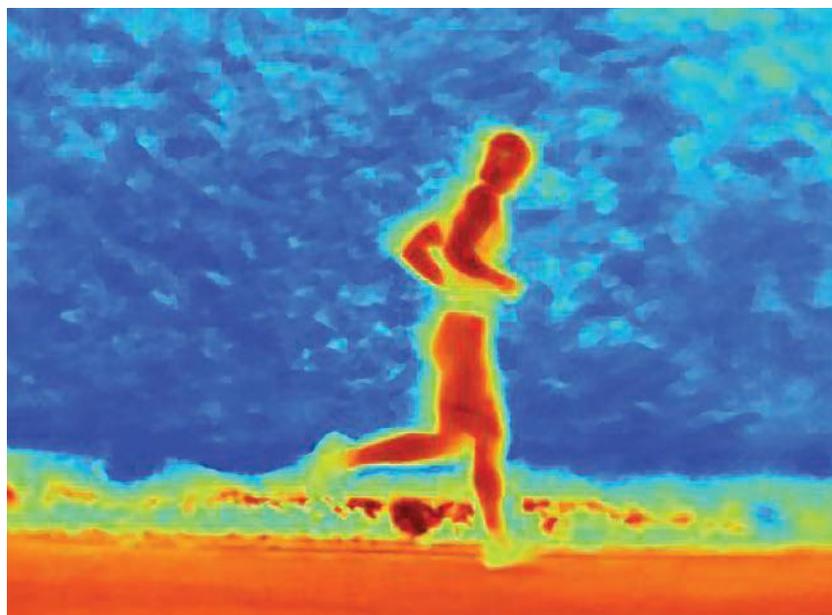
VIDEO  
Radiation

## 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 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.

**Figure 8.27** A thermal image of a person running. Notice how hot their body is (indicated in red), as well as how the heat is being transferred from the body to the surrounding air particles (indicated in green).



**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 mission at the NASA website.

**Quick check 8.6**

- 1 Explain the following features of cookware.
  - 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 8.3****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
- bosshead and clamp
- optional: heat lamp or radiant electric heater

**Be careful**

There is a risk of burns when handling heat sources. Use heat-resistant gloves for handling lamps.

**Planning**

- 1 Identify the independent variable.
- 2 Identify the dependent variable.
- 3 Read the method and then create a results table that will allow you to collect sufficient and relevant raw data.
- 4 Develop a hypothesis by predicting how a change in the independent variable will affect its dependent variable.

**Method**

- 1 Pour 100 mL of cold water into each can using a measuring cylinder and funnel.
- 2 Place a thermometer into each can. Use the retort stand, bosshead and clamp to suspend the thermometer so that it does not touch the base of the can.
- 3 Record the initial temperature of the water in each can in °C.
- 4 Place the cans close together in the Sun or other warm location. Otherwise, a heat lamp or radiant electric heater could be used.
- 5 Measure the temperature with the thermometer every 5 minutes for the next 30 minutes and record your results.

**Results**

- 1 Draw a single line graph to analyse the relationship between time and the change in temperature for each of the independent variable groups.
- 2 Add the lines of best fit to the graph if possible.

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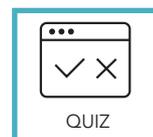
### Discussion

- 1 Describe any trends, patterns or relationships you found in your results.
- 2 Discuss the effectiveness of different colours at absorbing heat.
- 3 Based on the results of this experiment, what colours of clothing should people wear to stay warm in winter and cool in summer?

## Section 8.2 questions

### Remembering

- 1 **Define** the term 'thermal energy'.
- 2 **Recall** the conditions required for conduction to occur.
- 3 **State** the law of conservation of energy.
- 4 **Recall** what thermodynamics is.
- 5 **Recall** when thermal energy will no longer be transferred between two substances in contact.



### Understanding

- 6 **Explain** how an object with a higher temperature can have less thermal energy than an object that has a lower temperature.

### Applying

- 7 **Explain** why the energy received from the Sun is by radiation and not convection or conduction.
- 8 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, **describe** how the movement of particles differ.

### Analysing

- 9 **Classify** the following heat transfers as 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 **Differentiate** between insulators and conductors in terms of their ability to transfer heat.
- 11 Josh says insulation keeps out the cold. **Critique** this statement.

### Evaluating

- 12 **Explore** why a lake freezes at the top first, rather than throughout or at the bottom.
- 13 The amount of heat received by radiation is inversely proportional to the square of the distance to the heat source. **Predict** how the amount of thermal energy received from the Sun would differ if Earth was half the distance from the Sun as it is now.
- 14 Conduction occurs in liquids and solids. **Deduce** why convection does not occur in solids.

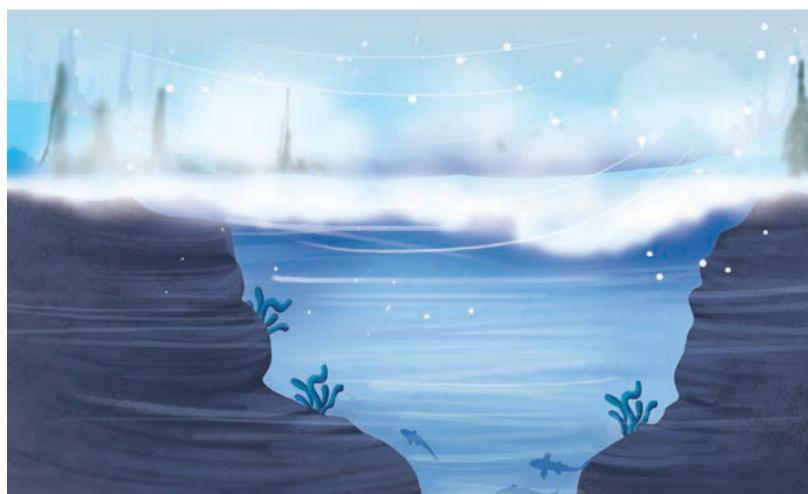


Figure 8.28 A frozen lake with unfrozen water beneath the surface

## 8.3

## Energy transfers and transformations



## Learning goals

- 1 To be able to calculate the efficiency of energy output.
- 2 To be able to interpret Sankey diagrams, illustrating energy transfers.

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.

When a firework explodes, 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.

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



**Figure 8.29** Fireworks are the result of many energy transformations.

conservation of energy in that energy is neither created nor destroyed.

## Explore! 8.4

## Nanotechnology improving energy transfer efficiencies

Nanotechnology is a combination of science and engineering that manipulates and uses individual atoms and molecules as its building blocks and moving parts. Nano refers to the nanoscale, about 1 to 100 nanometres, or 1 to 100 billionths of a metre. Research how new technologies in this area are helping to improve the efficiency of producing and transferring energy. For example:

- 1 high-efficiency light bulbs
- 2 stronger and lighter windmill blades
- 3 generating electricity from waste heat or friction
- 4 cheaper solar cells.

## Did you know? 8.4

## Aurora australis



**Figure 8.30** Aurora australis – the Southern Lights

Similar to the better-known Northern Lights (aurora borealis), the Southern Lights are the result of energy transformations caused when high-energy electrons (and sometimes 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.

## Energy efficiency

In Section 8.2, we saw that incandescent light globes transform electrical energy into thermal 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 purpose 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 disappeared, 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.

Hardly any energy conversion is 100% efficient – energy in some form is always lost to the

system. (However, in microscopic collisions, such as between gas particles, perfectly elastic collisions are commonplace where no kinetic energy is lost.) 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.



**Figure 8.31** 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  $E_k$  and  $E_p$  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.

**efficiency**

a measure of the ability to produce useful energy

**useful energy**

energy that can be used for a specific purpose

**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, 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). Wasted energy is usually lost to the environment and generally cannot be used to do work.

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

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

**Worked example 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?

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



## Practical 8.4: Investigation

### Investigating the efficiency of bouncing balls

#### Aim

To calculate and compare the efficiencies of balls that bounce.

#### Prior understanding

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

#### Useful formula

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

#### Materials

As chosen by students but most likely to include:

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

#### Planning

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

#### Design a method

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

#### Test and modify the method

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

#### Undertake your modified method

- 1 Follow the steps in your method to collect data from multiple trials.
- 2 Make note of any issues that may need to be discussed in your evaluation.

#### Results

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

#### Discussion

- 1 Compare the efficiency of the different types of balls. Justify your response using data.
- 2 Identify which bouncy ball is the most efficient.
- 3 Discuss how this data can be related to energy transformation and wasted energy.
- 4 How much variation was observed between the measurements between different student groups within the class?

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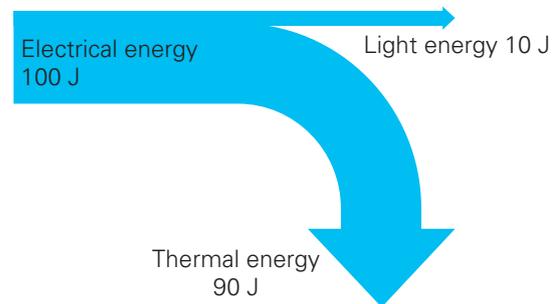
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- 5 Were other variables that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning with data.
- 6 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.
- 7 Write out an improved version of the method based on the answers to the evaluation questions above. Include instructions on how to control variables for validity.

### 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 8.32 shows a Sankey diagram for an incandescent light globe, where only 10% of output energy is in a useful form.

(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.



**Figure 8.32** 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.

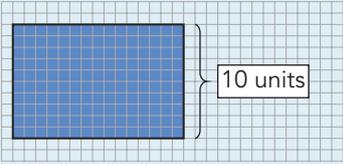
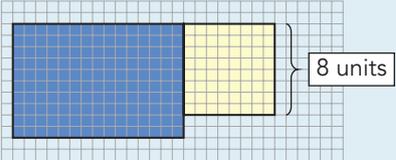
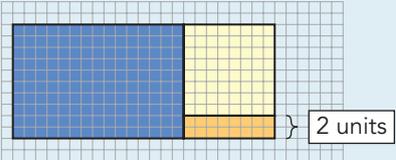
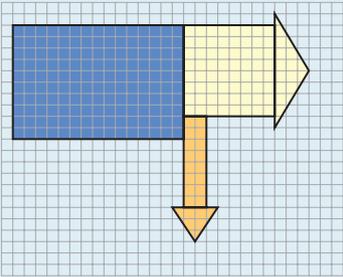
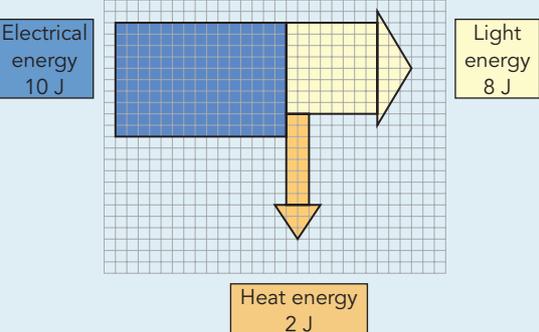
#### Sankey diagram

a flow chart that represents the flow of energy through a system

The Sankey diagram for an incandescent light globe shows that most of the electrical energy is transformed into thermal energy

### Worked example 8.6

Draw the Sankey diagram of an energy-efficient light bulb with an input energy of 10 J, an output energy of 8 J in the form of light and wasted output of 2 J in the form of heat.

Working	Explanation
	<p>The height of the box represents the amount of energy that is put in. In this case it is 10 J, so it should be 10 units in height.</p> <p>Note that the length of the box does not matter.</p>
	<p>The height of the next box represents the amount of useful energy. In this case, it is 8 units in height.</p>
	<p>The height of the final box represents the amount of wasted energy. In this case, it is 2 units in height.</p>
	<p>The wasted energy should be rotated 90° clockwise so it points down. This shows that it is wasted energy.</p> <p>Add arrows to the output boxes.</p>
	<p>Finally, add the labels.</p>

### Quick check 8.7

- 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.
- 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.
- Draw a Sankey diagram for the electric stove in Question 2.

## Practical 8.5

### 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.

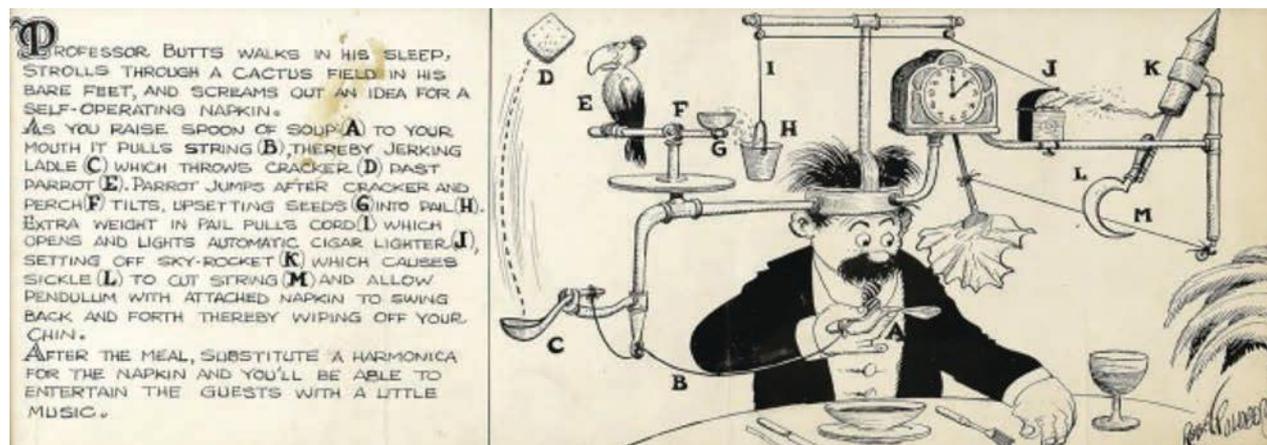


Figure 8.33 Original artwork for Rube Goldberg's 'self-operating napkin' machine.

#### Aim

To design and construct a Rube Goldberg machine to complete a common task.

#### Materials

As chosen by individual students or groups, 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, ensuring 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.

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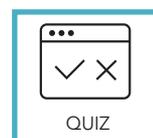
### Discussion

- 1 Explain the energy transfers and transformations that took place in your Rube Goldberg machine.
- 2 How could you reduce the amount of waste energy produced by your Rube Goldberg machine to make it more efficient?
- 3 Compare your final machine to your plan. Which parts (if any) are different? Why did you change them?
- 4 Propose any improvements or extensions you would make if you were to build another machine.

## Section 8.3 questions

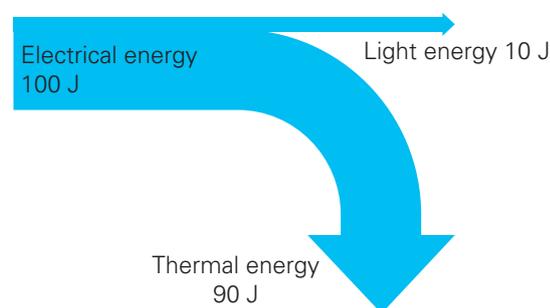
### Remembering

- 1 **Define** the term 'useful energy'.
- 2 **Recall** the energy transformations that occur when fireworks explode.
- 3 **State** what usually happens to wasted energy.



### Understanding

- 4 An organism uses 500 J of chemical potential energy stored in its body to produce 125 J of kinetic energy to climb a tree. **Calculate** the organism's efficiency.
- 5 A kettle has an energy efficiency of 89%. **Calculate** how much electrical energy is required to produce 1068 J of thermal energy.
- 6 The Sankey diagram on the right is of a light globe.
  - a **Identify** the useful energy output that the light globe is designed to produce.
  - b **Recall** the effect that the wasted energy has on the surrounding air.
  - c **Calculate** the efficiency of this light globe.



### Applying

- 7 A car has an energy efficiency of 35%. **Explain** what this means in terms of energy.
- 8 **Explain** what the term 'efficiency' means.
- 9 **Explain** how the law of conservation of energy still applies to a system despite energy being 'lost' during a transformation.
- 10 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.

### Analysing

- 11 **Organise** the following processes from the highest amount of energy to the lowest:
 

Falling raindrop: $85 \times 10^{-6}$ J	Deep Bay Meteor: $15.85 \times 10^{18}$ J
Cosmic ray: 51 J	Falling snowflake: $650 \times 10^{-9}$ J
Car driving on the Bruce Highway: $400 \times 10^3$ J	

### Evaluating

- 12 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.
- 13 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 **Propose** what Jane can do to minimise the amount of wasted energy.

## 8.4 Exploring energy in systems



### Learning goal

- 1 To explore energy transfers in pendulums, cranes, car crashes and refrigerators.

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.

### 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 8.34 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 that accounts for all of the mass of the system. We ignore the effects of air resistance 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 that, with each successive energy conversion, energy is lost to the system as heat and sound, primarily due to air resistance.



Figure 8.35 A pendulum tracing circles in sand as its motion decreases before coming to a stop due to friction

**Explore! 8.5****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 moving**

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 lowering objects such as the containers in Figure 8.36?

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 8.36** A container lifted by a crane in a shipyard has kinetic and gravitational energy.

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. 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 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.

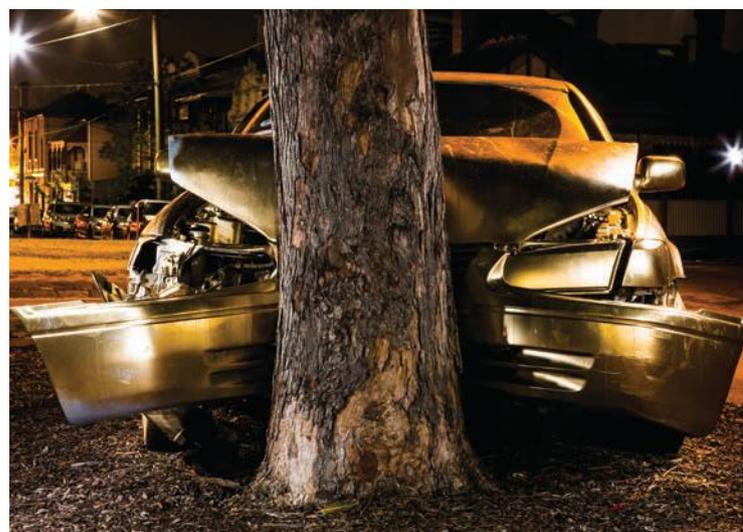
## Car crashes

Moving cars have large amounts of kinetic energy due to their motion. What happens to all 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 proportional to the amount of energy transferred. In other words, the more energy transferred, the more force applied. As the distances and the time involved are reduced, the forces involved increase.

In Figure 8.37, 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; therefore, it is the work done by the tree on the car that reduces the car's energy to zero.

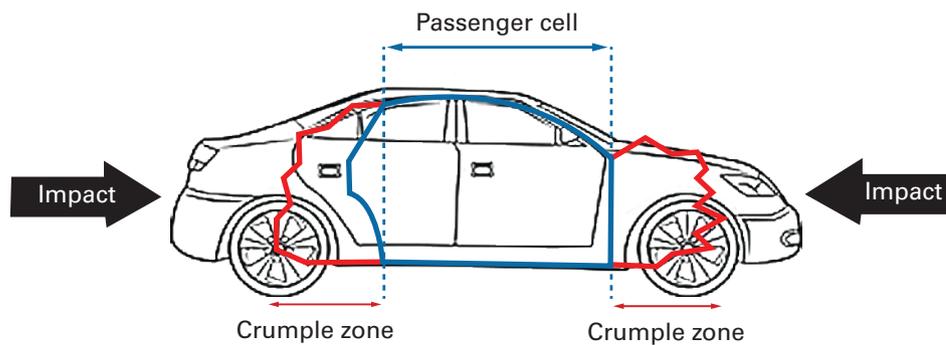


**Figure 8.37** What happens to the car's kinetic energy in a collision?

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.

### Crumple zones

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.



**Figure 8.38** Crumple zones are usually located at the front and back of cars, and are designed to absorb some of the energy in a collision.

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, for a set amount of work, by increasing the displacement we are decreasing the force applied.

### 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 8.39** A seatbelt is a safety device in car that prevents injuries by helping you come to a stop safely.

## Airbags

Airbags are 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.

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 8.40** An airbag inflating on impact protects a head from hitting the steering wheel or windscreen.

### Quick check 8.10

- 1 Discuss 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 and sound energy.

A refrigerator has a closed system of pipes filled with a liquid coolant that 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 passes through the



**Figure 8.41** A refrigerator is a common electrical appliance that uses the laws of thermodynamics to keep our food cold and fresh.

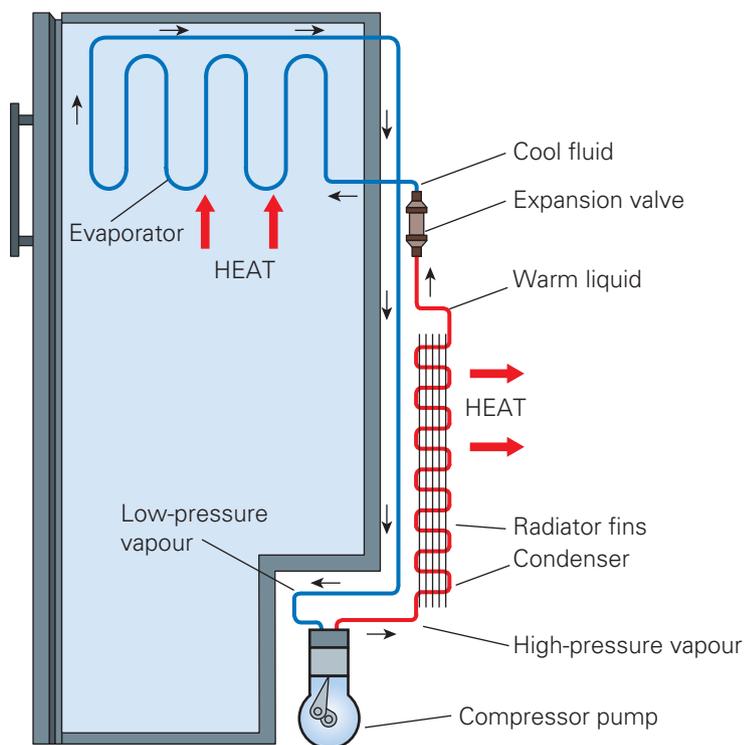


Figure 8.42 The cooling system of a refrigerator

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.

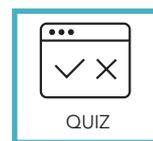
### Quick check 8.11

- 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

### Remembering

- 1 **Define** a 'system'.
- 2 **State** five examples of everyday systems that undergo energy changes.
- 3 **Identify** where on a car you would find the crumple zones and describe why they are located there.



### Understanding

- 4 **Explain** why a seatbelt is needed to stop the occupant in a collision.
- 5 **Explain** why a real pendulum's motion is not infinite and will eventually come to a stop.

### Applying

- 6 **Differentiate** between the forces felt by occupants in a car collision in a car with and without an airbag.

### Analysing

- 7 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.
- 8 Sports cars often have more crumple zones than other cars. **Propose** a reason for this.

### Evaluating

- 9 **Justify** why heating vents are often positioned on the floor while air conditioner vents are usually closer to the ceiling.

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
8.1 I can recognise the relationship between energy and work.	6	
8.1 I can identify different forms of potential and kinetic energy.	2	
8.2 I can distinguish between thermal energy, temperature and heat.	4	
8.2 I can explain the first law of thermodynamics.	3	
8.2 I can explain heat transfer by conduction, convection and radiation.	10	
8.3 I can describe energy transfers and transformations.	13	
8.3 I can calculate and illustrate the efficiency of energy transfers using a Sankey diagram.	9	
8.4 I can consider energy in different systems.	12	

## Review questions



### Remembering

- Identify** the term that each sentence defines.
  - The total kinetic energy of all of the particles that make up an object or system.
  - The transfer of thermal energy without the transfer of particles.
  - The average kinetic energy of all of the atoms that make up an object or system.
  - A flow chart that represents the flow of energy through a system.
- List** six different forms of energy, giving an example of (or where you would find) each.
- State** the first law of thermodynamics.

### Understanding

- Compare** thermal energy and temperature.
- Name** the two types or categories of energy into which all of the various forms of energy can be placed.
- Define** work qualitatively and quantitatively.
- Explain** how an airbag can reduce the impact of a collision on a person.

### Applying

- 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.
- 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.
- 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.

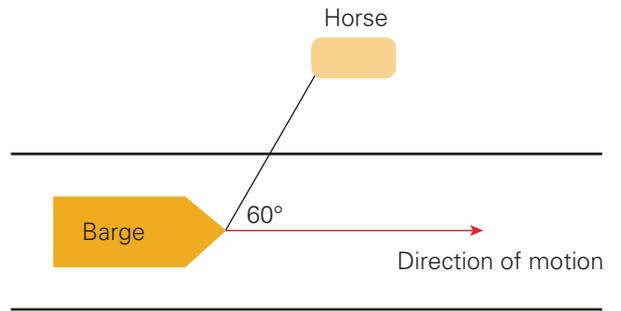
### Analysing

- Distinguish** between useful and wasted energy.
- 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.

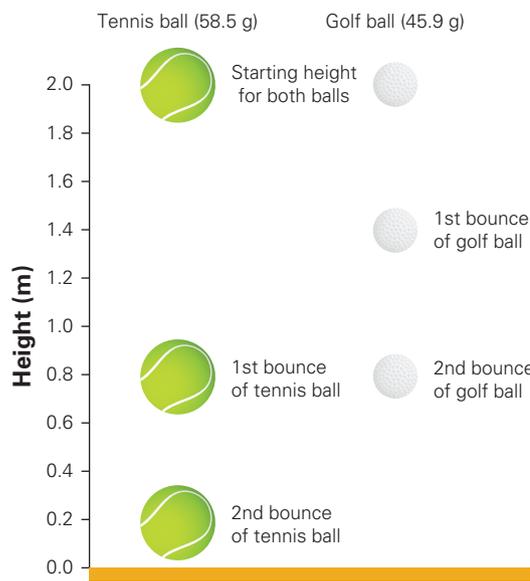
**Evaluating**

- 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  $60^\circ$ , 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  $F\cos\theta$ .)



**Data questions**

A tennis ball and golf ball are dropped from the same height and their first two bounces are recorded. The results are shown in Figure 8.43.



**Figure 8.43** Dropping a tennis and golf ball from the same height and recording the heights of their first two bounces

- 1 Use the data from Figure 8.43 to **calculate** the missing weight and height information in the table.

Ball	Weight (kg)	Starting height (m)	Height of 1st bounce (m)	Height of 2nd bounce (m)	GPE at starting height (J)	GPE at 1st bounce (J)	GPE at 2nd bounce (J)
Tennis	0.0585	2	0.8	0.2			
Golf	0.0459	2	1.4	0.8			

- 2 **Contrast** the differences between the two balls to determine which is more efficient in converting gravitational potential energy to kinetic energy and back again.
- 3 **Extrapolate** from the data to predict how high the golf ball will reach on its third bounce.
- 4 **Infer** where the 'missing' energy has gone for both balls.
- 5 **Deduce** why the golf ball is more efficient than the tennis ball.

## STEM activity: Building a prototype to use the heat energy from the Sun

### Background information

The Sun is the primary source of energy for our planet. Without the Sun, Earth would be a very different place. For example, almost 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 most commonly used 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. In addition to this, technology using solar thermal (heat) energy to heat up water and generate electricity is being developed.

**Design brief:** Design a method of capturing thermal (heat) energy from the Sun and propose a method of using this energy in your school.

### Activity instructions

In this activity, you and your colleagues will collaborate and build a prototype that uses the heat energy from the Sun and transforms this into a usable form.



**Figure 8.44** Solar energy has the potential to revolutionise the energy sector worldwide as we work towards mitigating the effects of climate change.

### 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 1 gram
- mirrors
- cardboard
- rubber/plastic tubing
- black paint

### Suggested location

School oval or soccer pitch on a sunny day

### Research and feasibility

- 1 Research solar thermal energy and how technology is used to capture heat energy.
- 2 Research the number of sunny days in your area and sunlight hours available for energy capture.
- 3 List all the ways heat energy is captured and how the energy is used.

Purpose of heat energy capture	Heat transfer
(e.g. heating pool) Water in pool	Pool water will increase in temperature.
(e.g. heating pool) Black plastic tubing on house roof	Water is pumped through the black tubing, which absorbs the heat energy from the Sun and pumps this into the pool.

### Design and sustainability

- 4 Decide how you and your group plan to use the heat energy and discuss the sustainability aspects of your prototype creation. For example, will the energy captured from the Sun be greater than the energy required to build the device?
- 5 Design a prototype that will use heat energy from the Sun and be usable in your school.
- 6 Annotate your design and list all the heat transfers and transformations.

### Create

- 7 Build your prototype and test your design using a thermometer.
- 8 Extension: Create a business logo that matches your prototype idea.

### Evaluate and modify

- 9 Present your prototype to the class with your measured energy capture.
- 10 Discuss the suitability of your design for a school and whether it could be used in other locations.

# Chapter 9

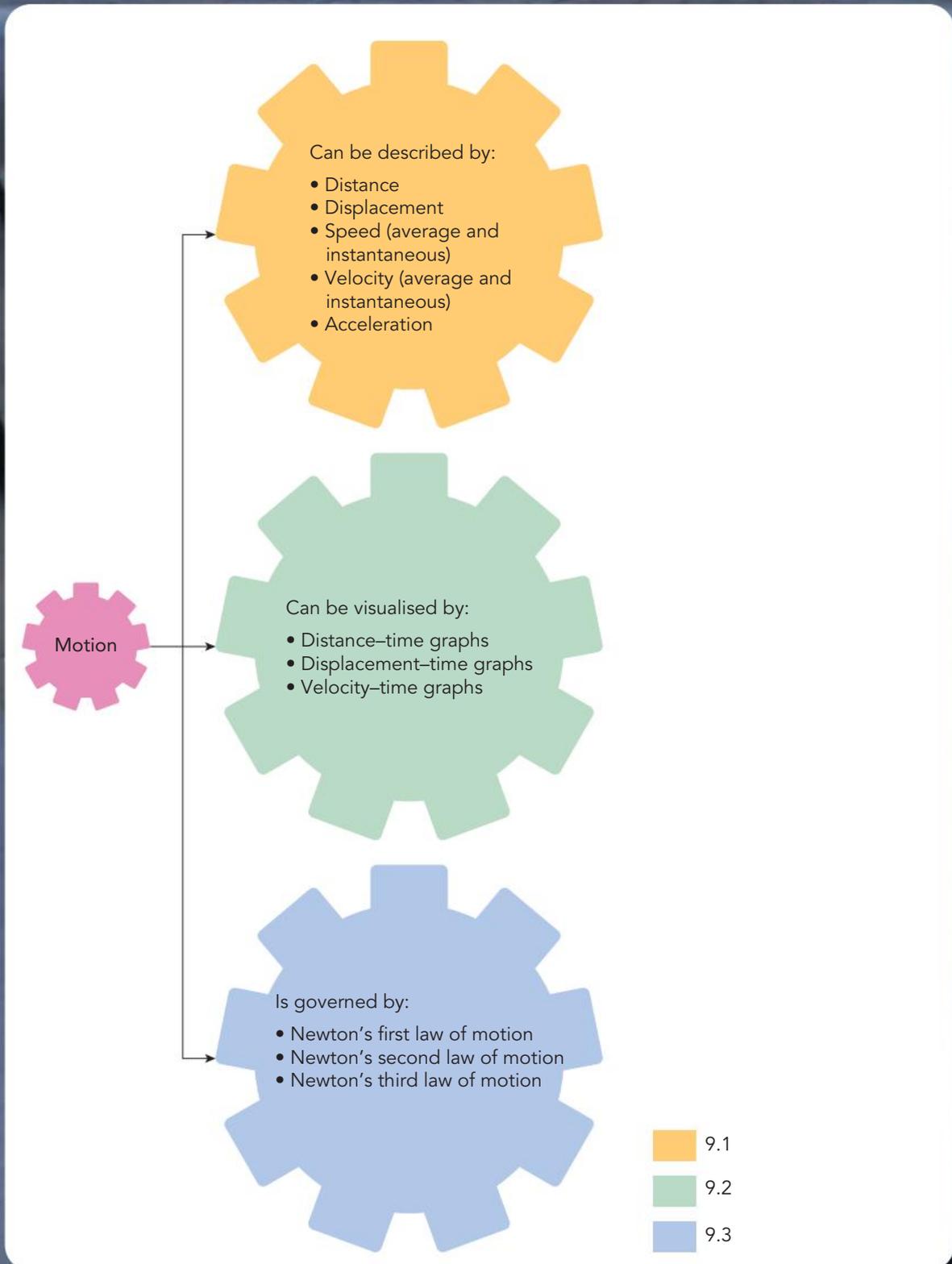
## Motion



### Chapter introduction

This chapter continues our exploration of the science of physics. Have you ever wondered how long it takes for sunlight to reach Earth or how quickly a raindrop falls to the ground? These questions can be answered in the domain of physics – the study of matter, energy and force. 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.

# Chapter map



# 9.1 Describing motion



## Learning goals

- 1 To be able to distinguish between quantities of distance and displacement.
- 2 To be able to convert between units of  $\text{m s}^{-1}$  and  $\text{km h}^{-1}$ .
- 3 To be able to distinguish between quantities of speed, velocity and acceleration.

## Try this 9.1

### Everyday motion

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?

## Distance

When motion is discussed, **distance** usually refers to how far something has travelled along a path. The symbol  $d$  is used to denote the overall distance an object has travelled. For example, the soccer ball in Figure 9.1 has travelled a distance of 20 metres.

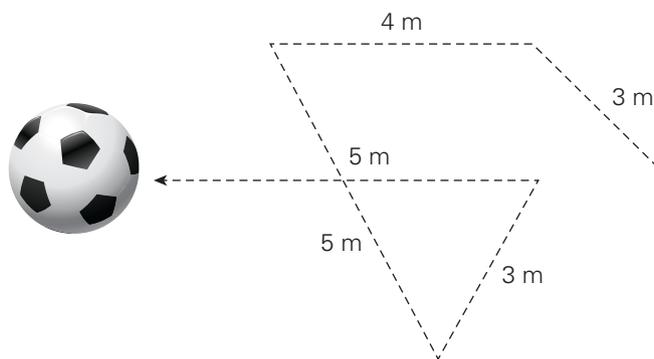


Figure 9.1 Distance travelled by a soccer ball

## Displacement

**distance**  
total distance travelled  
measured in metres

**displacement**  
how far you are from where  
you started and what  
direction you are from where  
you started

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



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.

with the symbol  $s$  and it has both magnitude and direction. You can remember this by thinking about displacement,  $s$ , as relating to spatial location in which distance and direction matter.

Figure 9.3 shows a scenario where the direction of travel matters. Your starting point is the cross in the middle. 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.

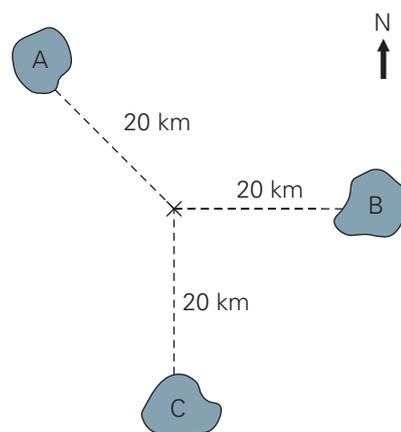
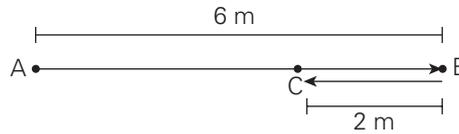


Figure 9.3 If you ended up on island B, your displacement would be 20 km east from your starting position.

### 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 6 metres forwards from point A to point B, and then 2 metres backwards to point C. The distance that they have travelled is 8 metres. However, since they have only ended up 4 metres from the starting position, the displacement from their starting point, A, is 4 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.

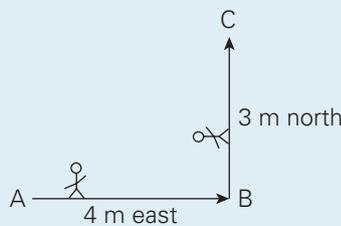
The total distance travelled from A to C is  $d = 6 + 2 = 8$  m.

The displacement from A to C is  $s = 6 - 2 = 4$  m to the right.

#### Worked example 9.1

##### Distance and displacement

A person walks 4 metres east and then 3 metres north. This can be represented in a simple diagram as follows.

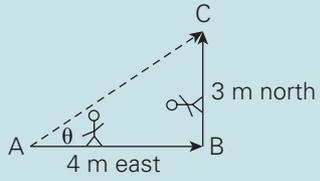


- a What is the distance travelled by the person?
- b What is the displacement?

Working	Explanation
<p><b>a</b> Distance</p> $d = 3 \text{ m} + 4 \text{ m} = 7 \text{ m}$	Add the two distances travelled to find the total distance that the person has travelled.
<p><b>b</b> Displacement</p> <div style="display: flex; align-items: center;"> <div style="margin-left: 10px;"> <p>Using Pythagoras' theorem, find the distance from A to C.</p> <math display="block">\begin{aligned} AC &amp;= \sqrt{4^2 + 3^2} \\ &amp;= \sqrt{16 + 9} \\ &amp;= \sqrt{25} \\ &amp;= 5 \text{ m} \end{aligned}</math> </div> </div>	
<p>Use Pythagoras' theorem to find the distance from A (the starting point) to C (the end point).</p> $a^2 + b^2 = c^2$ <div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-left: 10px;"> <math display="block">c = \sqrt{a^2 + b^2}</math> </div> </div>	

continued...

...continued

Working	Explanation
<p>To determine the direction requires trigonometry.</p>  <p><math>\tan \theta = \frac{3}{4}</math>  <math>\theta = 36.9^\circ</math> north of east            Therefore, the displacement <math>s</math> is 5 m <math>36.9^\circ</math> north of east.</p>	<p>Remember that you also need the direction travelled from the starting position to the final position.</p>

### 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 word *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 Differentiate between the terms 'distance' and 'displacement'.
- 2 A classmate travels between classrooms. From their initial classroom, they travel west 100 m and then north 50 m, where they arrive at the intended classroom.
  - a Represent this journey in a diagram.
  - b Calculate the distance travelled by the student.
  - c Calculate the displacement of the student, to the nearest metre. Remember to also give an angle in your answer.
  - d The student then travels back to the initial classroom. Determine their displacement.

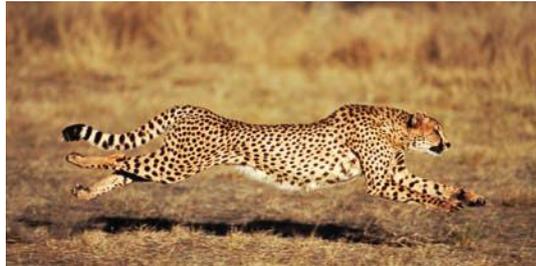
## Speed

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, speed is the distance ( $d$ ) travelled divided by the amount of time ( $t$ ) it took to travel that distance.

**speed**  
the change in distance  
divided by time



A rocket can travel at  $11 \text{ km s}^{-1}$ .



A cheetah can maintain a speed of  $31 \text{ m s}^{-1}$ .



The speed of a snail is more likely to be measured in units of  $\text{cm min}^{-1}$ .



The speed of cars is usually measured in  $\text{km h}^{-1}$ .

**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 ( $\text{m s}^{-1}$ ), or kilometres per hour ( $\text{km h}^{-1}$ ). However, depending on the motion, speed may sometimes be measured in  $\text{m min}^{-1}$ ,  $\text{cm h}^{-1}$  or even  $\text{km s}^{-1}$ .

Consider the examples of motion shown in Figure 9.5.

Speed is calculated as follows:

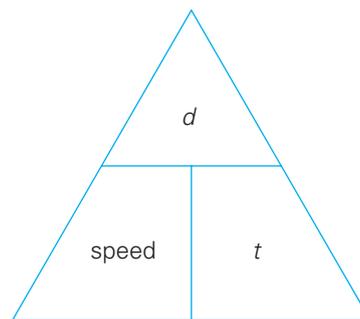
$$\text{average speed (m s}^{-1} \text{ or km h}^{-1}\text{)} = \frac{\text{distance travelled (m or km)}}{\text{time taken (s or h)}}$$

$$\text{Or speed} = \frac{d}{t}$$

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:

- $\text{speed} = \frac{d}{t}$
- $\text{time taken } t = \frac{d}{\text{speed}}$
- $\text{distance travelled } d = \text{speed} \times t$ .



**Figure 9.6** The average speed triangle

## Worked example 9.2

## Average speed

Consider two runners who are competing in a 100 m hurdles event. Runner 1 finishes in a time of 12.5 s. Runner 2 runs the race with an average speed of  $7 \text{ m s}^{-1}$ .

- a Who wins the race?  
 b How long does it take runner 2 to cross the finish line? Round your answer to one decimal place.

Working	Explanation
a Who wins?	
$d = 100 \text{ m}$ $t = 12.5 \text{ s}$ speed = ?	List the relevant information for runner 1.
$\text{speed} = \frac{d}{t} = \frac{100 \text{ m}}{12.5 \text{ s}}$ $= 8 \text{ m s}^{-1}$	Calculate the average speed using the formula for average speed.
Runner 1: speed = $8 \text{ m s}^{-1}$ Runner 2: speed = $7 \text{ m s}^{-1}$ Since runner 1 has a higher average speed, they finish before runner 2 does. Therefore, runner 1 wins the race.	Compare the average speed of each runner.
b Runner 2 time	
$t = ?$ speed = $7 \text{ m s}^{-1}$ $d = 100 \text{ m}$	List the information that you have for runner 2.
$t = \frac{d}{\text{speed}} = \frac{100 \text{ m}}{7 \text{ m s}^{-1}}$ $= 14.3 \text{ s}$	Calculate the time taken for runner 2 to complete the race using a rearranged average speed formula.
It takes 14.3 s for runner 2 to complete the 100 m hurdles race.	Interpret the solution, ensuring that you have correct units and decimal places.



Figure 9.7 Runner 1 won the race.

## Converting units

So far we have only used  $\text{m s}^{-1}$  for speed, but another common unit for speed is kilometres per hour ( $\text{km h}^{-1}$ ), which is commonly used to describe the speed of cars. Here is a quick guide for converting units.

$$1 \text{ km} = 1000 \text{ m}$$

$$1 \text{ h} = 3600 \text{ s}$$

$$1 \frac{\text{km}}{\text{h}} = \frac{1000 \text{ m}}{3600 \text{ s}} = \frac{1}{3.6} = \frac{\text{m}}{\text{s}}$$

Multiplying both sides by 3.6 and swapping the sides to make  $1 \text{ m s}^{-1}$  the subject gives:

$$1 \text{ m s}^{-1} = 3.6 \text{ km h}^{-1}$$

**Figure 9.8** Converting  $\text{m s}^{-1}$  into  $\text{km h}^{-1}$

To convert  $\text{m s}^{-1}$  to  $\text{km h}^{-1}$ , multiply by 3.6.

To convert  $\text{km h}^{-1}$  to  $\text{m s}^{-1}$ , 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  $4 \text{ m s}^{-1}$ . The dog travels a total distance of 500 m in that time.

- Does the dog or the cat travel further? Does the dog or cat win the race?
- 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  $\text{km h}^{-1}$  to  $\text{m s}^{-1}$ .

Are the results what you expected? Can you think of a scenario that would be appropriate to measure speed using  $\text{m s}^{-1}$  instead of  $\text{km h}^{-1}$ ?

## Did you know? 9.2

### Speed of light

Light travels at a constant speed of  $3 \times 10^8 \text{ m s}^{-1}$ . 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 kilometres!



**Figure 9.9** Light travels at  $3 \times 10^8 \text{ m s}^{-1}$ .

### Average versus instantaneous

When talking about the speed that something travels at, 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. Instantaneous speed is how fast something is travelling at a specific point in time.



**Figure 9.10** Speed detectors can capture the speed of an object in a fraction of a second.

#### average speed

the change in distance over a time interval

#### instantaneous speed

the speed at any particular instant

#### velocity

the change in displacement per unit of time

#### instantaneous velocity

the velocity of an object measured at a particular instant

#### average velocity

the rate at which an object is displaced or changes position over a time interval

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.

speed, velocity is a measure of the change in displacement of an object within a certain amount of time. Velocity includes more information than speed because it includes 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 that direction is important with the velocity, so displacement is used instead of distance. As with speed, velocity can be classified as **instantaneous velocity** and **average velocity**.

## Velocity

**Velocity** is a term used to describe how fast something travels in a particular direction. Like speed, the common units associated with velocity are  $\text{m s}^{-1}$  or  $\text{km h}^{-1}$ . However, unlike

**Figure 9.11** Terminal velocity is the highest attainable speed of a skydiver. It occurs when a skydiver is in freefall and the downward force of gravity is balanced by the upwards force of air friction so they are no longer accelerating. This skydiver's terminal velocity is at roughly  $60 \text{ m s}^{-1}$  down to Earth.



Mathematically, velocity can be described in the following ways:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

$$v_{\text{av}} = \frac{s}{t}$$

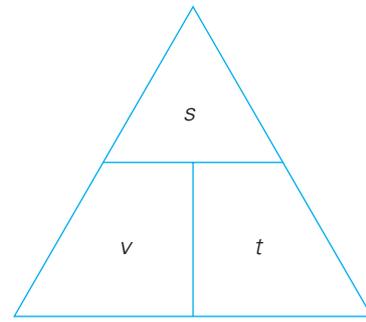


Figure 9.12 The average velocity triangle

### Worked example 9.3

#### Average speed versus average velocity

Consider the triangle in Figure 9.13 between Perth, Albany and Kalgoorlie. Imagine two aeroplanes that need to get from Perth to Kalgoorlie. Plane 1 travels directly to Kalgoorlie. Plane 2 must stop in Albany before flying to Kalgoorlie. It takes both planes 2.00 hours to reach Kalgoorlie. Let's assume that Kalgoorlie is straight east of Perth.



Figure 9.13 Travelling between Perth, Albany and Kalgoorlie

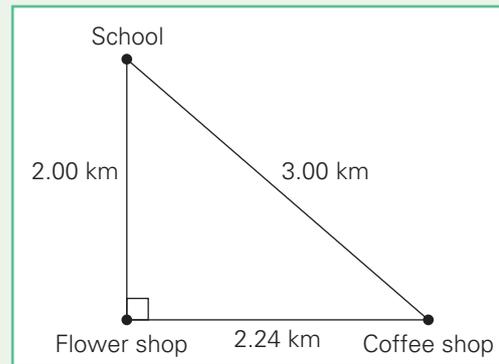
- What is the average speed of each plane?
- What is the average velocity of each plane?
- Which plane travels faster in the air?

Working	Explanation
<b>a</b> Average speed	
Plane 1: $\text{speed} = \frac{600}{2.00} = 300 \text{ km h}^{-1}$ Plane 2: $\text{speed} = \frac{(420 + 580)}{2.00} = \frac{1000}{2.00} = 500 \text{ km h}^{-1}$	For average speed, use this formula: $\text{speed} = \frac{d}{t}$
<b>b</b> Average velocity	
Plane 1: $v_{\text{av}} = \frac{600}{2.00} = 300 \text{ km h}^{-1} \text{ east}$ Plane 2: $v_{\text{av}} = \frac{600}{2.00} = 300 \text{ km h}^{-1} \text{ east}$	For average velocity, use this formula: $v_{\text{av}} = \frac{s}{t}$
<b>c</b> Comparing speeds	
Plane 2 is faster in the air.	The plane with the greater average speed travels faster as it covers more ground in the same amount of time.

## Quick check 9.3

Two students, Fatima and Aaron, leave school to meet at the local coffee shop. Aaron decides to jog to the coffee shop, but also stops at a flower shop along the way. Fatima decides to walk from school directly to the coffee shop. They arrive at the coffee shop at the same time, 30 minutes after they leave school. Use the diagram to answer the following questions.

- 1 Calculate how much further Aaron travels than Fatima.
- 2 If it takes them both half an hour to reach the coffee shop, calculate:
  - a Fatima's average speed in  $\text{km h}^{-1}$
  - b Aaron's average speed in  $\text{km h}^{-1}$
  - c their average velocities.



## Acceleration

**Acceleration** is defined as the rate at which an object changes its velocity. Acceleration can be thought about as 'speeding up/accelerating' or 'slowing down/decelerating'. Note that acceleration refers to a change in velocity over time, not speed, and therefore includes direction.

Consider a car at a set of traffic lights. Initially it is **stationary**; we would say that it has an initial velocity of  $0 \text{ km h}^{-1}$ . Imagine that when the light turns green the car speeds up to  $40 \text{ km h}^{-1}$  in the next 5 seconds. This change in velocity means that the car has an acceleration.

**acceleration**  
the rate of change of velocity of an object

**stationary**  
not moving

**deceleration**  
when an object is slowing down

**constant velocity**  
when an object is travelling at the same velocity and is not accelerating or decelerating

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 velocity over time; we call this **deceleration** (negative acceleration).

An object that does not change velocity is travelling with a **constant velocity**, meaning that the acceleration is zero.

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 velocity, as follows.

$$\begin{aligned} \text{Acceleration} &= \frac{\text{change in velocity}}{\text{time taken}} \\ &= \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}} \end{aligned}$$

or

$$a = \frac{\text{velocity}_2 - \text{velocity}_1}{t}$$

Using the acceleration triangle in Figure 9.14 is another helpful way to remember the formula for acceleration. The units for acceleration are  $\text{m s}^{-2}$ .

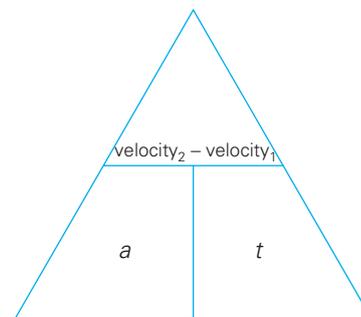


Figure 9.14 The acceleration triangle

Using this acceleration triangle, you can derive formulas for:

- acceleration,  $a = \frac{\text{velocity}_2 - \text{velocity}_1}{t}$
- time taken,  $t = \frac{\text{velocity}_2 - \text{velocity}_1}{a}$
- change in velocity,  $\text{velocity}_2 - \text{velocity}_1 = a \times t$

### Worked example 9.4

#### Acceleration

Consider the motion of a dirt bike.

- If it accelerates from rest to  $54 \text{ km h}^{-1}$  in a straight line in 3 seconds, calculate the acceleration.
- If that same bike travelling at  $54 \text{ km h}^{-1}$  comes to a stop in a straight line within 5 seconds, what is the acceleration? What does this mean?
- If better brakes were installed on the bike, it could decelerate at a quicker rate of  $10 \text{ m s}^{-2}$ . Calculate how long it would take to stop if it was initially travelling at a speed of  $72 \text{ km h}^{-1}$ .



Figure 9.15 A dirt bike in motion

Working	Explanation
<b>a</b> Acceleration	
$\text{velocity}_1 = 0 \text{ m s}^{-1}$ $\text{velocity}_2 = 54 \text{ km h}^{-1} = 15 \text{ m s}^{-1}$ $t = 3 \text{ s}$ $a = ?$	List the information that you have. Since the bike begins at rest, the initial velocity is zero.
$a = \frac{\text{velocity}_2 - \text{velocity}_1}{t} = \frac{(15 - 0)}{3} = 5 \text{ m s}^{-2}$	Calculate using the acceleration formula by substituting in all of the known values.
The bike accelerates at a rate of $5 \text{ m s}^{-2}$ (5 metres per second, every second)	Interpret the answer.
<b>b</b> Negative acceleration	
$\text{velocity}_1 = 54 \text{ km h}^{-1} = 15 \text{ m s}^{-1}$ $\text{velocity}_2 = 0 \text{ m s}^{-1}$ $t = 5 \text{ s}$ $a = ?$	List the information. In this example, the bike has an initial velocity of $54 \text{ km h}^{-1}$ , and a final velocity of $0 \text{ km h}^{-1}$ .
$a = \frac{\text{velocity}_2 - \text{velocity}_1}{t} = \frac{(0 - 15)}{5} = -3 \text{ m s}^{-2}$	Substitute the known values.
Since there is a negative acceleration, the bike is decelerating at a rate of $3 \text{ m s}^{-2}$ .	Interpret the solution and remember to include correct units.
<b>c</b> Faster stopping	
$a = -10 \text{ m s}^{-2}$ $\text{velocity}_1 = 0 \text{ m s}^{-1}$ $\text{velocity}_2 = 72 \text{ km h}^{-1} = 20 \text{ m s}^{-1}$ $t = ?$	List the known information.
$-10 = \frac{(0 - 20)}{t}$	Substitute the values into the acceleration formula.
$t = \frac{-20}{-10} = 2 \text{ s}$	Rearrange so that the unknown is the subject of the equation.
It takes the bike 2 seconds to decelerate from $72 \text{ km h}^{-1}$ to rest.	Interpret the solution.

## Try this 9.3

**Car acceleration**

Next time you are in a car and travelling in a straight line, use the stopwatch on your phone to time the change in velocity. Get the driver to read the speedometer to capture the instantaneous velocity along a straight road. 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 velocity	Final velocity	Time taken	Acceleration
Example:	$0 \text{ km h}^{-1} = 0 \text{ m s}^{-1}$	$10 \text{ km h}^{-1} = 2.8 \text{ m s}^{-1}$ (divide by 3.6 to convert)	5 s	$a = \frac{(2.8 - 0) \text{ m s}^{-1}}{5 \text{ s}} = 0.56 \text{ m s}^{-2}$
1				
2				
3				

## Quick check 9.4

- 1 Define the terms 'acceleration', 'deceleration' and 'constant velocity'.
- 2 An object increases its velocity from  $5.2 \text{ m s}^{-1}$  to  $7.7 \text{ m s}^{-1}$  in 4 seconds.
  - a Calculate the acceleration of the object.
  - b Assume that the object could decelerate at a rate of  $1.5 \text{ m s}^{-2}$  ( $a = -1.5 \text{ m s}^{-2}$ ). Calculate the time it would take for the object to stop if it was initially travelling at  $10 \text{ m s}^{-1}$  ( $v = 10 \text{ m s}^{-1}$ ). Give your answer to two decimal places.

## 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: Investigation

### Ramps and cars

#### Aim

To investigate the effect of ramp height on the average speed of a crash trolley or model car.

#### Materials

- ramp at least 90 cm long
- stopwatch
- metre ruler
- books or blocks that can be used to make a ramp
- crash trolley or model car

#### Planning

- 1 Develop a hypothesis by predicting how a change to the height of the ramp will affect the average speed of a model car.
- 2 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.

#### Method

##### Part 1: Prepare the results table

- 1 Draw the table shown in the results section into your science journal.
- 2 Identify and label the independent variables in the table.
- 3 Identify and label the dependent variable in the table.

##### Part 2: Collect the data

Set up the ramp as shown in Figure 9.16.

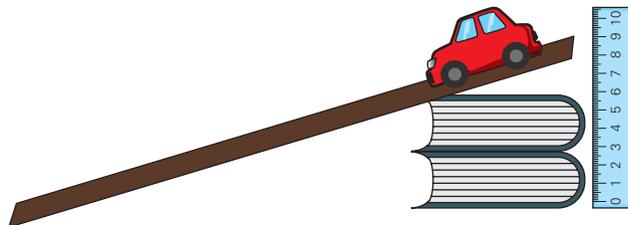


Figure 9.16 Experimental set-up

- 1 Measure the height of the ramp.
- 2 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.
- 3 Repeat steps 1 and 2 three times so you can mean the results.
- 4 Repeat steps 1–3 using some different heights and record your results in the table.

#### Results

- 1 Calculate the average time taken for the car to roll down the ramp.
- 2 Draw a scatterplot to analyse the relationship between the height and the speed.

*continued...*

...continued

- 3 Format the graph and insert a copy below the results table into your science journal.

Independent variable	Dependent variable			
	Trial 1	Trial 2	Trial 3	Mean

### Discussion

- 1 Describe the effect of different ramp heights on the mean speed of a model car.
- 2 Describe any limitations to your investigation and how these may have affected your results.
- 3 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

### Conclusion

- 1 State a conclusion as how increasing the height can affect speed.
- 2 Justify this conclusion using data from your results.

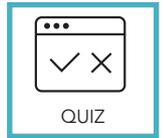
Figure 9.17 How would the incline and height of a half pipe affect the speed of a skateboarder?



## Section 9.1 questions

### Remembering

- 1 **Recall** the unit usually used for distance.
- 2 **Recall** the unit usually used for speed.
- 3 **Recall** the formula and unit for average acceleration in a straight line.



### Understanding

- 4 The average speed of a galloping horse is  $40 \text{ km h}^{-1}$ . If a horse is already travelling at that speed, **calculate** how much distance it will cover in 2.3 hours.
- 5 If a person walks at an average speed of  $4 \text{ km h}^{-1}$ , **calculate** how long it will take them to travel a distance of 50 m. Round your answer to the nearest second. Hint: First convert  $4 \text{ km h}^{-1}$  into  $\text{m s}^{-1}$ .
- 6 **Determine** the acceleration of a car travelling at a constant velocity of  $50 \text{ km h}^{-1}$ .

### Applying

- 7 A sprinter starts from rest. In the first 3 seconds they reach a velocity of  $2 \text{ m s}^{-1}$ . After the next 10 seconds they reach a speed of  $6.5 \text{ m s}^{-1}$ .
  - a **Calculate** the average acceleration in the first 3 seconds, and round to two decimal places.
  - b **Calculate** the average acceleration in the last 10 seconds.
  - c **Identify** when the sprinter's acceleration is the greatest, either the first 3 seconds or that last 10 seconds.
- 8 A car starts from rest and accelerates at a constant rate of  $5 \text{ m s}^{-2}$  for 3 seconds.
  - a **Calculate** the final velocity.
  - b **Calculate** the average velocity. Because the velocity increases at a constant rate, you can do this by using  $\frac{\text{velocity}_1 + \text{velocity}_2}{2}$  to find the average velocity.
  - c **Calculate** the displacement of the car after 5 seconds.
- 9 **Describe** displacement.

### Analysing

- 10 **Distinguish** between speed and velocity.
- 11 **Contrast** average speed and instantaneous speed.
- 12 **Categorise** the following motion as acceleration, deceleration or constant.
  - a A bike rider slowing down
  - b A textbook sitting on a desk
  - c A sprinter taking off at the start of a race
  - d A dog running at  $5 \text{ m s}^{-1}$  forwards
  - e A car crashing into a brick wall
  - f A car rolling down a hill and gaining speed

### Evaluating

- 13 Imagine you are trying to figure out how efficiently your car uses petrol. **Discuss** if you would use distance travelled or displacement covered with one tank full.

## 9.2 Graphing motion



**gradient**  
the rise over the run

### Learning goals

- 1 To interpret distance vs time and displacement vs time graphs.
- 2 To be able to calculate the velocity from a displacement vs time graph.
- 3 To be able to calculate acceleration and displacement from a velocity vs time graph.

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 distance, displacement, speed, velocity and acceleration.

### 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:

$$\text{speed} = \frac{d}{t} = \frac{\text{rise}}{\text{run}}$$

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 <sup>-1</sup> .
	A straight line with a non-zero gradient indicates that the object is moving at a constant speed.	$\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{2 \text{ m}}{2 \text{ s}} = 1 \text{ m s}^{-1}$ $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{1 \text{ m}}{2 \text{ s}} = 0.5 \text{ m s}^{-1}$ <p>The gradient of the first graph is steeper, which shows that object has a greater speed.</p>

Table 9.1 Two shapes of distance–time graphs

**Worked example 9.5**

**Distance–time graph**

Look at the distance–time graph in Figure 9.18, which shows Lin’s walk in a straight line for 6 seconds.

- a Calculate her speed at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.
- b When is Lin travelling the fastest?

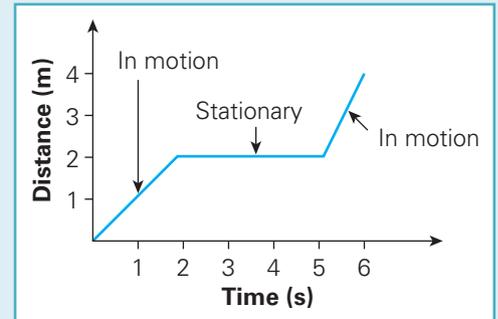


Figure 9.18 Distance–time graph of Lin’s walk

Working	Explanation
<p><b>a Speed</b></p> <p>0 to 2 seconds:  <math display="block">\text{speed} = \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}^{-1}</math></p> <p>2 to 5 seconds:                      A horizontal line indicates she is stationary.</p> <p>5 to 6 seconds:  <math display="block">\text{speed} = \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}^{-1}</math></p>	
<p><b>b Fastest interval</b></p> <p>She travels the fastest from the 5th to the 6th second. The steeper line indicates a faster speed.</p>	

**Quick check 9.5**

- 1 Look at the distance–time graph of a moving object in Figure 9.19.
  - a Calculate the average speed for each of the sections A, B and C.
  - b Describe the motion of the object in the graph.

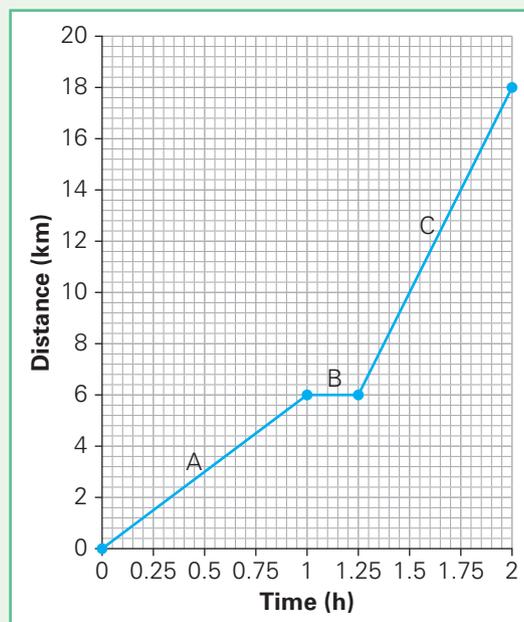


Figure 9.19 Distance–time graph of a moving object

## 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**. The gradient of a displacement–time graph gives the velocity for specific time periods.

### 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. Figure 9.20 shows her displacement–time graph for the same motion.

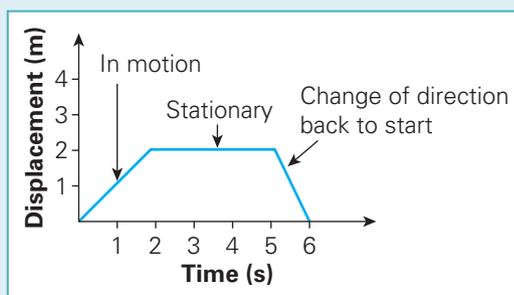


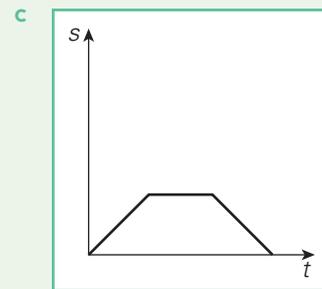
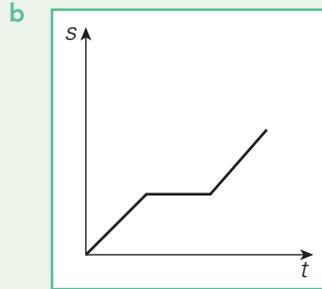
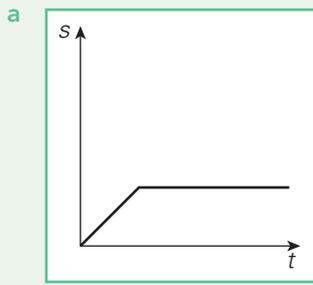
Figure 9.20 Displacement–time graph of Lin's walk

- Describe her movements in relation to her starting point.
- Calculate her velocity at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

Working	Explanation
<b>a</b> Describing movements	
For the first two seconds, Lin moves away from her starting position by 2 metres. For the next three seconds, she is stationary. In the final second, she increases her velocity moving back to the origin (her starting position).	The displacement 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.
<b>b</b> Velocity	
0 to 2 seconds: $v = \frac{\text{rise}}{\text{run}} = \frac{(2 - 0) \text{ m}}{(2 - 0) \text{ s}} = \frac{2 \text{ m}}{2 \text{ s}} = 1 \text{ m s}^{-1}$	Select two points from each interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the velocity.
2 to 5 seconds: A horizontal line indicates she is stationary, in other words, $v = 0 \text{ m s}^{-1}$ .	A negative velocity means that she has changed directions and is travelling in the opposite direction, in this case, back to the start.
5 to 6 seconds: $v = \frac{\text{rise}}{\text{run}} = \frac{(2 - 4) \text{ m}}{(6 - 5) \text{ s}} = \frac{-2 \text{ m}}{1 \text{ s}} = -2 \text{ m s}^{-1}$	She is travelling faster towards her original position (5 to 6 seconds) than when she was travelling away from it (0 to 2 seconds).

## Quick check 9.6

1 For each of the following displacement–time graphs, describe the motion of the object.



## 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 9.21.

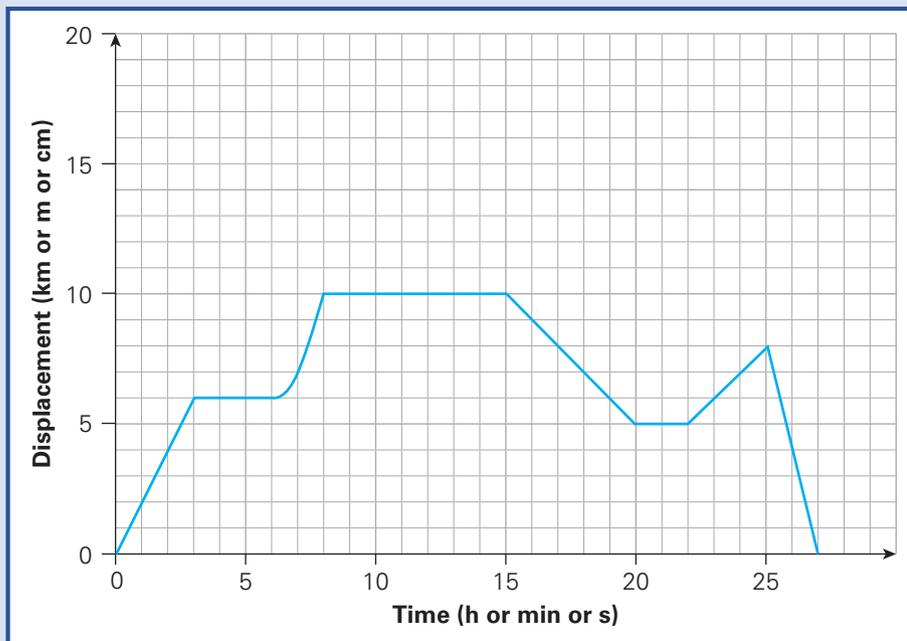


Figure 9.21 Displacement–time graph

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 velocity, stationary, acceleration, at rest.

Challenge: If you have finished your story, calculate the velocity at certain points along the path.

## Velocity–time graphs

Velocity–time graphs show the velocity of a travelling object as time passes. They are quite useful because they can be used to determine the displacement, the instantaneous velocity and the acceleration of a moving object. Velocity–time graphs have three important features.

- Instantaneous velocity can be read directly from the graph at any particular point in time.
- The gradient between two points on a velocity–time graph represents the average acceleration over that time interval of the object in motion.
- The area under a velocity–time graph represents the displacement of an object.

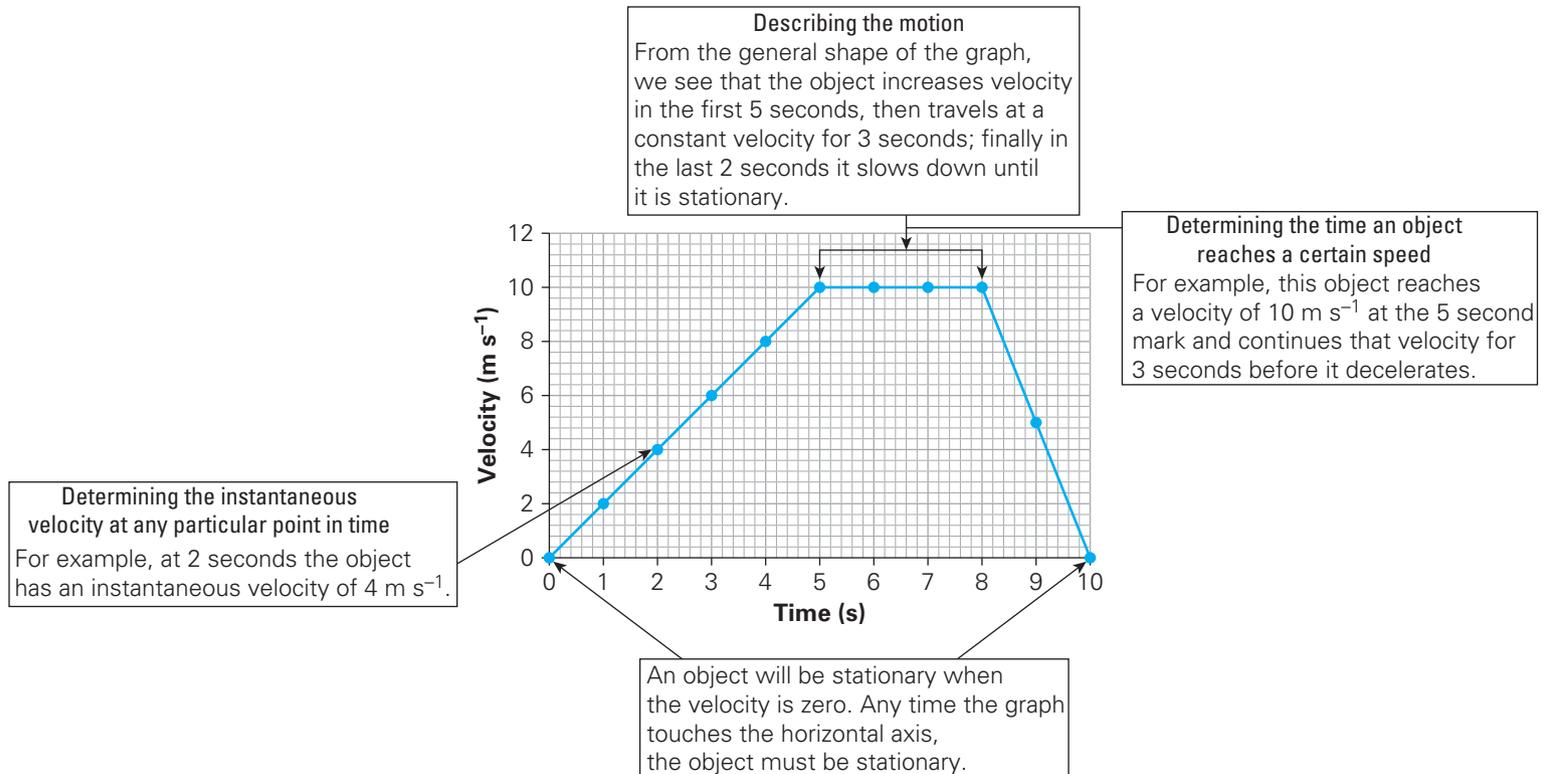


Figure 9.22 A velocity–time graph tells you a lot about an object's motion.

### Reading instantaneous velocity

Imagine that a detector is used to capture the instantaneous velocity of an object moving in a straight line away from the detector. It records at every second for a period of 10 seconds. The following table is created and then the data can be represented on a velocity–time graph.

Velocity ( $\text{m s}^{-1}$ )	0	2	4	6	8	10	10	10	10	5	0
Time (s)	0	1	2	3	4	5	6	7	8	9	10

### Finding acceleration from the gradient

Velocity–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 velocity.

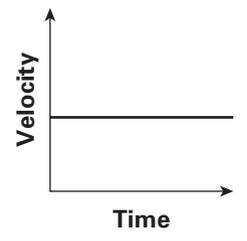
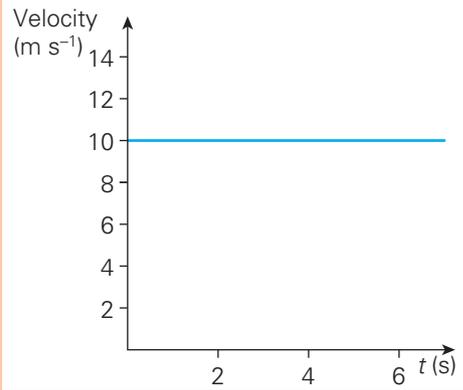
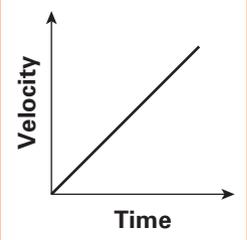
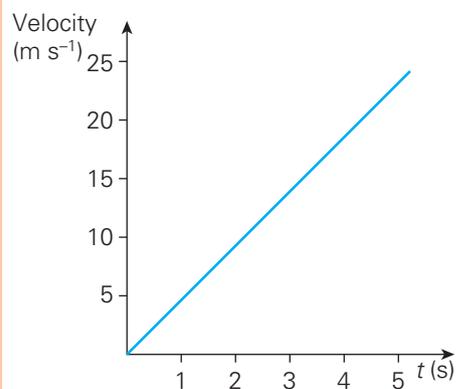
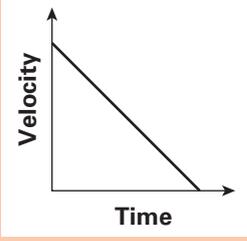
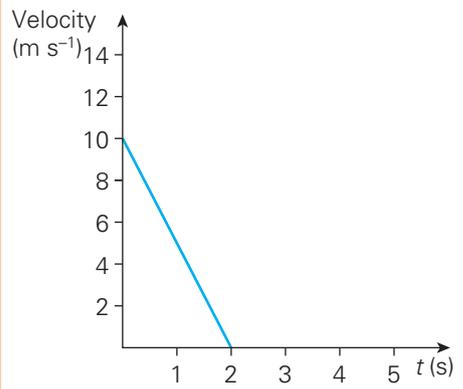
Shape	Explanation	Example
	<p>A horizontal graph indicates that an object is travelling at a constant velocity. For this journey acceleration is zero as the gradient of the line is zero.</p>	 $a = \frac{\text{rise}}{\text{run}} = \frac{0 \text{ m s}^{-1}}{10 \text{ s}} = 0 \text{ m s}^{-2}$
	<p>A positive gradient means positive acceleration (speeding up). The steeper the gradient, the more the object accelerates. The acceleration can be calculated from the gradient here to be <math>5 \text{ m s}^{-2}</math>.</p>	 $a = \frac{\text{rise}}{\text{run}} = \frac{25 \text{ m s}^{-1}}{5 \text{ s}} = 5 \text{ m s}^{-2}$
	<p>A negative gradient means negative acceleration (deceleration). The steeper the gradient, the quicker the object decelerates. The acceleration can be calculated from the gradient here as <math>-5 \text{ m s}^{-2}</math>.</p>	 $a = \frac{\text{rise}}{\text{run}} = \frac{-10 \text{ m s}^{-1}}{2 \text{ s}} = -5 \text{ m s}^{-2}$

Table 9.2 Three types of velocity–time graphs

## Calculating displacement

In some problems, you may be given the velocity–time graph and asked to work out the displacement. The displacement of an object can be calculated by calculating the area under the graph. Often it might be simpler to split the graph into smaller sections.

### Worked example 9.7

#### Calculating the distance

Consider the graph shown in Figure 9.23 of an object in motion.

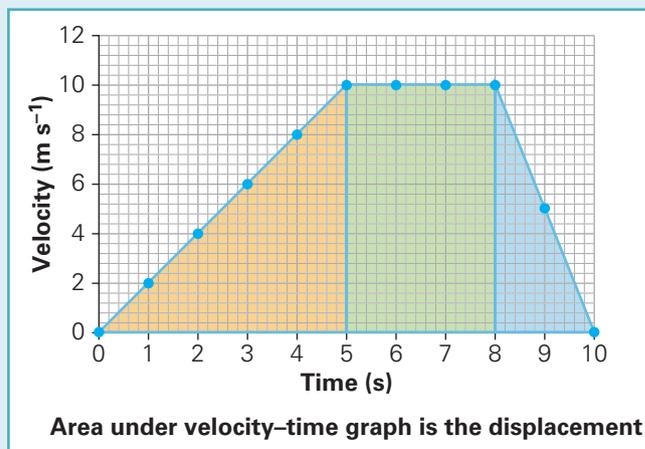
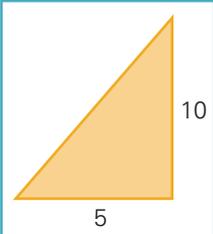
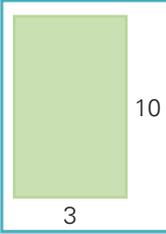


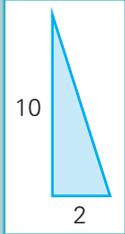
Figure 9.23 Velocity–time graph

- Calculate the displacement in the first 5 seconds.
- Calculate the displacement from  $t = 5$  to  $t = 8$ .
- Calculate the displacement in the final 2 seconds.
- What is the total displacement by the object, over the entire 10 seconds?

Working	Explanation
<p><b>a</b> Displacement in first 5 seconds</p> <p>The area in the first 5 seconds can be described by the following triangle.</p> $A_1 = \frac{1}{2}(5)(10) = 25$ <p>This means that in the first 5 seconds the object travels 25 metres.</p>	 <p>Redraw the shape and label the known sides. Calculate the area of the triangle by substituting values into the formula <math>A_1 = \frac{1}{2}bh</math>. Interpret the area, and check that units are correct.</p>
<p><b>b</b> Displacement from <math>t = 5</math> to <math>t = 8</math></p> <p>The area under the graph between <math>t = 5</math> and <math>t = 8</math> can be described by the following rectangle.</p> $A_2 = 3 \times 10 = 30$ <p>This means that the distance travelled over this period is 30 metres.</p>	 <p>Redraw the shape and label the known sides. Calculate the area of the rectangle by substituting values into the formula <math>A_2 = l \times w</math>. Interpret the solution with correct units.</p>

continued...

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Working	Explanation
<p><b>c</b> Displacement in final 2 seconds</p>	
<p>The area under the graphs in the final 2 seconds is represented by the following triangle.</p>  $A_3 = \frac{1}{2}(2)(10) = 10$ <p>In the final 2 seconds the object travels 10 metres.</p>	<p>Redraw and label the shape. Calculate the area. Interpret solution with correct units.</p>
<p><b>d</b> Total distance covered</p>	
<p>Sum each of the areas for the total distance covered.</p> $\begin{aligned} A_T &= A_1 + A_2 + A_3 \\ &= 25 + 30 + 10 \\ &= 65 \end{aligned}$ <p>Therefore, the total distance covered by the object over the 10 seconds is 65 metres.</p>	<p>Add up all of the area sections under the graph to get the total distance travelled.</p>

### Quick check 9.7

Consider the velocity–time graph shown in Figure 9.23.

- Describe the motion of the object shown in the graph.
- Calculate the acceleration over the first 2 seconds.
- Determine the acceleration between  $t = 2$  and  $t = 4$ .
- Calculate the displacement after the first 2 seconds.
- Determine how far the object travels in 4 seconds.

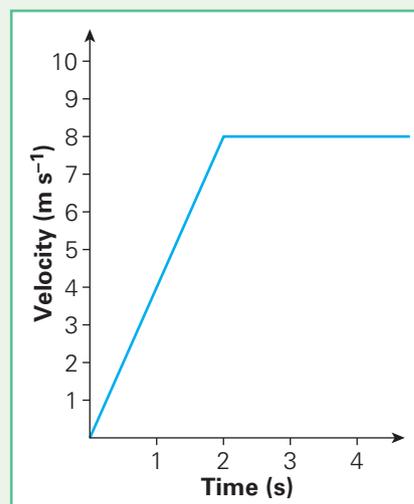


Figure 9.24 A velocity–time graph

## Try this 9.5

## Investigating the motion of students over 100 m

## Instructions

- 1 Copy the results tables below.
- 2 Choose at most five classmates to sprint 100 m.
- 3 Line up the remainder of your classmates at 20 m intervals along the 100 m track. Start the first sprinter.
- 4 Use stopwatches to capture the time from when a sprinter begins, to when they pass each 20 m interval. Ideally, there will be at least two classmates at each interval so that an average of the times can be calculated. Record these results in a table.

## Results

- 1 Calculate the difference in elapsed time for each 20 m interval.

Results of sprint times at each 20 m interval					
Student name	20 m	40 m	60 m	80 m	100 m

- 2 Calculate the average speed for each interval and complete the table of average velocity versus time.

Results of velocity ( $\text{m s}^{-1}$ ) vs time					
Student name	20 m	40 m	60 m	80 m	100 m

- 3 Plot the displacement–time and average velocity–time graphs by drawing smooth trend lines.

## Analysis

- 1 Are the shapes of the graphs generally similar?
- 2 Describe what is happening at each 20 m interval in terms of velocity.
- 3 Propose why it was important to gather data from various classmates instead of just from one.
- 4 Identify some potential sources of error (uncertainties or experimental method faults).
- 5 Imagine if your classmates walked, hopped or crawled. Predict what the graphs would look like.

## 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.

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 9.25** Wearable and mobile technology can help people correct their posture even when they are not at gait rehabilitation centres.

## Section 9.2 questions

## Remembering

- 1 **Recall** what the gradient of a displacement–time graph indicates.
- 2 **Recall** what the gradient of a velocity–time graph indicates.
- 3 **Recall** what the area under a velocity–time graph indicates.

## Understanding

- 4 Consider the velocity–time graph in Figure 9.26.
  - a **Describe** the motion of the object.
  - b **Calculate** the acceleration in the first 3 seconds.
  - c **Calculate** the acceleration for the next 2 seconds.
  - d **Calculate** the displacement of the object after 5 seconds.

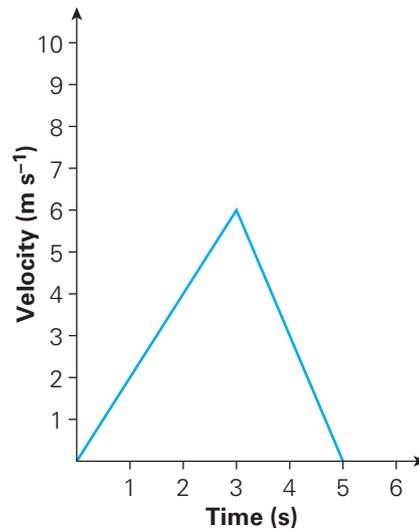


Figure 9.26 Velocity–time graph



## Applying

- 5 **Describe** what the shape of a displacement–time graph can reveal about an object's movements.
- 6 **Describe** what the shape of a velocity–time graph can reveal about an object's movements.
- 7 **Consider** reaction times. What things can affect reaction time?

## Analysing

- 8 The path of a caveman as he makes the trek to a nearby river then back to his cave is shown on the displacement–time graph in Figure 9.27.

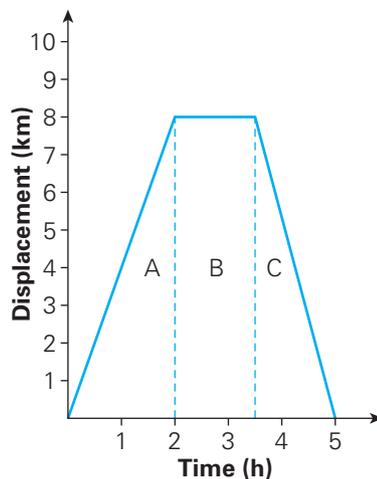


Figure 9.27 Displacement–time graph of a caveman's trek

- a **Determine** how far the river is from the cave.
- b **Determine** the velocity of the caveman as he walks from his cave to the river (section A).
- c **Determine** how long the caveman waits at the river (section B).
- d **Determine** how quickly the caveman returns back to his cave once he leaves the river (section C).

## Evaluating

- 9 Hundreds of thousands of animals in Australia are killed every year by vehicles. Consider the velocity–time graph in Figure 9.28.
- a If a driver travelling at  $90 \text{ km h}^{-1}$  ( $25 \text{ m s}^{-1}$ ) takes 0.5 seconds to react after spotting the animal, and they come to a stop according to the following velocity–time graph, **determine** the total stopping displacement from when they spot the animal to when the car stops.

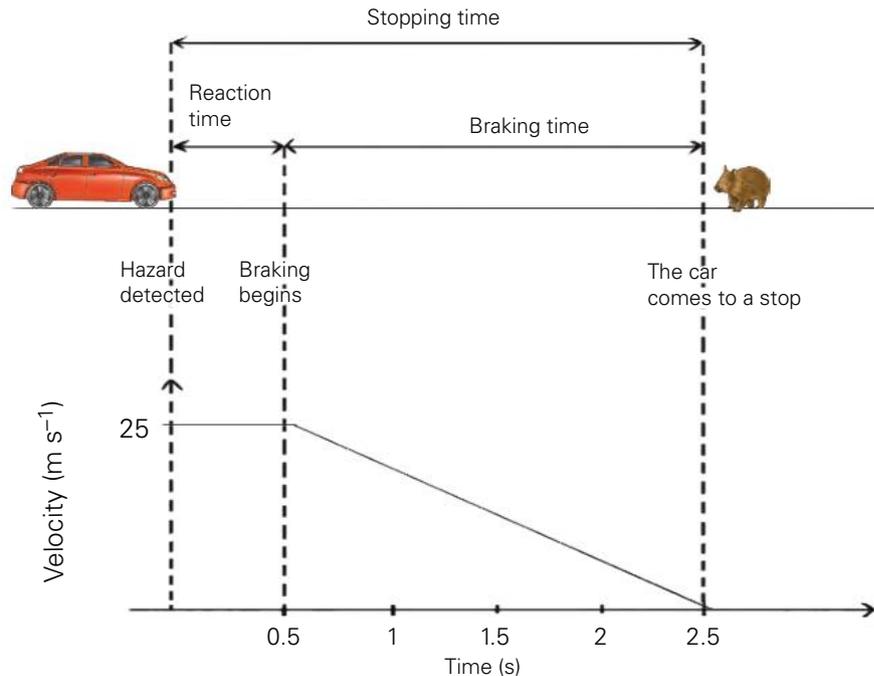


Figure 9.28 Velocity–time graph

- b If the reaction time was increased by 0.5 seconds (that is, the reaction time was 1 second), **decide** what the stopping distance would be.
- 10 a Use the following table to **construct** a displacement–time graph of an object.

Time (s)	Displacement (m)
0	0
2	2
5	3
7	3
9	4
10	5

- b Using the graph, **decide** what conclusions can be made about its movements, including whether we can tell the direction it went.

## 9.3 Forces and Newton's laws of motion

### Learning goals

- 1 To be able to recall Newton's first law of motion and define inertia.
- 2 To be able to use the equation  $F = ma$ , Newton's second law of motion.
- 3 To be able to recall Newton's third law of motion.



### 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 external 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 a change in the motion of the object. At any given time, multiple forces may act on any single object. These forces determine if the object will accelerate, continue to travel at a constant speed or remain at rest. Force has both

magnitude and direction; it can be represented using the symbol  $F$ , and is generally measured in newtons (N).

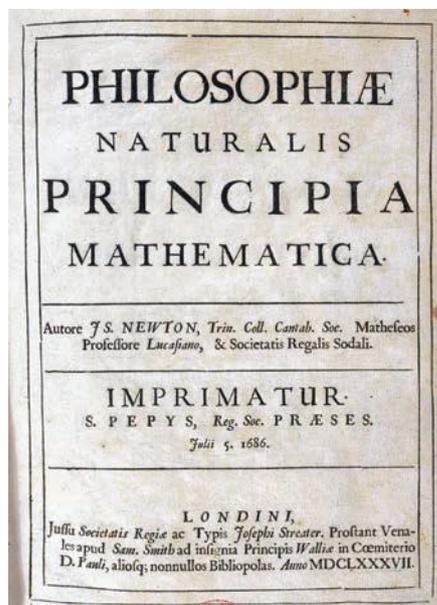
If the forces acting on an object are balanced, meaning equal in magnitude (size) and in opposite directions, then the object will not change its motion. That is, if the object is at rest, it will stay at rest, and if an object is travelling at a constant speed, it will continue at a constant speed in 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 ( $F_{\text{net}} = 0$ ), 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 ( $F_{\text{net}} \neq 0$ ), 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 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



**Figure 9.29** Newton's *Philosophiæ Naturalis Principia Mathematica* was published in 1687. It revolutionised the scientific thinking of the time by formulating the laws of motion.

$F_{\text{net}} = 0$	$F_{\text{net}} \neq 0$
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 a 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 when travelling by car, train, aeroplane or 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 9.30** 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.



### Try this 9.6

#### Inertia on bus rides

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 the bus:

- 1 is stationary
- 2 is travelling at a constant speed
- 3 is travelling at a constant speed, then suddenly stops
- 4 takes a sharp right or left hand turn
- 5 accelerates after a set of lights turns green.



**Figure 9.31** You can feel the effect of inertia when you travel on a bus.

### Newton's second law of motion

Newton's second law of motion is a 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  $\times$  acceleration

$$F_{\text{net}} = ma$$

From this equation, the following four 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.
- If there is an acceleration, then there is a net force.

Imagine hitting a baseball with a bat as in Figure 9.32. When a net force is applied to the ball it will accelerate. Consider what would happen if we were to swap the baseball with a larger baseball with twice the mass. Newton's second law tells us that if the same force were applied to a larger baseball with twice the mass, it would not accelerate as much as the smaller baseball because of the difference in mass. Lastly, if we were to apply a greater force on the baseball, it would increase the acceleration.



**Newton's second law of motion**  
an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force, and inversely proportional to the mass of the object

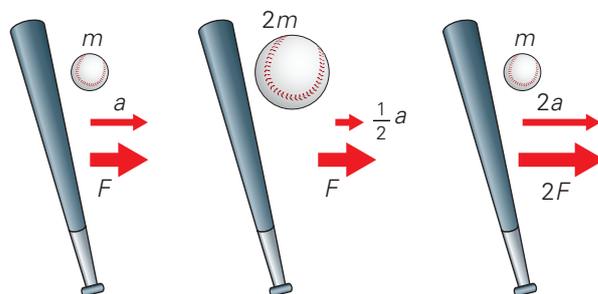


Figure 9.32 A baseball hit by a bat follows Newton's second law of motion

Using the force triangle (Figure 9.33), we have:

$$F_{\text{net}} = ma, \quad a = \frac{F_{\text{net}}}{m}, \quad m = \frac{F_{\text{net}}}{a}$$

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.

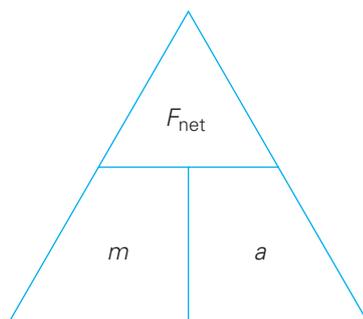


Figure 9.33 The force triangle

## 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.

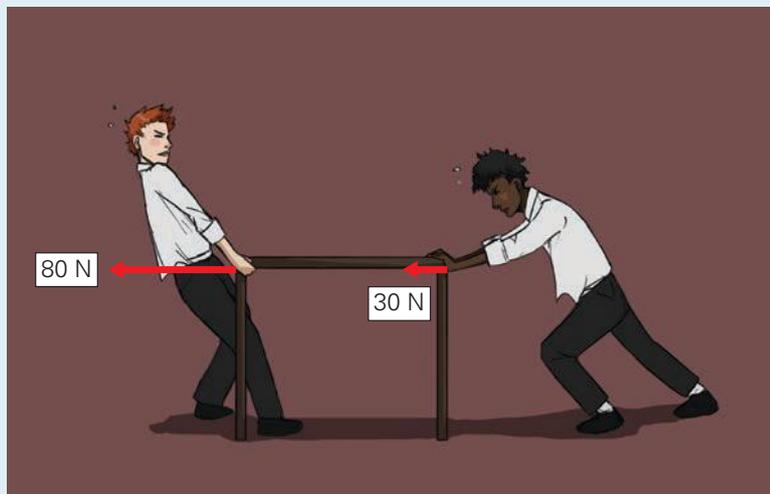


Figure 9.34 Two students trying to move a table.

- a What is the net force and direction of the table?  
 b What is the acceleration of the table?

Working	Explanation
<p>a Net force</p> $F_{\text{net}} = 30 + 80 = 110 \text{ N to the left}$ <p>There is effectively 110 N of force acting on the table towards the left direction.</p>	<p>Calculate the net force by 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.</p>
<p>b Acceleration</p> $a = \frac{F_{\text{net}}}{m}$ $a = \frac{110 \text{ N}}{13 \text{ kg}} = 8.46 \text{ m s}^{-2} \text{ to the left}$	<p>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 <math>60 \text{ N}/13 \text{ kg} = 4.62 \text{ m s}^{-2}</math> to the left.)</p>

### 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, just as 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** is a fundamental property of an object. Mass is measured in kilograms. However, **weight** is a force that 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  $9.8 \text{ m s}^{-2}$ , so a person with a mass of 70 kg will have a weight of  $70 \times 9.8 = 686 \text{ N}$ .

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  $\text{m s}^{-2}$ .

Remember the mass of an object is the same regardless of the strength of the gravitational field.

**mass**

the quantity of matter in a body regardless of its volume or of any forces acting on it

**weight**

the force of gravity on the object and is defined as the mass times the acceleration of gravity

Earth	the Moon	Mars	Jupiter
			
$g = 9.8 \text{ m s}^{-2}$	$g = 1.6 \text{ m s}^{-2}$	$g = 3.7 \text{ m s}^{-2}$	$g = 24.8 \text{ m s}^{-2}$

**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 the philosopher's stone; a substance that 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 9.35** Alchemists sought the philosopher's stone.

### Quick check 9.8

- 1 Calculate the force that is required to accelerate an object of mass 6 kg at  $2.3 \text{ m s}^{-2}$ .
- 2 Calculate the mass of an object that accelerates at  $0.2 \text{ m s}^{-2}$  when it is pushed with a force of 20 N. Give your answer to two decimal places.
- 3 If a car of mass 1000 kg is travelling at a constant velocity, calculate the deceleration when the brakes are applied with a force of 1500 N.

## Practical 9.2: Investigation

### Acceleration due to gravity

#### Aim

To accurately calculate acceleration due to gravity.

#### Useful equation

Acceleration due to gravity (vertical acceleration) =  $\frac{\text{distance travelled during vertical descent (m)}}{\text{time}^2 \text{ (s}^2\text{)}}$

#### Materials

- a number of objects to drop (e.g. marble, steel ball bearing, tennis ball)
- 3 m long measuring tape
- smartphone with high-speed slow-motion capabilities

#### Method

Use the formula given as a guide to design a method of accurately calculating acceleration due to gravity. For example, fix the 3 m long measuring tape to a wall, drop different objects a number of times, try a few different dropping heights, undertake analysis of the high-speed videos.

#### Results

- 1 Create a table for your results.
- 2 Record all the collected data.
- 3 Process the data to produce an estimate of the magnitude of the acceleration due to gravity.

#### Discussion

- 1 Discuss if the different objects accelerate at the same rate. Why or why not?
- 2 State how many trials there were of the same object and why this number of trials was selected.
- 3 Determine if air resistance affected your results. Explain your reasoning.
- 4 Explain why you did not measure the mass of the various objects that you were dropping.
- 5 Compare your results with the accepted value of the magnitude of the acceleration due to gravity.

## 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. Crash-test 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 crash-test 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 9.36 A car crash simulation

## Practical 9.3: Investigation

### Force and mass

#### Aim

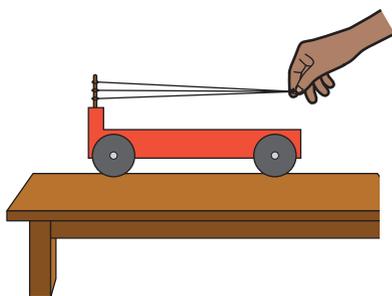
To investigate the effects of force and mass on acceleration.

#### 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.

#### Discussion

- 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

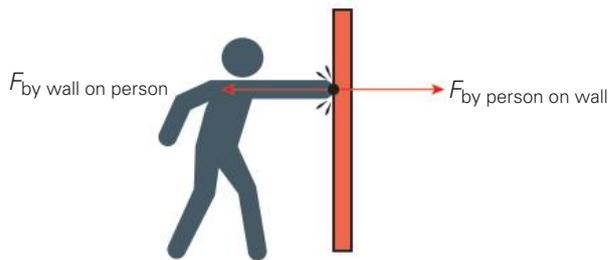
- 1 Make a claim about force, mass and acceleration based on this experiment.
- 2 Support the statement by using the data you gathered and include potential sources of error (experimental uncertainty or experimental faults).
- 3 Explain how the data supports the statement.

### 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 (Figure 9.37)! Newton's third law states:

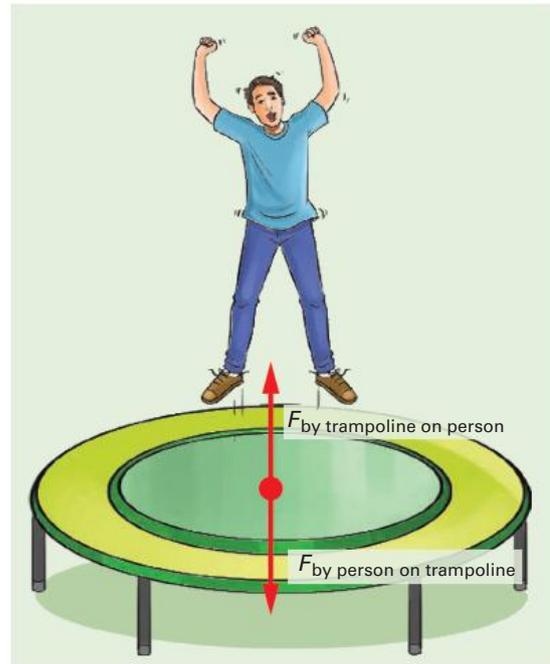
**Newton's third law of motion**  
for every action, there is an  
equal and opposite reaction

For every action, there is an equal and opposite reaction.



**Figure 9.37** The action of pushing against a wall has a reaction force that pushes back on the person with the same magnitude.

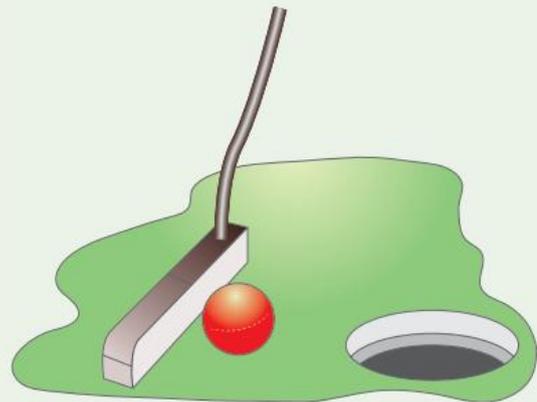
There are many examples of action–reaction pairs. Action–reaction pairs always act on different objects. For example, if the action force is the force the person's feet exert on the ground (a contact force), then the reaction force is the contact force that the ground pushes up on the person's feet (or 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!



**Figure 9.38** 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.

### Quick check 9.9

Copy the diagram in Figure 9.39 and label with the action force and the reaction force. Alternatively, describe where the action and reaction forces should be.



**Figure 9.39** Forces involved putting a golf ball

**Try this 9.7**

**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?

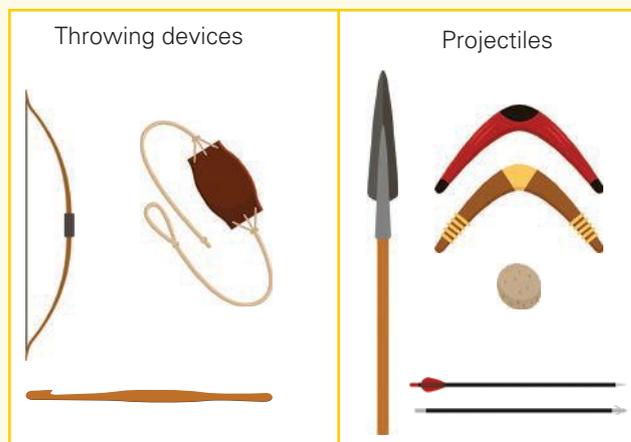
Action	Reaction
You are sitting on a chair.	
	The ground pushes against your foot in the direction you are walking.
You throw a ball against the wall.	

**Table 9.5** Action and reaction forces

**Explore! 9.3**

**Projectiles and throwing devices**

Aboriginal and Torres Strait Islander peoples have used spears, spear throwers and bows and arrows for millennia prior to European settlement. They recognised patterns in the data and had an understanding of the relationship between the mass of the projectile (spear/arrow), the force that the throwing device (spear thrower/bow) applied to it, and the effect on its velocity, range and impact force. Use your preferred search engine to investigate how Aboriginal and Torres Strait Islander peoples achieved an increase in velocity and subsequent impact force by using spear throwers and bows.



**Figure 9.40** What is the throwing device of the boomerang? *The human arm*

**Practical 9.4: Design**

**Crash-test eggs**

**Aim**

To design and build a car with safety features that will protect an egg from breaking during a collision.

**Materials**

As chosen by students but may include:

- rubber bands
- wheels
- icy-pole craft sticks
- dowels
- plastic cups
- straws
- rubber bands
- string
- springs
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- plastic bottles
- flat cardboard
- sticky tape

**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.

*continued...*

...continued

### Results

Take a high speed video of your collision and slow it down to see the forces in effect.

### Discussion

- 1 Compare your safety device to a safety feature in a car.
- 2 Draw the forces acting on the egg during the collision.
- 3 What difficulties or errors did you encounter during this experiment? How could you improve the experiment to avoid these in the future?

### Conclusion

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

## Section 9.3 questions



### Remembering

- 1 a If there is zero net force applied to an object that is travelling at a constant speed in a straight line, **recall** what happens to the object.  
b **Identify** the Newton's law that applies to the situation in Question 1a.

### Understanding

- 2 **Calculate** the mass of an object that accelerates at  $0.63 \text{ m s}^{-2}$  when it is pushed with a force of 20 N. Give your answer to two decimal places.
- 3 If a car of mass 1500 kg is travelling at a constant velocity, **calculate** the deceleration when the brakes are applied with a force of 1200 N.

### Applying

- 4 **Describe** what is meant by the term 'inertia'.
- 5 **Describe** the term 'net force'.
- 6 **Describe** the term 'weight'.

### Analysing

- 7 **Contrast** the quantities of weight and mass.

### Evaluating

- 8 A 50 kg person sits on a chair with their feet dangling above the ground. **Construct** a diagram to represent the action–reaction pair of forces acting on the scenario and include labels to indicate the force quantities. (Remember that acceleration due to gravity is  $g = 9.8 \text{ m s}^{-2}$ .)
- 9 Two students are trying to push a mass towards each other, shown in Figure 9.41. Student 1 on the left exerts a force of 155 N on the mass and Student 2 exerts a force of 220 N. Ignore frictional forces.
  - a **Determine** the net force acting on the mass.
  - b **Deduce** the direction in which the mass will move.
  - c Using Newton's second law, if the mass is 216 kg, **determine** the acceleration of the mass.
- 10 **Elaborate** on whether there are action–reaction pairs in the system from the previous question. Can you quantify the forces?

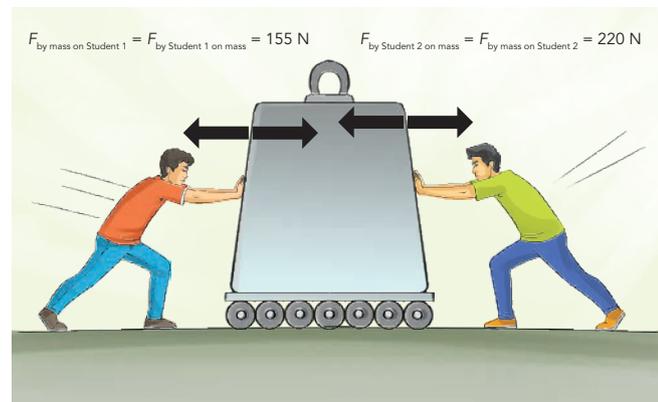


Figure 9.41 Forces acting on a mass

# Chapter review

## Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked questions	Check
9.1 I can distinguish between distance and displacement.	1	
9.1 I can calculate the speed of an object.	5	
9.1 I can convert between units of $\text{m s}^{-1}$ and $\text{km h}^{-1}$ .	8a	
9.1 I can distinguish between instantaneous and average speed.	4	
9.1 I can distinguish between speed and velocity.	2	
9.1 I can calculate the acceleration of an object.	8b	
9.2 I can use velocity–time, distance–time and displacement–time graphs to communicate an object’s motion.	7, 8c	
9.3 I can explain Newton’s three laws of motion.	3	

## Review questions

### Remembering

- 1 **Distinguish** between distance and displacement.
- 2 **Recall** what the gradient of a displacement–time graph indicates.
- 3 **Describe** Newton’s three laws of motion.

### Understanding

- 4 Provide 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 sprints.

Distance (m)	0	20	40	60	80	100
Time (s)	0	2.87	4.65	6.32	7.96	9.69

- a **Calculate** the average speed of Usain Bolt for the entire 100 m; that is, from  $t = 0$  to  $t = 9.69$ .
- b **Determine** whether he travels quicker in the first 40 m or the last 40 m.

### Analysing

- 6 **List** all the action–reaction pairs in Figure 9.42.



Figure 9.42 Action–reaction pairs



- 7 Consider the path of a bungee jumper. For simplicity, assume that the path of motion is straight up and down.

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.

The first 10 seconds of the jump are recorded on the two graphs in Figure 9.44 and 9.45, where the origin represents the position of the jumper just before they leap from the platform.

Use Figures 9.44 and 9.45 to answer the following questions.



Figure 9.43 A bungee jumper

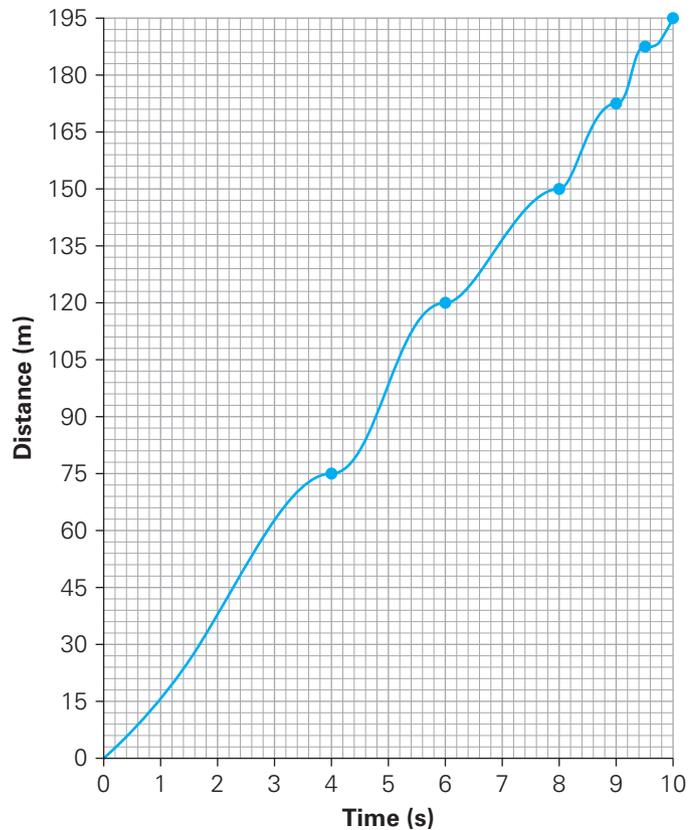


Figure 9.44 A distance–time graph for a bungee jumper

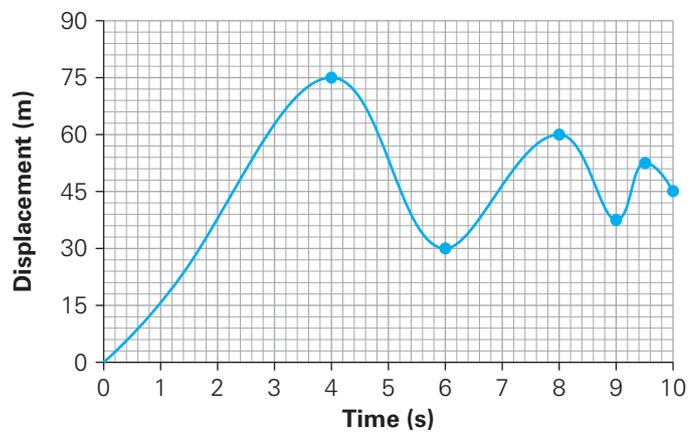
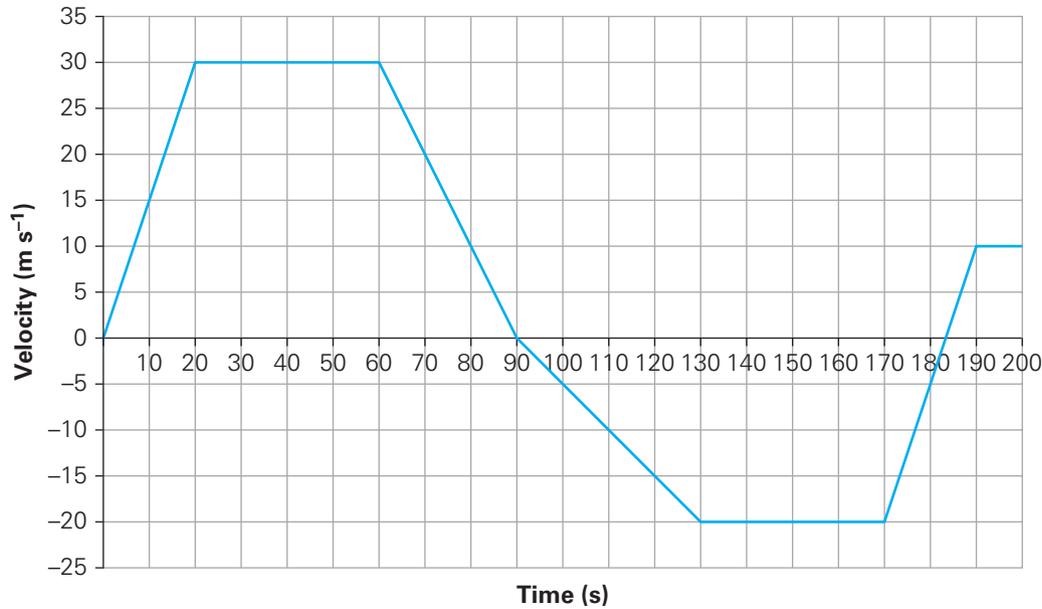


Figure 9.45 A displacement–time graph for a bungee jumper

- Determine** the distance that the jumper travels in the first 4 seconds.
- Determine** the displacement of the jumper after 4 seconds.
- Determine** the distance covered by the jumper in the first 10 seconds.
- Determine** how far is the jumper from the platform after 10 seconds (i.e. the displacement).
- Calculate** the average speed in the first 4 seconds.
- Determine** the speed at the 6-second mark.

**Evaluating**

- 8 A car starts from rest and accelerates at a constant rate in a straight line for 5 seconds to a final velocity of  $54 \text{ km h}^{-1}$ .
- Calculate** the final velocity in  $\text{m s}^{-1}$ .
  - Calculate** the constant acceleration, in  $\text{m s}^{-2}$ , over the 5 seconds.
  - Construct** the velocity–time graph for this scenario and use it to calculate the distance the car had moved using the area under the graph.

**Data questions**

**Figure 9.46** Velocity–time graph of unknown object

- Using the velocity–time graph in Figure 9.46, **identify** the velocity of the object at the 10, 40, 90 and 140 s marks.
- Calculate** the acceleration of the object at the 10, 40, 80 and 110 s marks.
- Calculate** the displacement of the object after 170 s.
- Interpret** the velocity–time graph to describe the motion of the object in words.
- Deduce** a potential identity of the object.
- Deduce** why it is unlikely to be a standard car.

## STEM activity: Transportation and energy usage

### Background information

Transportation is a major part of everyday life and whether it's a car, train, bus, plane or even a boat, energy is used in some form. Some of the energy being used is still coming from fossil fuels which makes it even more important to be efficient in transportation design and how energy is being transferred and transformed.

Energy is lost in engines to heat going into the surrounds rather than directly into moving the

wheels in a standard engine. Also, kinetic energy, which comes from the transformation of mechanical energy, is lost to heat energy within the tyres and the road. It is estimated that approximately 75% of the energy input into a petrol-powered car engine is lost. Of this, the majority is engine losses; however, there are still losses in the drivetrain and tyres. The aerodynamics of the vehicle shape also contributes to the energy efficiency issues.



Figure 9.47 Tesla Model S

**Design brief:** Decide on a mode of transportation and design improvements that will increase the efficiency of energy usage of a model.

### Activity instructions

In groups of three, decide on a mode of transportation that you are interested in and research the ways in which energy is lost due to inefficiencies in design. Then, design and test improvements that could be made to improve efficiency of energy.

### Suggested materials

- cardboard boxes
- cardboard
- tape
- various types of materials
- glue
- force meter
- measuring tape

### Research and feasibility

- 1 Discuss and decide within your group which type of transportation you would like to learn about.
- 2 List all the ways energy goes in and then is used or lost.
- 3 Research ways to increase efficiency of energy as it goes in and is used or lost. This can be done in a table – an example is shown below.

Energy	Possible issues	Ideas for design
e.g. Car Energy in – petrol	Engine can be dirty and incomplete combustion occurs	Recommend engine regularly serviced
e.g. Car Energy out – axle turning	Axle can have friction	Lubricate axle
e.g. Car Energy out – car shape	Air resistance	Make car bonnet smooth to allow less friction from air resistance

### Design and sustainability

- 4 Discuss available materials in your group and decide how you will design your initial prototype for preliminary testing.
- 5 Design your prototype without any efficiency ideas in place and decide how you will test this prototype.
- 6 Design a prototype or changes to your initial prototype that includes all efficiency ideas. You may choose to test them one by one or altogether depending on time and materials.
- 7 Discuss and justify why efficient design components are important for sustainability and how they contribute on a global energy scale.

### Create

- 8 Construct your prototype and then complete testing.

### Evaluate and modify

- 9 Using your energy equations, perform calculations on energy you supplied to your prototype and consider how effectively this energy was used.
- 10 Explain your prototype improvements to the class and justify why your changes resulted in improved efficiency of energy transformation, or why they did not.

# Glossary

## Chapter 1

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

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

**acid–base titration** a procedure used to determine the concentration of an acid or base solution

**confidentiality** participants' data and results must be kept private

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

**data logging** the process of using electronic equipment to collect data through sensors where information needs to be collected faster than a human can do independently, or where accuracy is essential

**dependent variable** the variable that is measured with respect to a changed independent variable

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

**fieldwork** practical work conducted by a scientist in a natural environment, rather than in a laboratory

**independent variable** the variable that 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

**mean** the sum of all the values divided by the number of values

**median** the middle value of the dataset after all of the values have been ranked (sorted in ascending order). There should be as many numbers below the median as there are above

**mode** the most frequently occurring value in a dataset

**outlier** an extreme data value that does not seem to fit the rest of the data

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

**precision** how closely repeated measures agree with each other

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

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

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

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

**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

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

**systematic error** measured values are either consistently larger or smaller than the true value of the data

**validity** the degree to which an experiment addresses 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

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

## Chapter 2

**allele** one of two or more different forms of a gene

**aneuploidy** when an individual has an abnormal number of chromosomes

**autosomes** in humans, chromosome pairs 1 to 22

**base triplet** three DNA bases that code for an amino acid

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

**carrier** an individual with a recessive allele for a disease, but who does not have the disease due to being heterozygous

**centromere** a structure that holds two sister chromatids together

**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

**codon** three nucleotides (base triplet) on mRNA that code for an amino acid

**complementary base pairing** in DNA 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 (2n)** a cell containing two sets of chromosomes

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

**dominant** a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

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

**embryo** a zygote eventually becomes an embryo

**fertilisation** the fusing of an egg nucleus and sperm nucleus

**gametes** sex cells that combine to produce new offspring

**gene** a section of DNA which codes for the synthesis of proteins

**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 which can be inherited

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

**haploid (n)** 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 interactions that hold the two strands of DNA together

**incomplete dominance** a form of inheritance in which neither allele is dominant over the other, producing a third type of phenotype

**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 the order of two nucleotides is reversed

**karyotype** a pictorial 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 for growth 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, consisting of a phosphate group bound to a deoxyribose sugar, which in turn is bound to a nitrogenous base

**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 genetic crosses

**recessive** a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

**recombinant** produced by combining genetic material from different places

**reduction division** a 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

**sister chromatids** two copies of the same chromosome, connected at a centromere

**somatic cells** the body cells of an organism

**somatic mutation** a mutation that occurs in somatic (body) cells which cannot be inherited

**spontaneous mutation** a naturally occurring mutation

**substitution** a type of point mutation in which one nucleotide is replaced 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

**transcription** the first stage of protein synthesis where the base sequence of DNA is copied into mRNA

**transgenic organism** an organism that possesses a 'foreign' gene or segment of 'foreign' DNA in its genome as a result of human experimentation

**translation** the second stage of protein synthesis where a sequence of mRNA is translated into a sequence of amino acids

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

**analogous structure** a structure that has a similar function but evolved separately

**artificial selection** intentional breeding of plants and animals to produce desirable traits

**biodiversity** the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur

**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

**biota** the animal and plant life in a particular region at a particular time

**bottleneck effect** when the size of a population is rapidly decreased, often due to factors such as natural disasters or human activities such as overhunting

**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 of time

**fossil record** the record of past life and evolution inferred from fossils

**fossilisation** the process of forming a fossil

**founder effect** the decrease in genetic diversity that occurs when a small population is separated from a larger one

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

**genetic diversity** the range of genetic traits within a species

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

**half-life** the length of time needed for the radioactivity of a radioactive substance to be reduced by half

**homologous structure** a structure that is similar because it has 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** see radioisotope

**megafauna** large animals with a body mass of over 45 kilograms

**natural selection** the process that 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

**radioisotope** a version of a chemical element that has an unstable nucleus and emits radiation during its decay to a stable form

**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 advantage** a characteristic that enables an organism to survive and reproduce better than other organisms in a population

**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 group of organisms in which the members have similar characteristics to each other and can breed with each other

**species diversity** the number and abundance of different species in a given area

**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

**alkali metals** the group 1 metals, which form an alkaline solution when they react with water

**alkaline earth metals** the group 2 metals, which 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 that share electrons, forming a molecule

**displacement reaction** when a more reactive metal removes a less reactive metal from its compound

**electron** the smallest subatomic particle in an atom arranged around the nucleus in shells

**electron shell** houses the electrons that orbit the nucleus of an atom

**electron configuration** the arrangement of an atom's electrons in the shells around the nucleus

**electrostatic attraction** the attraction between oppositely charged particles

**element** a substance made up of only one type of atom

**ground state** the lowest energy level of an atom

**group** a vertical column in the periodic table

**halogens** the group 17 elements (e.g. chlorine and iodine)

**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; metalloids 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 (e.g. neon and krypton)

**octet rule** atoms tend to lose, gain or share valence electrons to achieve eight electrons in their outer shell

**ore** a substance formed naturally in the ground and from which metal can be obtained

**period** a horizontal row in the periodic table

**reactivity series** a series of metals ordered by their reactivity, from highest to lowest

**transition metals** the block of metals in the periodic table containing the elements in groups 3 to 12 and in periods 4 to 7

**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

**aqueous** a physical state of matter which means dissolved in water (e.g. salt water)

**biofuel** a fuel that is derived from living materials

**catalyst** a chemical that speeds up a chemical reaction by lowering the activation energy, and does not get used up in the process

**chemical formula** chemicals written using their elemental symbols

**chlorofluorocarbons** chemicals containing atoms of carbon, chlorine and fluorine that are non-toxic and non-flammable

**coefficient** the number placed before a molecule/ formula unit in a chemical equation to ensure that it is balanced

**collisions** particles must collide for a chemical reaction to occur

**concentrated solution** a solution that contains a large amount of solute compared to solvent

**concentration** the amount of substance in a given volume

**diatomic** two atoms bonded together

**dilute solution** a solution that contains a small amount of solute compared to solvent

**elementary entity** a small particle such as an atom, molecule or ion

**galvanising** coating iron or steel with a protective layer of zinc

**molar mass** the mass of one mole of an elementary entity

**mole**  $6.022 \times 10^{23}$  elementary entities

**monatomic** one atom, sometimes spelled 'monoatomic'

**monomer** a single unit that when joined together repeatedly make a polymer

**particle diagram** a representation of elements and compounds where atoms are drawn as balls or circles

**polymer** a long-chain molecule made of repeating subunits called monomers

**pressure** the force produced by collisions of gas particles per unit area of the container walls

**products** the chemicals produced in a reaction

**reactants** the chemicals that react together in a reaction

**reaction rate** the quantity of reactant used up or product made per unit time; how fast the reaction goes

**relative atomic mass** the sum of the number of protons and average number of neutrons in an atom

**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

**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 it 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 outside our solar system, orbiting a star other than our Sun

**galaxy** a gravitationally bound system of gas, dust and millions or billions of stars and solar systems

**geocentric** a model of the solar system with Earth at the centre

**Goldilocks zone** the habitable zone around a star where it is not too hot and not too cold in order for water to exist in liquid form

**heliocentric** a model of the solar system with the Sun at the centre

**H-R diagram** a graph of star luminosity 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 kilometres)

**luminosity** the intrinsic brightness of a celestial object

**main sequence** the phase during which stars 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 kilometres)

**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 infinitely dense matter occupies an infinitely small space

**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 7

**ammonification** the process in which decomposers in the soil convert dead plant and animal material into ammonia

**ATP** a chemical (adenosine triphosphate) in living organisms that stores energy and releases it when needed

**atmosphere** the mixture of gases mainly above the surface of Earth

**biodiversity** the variety of species, ecosystems and genes that exist in a particular area

**biosphere** all the parts on Earth and in its atmosphere that contain life

**carbon sinks** areas where carbon is stored (e.g. fossil fuels)

**carbon sources** processes or areas that release carbon

**climate** the average or prevailing weather conditions of an area over long periods of time

**decomposer** a living organism, such as bacteria and fungi, that breaks down dead organic matter

**denitrification** the process of converting nitrates into nitrogen gas to be released back into the atmosphere

**egestion** the process of removing undigested waste material from the body in the form of faeces

**enhanced greenhouse effect** the intensifying of the natural greenhouse effect due to human activity

**geosphere** includes the Earth's magma, lava, rocks and minerals

**glacial period** a period 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 (e.g. lakes and rivers)

**interglacial period** a period in Earth's history when an increase 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 geological 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 or other related nitrogenous compounds 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 that 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 8

**conduction** the transfer of thermal energy through a substance, or between substances, as a result of collisions between particles

**conductor** a material that can transfer heat via conduction

**convection** the 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** 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** the transfer of thermal energy caused by a difference in temperature

**insulator** a material that is a poor conductor of heat

**internal energy** the total potential energy stored in bonds and kinetic energy of the particles in a system

**kinetic energy** energy possessed by an object due to its motion

**law of conservation of energy** the total amount of energy in an isolated system is constant

**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** the transfer of thermal energy without the presence of particles of matter

**Sankey diagram** a flow chart that represents the flow of energy through a system

**system** a portion of the universe that is being analysed

**temperature** a measure of the average kinetic energy of all the particles in a substance

**thermal energy** the internal energy present in a system due to its temperature

**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** the rate of change of velocity of an object

**average speed** the change in distance over a time interval

**average velocity** the rate at which an object is displaced or changes position over a time interval

**constant velocity** 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 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

**instantaneous velocity** the velocity of an object measured at a particular instant

**mass** 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 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** the change in distance divided by time

**stationary** not moving

**velocity** the change in displacement divided by change in time

**weight** the force of gravity on the object and is defined as the mass times the acceleration of gravity

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