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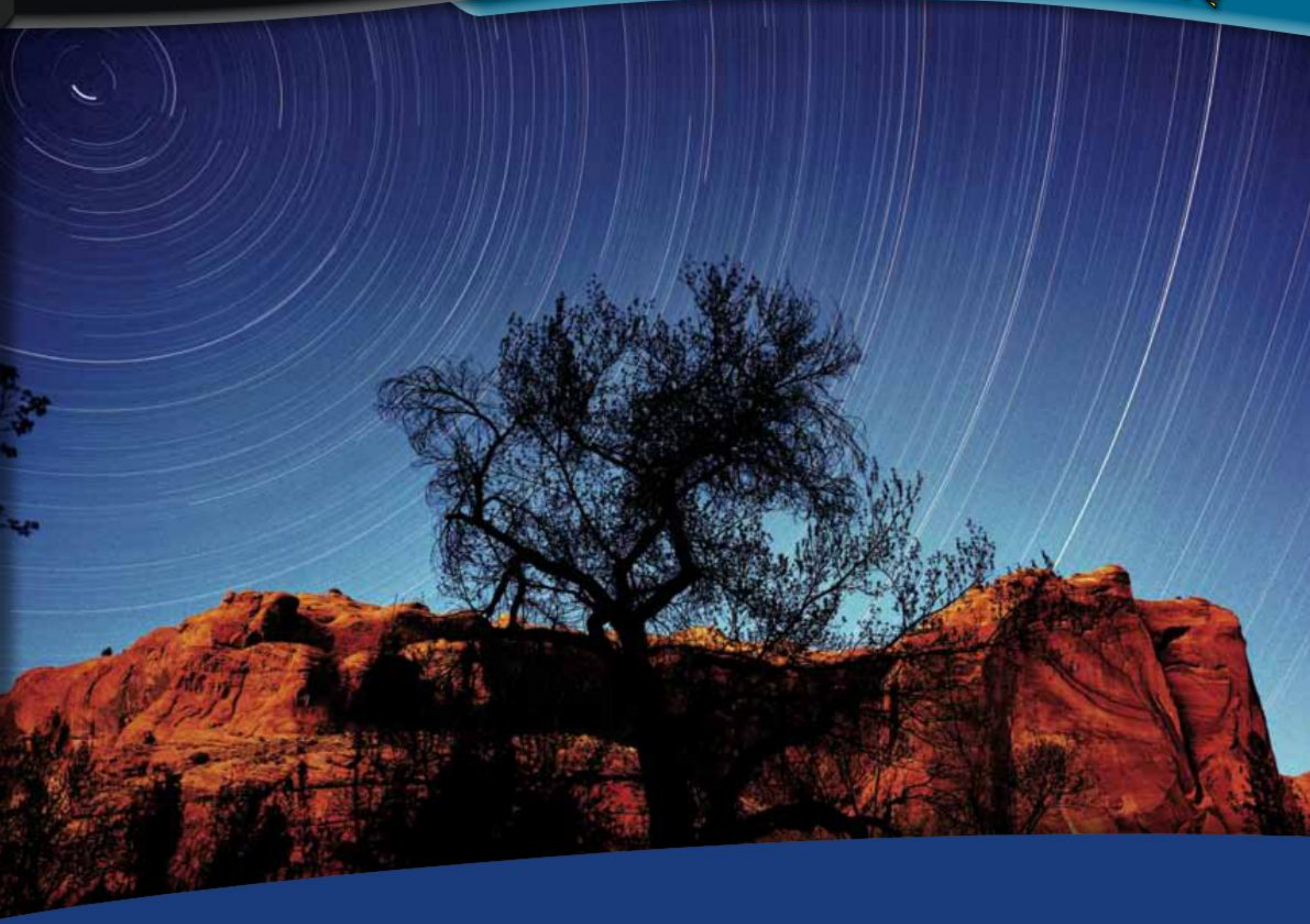

ScienceWorld 10

Australian Curriculum edition

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Macmillan

Australian Curriculum

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Australian Curriculum edition

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SIS: Science Inquiry Skills
SHE: Science as a Human Endeavour

Transition science

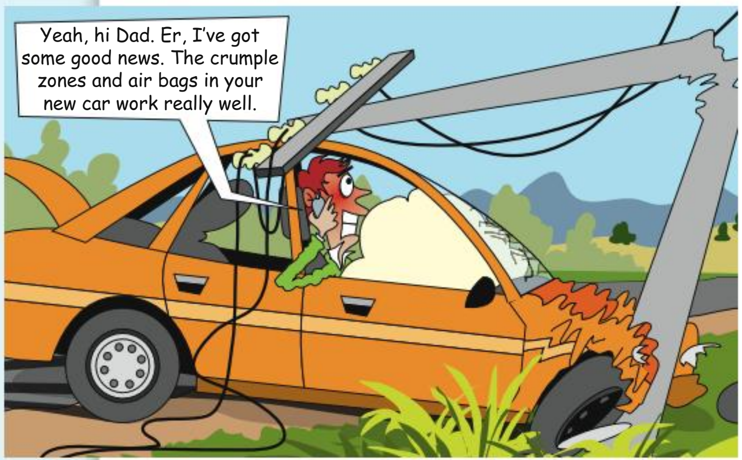
ScienceWorld 10 is designed to help you make the transition from the junior school to the senior school. It will help you clarify the ideas you have about science subjects that you may study in Year 11. If you are not sure what senior biology, chemistry and physics are like, the chapters in this book will give you some idea.

Work in small groups to discuss these questions.

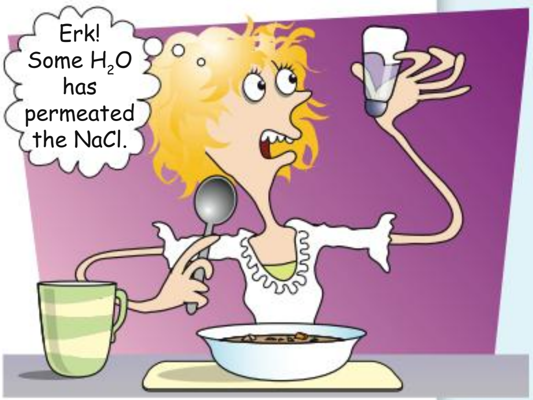
1. To solve everyday problems you often need to use **Science Inquiry Skills**. What does this mean?
2. You use science enquiry skills in the four areas of science below. Check the contents list on the previous page. Can you work out which chapters are Physical sciences. Which ones are Biological sciences? Which are Chemical sciences? And which are Earth and space sciences?
3. Which of the four areas do you like best? Why?
4. Which of the four areas would you need to study environmental science? Explain.
5. Whether or not you do science next year, this book explores **Science as a Human Endeavour**. It contains many ideas and issues that you will hear about in the news and discuss with others. For instance:
   - gene technology and cloning (Chapter 3)
   - use of nuclear power (Chapter 5)
   - what to do about rising levels of CO_2 in the atmosphere (Chapter 8)
   - cosmic catastrophes such as a meteorite crashing into the Earth (page 257).

   Do you think that science can solve all our problems? Explain.

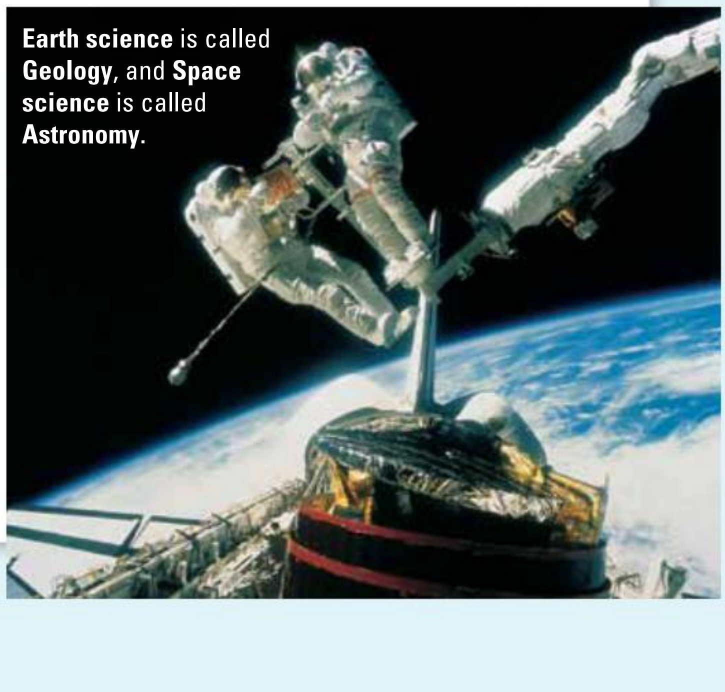
Physical sciences or **Physics** is the study of how objects, from the very tiny to the very big, behave.



Chemical sciences or **Chemistry** is the study of matter, of natural and processed materials. You study what substances are made of and how they react with each other.



Biological sciences or **Biology** is the study of life and living things.


Earth science is called **Geology**, and **Space science** is called **Astronomy**.

Links to the Australian Curriculum

The content elaborations in the right-hand column are listed at the beginning of each chapter. They indicate *some* of the ways in which the Australian Curriculum content descriptions have been elaborated in *ScienceWorld 10*.

Science Understanding	ScienceWorld 10 Elaborations
Science Understanding is fully integrated with Science Inquiry Skills, as indicated in the elaborations.	
Biological sciences The transmission of heritable characteristics from one generation to the next involves DNA and genes (ACSSU184)	**Chapter 3 Inheritance** • describe the role of DNA as a blueprint for controlling the characteristics of organisms • use diagrams to show how sex cells are produced by the process of meiosis • use a model to show how the bases in DNA code for different amino acids • use Punnett squares to predict the genotypes and phenotypes in dominant/recessive gene pairs • use a model to show how gene technology can be used to cut and recombine genes
The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (ASSSU185)	**Chapter 9 Evolution** • gain an understanding of how sexual reproduction results in variations in organisms • model and discuss the processes involved in natural selection and the formation of new species • evaluate and interpret evidence for evolution—the fossil record, biogeography, embryo similarities and comparative DNA studies
Chemical sciences The atomic structure and properties of elements are used to organise them in the periodic table (ACSSU186)	**Chapter 7 Periodic table** • recognise that elements in the same group of the periodic table have similar properties • use diagrams to describe the structure of atoms in terms of electron shells • understand how the electronic structure of an atom determines its properties and its position in the periodic table • test the chemical properties of metals and arrange them in order of their chemical activity **Chapter 11 Electrochemistry, pp. 293–296** • appreciate the significance of the chemical activity of metals in electrochemistry
Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	**Chapter 1 Experiment 1, p. 8** • investigate how the rate of chemical reactions is affected by temperature, concentration, surface area and catalysts **Chapter 4 Explaining reactions** • write chemical formulas for ionic and covalent compounds • write correctly balanced symbol equations for chemical reactions • predict the products of a reaction between solutions of two ionic compounds **Chapter 11 Electrochemistry** • use a knowledge of chemical reactions to explain how different types of batteries produce electric current • give examples of how chemistry can be used to produce a range of useful substances

continued …

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Science Understanding	ScienceWorld 9 Elaborations
Science Understanding is fully integrated with Science Inquiry Skills, as indicated in the elaborations.	
Earth and space sciences The universe contains features including galaxies, stars and solar systems and the Big Bang theory can be used to explain the origin of the universe (ACSSU188)	**Chapter 10 Exploring the universe** • explain how the sun produces energy, and compare its brightness and colour with other stars • correctly use terms like nebula, supernova, neutron star and black hole to describe the birth and death of stars • outline the Big Bang theory and the evidence supporting it
Global systems, including the carbon cycle, rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere (ACSSU189)	**Chapter 8 Earth systems** • give examples of how global systems rely on interactions between the biosphere, lithosphere, hydrosphere and atmosphere • use a model greenhouse to explain how the atmosphere affects the temperature of the Earth • consider scenarios for future greenhouse gas emissions
Physical sciences Energy conservation in a system can be explained by describing energy transfers and transformations (ACSSU190)	**Chapter 2 Road science** • use the law of conservation of energy to describe what happens in a road accident • explain in terms of energy why no machine can be 100% efficient **Chapter 5 Our energy future, pp. 116, 121–127** • define renewable and non-renewable energy systems and give examples of each
The motion of objects can be described and predicted using the laws of physics (ACSSU229)	**Chapter 2 Road science** • use a ticker timer or datalogger to gather data to analyse the motion of everyday objects • use Newton's second law (F = ma) to predict how a force affects the movement of an object **Chapter 6 Space science** • use Newton's second law (F = ma) to calculate the force of gravity on an object • apply Newton's third law (action and reaction) to describe the operation of rockets • identify the forces acting on an object in orbit

Science as a Human Endeavour	ScienceWorld 10 Elaborations
Science as a Human Endeavour is integrated with Science Understanding.	
Nature and development of science Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community (ACSHE191)	**Chapter 1 Investigating reactions, p. 19** • discuss why the work of Lavoisier led to the abandonment of the phlogiston theory **Chapter 9 Evolution, pp. 232–237** • use evolution to illustrate that scientific theories are contestable and are refined over time
Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE192)	**Chapter 11 The first battery, p. 301** • follow the historical development of batteries **Chapter 3 Inheritance, pp. 69–70** • gain an understanding of how mapping of the human genome has led to better understanding of human diseases

continued …

Use and influence of science People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions (ACSHE194)	**Chapter 5 Managing energy, pp. 131–136** • suggest ways of saving energy at home and for transport **Chapter 5 Your own solar power station, p. 141** • investigate whether it is a good idea to install solar panels on your roof **Chapter 8 Activity, pp. 206–207** • make a group decision about the construction of a freeway through a koala habitat **Chapter 10 Aboriginal astronomy, p. 276** • research Australian Aboriginal people's knowledge of the night sky and how they used this knowledge
Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating career opportunities (ACSHE195)	**Chapter 6 Living in space, pp. 158–160** • gain an understanding of the problems of living in space **Chapter 7 Periodic table, pp. 182, 194** • predict the impact of future applications of buckyballs and carbon nanotubes on people's lives **Chapter 9 Evolution, pp. 243–245** • research, discuss and debate the way in which GM foods, cloning and human gene therapy are affecting people's lives **Chapter 10 Exploring the universe** • use the internet to research the latest discoveries in space
The values and needs of contemporary society can influence the focus of scientific research (ACSHE230)	**Chapter 3 Inheritance, pp. 57, 70, 82, 85** • discuss issues associated with DNA fingerprinting and testing for genetic diseases **Chapter 5 Light up the world, p. 137** • discuss the work of Dave Irving-Halliday in developing inexpensive lighting systems for developing countries **Chapter 6 Activity, p. 156** • use internet research to find out the latest on a replacement for the space shuttle

Science Inquiry Skills	ScienceWorld 10 Elaborations
Science Inquiry Skills are fully integrated with Science Understanding and can be developed through the various learning activities in *ScienceWorld*—Getting started, Activity, Investigation, Skillbuilder, Check, Challenge and Science inquiry skills.	
Questioning and predicting Formulate questions or hypotheses that can be investigated scientifically (ACSIS198)	**Chapter 1 Getting started, p. 2** **Chapter 6 Space experiment, p. 167** • design an experiment to be carried out on the International Space Station
Formulate questions that can be investigated scientifically and develop testable hypotheses based on prior observations, scientific knowledge and primary and secondary sources (ACSIS209)	**Chapter 1 Experiment 2, p. 20** • carry out an experiment to test the hypothesis that mass does not change in a chemical reaction **Chapter 11 Experiment 6, p. 294** • design a controlled experiment to investigate the corrosion of iron

continued …

Science Inquiry Skills	ScienceWorld 9 Elaborations
Planning and conducting Plan, select and use appropriate investigation methods, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods (ACSIS199)	**Chapter 1 Experiment 1, p. 8** • design and evaluate an experiment to investigate how a particular factor affects the rate of a reaction **Chapter 11 Electrochemistry** • describe and implement safety precautions when working with acids and electrical apparatus
Select and use appropriate equipment, including digital technologies, to systematically and accurately collect and record data (ACSIS200)	**Chapter 1 Investigation 3, p. 18** • investigate whether common compounds produce heat (exothermic) or take heat from their surroundings (endothermic) when they dissolve **Chapter 5 Experiment 4, p. 134** • design a model house to test the effectiveness of insulation **Chapter 10 Investigation 18, p. 255** • locate and record the positions of stars and constellations in the night sky
Processing and analysing data and information Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies (ACSIS203)	**Chapter 2 Speed and acceleration, pp. 28–36** • draw and interpret graphs of distance, speed and acceleration versus time **Chapter 2 Using maths equations, p. 37** • use motion equations to calculate distance, speed, acceleration and time **Chapter 4 Science inquiry skills, p. 111** • classify common chemical reactions
Use knowledge of scientific concepts to draw conclusions that are consistent with evidence (ACSIS204)	**Chapter 4 Investigation 7, pp. 105–106** • use the results of chemical tests to draw a conclusion about the product of a chemical reaction **Chapter 5 Energy supply proposal, p. 128** • research energy supply alternatives, using the internet and library **Chapter 12 Investigation 22, p. 291**
Evaluating Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data (ACSIS205)	**Chapter 1 Evaluating experiments, p. 25** • evaluate students' experimental reports to see if their results are reliable and their conclusions valid **Chapter 3 Experiment 3, p. 39** **Chapter 7 Investigation 14, pp. 188–189** • carefully follow a series of steps to extract copper from an ore, and evaluate your method
Critically analyse the validity of information in secondary sources and evaluate the approaches used to solve problems (ACSIS206)	**Chapter 8 When scientists disagree, p. 219** • evaluate scientific data about the possible causes of the rising concentration of CO_2 in our atmosphere **Chapter 9 Evolution and creation, p. 249**
Communicating Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (ACSIS208)	**Chapter 4 Chemical bonds, pp. 88–94** • distinguish between ionic and covalent bonds in terms of the sharing of electrons between atoms **Chapter 8 Presenting a persuasive speech, pp. 217–218** • prepare and present a persuasive speech on an environmental issue

1

Investigating reactions

In this chapter you will …

Science Understanding

- investigate how the rate of chemical reactions is affected by temperature, concentration, surface area and catalysts

Science as a Human Endeavour

- discuss why the work of Lavoisier led to the abandonment of the phlogiston theory

Science Inquiry Skills

- design and evaluate an experiment to investigate how a particular factor affects the rate of a reaction
- investigate whether common compounds produce heat (exothermic) or take heat from their surroundings (endothermic) when they dissolve
- carry out an experiment to test the hypothesis that mass does not change in a chemical reaction
- evaluate students' experimental reports to see if their results are reliable and their conclusions valid

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

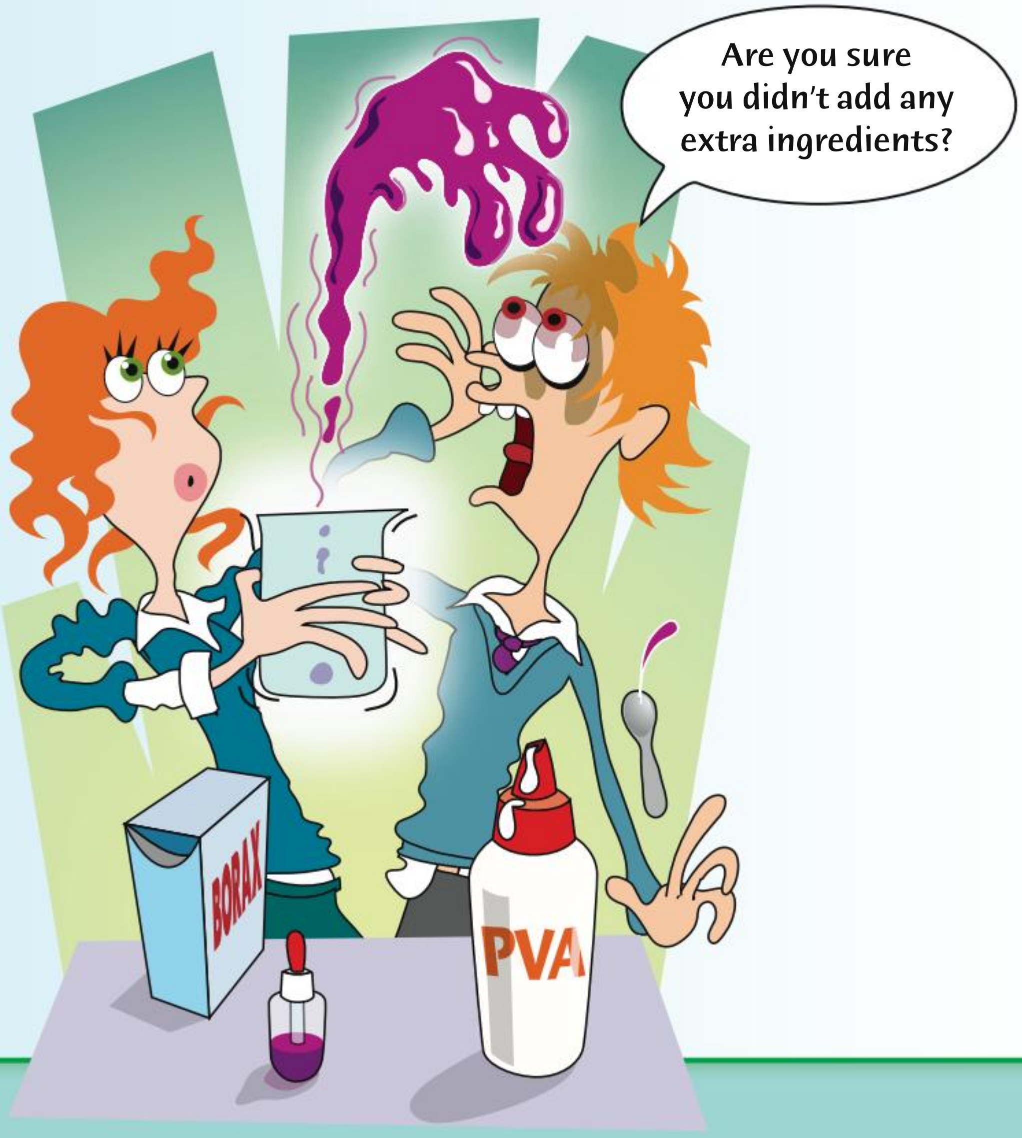
Silly putty

Try making silly putty using the instructions below. You may be able to do it at home.

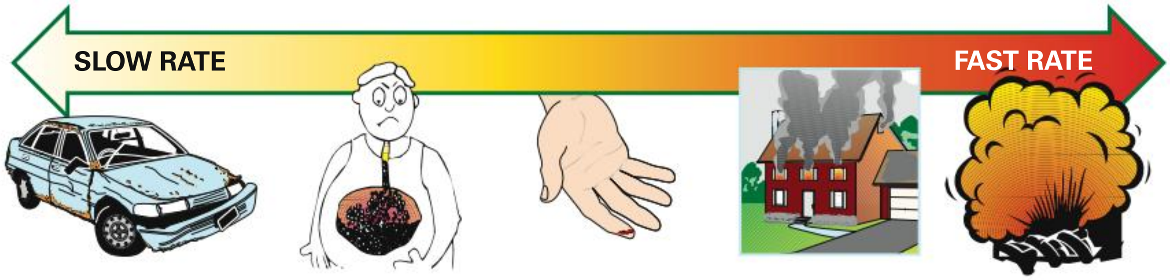
1 Measure out about 6 teaspoons of PVA glue into a small container, and add two or three drops of food colouring.
2 In another container dissolve about a quarter of a teaspoon of borax in 20 mL of water. (Wash your hands after using the borax.) Slowly add this solution to the glue, stirring constantly.
3 When the mixture has turned to a thick slime, wash it thoroughly in running water and dry it with a paper towel.

- Experiment with the slime to see what its properties are. For example, can you stretch it? Does it bounce? . . .
- Was there a chemical reaction when you mixed the glue and the borax solution? How do you know?
- Did the food colouring take part in the chemical reaction? How could you find out?

You can store your slime in a sealable plastic bag or container.



1.1 Reaction rates



When you toast a piece of bread, the toast looks and tastes different from the bread you started with. The toasting of the bread is a chemical reaction. Reactions occur whenever new substances with different properties are formed.

Some reactions occur very slowly. For example, the chemical weathering of rocks can take thousands of years. The rusting of iron and the decay of dead plants and animals both involve slow reactions. The digestion of food is faster, but it still takes 3–5 hours to digest a meal. If you cut yourself, it takes a few minutes for your blood to clot.

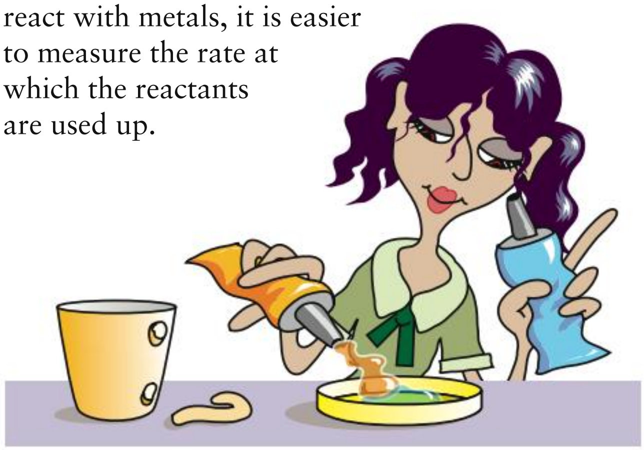
At the other end of the scale are very rapid reactions. The borax and glue in the Getting started activity reacted instantly, burning is a fast reaction, and the reactions in an explosion occur in less than a thousandth of a second!

The speed of a reaction is called its **reaction rate**. A slow rate means the reaction takes a long time. A fast rate means it takes only a short time.

Temperature and rate

Belinda often fixes things around the house using Araldite glue, for which you mix the materials in two tubes to make a glue. She has noticed that the glue sets more quickly on warm days than on colder days. She wonders whether the glue-setting reaction is faster at higher temperatures. When she asks her teacher about this, he suggests that she does an experiment to find out.

Belinda's teacher discusses with her how to measure the rate of the reaction. He talks about reactants and products, and tells Belinda she could measure the rate at which the product is formed. In other reactions, such as when acids react with metals, it is easier to measure the rate at which the reactants are used up.



Part A (liquid) + Part B (liquid) → epoxy glue (solid)
REACTANTS — PRODUCT

The teacher tells Belinda about a reaction where it is easy to measure the effect of temperature on reaction rate by measuring the rate at which the product is formed. When hydrochloric acid is added to hypo (sodium thiosulfate), the solution turns cloudy after a while. The cloudiness is due to a reaction in which the element sulfur forms a colloid.

sodium thiosulfate + hydrochloric acid → sulfur + other products

In Investigation 1 you can try this reaction yourself. The aim of the investigation is to find an answer to the research question.

Investigation 1 Temperature and reaction rate

Research question

How does temperature affect the rate of reaction between hypo and dilute hydrochloric acid?

Materials

- dilute **hydrochloric acid** (1 M)
- sodium thiosulfate (hypo) solution (0.2 M)
- 10 mL and 50 mL measuring cylinders
- 100 mL flask
- stopwatch
- sheet of white paper
- thermometer
- 500 mL beaker
- ice

Working with technology

Teacher note: You can obtain more reliable results if you use a light intensity probe and datalogger to measure when the mixture goes cloudy.

Planning and Safety Check

- Discuss with your partners what you will be doing in each part. Sort out who will do what.
- Which variables will you need to control (keep the same) in this investigation?
- What safety precautions will be necessary?
- Design a data table for Part B.

PART A The hypothesis

1 In your science notebook, write an answer to the research question. In other words, write a hypothesis about how temperature affects reaction rate.
(A hypothesis is a generalisation that can be tested.) You can write your hypothesis in several different ways. You could say ***If*** *the temperature is ______,* ***then*** *the reaction rate will be _____*. Alternatively, you could say *The ______ the temperature, the ______ the reaction rate.*

2 Will hypo and hydrochloric acid react faster at 10°C or at 40°C? Use your hypothesis to write a prediction.

PART B Testing the hypothesis

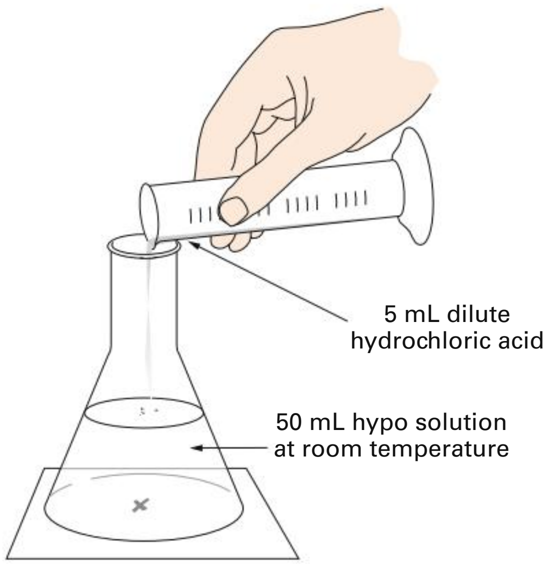
Method

1 Measure out 50 mL of hypo solution into the small flask. Use a thermometer to measure the temperature of the solution.
Record this as room temperature in your data table.

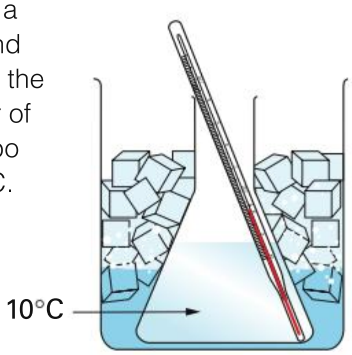
2 Mark a cross with a pen on a sheet of white paper. Stand the flask on top of the cross.
When hydrochloric acid is added to the hypo solution, it goes cloudy due to a sulfur colloid. The cross will seem to disappear when you look down through the neck of the flask.

3 Add 5 mL of acid to the flask and start timing. Swirl the flask twice and note the time when the cross disappears.
Record the time for the reaction. This is called the reaction time.

4 Wash out the flask. Measure out another 50 mL of hypo and add it to the flask.



5 Put some water in a 500 mL beaker, and add some ice. Put the flask in the beaker of ice and let the hypo cool to about 10°C.

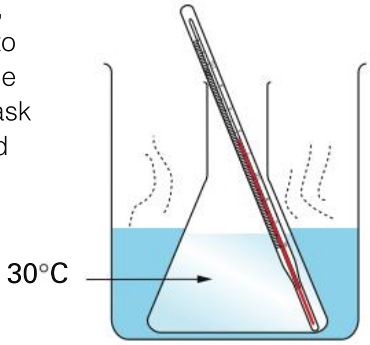


6 When the hypo has cooled, quickly take the flask out of the ice, wipe the water from the outside, and put the flask over the cross. Add 5 mL of acid immediately, start timing, and swirl the flask twice.

Record the reaction time and the temperature of the hypo.

7 Wash out the flask again. Measure out another 50 mL of hypo, and add it to the flask.

8 Put some hot water (from the hot tap, or water heated to about 60°C) in the beaker. Sit the flask in the beaker and let the hypo warm to about 30°C.



9 Repeat Step 6.

10 Repeat for 40°C, and again record your results.

Discussion

1 At which temperature was the reaction fastest? Was your prediction in Part A Step 2 correct?

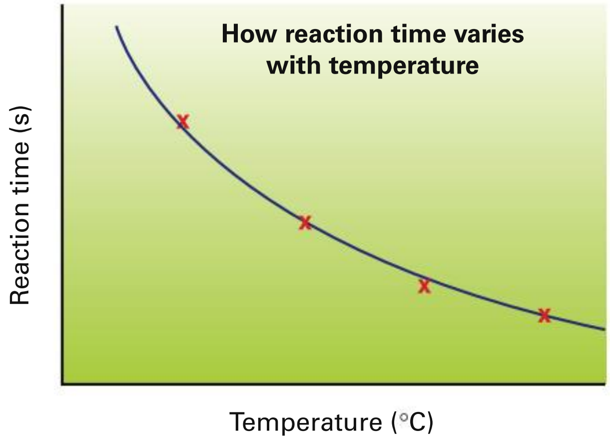
2 Use your results to decide whether your original hypothesis was correct. If necessary, rewrite it.

3 Which was the *independent* variable in this experiment—the variable you purposely changed? Which was the *dependent* variable—the variable you measured?

4 Which were the *controlled* variables in this investigation?

5 To give you a better idea of how the reaction rate changes with temperature, draw a graph of reaction time against temperature, as shown below.

First decide on a suitable scale for the reaction time and the temperature axes. Mark each point on the graph with a cross. Then join up the crosses with a *smooth* curve. Remember, the curve does not have to go through each point—so long as it shows the general trend of the results.



6 Explain the shape of the graph. Does the graph support your hypothesis?

7 Why did you swirl the flask twice for each reaction?

8 Do you think the investigation could be improved? If so, give details.

PART C Predicting

1 Using your graph from Part B, what do you predict for the reaction time at 35°C? At 50°C?

2 Repeat the reaction at 35°C and 50°C.

How accurate were your predictions?

Everyday reactions

In her science project Belinda studied many different reactions. She found the same thing for each reaction—*the reaction rate increases as the temperature increases*. An everyday example of this occurs in cooking, where you need heat to make reactions go. As you increase the temperature, these reactions go faster.

Many reactions that depend on temperature also occur inside living things. Plants usually grow more rapidly in summer than they do in winter. The body temperature of all animals except birds and mammals changes with that of their surroundings, which is why snakes and lizards are inactive in winter and much more active in warmer weather.

In some cases, it is important to slow down reactions by decreasing the temperature. For example, the spoiling of food is caused by chemical reactions that can be slowed down by keeping food cold in a refrigerator.

Fig 1 Dead bodies are kept refrigerated to slow down decomposition reactions.

Explaining reaction rates

Chemical reactions can be explained in terms of the particle theory of matter, which you have learnt about in previous studies.

The particle theory of matter

1. All matter is made up of tiny particles too small to see.
2. There are spaces between the particles.
3. There are attractive forces between particles. The weaker these forces are, the further apart the particles are.
4. The particles are always moving.
5. At high temperatures the particles move faster than they do at low temperatures.

Temperature

A reaction can occur only when the particles of the reacting substances come into contact with each other. According to the particle theory, as the temperature increases the particles move faster and collide more often. They also collide more violently (more energetically) than they do at lower temperatures. For these two reasons, reaction rate increases with temperature.

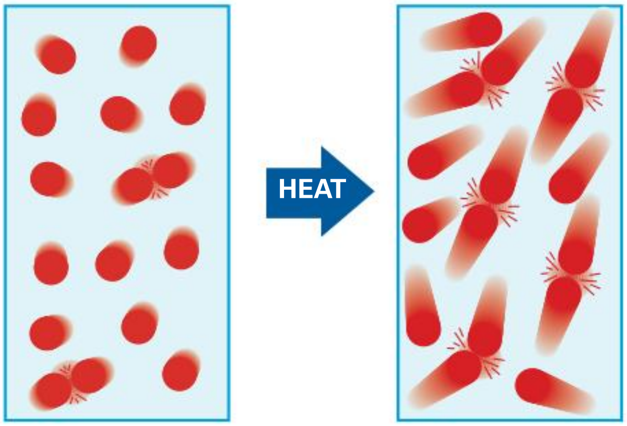
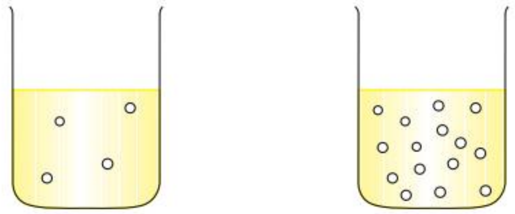


Fig 2 At higher temperatures the particles have more energy and collide more often and more violently. This is why chemical reactions are more likely to occur.

Concentration

There are other variables besides temperature that affect reaction rate. **Concentration** is a measure of how much solute is dissolved in a certain volume of solution.



A **dilute** solution contains only a small amount of dissolved solute in a certain volume of solvent.

A **concentrated** solution contains a large amount of solute dissolved in the same volume of solvent.

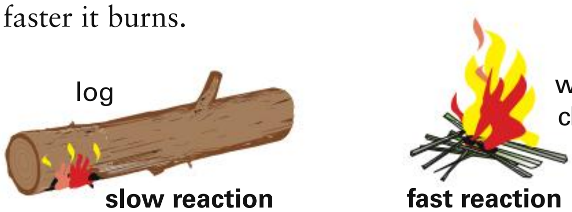
A higher concentration of a reactant usually increases the reaction rate. This is because the reacting particles are closer together and collide more often. For example, household bleach can be used to remove stains on clothing. If the stains are particularly bad, you need to put more bleach into the wash to increase its concentration. Similarly, concentrated acids 'eat away' cloth more rapidly than dilute acids.

Fig 3 Sawdust has a large surface area and burns so rapidly it can explode.

Surface area

The rate of a reaction is also affected by whether the reactants are in big pieces or are finely powdered, or somewhere in between. For example, a wooden log burns fairly slowly, but chips of wood burn almost instantly. The reason for this is that only the wood on the outside of the log can burn (react with the oxygen in the air). Once the outside layer has burnt, the next layer can burn, but the process is slow.

When the log is broken up into chips, there is much more wood that can burn. In other words, the chips have a greater *surface area* than the log. So the greater the surface area of the wood, the faster it burns.



Another good example to show the effect of surface area is the reaction of zinc with dilute hydrochloric acid. Pieces of zinc react slowly, whereas zinc foil reacts more rapidly, and zinc powder reacts very rapidly. This is why powdered metals such as zinc are dangerous. They react so quickly with some substances that an explosion may occur.

Working with technology

To see an explanation of reaction rates, open the **What affects the rate?** animation at www.OneStopScience.com.au.

OneStopScience

Experiment 1 What affects the rate?

Research question

How is the rate of a reaction affected by the:

1 concentration of the reactants?

2 surface area of the reactants?

3 mixing of the reactants, e.g. by shaking or stirring?

Design an experiment (or experiments) to answer one or more of the questions above.

Planning and reporting hints

1 Decide which question you are going to investigate. Then plan your experiment carefully, keeping safety in mind. Read the following hints.

- To answer Question 1 you could use the reaction between hypo and hydrochloric acid (Investigation 1). You could vary the concentration of either the hypo solution or the hydrochloric acid. To make a solution less concentrated you need to add a measured volume of water.
- You could try the reactions of hydrochloric acid with magnesium ribbon or marble chips (calcium carbonate). For Question 2 magnesium ribbon could be cut into smaller pieces, and marble chips could be crushed.
- Try to make quantitative observations by working out a way of measuring the rate of reaction. Display your results in a data table and in a graph.
- Make sure you control all variables except the one you are purposely varying.
- If possible, repeat your experiment to see if you get the same results. If you do, then you can be more confident your conclusions are correct. If someone else repeats your experiment and gets the same results, you can be even more confident. Results like this are said to be **reliable**.

2 Discuss your design and safety precautions with your teacher before you start the experiment.

3 Write a report of your experiment (or experiments) using these five headings:

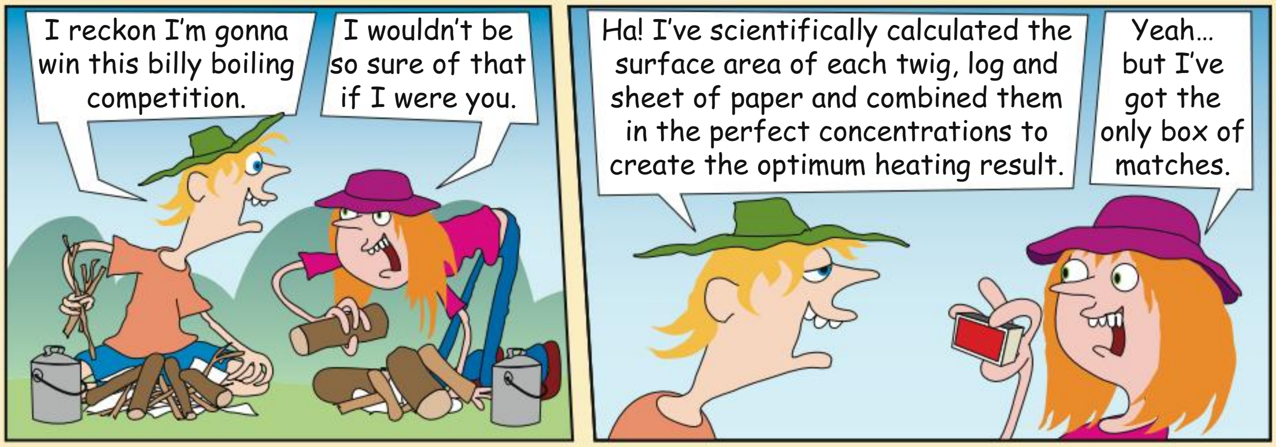
a In the *Aim* make sure you state the hypothesis you plan to test.

b In the *Method* list the materials you used and what you actually did, including how you controlled variables.

c Under *Results* include your observations. Use data tables and graphs where appropriate.

d In the *Discussion* suggest where you might have made an error or how the experiment could be improved.

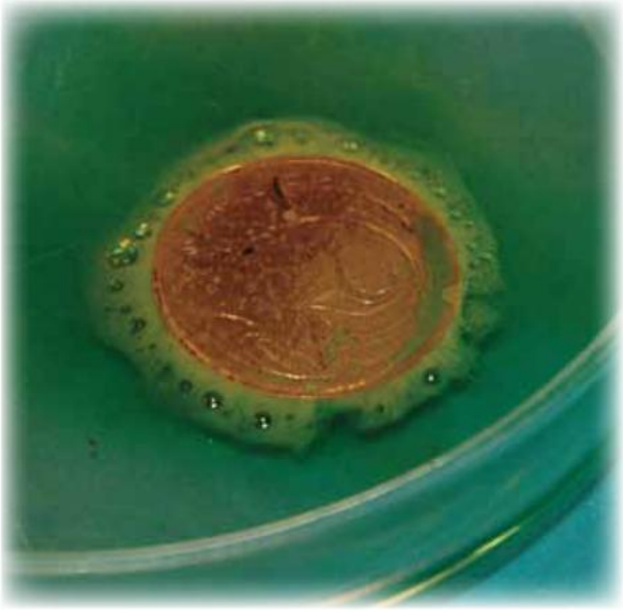
e In the *Conclusion* state whether or not the results support (agree with) your hypothesis.



Check

1 The teacher added acid to a copper coin in a petri dish. The students made the following observations. Which one of these observations is to do with the *rate* of the reaction?
- A A brown gas was produced.
- B The solution turned a greenish-blue.
- C The coin was partly eaten away.
- D The bubbling stopped after about 5 minutes.

2 List *three* variables that can affect the rate of a reaction.



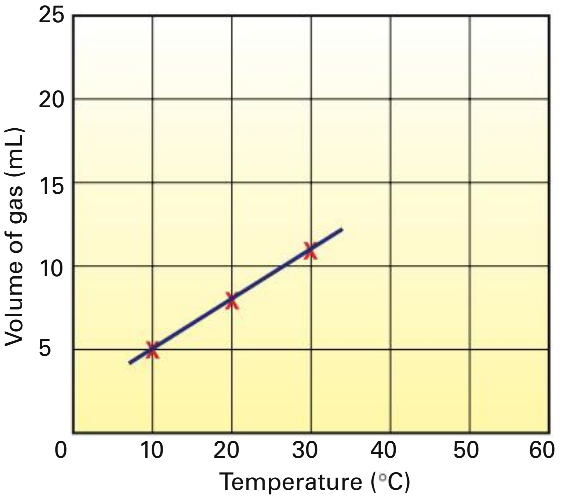
3 Green tomatoes can be picked and left in a warm place to ripen. However, if they are put in a refrigerator, they ripen much more slowly. Why is this?

4 Suppose you want to react iron with hydrochloric acid. You can use an iron bolt or iron filings. The acid can be dilute or concentrated. And you can do the reaction at 0°C, room temperature (about 20°C) or 60°C.
Which conditions would give you the fastest reaction? Which conditions would give the slowest reaction?

5 Write a complete sentence to explain each of the following statements.
- a Antacid powders work faster than antacid tablets.
- b Concentrated acids are more hazardous than dilute acids.
- c The exhaust pipe of a car rusts much faster than other parts of a car.
- d Milk needs to be kept in a refrigerator.
- e Potatoes cook more quickly if you cut them into small pieces.

6 Which will corrode more quickly—a pipe that carries hot water or one that carries cold water? Explain.

7 The graph below shows the volume of gas produced in a minute during a chemical reaction at three different temperatures. Use the graph to answer these questions.
- a What was the volume of gas produced during the reaction when the temperature was 30°C?
- b Predict the volume of gas that would be produced if the temperature was 60°C.
- c Predict the temperature of the reaction that would produce approximately 15 mL of gas in 1 minute.



8 A reaction that is producing bubbles of gas is occurring in a test tube. What *two* things could you do to slow down the amount of bubbling?

Challenge

1 Which would rust more quickly—an iron nail or iron filings? Design an experiment to find out.

2 Aluminium frying pans can be used in cooking, yet the label on a container of very fine aluminium powder warns that the contents are *highly flammable*. Explain the difference.

3 Use the particle theory on page 6 to explain the following.

a Why does increasing the concentration of the reactants usually increase the reaction rate?

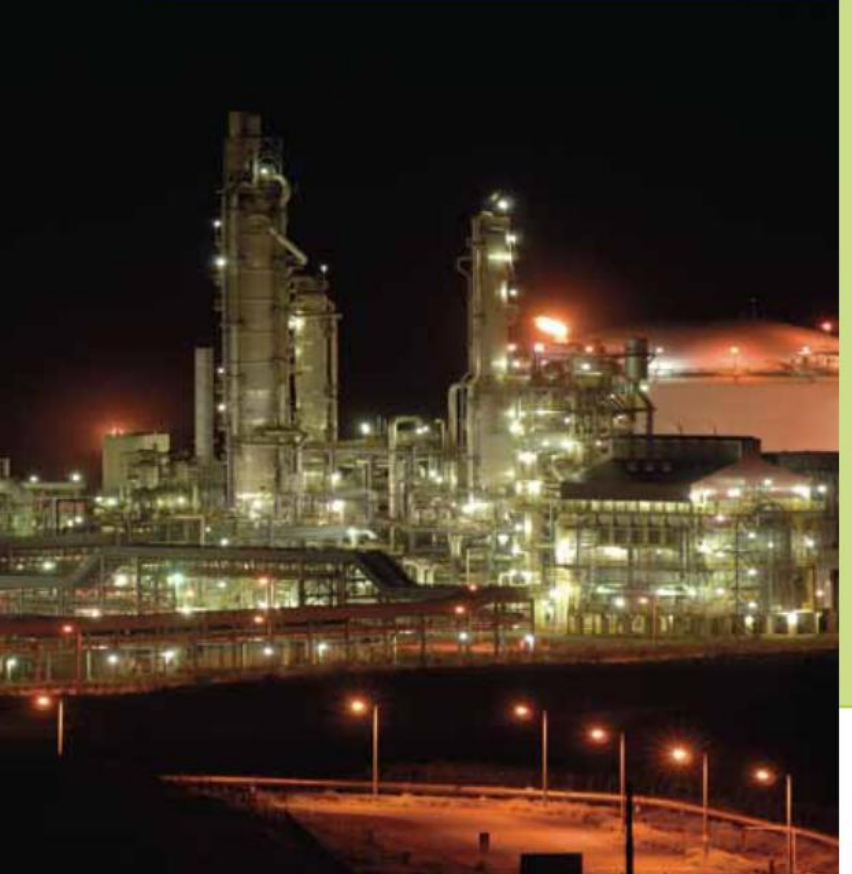
b Why does increasing the surface area of the reactants usually increase the reaction rate?

4 Ammonia gas is used to manufacture fertilisers. It is made by reacting together the two gases nitrogen and hydrogen. Temperatures ranging from 400°C–500°C are required, and the gases are at pressures about 250 times normal air pressure. A porous iron catalyst is used.

a Suggest why high pressures speed up the reaction between nitrogen and hydrogen.

b What are the other ways in which the reaction is speeded up?

Fig 4 This factory in Western Australia manufactures ammonia. The nitrogen and hydrogen react in the towers.

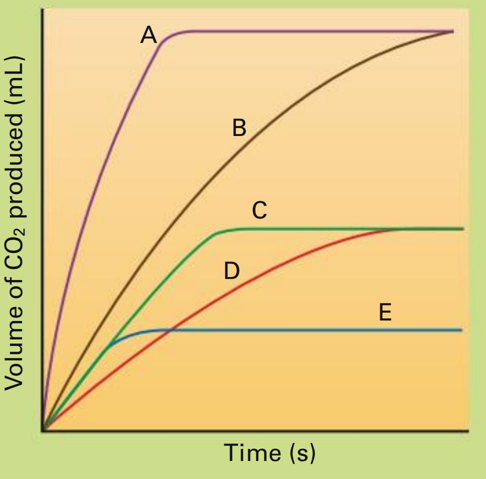


5 Kee noticed that the number of chirps a cricket makes in a minute seems to depend on the temperature. The higher the temperature, the more chirps per minute. Design an experiment to test Kee's hypothesis.

6 The table gives the results of an experiment involving five reactions between hydrochloric acid and marble (calcium carbonate).

Reaction	1	2	3	4	5
Volume of conc. acid (mL)	60	30	30	15	60
Volume of water (mL)	60	30	30	15	60
Temperature (°C)	40	20	40	40	40
Marble (c = chips) (p = powdered)	c	c	c	c	p

The graph below shows the results.



a For each reaction (1–5), identify the correct graph (A–E). Give reasons for each of your choices.

b Which reaction was the fastest? Which was the slowest? How do you know?

c Which reaction finished first?

1.2 Speeding up reactions

Reactions can be speeded up by increasing the:

- temperature
- concentration of the reactants
- surface area of the reactants.

Reactions can also be speeded up by using **catalysts** (CAT-a-lists).

Activity

For this activity you will need two sugar cubes, a glass dish, matches and some ash from burnt paper.

1. Put a sugar cube on a dish and see if you can set fire to it with a match. It melts and chars but doesn't burn.
2. Now dip a second cube in some ash and again try to burn it. What happens?

The ash is acting as a catalyst for the burning of the sugar cube. It speeds up the reaction, *without being changed itself*.

Catalysts are used in industry to control the speed of reactions and to reduce the costs of producing chemicals. For example, nickel is used to make margarine from vegetable oils. Self-cleaning ovens are coated with a catalyst that helps to burn small food particles that stick to the oven walls.

Although catalysts are mostly used to speed up reactions, they can also be used to slow down reactions. Nitroglycerine has a tendency to explode unexpectedly of its own accord. To make explosives containing nitroglycerine safer, a small amount of another chemical (urea) is added. It acts as an *inhibitor*—slowing down the reaction. Rubber perishes as a result of a slow reaction with the oxygen in the air. To slow down this reaction, an inhibitor is added to the rubber during manufacture.

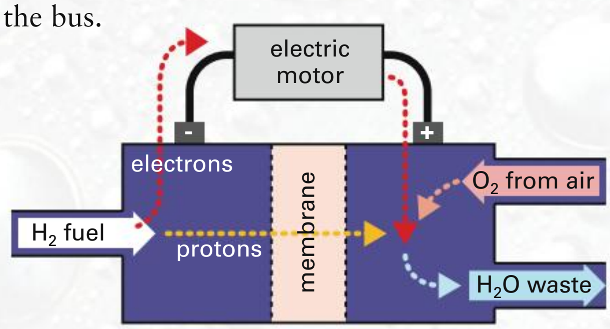
Science as a human endeavour

Fuel cells

Because of the shortage of oil in the world, scientists and engineers are experimenting with alternative fuels. They have developed **fuel cells**, which use the reaction between hydrogen and oxygen to produce electricity.

The key component of the fuel cell is a membrane, a sheet of plastic coated with a platinum catalyst. The catalyst splits hydrogen gas into protons and electrons. The protons pass through the membrane, and the electrons pass out of the cell as an electric current. When the protons and electrons meet again on the other side of the membrane, they combine with oxygen from the air to form water. As long as there is a supply of hydrogen, the cell continues to produce electricity.

From 2004 to 2007, three experimental Mercedes-Benz buses were trialled in Perth. They ran on hydrogen, and in the photo below, you can see the exhaust of pure water vapour above the bus.



Investigation 2 Action of catalysts

Aim

To investigate whether manganese oxide and other substances act as catalysts for the decomposition (breakdown) of hydrogen peroxide.

Materials

- beaker, e.g. 250 mL
- fresh hydrogen peroxide solution (3%)
- 6 test tubes and test tube rack
- iron filings
- sand or dust
- piece of fresh potato
- piece of liver (or other red meat)
- short piece of string (jute) or taper
- spatula
- **manganese dioxide**
- **iron(III) chloride**

Note: If you add two drops of detergent to each tube, the height of the foam produced in a certain time gives you an indication of the rate of the reaction.

Planning and Safety Check

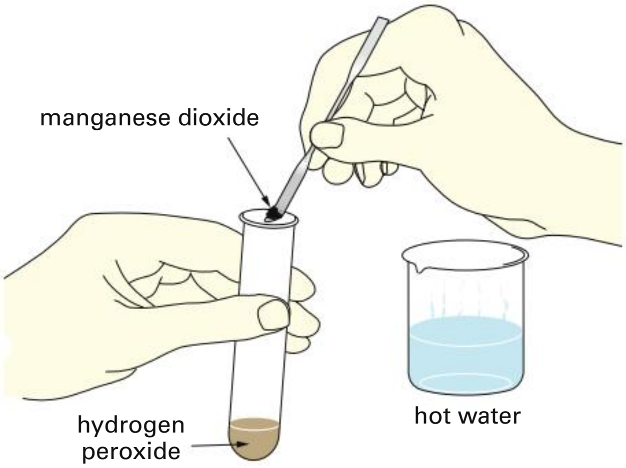
- Which substances will you test as catalysts?
- If you need a data table, design one.

Method

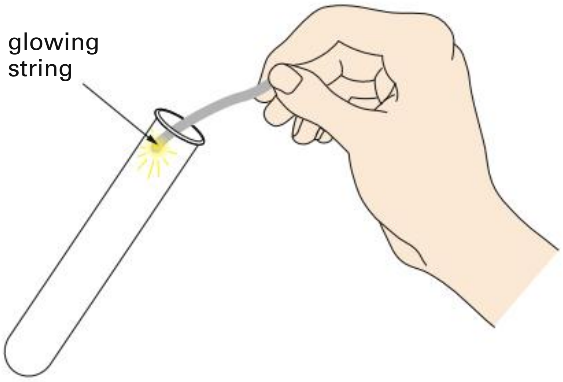
1 Add 2 mL of hydrogen peroxide to a test tube.
Is there any reaction at room temperature?

2 Half fill a beaker with hot water. Put the test tube in the hot water and watch it carefully.
Record your observations.

3 Put 2 mL of hydrogen peroxide in a second test tube and add a small amount of manganese dioxide powder (about this size ●).
Record your observations.
Do this at room temperature and in hot water.



4 Light one end of the piece of string, then blow it out so that it has a glowing tip. Put this glowing tip into the test tube. If the string bursts into flame, oxygen is present.



5 Observe what is left around the mouth of the test tube.

6 Repeat the experiment using other substances instead of manganese dioxide. You could use iron chloride, iron filings, sand, a piece of fresh potato, a piece of liver (or other meat).
Record your results in a data table. For each substance tested, say whether or not it speeded up the reaction.

Discussion

1. Suggest why you heated the hydrogen peroxide in Step 2.
2. Did the manganese oxide act as a catalyst for the decomposition of hydrogen peroxide? Explain your answer.
3. What substance was produced as the hydrogen peroxide decomposed?
4. If the other product of the decomposition is water, write a word equation to describe the reaction.
5. If a catalyst is not used up in a reaction, predict what should happen if you added another 2 mL of hydrogen peroxide to the test tube after Step 5.
6. Which of the other substances you tested was the best catalyst for the decomposition of hydrogen peroxide?

Inquiry

Some living or once-living things contain a biological catalyst that acts on hydrogen peroxide. Test various plant and animal materials to see if they contain this catalyst. You could bring these substances from home. (You may need to grind up most of the substances with sand before adding them to the peroxide. You could use a mortar and pestle to do this.)

Does boiling the substances affect their ability to act as catalysts?

Enzymes

Many chemical reactions occur in living things. These reactions need biological catalysts called **enzymes** (EN-zimes) to control them, otherwise they would occur much too slowly to keep the organisms alive. Your own body contains thousands of enzymes, each one acting to speed up, or sometimes slow down, one type of reaction. Particular enzymes do particular jobs. Those in your saliva, stomach and intestines control the digestion of food. Others assist in extracting energy from food.

Hydrogen peroxide is normally produced in the body. However, hydrogen peroxide is toxic, so the body produces an enzyme to decompose it. This enzyme is called *catalase*. It is produced in the liver, and is found in nearly all animal cells, especially in blood. That is why blood and liver rapidly decompose hydrogen peroxide, as you probably found in Investigation 2. (One molecule of catalase can decompose 44 000 molecules of hydrogen peroxide per second at 0°C.) Catalase is also found in plant cells.

Working with technology To see an animated version of Fig 5, open the **Enzyme action** animation at www.OneStopScience.com.au.

OneStopScience

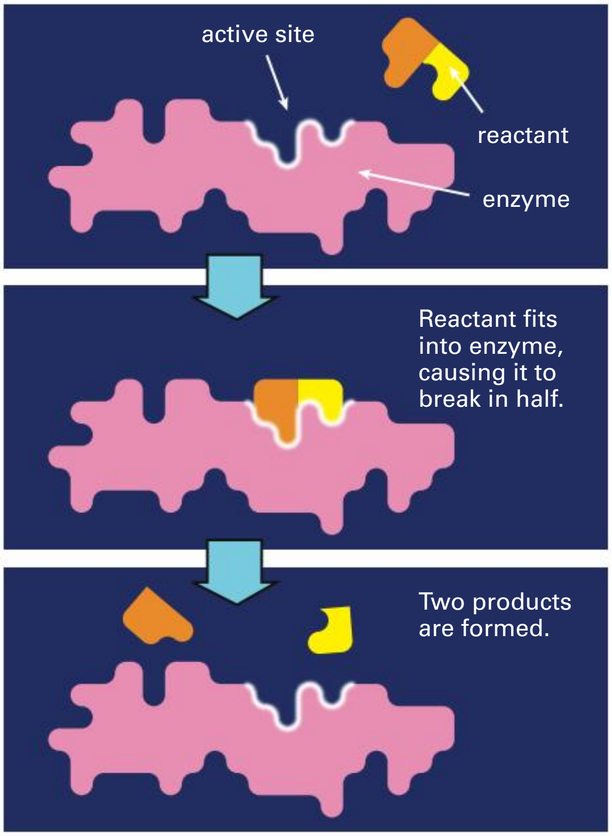


Fig 5 This model shows how an enzyme works by breaking down a reactant. Notice that the enzyme is not used up in the reaction.

Check

1 Hydrogen peroxide is best kept in a refrigerator. Why?

2 A scientist did an experiment to see how effective the following solids were as catalysts for the decomposition of hydrogen peroxide solution: copper oxide CuO, lead oxide PbO_2, manganese dioxide MnO_2. He obtained the results below in a series of experiments using equal volumes of hydrogen peroxide of the same concentration.

Solid	Mass of solid added (g)	Volume of oxygen (mL) produced in the first minute of the reaction
granular MnO_2	0.1	3
powdered MnO_2	0.1	24
powdered MnO_2	0.2	56
powdered PbO_2	0.1	90
powdered CuO	0.1	0

a Which of the solids in the table does not act as a catalyst for the decomposition of hydrogen peroxide?
b Which of the solids is the most effective catalyst for the reaction?
c Explain the differences between the results for the three tests with manganese dioxide.
d Did the scientist control variables in this experiment? If so, how?

3 Two solutions X and Y are being reacted together in an industrial plant by mixing them in a large container. Suggest at least two ways in which the reaction could be speeded up.

4 Amylases are enzymes that break down starch to form glucose (a sugar). One of these amylases is found in saliva.

Mick decided to study the rate of the amylase reaction at different temperatures. He did this by timing how quickly a glucose test strip changed colour when saliva was added to a starch suspension. Below is the data table of Mick's results.

Temperature of starch solution (°C)	Time of colour change (min)
20	30
30	12
35	9
40	7

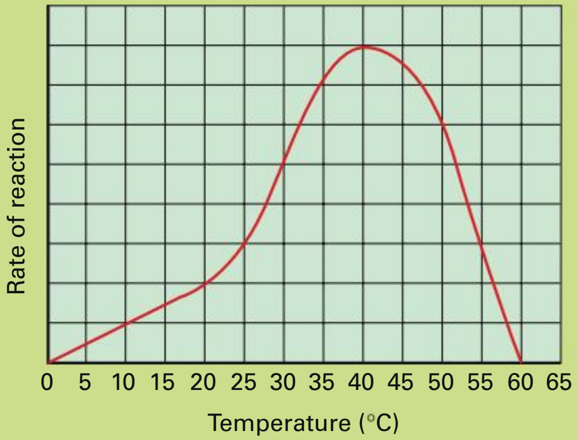
a Why did the glucose test strip change colour after the saliva was added?
b Draw a graph of the results.
c What is the relationship between temperature and reaction time? Write a generalisation.

5 Write a paragraph explaining why catalysts are important to life.

6 Suggest why some washing powders contain enzymes.

Challenge

1 All enzymes are proteins, which are easily destroyed by high temperatures. The graph below shows how a particular biological reaction is affected by temperature. The reaction is catalysed by an enzyme.



a At which temperature did the reaction take place most quickly?

b What happened to the reaction rate as the temperature was raised from 0°C to 40°C?

c What happened to the reaction at 0°C and at 60°C?

d Suggest why the reaction got slower as the temperature was raised from 40°C to 60°C.

2 The thyroid gland (which is in the throat) produces a hormone called thyroxine, which helps the body 'burn up' fat. People who are abnormally thin sometimes have part of their thyroid gland removed surgically. Suggest a reason for this.

3 Rennin is an enzyme produced in the stomachs of young mammals. It reacts with the protein in milk and solidifies it in a process called *clotting*.

Imagine that you have been asked to investigate how the reaction time for the clotting of milk is affected by temperature. You have a supply of rennin solution and all the necessary laboratory apparatus.

a Describe how you would carry out this experiment.

b What results would you expect?

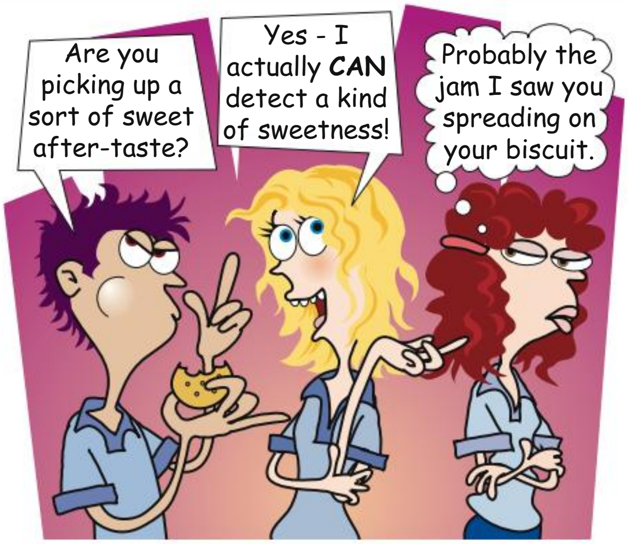
4 Enzymes help in the manufacture of substances in our bodies as well as breaking them down. Use Fig 5 on page 13 to draw a labelled diagram showing how they can manufacture a product.

TRY THIS

1 Use library resources or the internet to find out the uses of hydrogen peroxide.

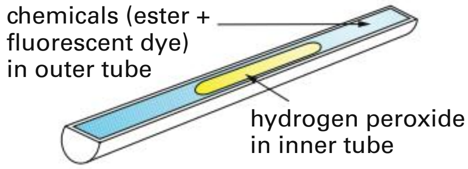
2 There is a way to test the action of saliva on food. Chew a piece of dry savoury biscuit for a minute or two. Move it about with your tongue. Can you notice any changes in taste before you swallow it?

You should find that the biscuit tastes sweeter after a while. This is because the starch in the biscuit has been broken down to sugar by the enzymes in your saliva.



Everyday reactions

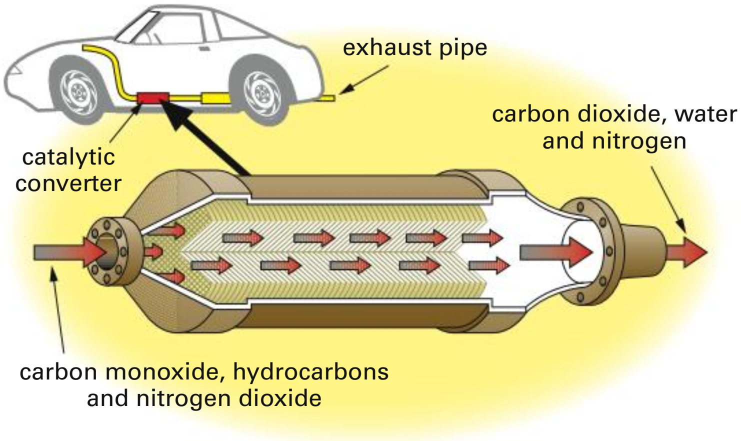
At the Sydney 2000 Olympics the people in the crowd were given light sticks (glow lights) to wave around. How do these light sticks work? They contain two parts—an outer plastic tube and an inner one. When you bend the stick, you break the inner tube and the chemicals react, producing light.



- Suggest why light sticks only work for a few hours.

Cars are fitted with antipollution devices called **catalytic converters**. These are packed with plates that are coated with platinum or rhodium. These metals are catalysts for reactions that convert the exhaust gases to less harmful ones.

- Suggest why a catalytic converter contains so many honeycombed plates.



The rapid inflation of an airbag in a car accident is the result of a very rapid chemical reaction. When the crash sensor detects a collision, a chemical reaction occurs, which fills the nylon bag with nitrogen gas in less than a second.

- Would the reaction between zinc and hydrochloric acid be suitable for inflating an airbag? Explain.

WEBwatch

For videos of crash tests with air bags, go to **www.OneStopScience.com.au** and follow the links to **Crash test**.

1.3 Energy and mass in reactions

Exothermic and endothermic

Whenever there is a chemical reaction, an energy change occurs. Energy is produced in some reactions, and is needed to start other reactions.

An **exothermic reaction** is one that releases energy. This energy is usually in the form of heat, but sound, light and electrical energy can also be produced. You may have noticed that when you mix certain chemicals the test tube becomes warm, indicating that heat energy has been released. An important exothermic reaction is **combustion** (or burning), which releases heat energy, light energy and some sound energy.

Another exothermic reaction occurs inside your body during the process of respiration. Most of the energy from respiration is used to keep your body working, but some of it is released as heat. This keeps your body temperature at about 37°C, even when the temperature around you is much lower. Some exothermic reactions produce electricity. For example, the chemicals inside a torch battery react to produce electricity.

An **endothermic reaction** is one where some form of energy must be supplied. For example, plants need energy from sunlight to be able to make food from carbon dioxide and water during photosynthesis.

glucose + oxygen → carbon dioxide + water + ENERGY

Fig 6 Our bodies release heat in the process of respiration. In this heat image of a person on a treadmill, the warmest areas are red and the coolest areas are blue.

carbon dioxide + water + ENERGY → plant food + oxygen

Sherbet is a mixture of baking soda and citric acid. When it is mixed with the water in your mouth, an endothermic reaction occurs, taking heat energy from your mouth and making it feel cooler. Cold packs used for treating sports injuries work in the same way. When the pack is broken, an endothermic reaction occurs, taking heat from the surroundings and making the pack feel cold.

Some endothermic reactions require electrical energy to make them go. For example, when you charge a car battery, the electricity produces chemical reactions inside the battery. Electricity is also needed for **electroplating**. For example, when electricity is passed through the silver nitrate solution (Fig 7), chemical reactions occur and silver moves from the rod to be deposited as a thin layer on the teapot.

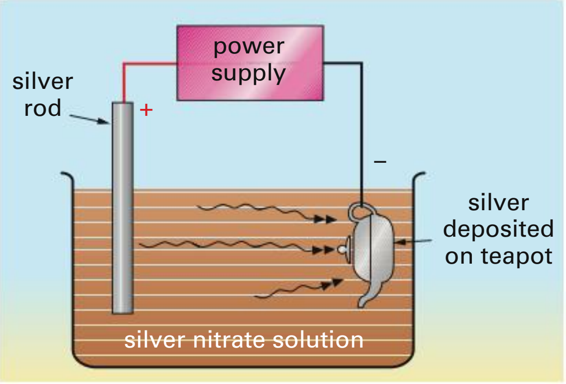


Fig 7 Electroplating a teapot

Investigation 3 Exothermic or endothermic?

Research question

Which reactions are exothermic (produce heat) and which are endothermic (take heat from their surroundings)?

PART A

Materials

- 2 test tubes
- thermometer
- datalogger and temperature probe (optional)
- zinc
- sodium thiosulfate (hypo)
- dilute **hydrochloric acid** (1 M)

Method

1 Add dilute hydrochloric acid to a piece of zinc in a test tube. Feel the test tube.

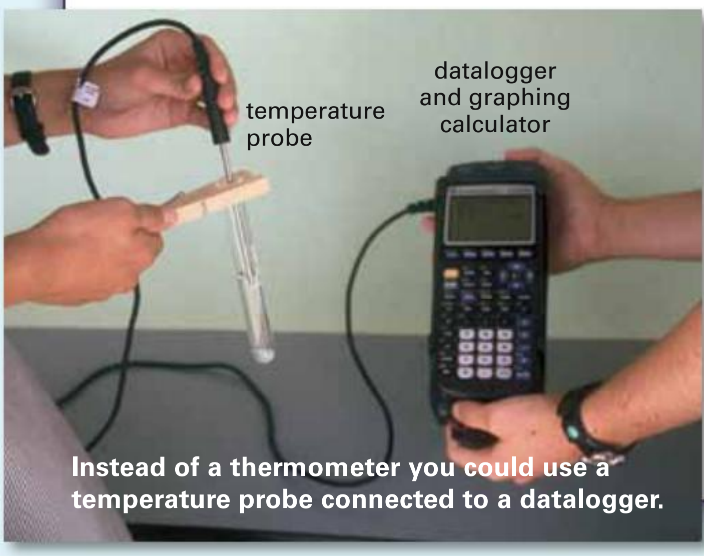
Is the reaction exothermic or endothermic?

2 In a second test tube, dissolve a small amount of sodium thiosulfate in water.

Is the reaction exothermic or endothermic?

3 Your observations so far are *qualitative*. You can say that the temperature increased or decreased, but you cannot say by how much. Repeat Steps 1 and 2, but this time use a thermometer to measure the change in temperature.

Record your *quantitative* results.



Instead of a thermometer you could use a temperature probe connected to a datalogger.

PART B

Materials

- a range of compounds, e.g. ammonium chloride, anhydrous calcium chloride, potassium chloride, potassium hydroxide, potassium nitrate, sodium chloride

Planning and Safety Check

Each of the salts in the list above dissolves in water. The process either releases heat or absorbs it. Your task is to design a fair test so that you can arrange the dissolving salts in order, from the most exothermic reaction to the most endothermic.

- Write out your plan, explaining how you will control variables.
- Make a list of the equipment you will need.
- Design a data table for your results.
- Some of the salts are corrosive and some are toxic. What safety precautions will you need to take when using them?

Report

Carry out your experiment and write a report using the five headings listed in Step 3 on page 8.

Inquiry

Investigate ways of making your results from Part B more accurate. Here are some hints.

- Measure the amount of heat produced or taken from the surroundings. To do this you need to use the formula:

  heat change (joules) = volume of water (mL) × change in temperature (°C) × 4.2

- To compare different salts accurately, you need to measure the heat change per gram of compound.
- To reduce heat transfer, you need to insulate the reaction container.

Science as a Human Endeavour

Lavoisier and combustion

In the 18th century, scientists could not explain what happened during combustion. They tried to explain it in terms of the 'phlogiston' theory. This theory said that all metals contained a mysterious thing called *phlogiston* (flo-JIST-on). When a metal was heated, the phlogiston escaped, thus producing a new substance. However, this theory was unsatisfactory since most metals increased in mass when they were heated. If the phlogiston theory was correct, the metals should *decrease* in mass when heated; hence the problem.

A French scientist called Antoine Lavoisier (la-VWAH-zee-ay) set out to solve the combustion problem. He heated various metals in air and they all increased in mass. However, when he heated tin in a *sealed* flask, there was no change in mass. When he opened the flask, however, air rushed in and its mass increased.

From these observations, Lavoisier inferred that when the tin was heated, it reacted with something in the air. He then predicted that the mass gained by the tin should be the same as the mass of air used up. If this was true, then there should be no change in mass during *any* chemical reaction. To test this hypothesis Lavoisier made more careful measurements and was able to convince himself that 'matter cannot be created or destroyed'. It can only be changed during a chemical reaction.

In 1774, Joseph Priestley, the British clergyman who had discovered oxygen, visited Lavoisier in Paris. Lavoisier saw the importance of oxygen immediately. By doing more carefully planned experiments, it was not long before he had discovered that both oxygen and nitrogen are present in air. When substances burn in air, they combine with oxygen but not with the nitrogen. Lavoisier also applied his ideas to respiration in the body, and showed that food reacts with oxygen to produce energy, as in combustion. In 1786, he published the results of his experiments—and the phlogiston theory had to be abandoned.

Lavoisier was very good at organising and interpreting information, and has been called the 'father of modern chemistry'. Perhaps the most important thing he did was to stress the need for careful measurements—one of the most important skills in science. Because he was a nobleman as well as an unpopular tax collector, Lavoisier was executed by guillotine during the French Revolution.

In the experiment on the next page you can test Lavoisier's hypothesis for yourself.

Questions

1 What was phlogiston?
2 Why was the phlogiston theory unsatisfactory?
3 What happened when Lavoisier heated metals in air?
4 Lavoisier heated tin in a sealed flask. When he opened the flask, air rushed in. How can you explain this?
5 Complete this sentence. Lavoisier discovered that air is a mixture of ______ and ______. When you burn something in air, it reacts with the ______.

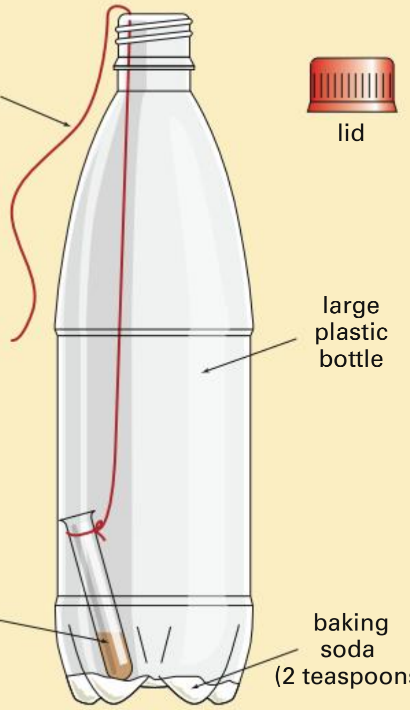
Experiment 2 Does mass change in a reaction?

Research question

Does the mass change when vinegar reacts with baking soda?

Materials

- large plastic soft drink or sports drink bottle, with lid
- 2 small test tubes
- piece of string
- baking soda (sodium hydrogen carbonate)
- vinegar (acetic acid)
- teaspoon
- measuring cylinder
- balance (accurate to 0.01 g)



Planning and Safety Check

Your task is to design an experiment to answer this question:
Does the mass of the bottle and its contents change when the vinegar reacts with the baking soda?

- Study the diagram and the list of materials. In a group, discuss how you will do the experiment. When you have worked this out, write down your Method—giving in detail the steps you will take.
- Why do you need to do the experiment with and without the lid?
- List the safety precautions that will be necessary.
- Design a suitable data table to record your results. How many rows will you need? How many columns?
- Before you start, predict what you think the results of the experiment will be.

Method

Check the steps in your method with your teacher, then carry out the experiment.

Results

1 Without the lid, did the mass increase, decrease or stay the same? Suggest why this happened.

2 With the lid on, did the mass increase, decrease or stay the same? Explain.

Discussion

1 Were your results accurate? Explain.

2 Could you improve your method? How?

3 Would it be worth repeating the experiment? Explain.

Conclusion

Were your predictions in the Planning and Safety Check correct? In other words, do your results support the hypothesis that the total mass of the substances in a reaction does not change?

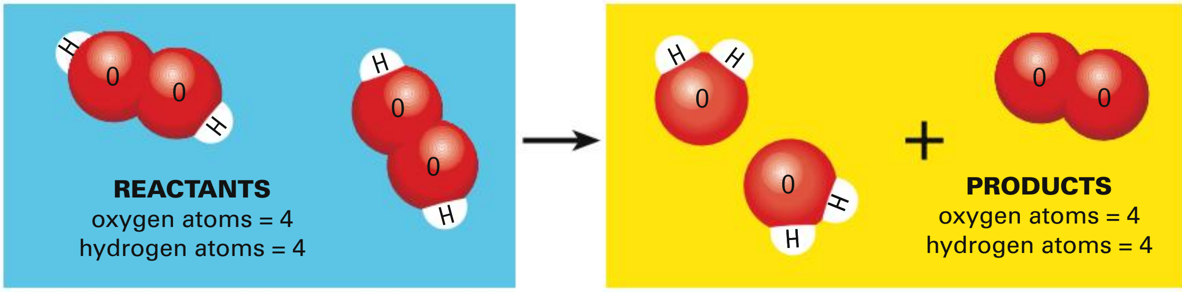
Law of conservation of mass

Many different reactions have been studied to test Lavoisier's hypothesis, and it has always proved correct. Hence the hypothesis is now called the law of **conservation of mass.**

> **Law of conservation of mass**
> The total mass of the reactants is always equal to the total mass of the products.

What this means is that the number of atoms that take part in a chemical reaction is equal to the number of atoms in the products. For example, the decomposition of hydrogen peroxide to form water and oxygen can be shown using the models below. No atoms are lost in the reaction—they are simply rearranged.

hydrogen peroxide	→	water	+	oxygen
$2H_2O_2$	→	$2H_2O$	+	O_2

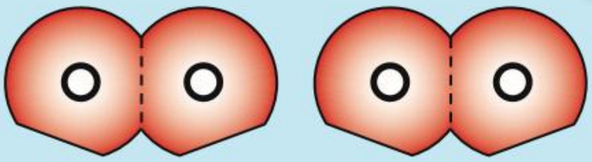


Activity

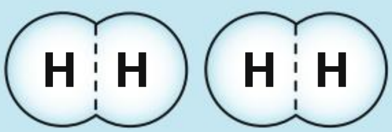
You can use cardboard cutouts to make models of chemical reactions. The cut-outs below represent molecules of oxygen and hydrogen.

1. Photocopy or trace the oxygen (O_2) and hydrogen (H_2) molecules below and cut them out.
2. Use the H_2 and O_2 molecules to make a molecule of hydrogen peroxide H_2O_2 as shown above. You will need to break the molecules into their atoms by cutting along the dotted lines. Unless you do this, the 'reaction' cannot occur.
3. Now take the H_2O_2 molecule apart to show that you need two of them to form two H_2O molecules and one O_2 molecule, as in the equation above.
4. Use your models to show what happens when water decomposes to form H_2 and O_2. Try to write an equation with the same number of atoms on both sides of the equation.

> **Working with technology**
> If you have a molecular models kit, you can make three-dimensional models. You may even be able to animate the equation models using computer software such as DreamWeaver, Photoshop or Flash.



oxygen (O_2)



hydrogen (H_2)

Check

1 Copy and complete these sentences.
  a Burning is a chemical reaction that produces mainly ______ and ______.
  b The electricity produced by a torch battery is caused by a ______ ______.
  c The reaction used to silverplate a teapot needs ______ to make it go.
  d Combustion is an example of an ______ reaction.
  e ______ is a type of chemical reaction in which a substance breaks down into simpler substances.
  f The total mass of the ______ is always equal to the total mass of the ______.

2 50 mL of hydrochloric acid was added to a beaker. The mass of the beaker plus acid was found to be 151.0 g. Then 5.0 g of magnesium ribbon was added to the acid. After a fizzing reaction in which all the magnesium was used up, the mass of the beaker and its contents was 155.6 g.
  a Does this experiment agree with the law of conservation of mass? Explain.
  b How could you modify the experiment to show that mass is conserved in this reaction?

3 Which forms of energy can be produced in exothermic reactions?

4 A log of wood burns, leaving a pile of ashes. What other new substances are produced during the reaction? Is the mass of the new substances produced during the reaction the same as the mass of the log to start with? Explain your answer.

5 Keeping in mind the law of conservation of mass, explain the following.
  a When a match burns, the mass of the charred wood and ash left is *less than* the original mass of the match.
  b When steel wool burns, the mass of the blackened material is *more than* the original mass of the steel wool.
  c As a plant grows, the mass of the plant is *more than* its original mass.

Challenge

1 What are the similarities and differences between combustion and respiration?

2 a When two molecules of hydrogen peroxide decompose, how many molecules of water are formed? How many molecules of oxygen? (Hint: Use the equation on the previous page.)
  b If a million molecules of hydrogen peroxide decompose, how many molecules of oxygen will be produced?

3 a Joseph Priestley produced oxygen by decomposing mercury oxide by heating. Write a word equation for this reaction.
  b Write a word equation for what happens when mercury is heated and reacts with air (oxygen).

4 Lavoisier found that metals increased in mass when heated, yet a diamond (carbon) burnt away completely. Try to explain what happened, using a word equation if possible.

5 Indira finds that 7 grams of iron filings combine with exactly 4 grams of sulfur to form 11 grams of iron sulfide. She repeats the experiment using 5 grams of iron filings and 5 grams of sulfur.
  a How much iron sulfide will be formed?
  b Part of one of the reactants will be left unreacted this time. Which one, and how much of it will be left?

TRY THIS

Next time your lawn is mowed, make a large heap from the lawn clippings. Several days later open the heap with a garden fork and put your hand close to the grass.
Write an inference to explain your observations.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 Some reactions occur slowly, while others occur quickly. The speed of a reaction is called its ______.

2 The rate of a reaction usually ______ as the temperature increases. Similarly, the rate usually decreases as the ______ decreases.

3 Increasing the ______ of the reactants usually increases the rate of a reaction.

4 Increasing the surface ______ of the reactants usually increases the rate of a reaction.

5 ______ are substances that increase the rate of a reaction without being used up.

6 Reactions that release energy are called ______. Reactions that take in energy are called ______.

7 The law of ______ of mass says that the total mass of the reactants in a chemical reaction is always equal to the total mass of the ______.

area
catalysts
concentration
conservation
endothermic
exothermic
increases
products
rate
temperature

Working with technology

Try doing the Chapter 1 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

1 Which of the following is *not* true?
A Heating sometimes causes a reaction.
B Some reactions produce electricity.
C Reactions usually take only a few seconds.
D Reactions sometimes produce colour changes.

2 John heated a solid in a test tube and found that its mass decreased. He repeated the experiment several times—with the same result. Which of the following is the *most likely* explanation for the decrease in mass?
A The solid gave off an invisible gas during heating.
B Some of the solid melted into the test tube during heating.
C John spilt some of the solid during the experiment.
D The test tube expanded when heated and became lighter.

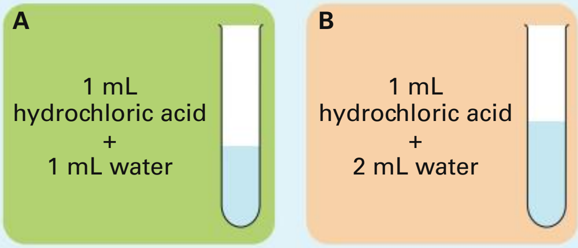
3 Which of the following reactions are exothermic, and which are endothermic?
a acid reacting with lead in a car battery
b baking a loaf of bread
c combustion
d photosynthesis
e respiration inside your body

4 Which of the following can be used as an indication of how fast a chemical reaction occurs? (There may be more than one answer.)
A how much product is formed in a given time
B how rapidly the solutions are mixed
C how much heat is given off in a certain time
D how quickly the reactants are used up
E how long it takes to observe a change

5 What effect does each of the following have on a chemical reaction (speeds it up, slows it down or has no effect)?

- **a** adding water to the reactants
- **b** heating the reactants
- **c** increasing the *amount* of each reactant
- **d** increasing the *concentration* of the reactants
- **e** lowering the temperature of the reactants
- **f** using a catalyst
- **g** using the reactants in powdered form

6 Peter has set up two test tubes as shown. If he adds the same amount of zinc filings to each tube, predict which reaction will be faster. Explain your answer.



7 To each of four test tubes, Carol added 1 mL of hydrogen peroxide and 5 drops of liquid detergent. She warmed the tubes by placing them in a beaker of hot water, and then added substances A, B and C as shown in the table.

In each tube the mixture frothed up, and Carol measured the height of the foam.

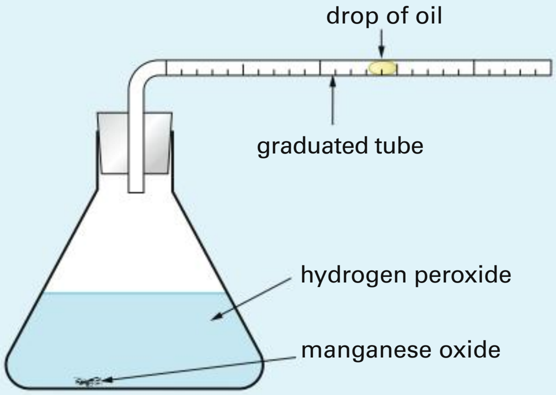
Test tube	Substance added	Height of foam produced (cm)
1	–	2
2	A	8
3	B	5
4	C	2

- **a** Are any of the three substances catalysts for the decomposition of hydrogen peroxide? Which one(s)? How do you know?
- **b** What is the purpose of test tube 1?

8 Flour in a sack will not burn very well, even when heated with a blowtorch. However, flour dust in the air in a flour mill burns so rapidly at room temperature that a small spark can cause it to explode violently.

How can you explain this difference in reaction rates?

9 The apparatus shown was used to measure the volume of oxygen produced when the catalyst manganese oxide was added to hydrogen peroxide solution.



Time (min)	0	1	2	3	4	5	6
Volume (mL)	0	15	20	23	24	25	25

- **a** Draw a graph displaying the results.
- **b** How long did it take for 10 mL of oxygen to be produced?
- **c** How much oxygen was produced in $1\frac{1}{2}$ minutes?
- **d** How long did the reaction take to reach completion?
- **e** How did the rate of the reaction change with time?
- **f** It was suggested that powdered copper is a better catalyst for the decomposition of hydrogen peroxide than manganese oxide. Write a brief plan of an experiment to find out if this is true.

Check your answers on page 302.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science Inquiry Skills

Evaluating experiments

Students in a Year 10 science class were asked to design and conduct their own experiments to investigate how quickly sugar dissolves in water. Below are the experimental reports written by two of the students.

Pedro's report

Aim

To show that the amount of sugar added to water changes how long it takes to dissolve.

Method

1 We put a sugar cube into 100 mL of hot tap water.
2 We measured the time it took for the cube to dissolve completely.
3 We repeated the experiment using 2, 3, 4, 5 and 6 cubes of sugar.

Results

Number of sugar cubes	Time for sugar to dissolve (seconds)
1	5
2	11
3	15
4	20
5	25
6	30

Conclusion

If you double the amount of sugar, it takes twice as long to dissolve.

Libby's report

Aim

To see if the amount of sugar changes the time taken for the sugar to dissolve in water.

Method

1 We put a level teaspoon of sugar in a beaker of water kept at 80°C using a Bunsen burner.
2 We stirred the water and measured the time taken for all the sugar to dissolve.
3 We did this three times and then calculated the average dissolving time.
4 We repeated the whole experiment using 2, 3 and 4 teaspoons of sugar.

Results

Amount of sugar (teaspoons)	Temp (°C)	Time to dissolve (s)	Average time to dissolve (s)
1	80	3, 3, 3	3
2	80	8, 7, 9	8
3	80	13, 14, 12	13
4	80		

Conclusion

The more sugar you add to a beaker of water at the same temperature, the longer it takes for the sugar to dissolve.

Questions

1 Is Pedro's conclusion correct? Explain your answer.
2 Complete Libby's table by predicting the average time taken for 4 teaspoons of sugar to dissolve.
3 The teacher said both experiments had some weaknesses and could be improved. Give two weaknesses in Pedro's method and explain why you think each is a weakness.
4 Give two weaknesses in Libby's method and explain why you think they are weaknesses.
5 Whose results do you think were more *reliable*? Justify your answer; that is, give a sound reason for it.
6 From these two experiments is it **valid** to conclude that a teaspoon of sugar dissolves faster in water than a sugar cube does? To draw a valid conclusion from an experiment the variables must be properly controlled. The results must also be logical and relevant to what you are trying to find out.

2 Road science

In this chapter you will …

Science Understanding

- use a ticker timer or datalogger to gather data to analyse the motion of everyday objects
- use Newton's second law (F = ma) to predict how a force affects the movement of an object
- use the law of conservation of energy to describe what happens in a road accident
- explain in terms of energy why no machine can be 100% efficient

Science Inquiry Skills

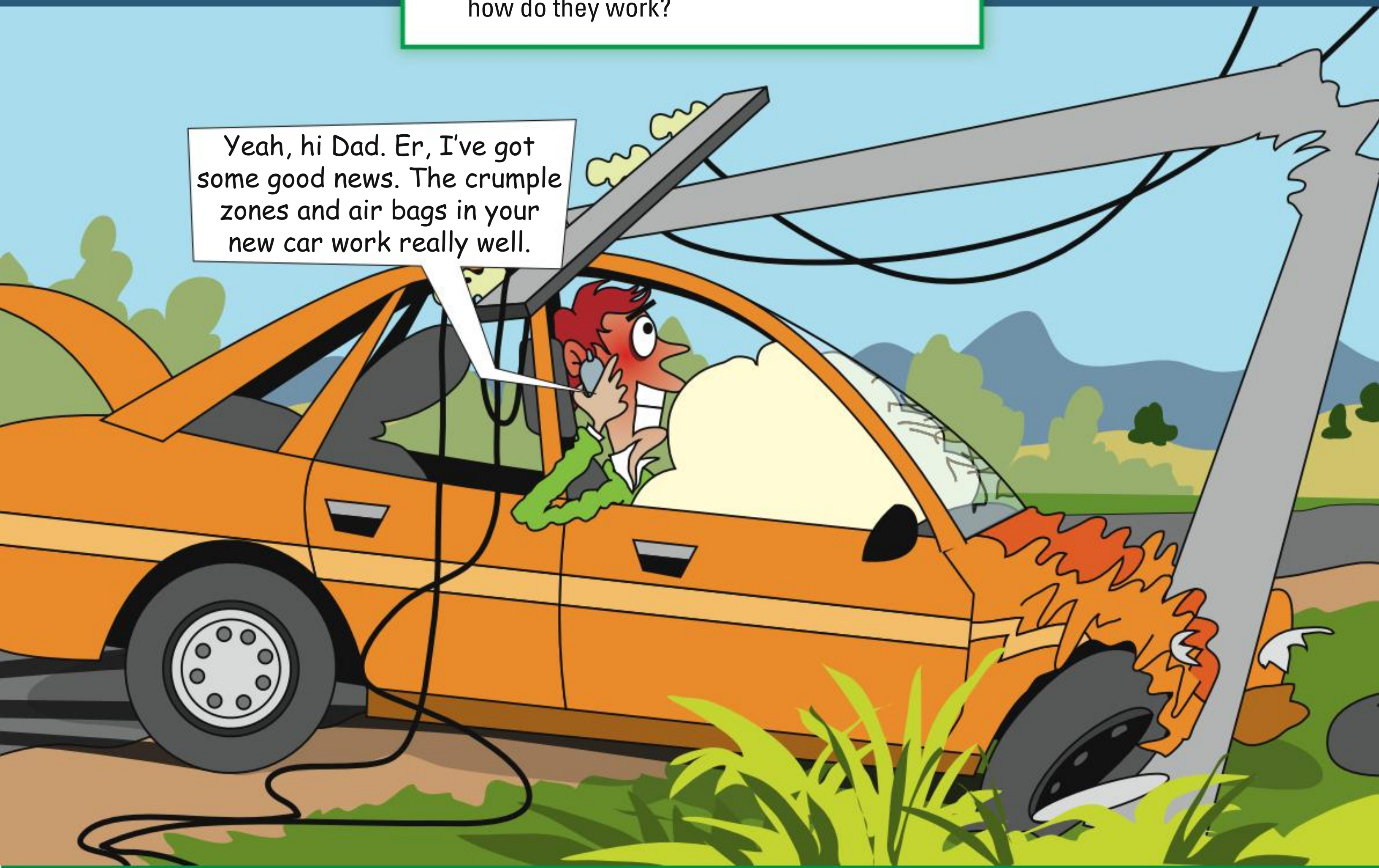
- draw and interpret graphs of distance, speed and acceleration versus time
- use motion equations to calculate distance, speed, acceleration and time

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

In a small group, decide on answers for each of the questions below. This should give you some idea of how much you already know about the science involved in driving a car.

1 How do you calculate your average speed for a trip?
2 What is deceleration?
3 When you have to stop in an emergency, what is meant by the term ‘reaction time’?
4 When you brake hard you sometimes lose control of the car. Why is this?
5 Why do you fall forward when a car brakes suddenly?
6 What are the crumple zones in a car, and how do they work?



2.1 Speed and acceleration

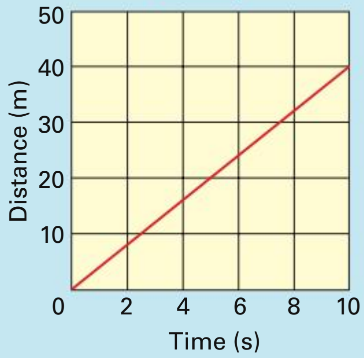
Activity

Three radio-controlled cars, A, B and C, were being raced against each other. They all crossed the starting line together. The motion of the three cars was recorded using a motion detector and datalogger. The graphs show the position of each car, measured from the starting line, for the first 10 seconds of the race. Use the graphs to answer these questions.

1. Which variable is measured on the horizontal axis of each graph?
2. What is measured on the vertical axis?
3. Which car moved at a constant speed throughout the 10 seconds? How do you know?
4. Which car stopped during the race? How do you know?
5. How far did each car travel in 10 seconds?
6. Which car was winning the race after 10 seconds? Explain your answer.
7. Which car was travelling the fastest at:
   - **a** 4 seconds?
   - **b** 10 seconds?

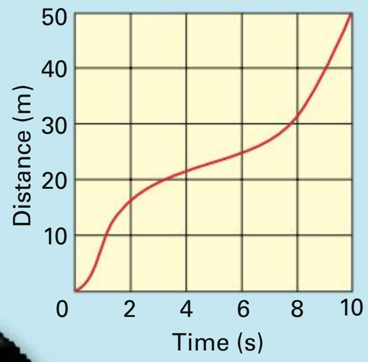
   Give reasons for your answers.
8. At what speed did car A travel during the first 10 seconds?

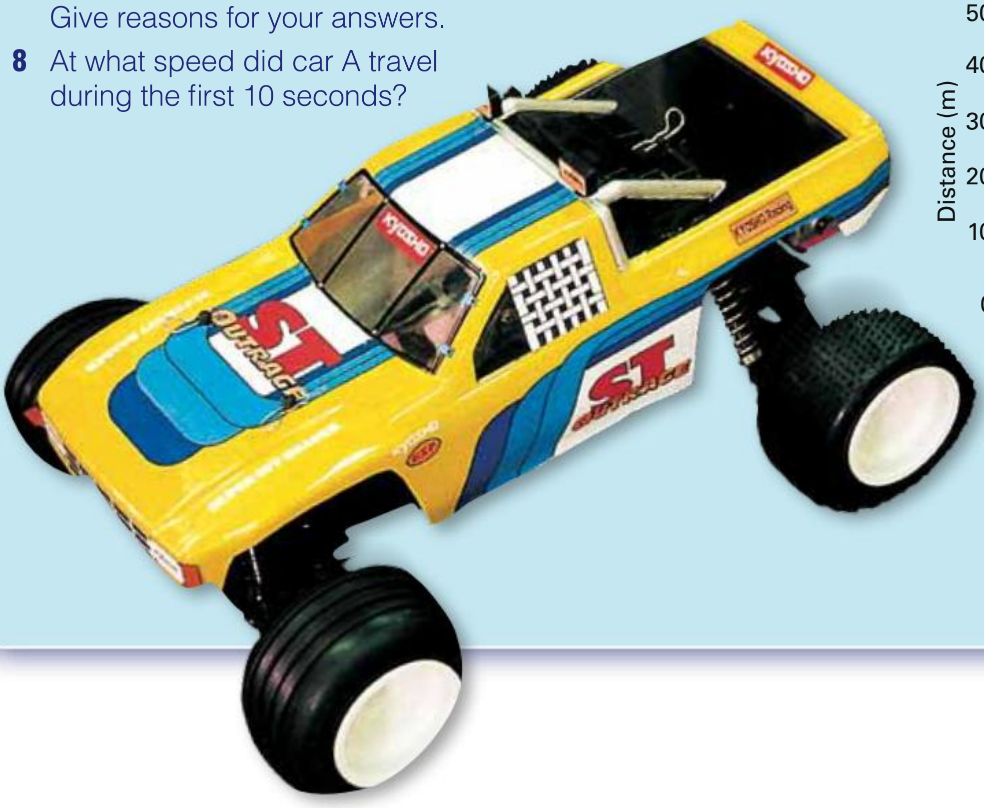
Car A



Car B

Car C





Speed

Look at the graph for car A. It travelled 40 metres in 10 seconds. To calculate its **average speed** you divide the distance travelled by the time it takes to travel that distance. The speed is usually measured in kilometres per hour (km/h) or, in this case, metres per second (m/s).

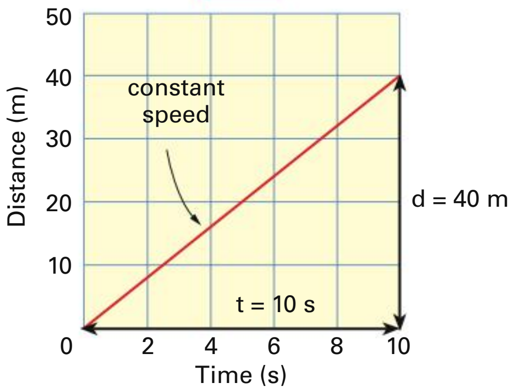
$$\textbf{average speed} = \frac{\textbf{distance travelled}}{\textbf{time taken}}$$

$$v_{av} = \frac{d}{t} = \frac{40\text{ m}}{10\text{ s}} = 4\text{ m/s}$$

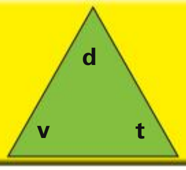
You can also find the average speed by calculating the slope of the distance–time graph.

$$v_{av} = \frac{d}{t} = \text{slope of graph}$$

Car A



You can rearrange the equation using the triangle rule:



$$d = vt$$

$$t = \frac{d}{v}$$

You can also calculate the average speed in the same way you calculate any average:

$$v_{av} = \frac{v + u}{2}$$

where v is the final speed and u is the initial speed.

Notes

1 To convert m/s to km/h you multiply by 3.6.

$$1\text{ m/s} = \frac{1}{1000}\text{ km/s} = \frac{60 \times 60}{1000}\text{ km/h} = 3.6\text{ km/h}$$

To convert km/h to m/s you divide by 3.6.

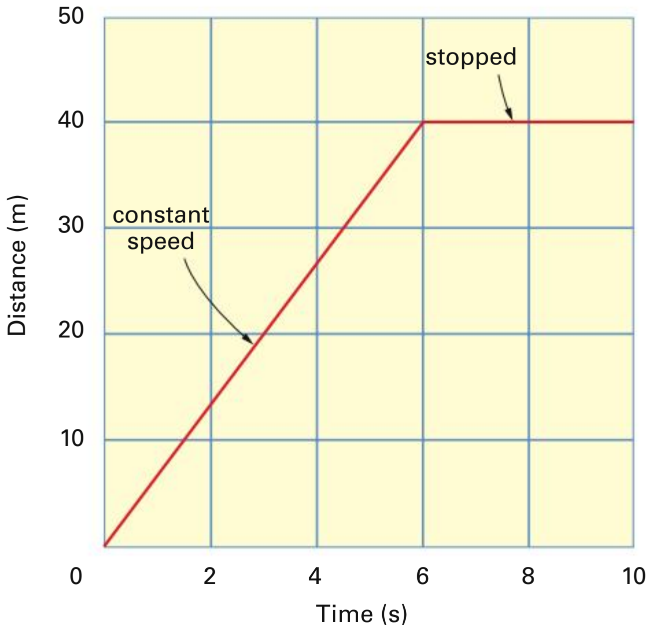
2 The symbol v is used for speed because v stands for *velocity*. Velocity is the same as speed except it includes a direction; for example, an aeroplane might have a velocity of 400 km/h *north*.

Now look at the graph for car B. For the first 6 seconds car B also travelled at a constant speed. You know this because the graph is a straight line. The graph is steeper than for car A, which means that for the first 6 seconds it travelled faster than car A. You can calculate the speed as before:

$$v_{av} = \frac{d}{t} = \frac{40\text{ m}}{6\text{ s}} = 6.7\text{ m/s}$$

From 6 seconds to 10 seconds the graph is flat (zero slope). This means that the speed was zero, or the car had stopped.

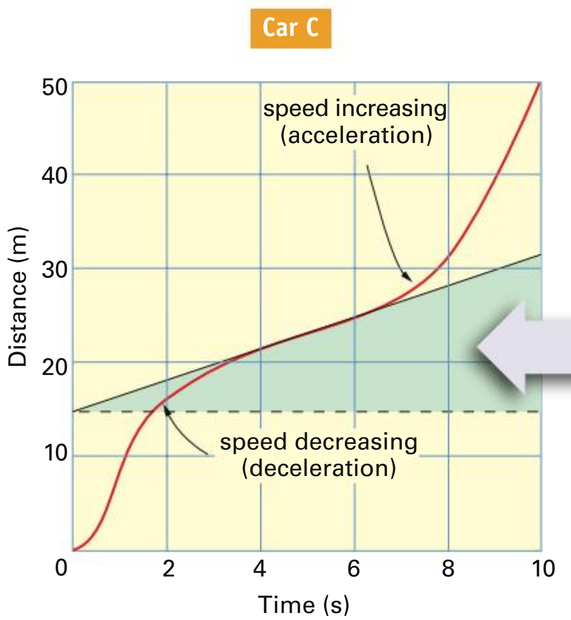
Car B



Finally, look at the graph for car C. The average speed can be calculated as usual:

$$v_{av} = \frac{50\text{ m}}{10\text{ s}} = 5\text{ m/s}$$

From the slope of the graph, however, you can tell that the speed varied over the 10 seconds. After 1 second the car was moving very quickly (steep slope). Around 5 seconds it had slowed down (not so steep), and finally it sped up again.



$$\text{slope of tangent at 5 seconds} = \frac{32\text{ m} - 15\text{ m}}{10\text{ s}} = \frac{17\text{ m}}{10\text{ s}} = 1.7\text{ m/s}$$

Fig 1 The slope of the distance–time graph gives the instantaneous speed at a particular time.

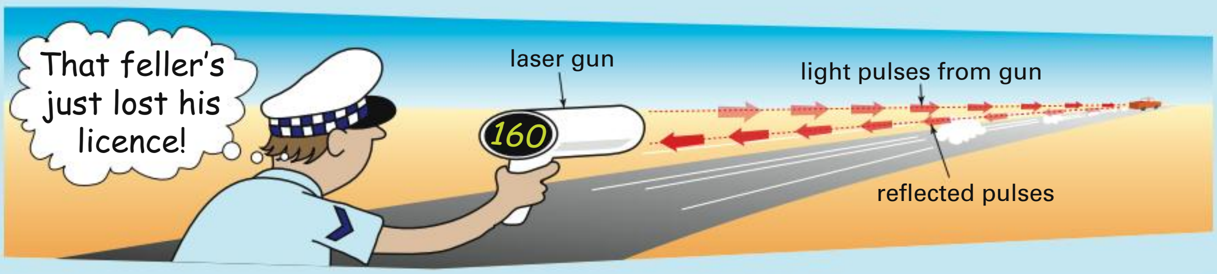
You can find the speed at any particular time by drawing a tangent to the curve and calculating its slope. This is called the *instantaneous speed*. For example, at 5 seconds the slope (and the instantaneous speed) is about 1.7 m/s, and at 10 seconds it is about 11.1 m/s. (Check it yourself.)

The speedometer on a car measures your instantaneous speed. Suppose you go on a trip to the beach and it takes you an hour to travel 60 km. This means your average speed is 60 km/h, even though there were times when your instantaneous speed was greater than 60 km/h, and there were times when you were going slower than this or were even stopped.

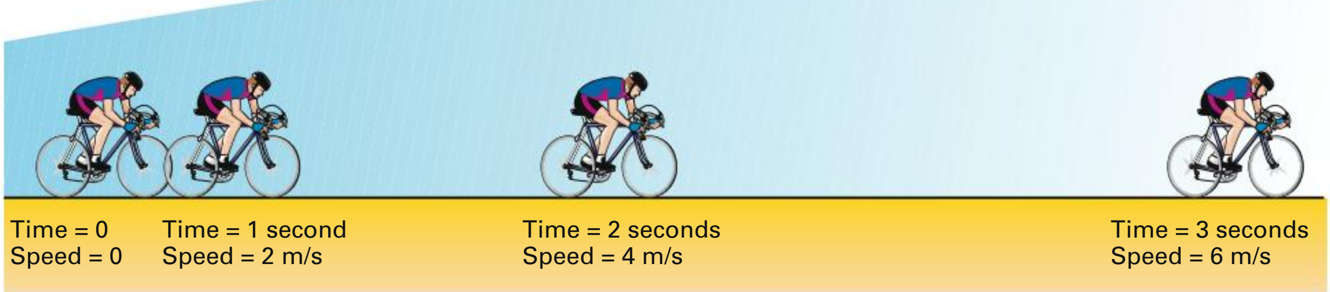
Radar and laser guns

Police use radar and laser guns to find the instantaneous speed of cars. A radar gun emits high-frequency radio waves, which are reflected by the car. If the car is coming towards the gun, the reflected waves have a shorter wavelength than those sent out. If the car is moving away from the gun, the reflected waves are longer. The gun picks up the reflected waves and calculates the speed from the difference in wavelength.

A laser gun emits a very short pulse of infrared light in a narrow beam. This beam is reflected back to the gun, which measures the time for the round trip. Multiplying this time by the speed of light and dividing by two (because of the round trip) gives the distance to the car. The gun measures the distance many times during an interval of about half a second, and from this the computer in the gun can calculate the speed. For more information go to www.OneStopScience.com.au and follow the links to **How does a laser speed gun work?**



Acceleration



When an object gets faster, we say that it accelerates. The diagram above shows the position of a cyclist each second, and his speed. The speed is increasing steadily, and we say that there is a constant **acceleration**. Acceleration is the rate at which the speed increases. In this case, it is increasing at 2 metres per second each second. We write this as 2 m/s/s or 2 m/s^2.

Acceleration is important when considering the performance of cars. For example, Kartika wants to compare a VW Golf R with a Porsche 911 Turbo. She has found the following performance figures in a car magazine. The Golf takes 3.3 seconds to reach 60 km/h, whereas the Porsche takes only 1.8 seconds.

Performance	**VW Golf R**	**Porsche 911 Turbo**
Standing start to ...		
60 km/h	3.3 s	1.8 s
80 km/h	4.7 s	2.5 s
100 km/h	6.6 s	3.4 s
120 km/h	8.9 s	4.4 s

from *Wheels*, October 2010

To calculate the acceleration of each car, Kartika used this equation:

$$\text{average acceleration} = \frac{\text{change in speed}}{\text{time taken}} = \frac{\text{final speed} - \text{initial speed}}{\text{time taken}}$$

$$\text{or} \quad a_{av} = \frac{v - u}{t}$$

Fig 2 A dragster decelerating

For the Golf the speed increases from 0 to 60 km/h in 3.3 s (60 km/h = 60/3.6 = 16.7 m/s). So:

$$\text{acceleration} = \frac{16.7 - 0 \text{ m/s}}{3.3 \text{ s}} = 5.1 \text{ m/s}^2$$

For the Porsche:

$$\text{acceleration} = \frac{16.7 - 0 \text{ m/s}}{1.8 \text{ s}} = 9.3 \text{ m/s}^2$$

So the Porsche accelerates much more quickly than the Golf.

When a car slows down it is said to *decelerate*; for example, a dragster at the end of its run (Fig 2). Deceleration is the rate at which the speed *decreases*. It is negative acceleration.

Look at the distance–time graph for radio-controlled car C on the previous page. From 1 to 4 seconds the slope of the graph decreases. This means the car is decelerating. From 6 to 10 seconds the slope increases—the car is now accelerating.

Investigation 4 Investigating motion

Aim

To use a ticker timer or a motion detector and datalogger to measure the distance, speed and acceleration of various objects and analyse this motion.

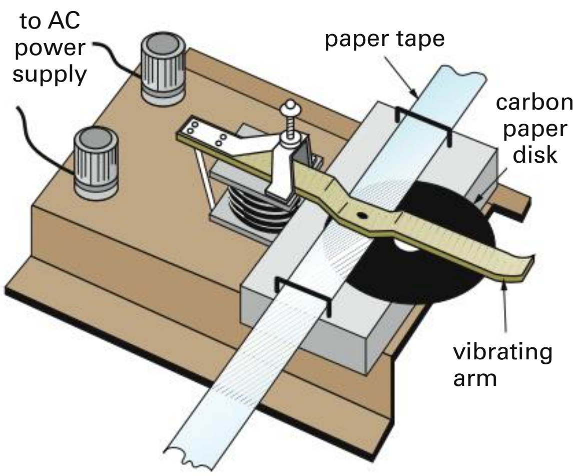
Planning and Safety Check

Discuss with your teacher how you will do this experiment. You will need to be able to work as a team, with different people doing different things.

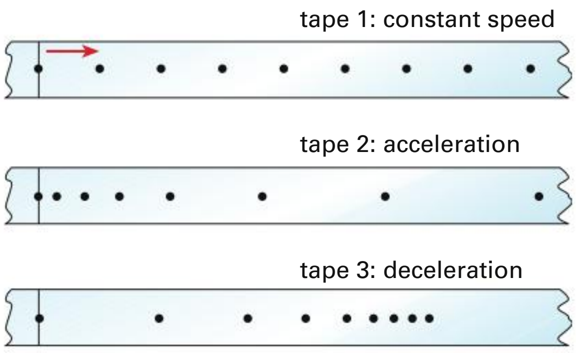
Teacher note: Depending on your school situation, you can do this experiment using ticker timers or a datalogger (Part B).

PART A Using a ticker timer

The diagram below shows how a ticker timer works. The vibrating arm strikes the carbon paper and leaves dark marks on the paper tape. If the tape is attached to a moving object, a series of dots is left on the tape. Because the ticker timer vibrates 50 times per second, the dots are made $^{1}/_{50}$ of a second apart.



The further apart the dots are, the faster the object is moving. The closer together the dots, the slower the object. If the dots are evenly spaced, then the object has a constant speed (tape 1). If the distance between the dots is increasing, the object is accelerating (tape 2). And if the dots are getting closer together, the object is decelerating (tape 3).



Materials

- ticker timer, complete with carbon disk
- ticker tape
- AC power supply and connecting wires
- dynamics trolley
- G-clamp
- pair of scissors
- adhesive tape
- board for ramp approx. 1.5 m long and 30 cm wide (e.g. old table top)

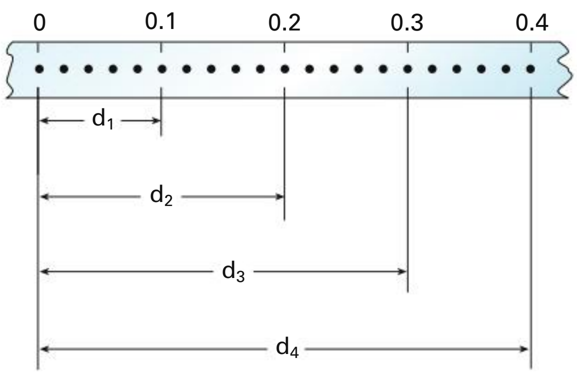
Method

1. Set up the ticker timer as shown on the left. Clamp it to the bench. Cut off several 1 m lengths of ticker tape.
2. Start the timer and pull a piece of tape through at a *constant speed* until about 60 cm of tape has gone through. Label the tape and show the direction of movement.
3. Repeat Step 2 for several different tapes, with a new piece of tape each time.
4. Examine the tapes.

   What do you notice about the spacing between the dots on each tape?

   Explain the differences between the tapes.

5 Select one of the tapes and mark a starting point. Count along the tape from the first dot, marking off every fifth dot, as shown below. Five dots represent 0.1 second.

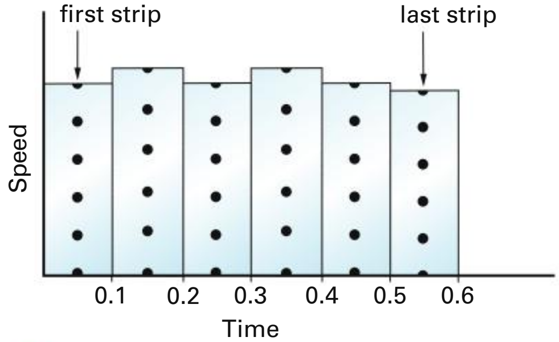


6 Measure the distances d_1, d_2, d_3, d_4, etc and record them in a data table.

7 Plot a graph of distance versus time and draw a line of best fit.

Calculate the slope of the graph, which gives you the average speed of the trolley for this tape. (Give your answer in cm/s.)

8 Cut the tape at each 0.1 second mark. Then stick the strips onto graph paper in the correct order, as shown. (It is a good idea to number them.) Each strip represents the distance travelled in 0.1 second, so you have made a graph of speed against time.



Describe in your own words what you can infer from this graph.

If the speed is not constant, suggest a reason for this.

Estimate the average speed. Does this agree with what you calculated in Step 7?

9 If you have time, analyse the other tapes as well.

10 Repeat the experiment, but this time pull the tape through at *increasing* speed. (Give it a quick pull.) To get a steadily increasing speed you can attach the tape to a trolley that can run down a steep ramp. Another way is to set up the ticker timer vertically, attach the tape to a mass and let it fall.

11 Analyse the tape and draw a distance–time graph. Then cut up the tape to make a speed–time graph.

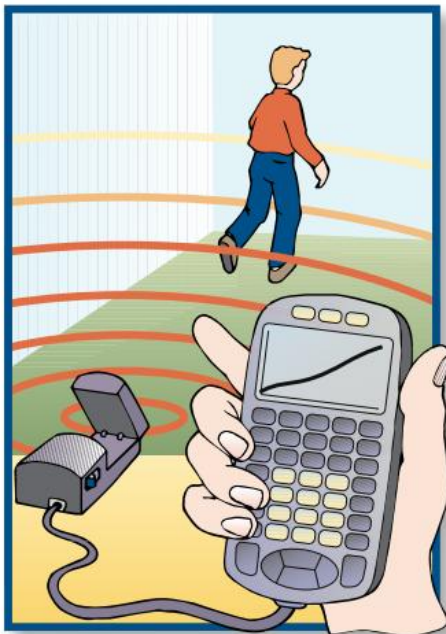
How does this graph compare with those for constant speed?

How do you know there was an acceleration? Was it constant?

12 Estimate the acceleration. This is the average increase in speed in each 0.1 second interval. Give your answer in cm/s^2.

PART B Using a datalogger

A motion detector is similar to a police radar or laser gun (page 30), but it sends out ultrasound waves that are reflected back to it from the moving object. From these reflected waves



the detector can calculate the distance of the object every tenth of a second, or other chosen time interval.

The data from the motion detector is sent either directly or via a datalogger to a computer or graphing calculator. The data can then be displayed in a table or as a graph, e.g. distance versus time or velocity versus time.

Materials

- datalogger and motion detector
- computer or graphing calculator

> **Working with technology:** Detailed instructions on how to set up and operate dataloggers, as well as suggested experiments, are available from the suppliers. The output of the datalogger can be displayed on a computer screen.

Method

1. Set up the motion detector with a clear space in front of it so that you can walk backwards and forwards. You can get as close as 0.5 m and as far away as 6 m.
2. Carefully connect the motion detector to the datalogger and computer or graphing calculator. Set up the datalogger to show a distance–time graph.
3. Move slowly away from the detector.
4. Look at the distance–time graph. Print it out and put it in your notebook.
   How can you explain the shape of the graph?
5. Repeat Step 3 to collect a new set of data, but move in a different way, e.g. slowly or quickly, away from or towards the detector, speeding up or slowing down, stopping. It is probably best to try only one or two things at a time and then see if you can make sense of each graph.
   Print out the graphs and label them, e.g. moving away, moving fast, slowing down, stopped.
6. To check that you understand what the graphs mean, you can record a distance–time graph and ask someone who didn't see how you moved to try to match it by moving in the same way.
7. Now that you understand the distance–time graphs, look at the velocity–time graphs.
   How can you explain the shapes of the graphs?

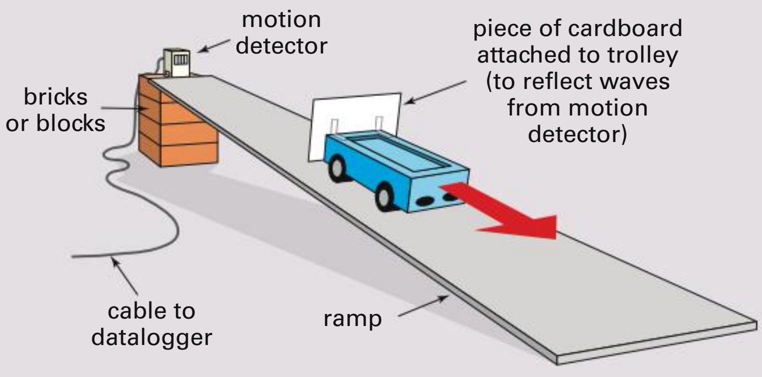
> **Working with technology:** To help you understand how the motion of an object can be represented by graphs, open **Motion graphs** at www.OneStopScience.com.au.
>
> OneStopScience

Inquiry

Choose a moving object to investigate using a datalogger. You could try:

- a trolley rolling down a ramp (see diagram)
- a falling object
- a bouncing ball
- a pendulum
- someone starting a sprint
- a radio-controlled car.

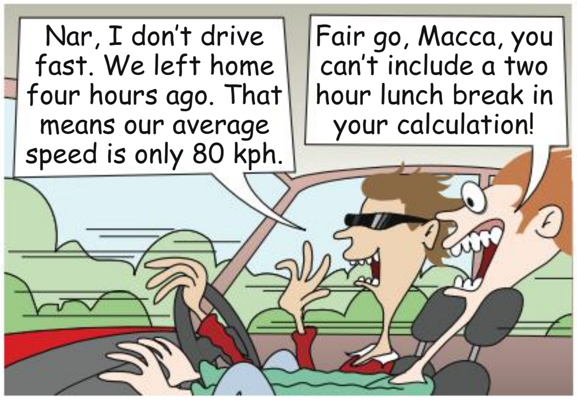
Analyse the distance, velocity and acceleration graphs, and write a report of your investigation.



Hint: Stop the trolley before it reaches the bottom of the ramp.

Check

1 Use what you have learnt in this section to explain the cartoon below.



2 Find the average speed of a jet that flies 2700 km from Melbourne to Perth in 3.5 hours.

3 If the average speed of a spaceship is 32 000 km/h, how long would it take to travel the 80 million kilometres from Earth to Mars? (Give your answer in days.)

4 If you can run at an average speed of 7 m/s, how far can you run in 30 seconds?

5 A car started from rest and reached a speed of 30 m/s in 10 seconds.
- a What was its average speed?
- b How far did it travel in this time?

6 A train travelling at 10 m/s accelerates to 20 m/s in 5 seconds.
- a What is its acceleration?
- b What will its speed be after another 3 seconds if it continues to accelerate at the same rate?

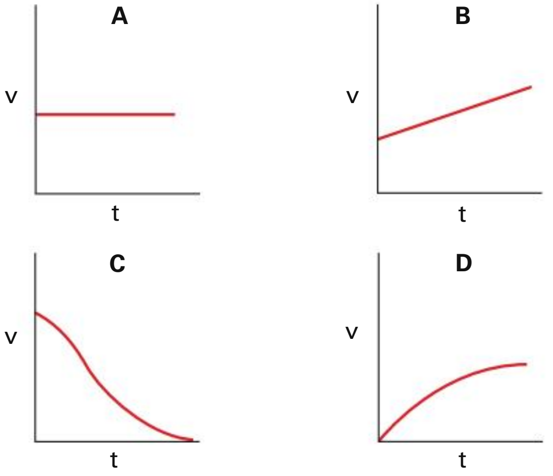
7 A bike coasts down a hill. Its acceleration is 3 m/s^2. How long does it take to accelerate from 5 m/s to 16 m/s?

8 At the bottom of a waterslide, Stacey is travelling at 10 m/s. She skids across the pool, coming to a stop after 2.5 seconds. What is her deceleration?

9 Draw a distance versus time graph for a car that stops at lights, then accelerates away.

10 Draw a velocity versus time graph for a person who is walking, stops briefly, then starts to run. (You could check your answers for questions **9** and **10** using a motion detector.)

11 Which of the speed–time graphs below could possibly represent the motion of a car:
- a coming to a stop?
- b travelling at constant speed?
- c moving from a stop at traffic lights?
- d accelerating?



Challenge

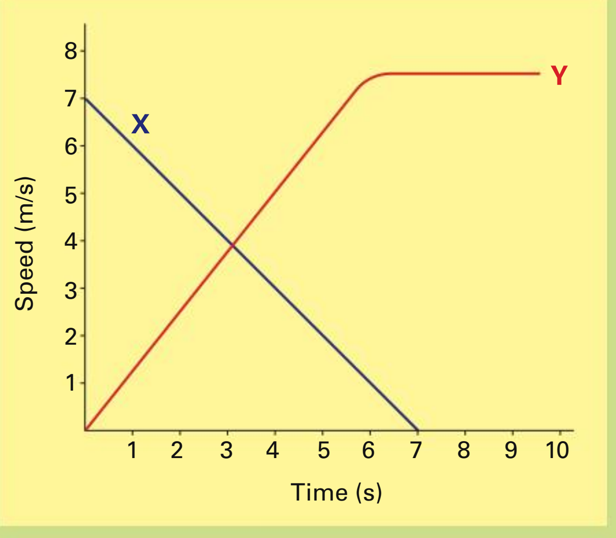
1 Two cars make the same trip, a distance of 160 kilometres. Both cars travel at a constant speed, but one averages 50 km/h and the other 100 km/h. Represent these two trips on a single distance–time graph.

2 After 6 seconds of accelerating at 2.5 m/s^2, a car is moving at 50 m/s. What was the initial speed of the car if the acceleration was:
- a positive?
- b negative?

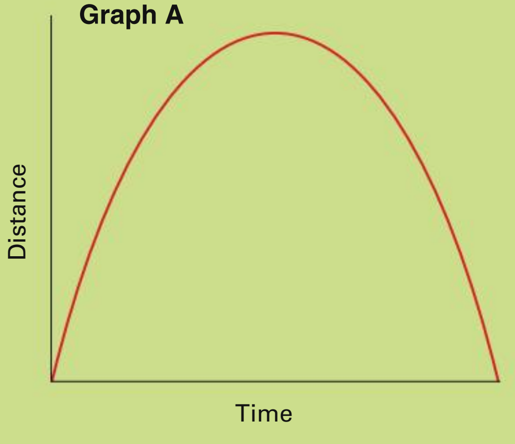
3 Use the internet to find answers to these questions about police radar and laser guns.
- a What is the Doppler effect?
- b What advantages do laser guns have over radar guns?
- c What is the range of laser guns?
- d How do speed cameras work?

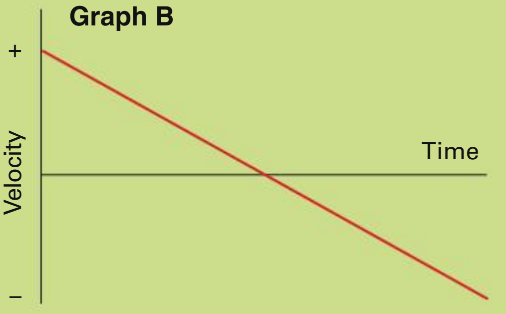
4 The graph below shows the motion of two objects, X and Y. Use the graphs to answer these questions.

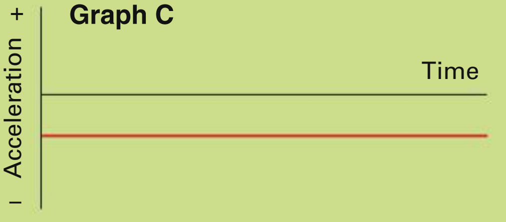
a What was the speed of X after 4 seconds?
b What was the maximum speed of Y?
c What happened to X at 7 seconds?
d When did X and Y have the same speed?
e Calculate the acceleration of X.
f What was the acceleration of Y between 6 seconds and 10 seconds?
g At which time was Y travelling twice as fast as X?



5 Hannah and Kirralee investigated the motion of a ball tossed into the air above a motion detector. They obtained these graphs from their datalogger. Explain the shape of each of the three graphs.



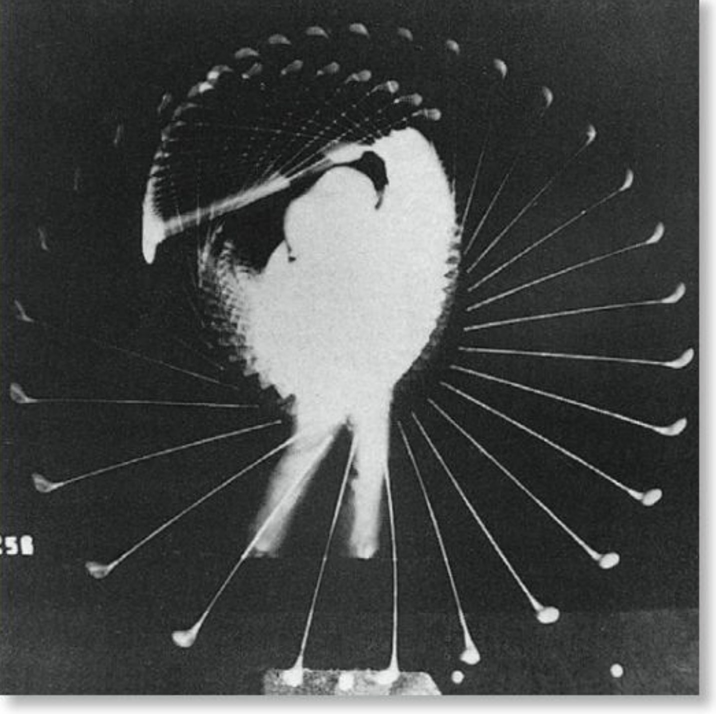




6 Look at the special photograph below of a golfer's swing. It was taken using a stroboscopic light that flashed 50 times per second (so that the time between flashes is 0.02 s).

a What was the speed of the golf club just before and just after it struck the ball?
b Suggest why these speeds are different.
c What was the speed of the ball in the first 0.02 s and the second 0.02 s? What does this tell you about the motion of the ball?

Fig 3 Analyse the golfer's swing (scale = 1:30).



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Extra for experts

Using maths equations

In this section you have used several mathematical equations. For example:

$$a = \frac{v - u}{t}$$

Using algebra, this equation can be rearranged to give:

$$v = u + at$$

where **v** is the final speed,
u is the initial speed,
a is the acceleration, and
t is the time.

From this equation you can obtain a second equation:

$$d = ut + \tfrac{1}{2}at^2$$

where **d** is the distance travelled.

You can use these two equations to solve various problems.

Sample problem 1

A car was travelling at 15 m/s. It then accelerated at 2 m/s^2 for 4 seconds. What was its final speed?

Step 1 List the things you know and what you want to find.

$$\begin{aligned} u &= 15 \text{ m/s} \\ a &= 2 \text{ m/s}^2 \\ t &= 4 \text{ s} \\ v &= ? \end{aligned}$$

Step 2 Write down the appropriate equation and substitute the values into it.

$$\begin{aligned} v &= u + at \\ &= 15 + (2 \times 4) \\ &= 15 + 8 \\ &= 23 \text{ m/s} \end{aligned}$$

Sample problem 2

A car and a semitrailer are travelling at 90 km/h (25 m/s). To overtake the semitrailer, the car accelerates at 1.6 m/s^2 for 5 seconds. How far does the car travel in this time?

$$\begin{aligned} u &= 25 \text{ m/s} \\ a &= 1.6 \text{ m/s}^2 \\ t &= 5 \text{ s} \\ d &= ? \end{aligned}$$

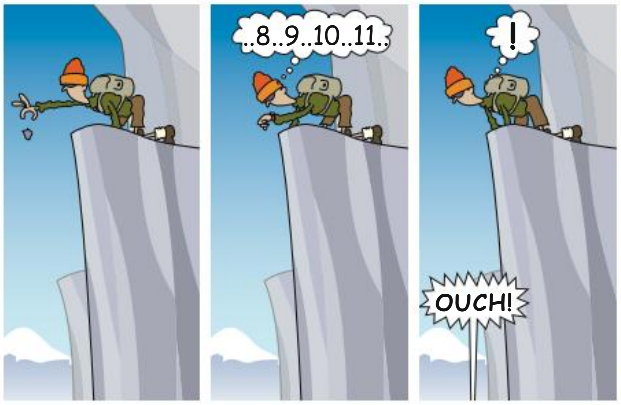
$$\begin{aligned} d &= ut + \tfrac{1}{2}at^2 \\ &= (25 \times 5) + \tfrac{1}{2}(1.6 \times 25) \\ &= 125 + 20 \\ &= 145 \text{ m} \end{aligned}$$

Questions

1 A car was stopped at traffic lights. When the lights changed, it accelerated at 3 m/s^2 for 6 seconds.
   a What was the car's initial speed?
   b What was its speed after 6 seconds (in km/h)?

2 A spacecraft is moving at 250 m/s when it fires its retro-rockets for 6 seconds to slow it down. This causes it to decelerate at 10 m/s^2. What is the spacecraft's speed after the 6 seconds?

3 Owen drops a stone from the top of a mountain pass. If it takes 12 seconds to reach the valley below, how high is the pass. (Hint: The acceleration due to gravity is 9.8 m/s^2.)



4 A dragster accelerates at 9 m/s^2 from a stationary start for 7 seconds.
   a What speed does the dragster reach?
   b How far does it travel in 7 seconds?

5 A motorist is travelling at 70 km/h along a road that crosses a railway line. He notices a train approaching and applies the brakes 55 m from the crossing. The brakes cause the car to decelerate at 4 m/s^2. Will the car stop before the crossing?

2.2 Stopping

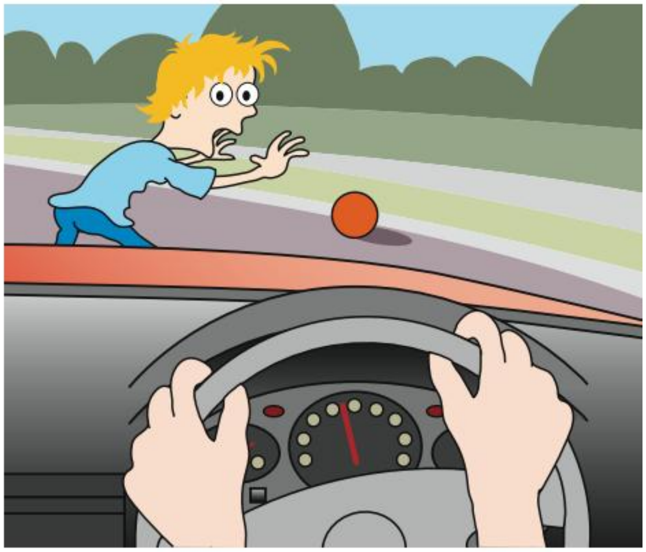
Imagine you are driving along a road and a child suddenly runs onto the road in front of you. You apply the brakes, and the car stops just in time.

Here is an action replay. The child runs onto the road. Your eyes record the scene. This information passes to your brain, which sends a signal to your right leg to push hard on the brake pedal. All this takes about a second. This time is called your **reaction time**. The distance the car travels in this time is called the *reaction distance*.

Under test conditions, reaction time is usually about 0.75 seconds. In real driving situations it is about 1 second, but may be much longer, depending on the individual and their alertness. The faster you are going, the further the car travels during this reaction time. For example, at 60 km/h (16.7 m/s):

reaction distance = vt = 16.7 m/s × 1 s = 16.7 m

When you put your foot on the brake pedal, the car takes a certain distance to stop. This is called the *braking distance*. Good brakes and good tyres can slow a car about 23 km/h every second (about –6 m/s^2) on a good road. If you



double your speed, the braking distance is four times as far! And on gravel or wet bitumen, the braking distance is even longer.

The distance it takes your car to stop is made up of the reaction distance plus the braking distance. This is called the *stopping distance*. The chart below shows the stopping distances when travelling at various speeds in a car.

In the experiment on the next page you can investigate the variables that affect stopping distance.

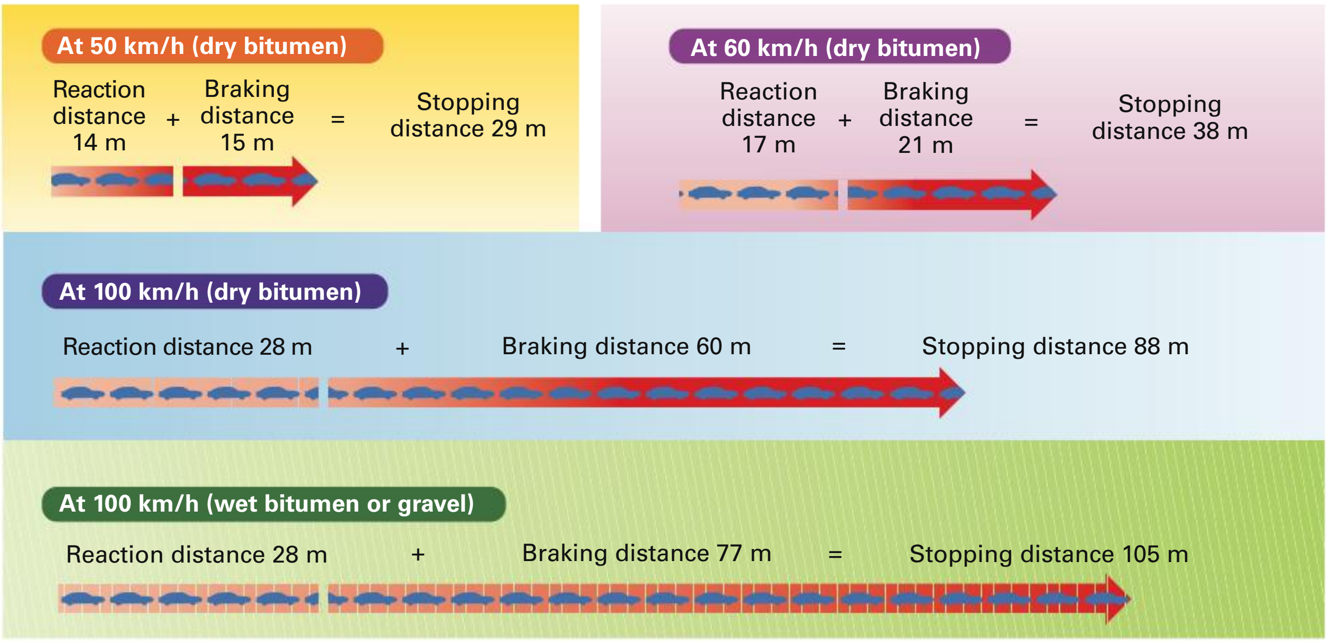


Fig 4 Stopping distance = reaction distance + braking distance

Experiment 3 Stopping distances

Problem to be solved

What is the relationship between speed and stopping distance?

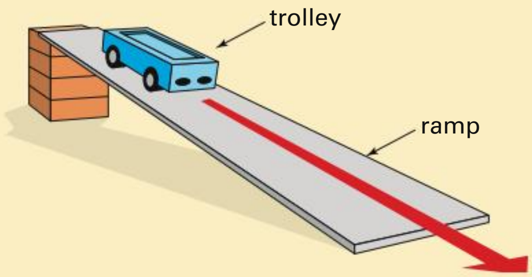
Planning the experiment

In a group, use the questions below to help you design an experiment to solve the problem above. Then carry out your experiment and write a report.

- How are you going to do the experiment? If you work outside, you could use a bicycle. If you work in the laboratory, you could let a trolley run down a ramp and vary the slope of the ramp.

Whichever method you use, you will need to answer these questions:

- How will you measure the speed of the bicycle or trolley?
- What variables will you need to control?
- How can you make your measurements more reliable?



Processing the data

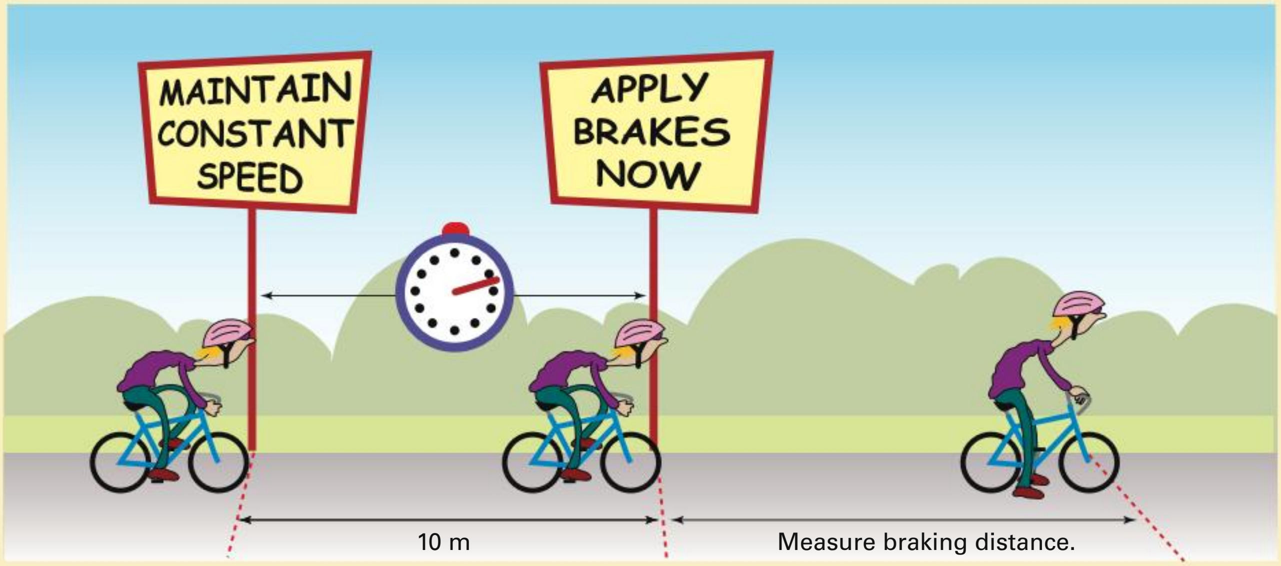
- How will you record your data? For example, can you put them into a spreadsheet such as Excel?
- How will you work out the relationship between stopping distance and speed? Will you need to draw a graph? Will the spreadsheet do this for you?

Evaluating the experiment

- How well did your method work?
- Do you think your results are reliable?
- Is your conclusion valid?

Inquiry

What other variables affect the stopping distance? Choose one of these variables and then investigate how it affects the stopping distance.



Friction

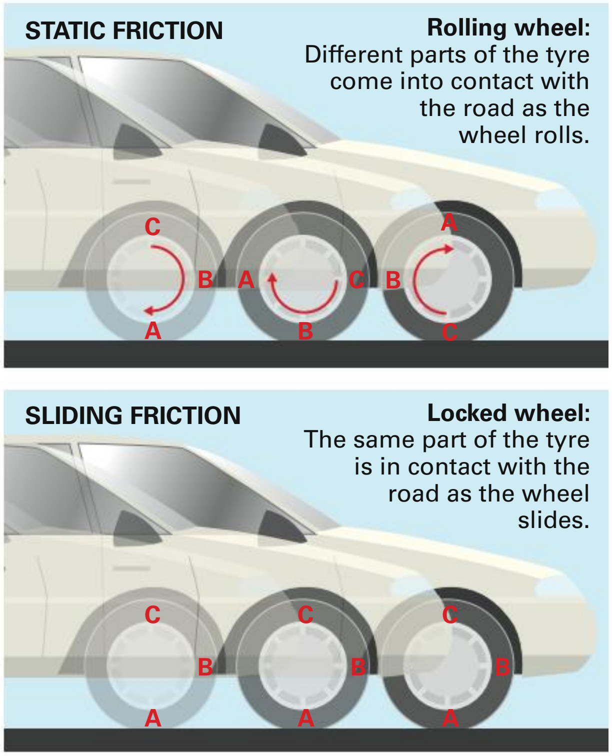
After an accident Teresa said: *When I saw the other car coming I slammed on the brakes, but I didn't seem to have control. The car just kept skidding until it hit the pole.* What happened here was that Teresa had put the brakes on too hard, stopping the wheels from turning. The brakes had 'locked'.

Tyres grip the road by **friction**, and this is what allows a driver to control the car. There has to be enough friction between the tyres and the road to enable the tyres to grip the road. Then, when the engine turns the wheels, the car will go forward. When you turn the steering wheel, the car will turn. And when you put on the brakes, the car will stop.

If the friction between the tyres and the road is reduced, driving can become dangerous. That is why you have to take extra care driving on wet roads. The water acts as a lubricant between the tyres and the road, reducing the friction and increasing the braking distance considerably.

Fig 5 A tyre photographed at high speed through a wet glass roadway

There are two types of friction—**static friction** and **sliding friction**. Static friction holds the tyre on the road. As the wheel rolls, another part of the tread comes into contact with a different part of the road, as shown below. The wheel does not slide.

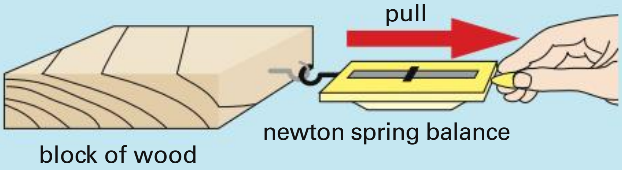


When a wheel locks or slides sideways, the same part of the tyre tread slides along the road. The gripping force in this case is sliding friction, which is less than static friction (see the activity on the next page). Hence the tyres have considerably less grip on the road in a skid than when the wheels are rolling.

A skilled driver knows just how hard to brake without locking the wheels. However, most new cars are equipped with an antilock braking system (ABS). It senses that a wheel is about to lock up or skid and pumps the brake off and on rapidly. When the brakes are released, the wheels start rolling again, and when the brakes are reapplied, the larger static friction forces help stop the car. The 'brains' behind ABS is a computer chip, which can detect whether one wheel is turning more slowly than the others.

Activity

Use the set-up below to investigate the difference between static friction and sliding friction.



1 Pull gently on the spring balance, without moving the block.
   Which type of friction is operating?
2 Gradually increase the pull until the block starts to slide. Carefully watch the reading on the spring balance.
   What happens to the frictional force when the block slides?
   Which type of friction is operating now?

Crash tests

Crash testing is designed to collect data on what happens to cars and their occupants during a crash. This data can then be used to make cars safer. Each vehicle that is tested is given a rating to indicate how safe it is.

A crash-test dummy is designed to simulate a person and is built from materials that mimic the physiology of the human body. For example, it has a spine made from alternating layers of metal disks and rubber pads. The dummy has accelerometers all over it to measure the acceleration in all directions. For example, the sudden deceleration of the driver's head during the crash is measured. There are load sensors to measure the amount of force on different parts of the body. For example, the force on the thigh bone is measured to determine the probability of it breaking. There are also movement sensors in the dummy's chest to measure how much it is pushed in during a crash. The dummy's knees, face and parts of the head are painted different colours. In the photo, you can see that blue paint from the dummy's face is smeared on the airbag and that its left knee (painted red) hit the steering column. Each crash-test dummy costs about $250 000.

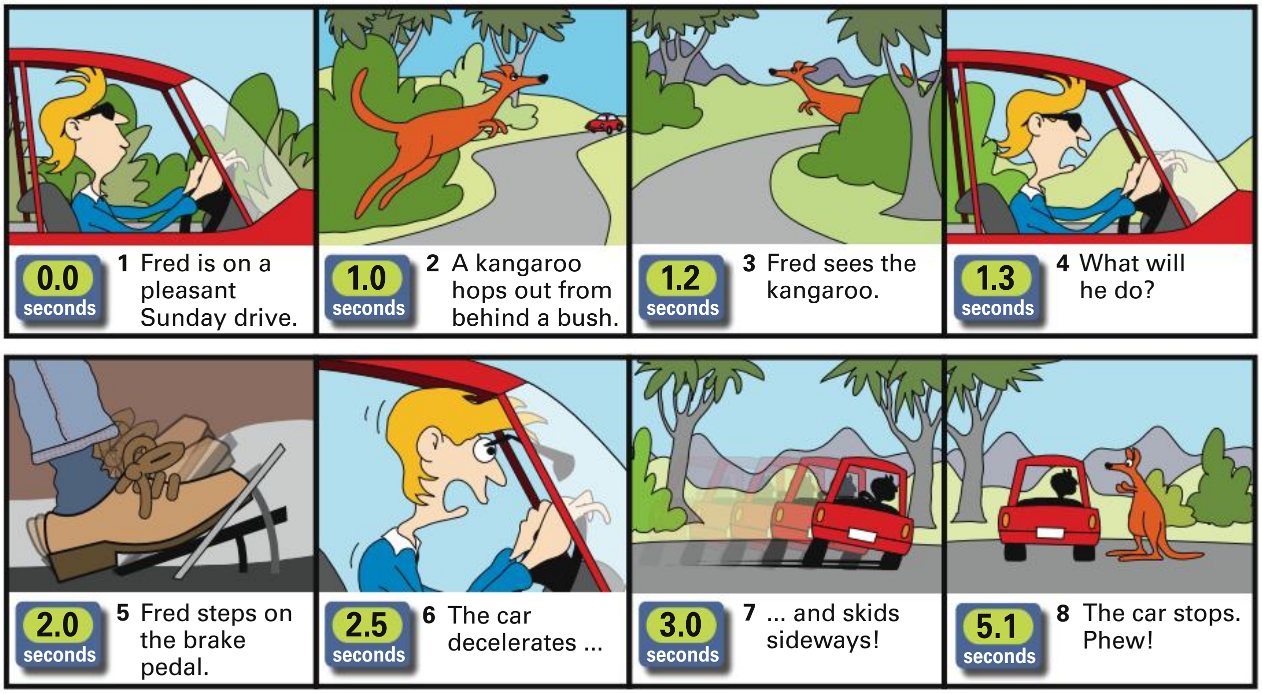
Ballast is added to the car to give it the correct weight. There are calibration marks on the car to help the testers analyse the slow-motion replays. The area is well lit and there are 15 or so high-speed cameras. The car is mounted on a track and propelled into a solid concrete barrier at about 60 km/h. A huge amount of data is temporarily stored in the dummy's chest and then downloaded to a computer. Side-impact tests are also carried out, in which a trolley is crashed into the side of the car.

WEBwatch

For more information on crash tests go to **www.OneStopScience.com.au** and follow the links to **How crash testing works.** This site has an excellent video of a crash test.

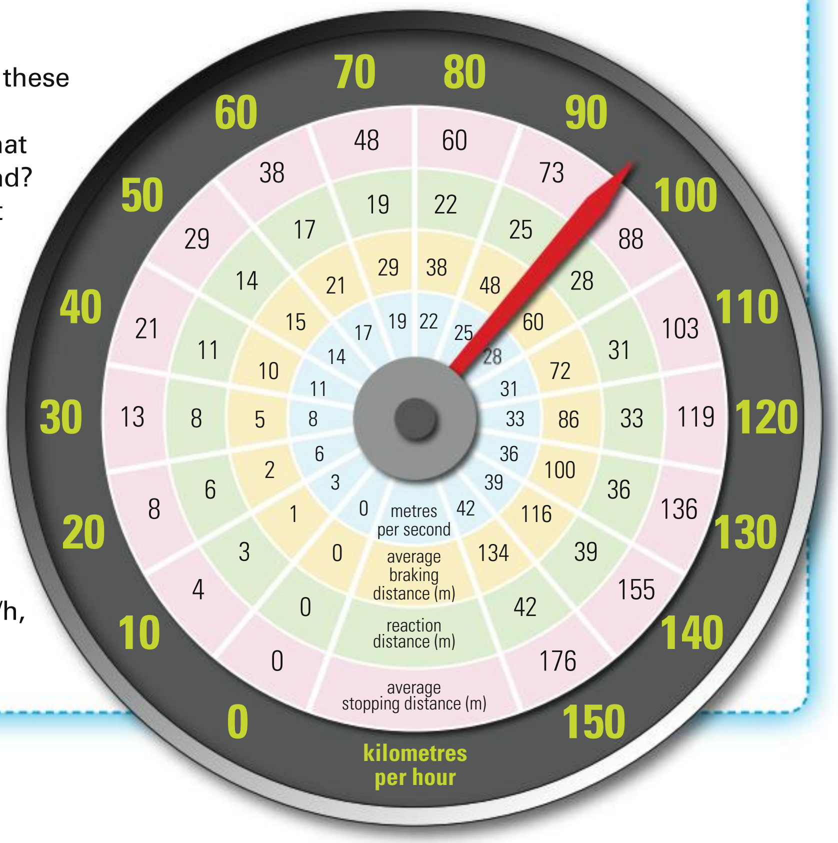
OneStopScience

Check



1 The cartoon strip above shows what happened to Fred while driving in the country.
  a What is Fred's reaction time?
  b What is his braking time?
  c What is his stopping time?

2 Use the chart on the right to answer these questions.
  a You are travelling at 50 km/h. What speed is this in metres per second?
  b What is your reaction distance at this speed?
  c What happens to the braking distance and stopping distance when the speed doubles from 40 km/h to 80 km/h?
  d The chart assumes a reaction time. What is it? How do you know?
  e Two identical cars side by side on the freeway brake at the same time. If one is travelling at 80 km/h and the other at 100 km/h, how far apart will they be when they stop?
  f You are 50 m from a pedestrian crossing when an elderly person starts to cross. If you are travelling at 60 km/h, will you stop in time? What if the road is wet?



3 Why is the braking distance greater on a wet road than on a dry one?

4 The stopping distances on the chart on the previous page are for an alert driver in a car with good brakes and tyres, on a dry road. What difference would each of the following make to the stopping distance?
- a rain
- b tired driver
- c drunk driver
- d fog

5 Gayle wants to move a heavy cupboard. She pushes harder and harder, then suddenly it moves with a jerk. Try to explain why this happens.

6 What is ABS in a car and how does it work?

7 Why is it that the reaction distance increases with speed while the reaction time stays the same?

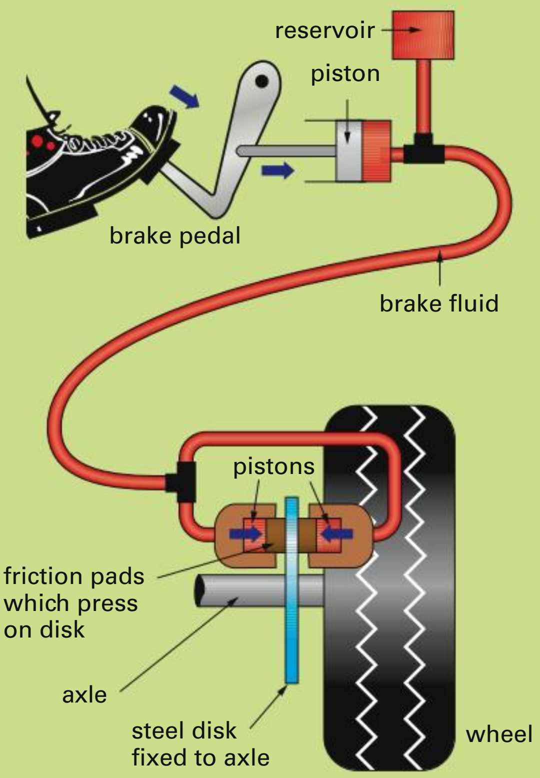
Challenge

1 It is often recommended that, under good conditions, you should drive at least 2 seconds behind the car in front. (This means that it should take your car at least 2 seconds to reach the present position of the car in front.)
- a How far behind should you be when travelling at 60 km/h? At 100 km/h?
- b Try to explain why a time of 2 seconds is recommended.

2
- a Use the chart on the previous page to draw a graph of average braking distance versus speed. Plot reaction distance versus speed on the same graph.
- b Use your graph to find the reaction distance, braking distance and stopping distance at 65 km/h.

3
- a Use the diagram on the right to write a paragraph explaining how disk brakes work.
- b If you drive through water over the road, the brakes become wet and they do not work as well. Suggest a reason for this.
- c Suggest what you could do to get the brakes working properly again.

4
- a A car is travelling at 60 km/h. If its brakes can decelerate the car at 6 m/s^2, what is its braking distance? Use the formula $v^2 = u^2 + 2ad$, where v is the final speed, u the initial speed, a the acceleration and d the distance travelled.
- b If the driver has a reaction time of 0.8 seconds, what is the reaction distance?
- c What will the stopping distance be?



TRY THIS

1 Design and carry out an experiment to test whether wider tyres give you better grip than narrow ones.

2 Does it make any difference whether the front wheels, the back wheels or all four wheels are locked up during braking? Design and carry out an experiment to test this.

2.3 Collisions

Inertia

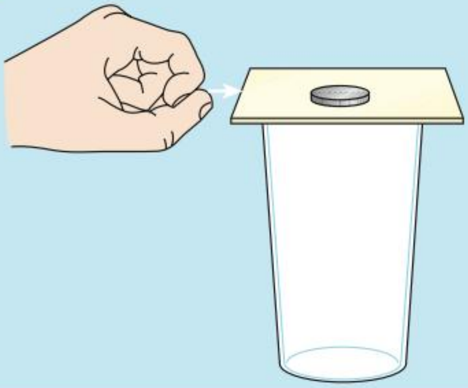
Suppose you are in a car travelling at 60 km/h. Your body is also moving at 60 km/h. If the driver brakes suddenly, the car slows down, but because your body is not attached to the car it tends to keep moving at the same speed of 60 km/h. This is why you feel as though you are falling forwards. A seatbelt holds you so that you do not crash into the dashboard, windscreen or front seats.

Similarly, if you are standing in a bus or a train, you may be thrown off balance when it starts to move. Your body tends to stay at rest as the bus begins to move. If the bus suddenly speeds up, you may fall backwards. And if the bus turns a sharp corner you may be thrown to the other side.

Activity

Here is a fun way to illustrate inertia. Place a 20 cent coin on a piece of cardboard on top of a glass as shown. Then flick the card.

Explain what happens in terms of inertia.



The train's sudden acceleration was about to cause Mikie a few embarrassing moments.

An object will stay at rest, or will not change its speed or direction, unless acted on by a force. The object is said to have **inertia** (in-ER-sha). This inertia depends on the mass of the object—the greater the mass, the greater the inertia. For example, a bus has more mass than a car. Therefore it has more inertia. A bus is harder to start or stop than a car. That is, it takes a larger force to change its motion.

To sum up, if an object is at rest, it tends to remain at rest; and if it is moving, it tends to keep on moving at the same speed and in the same direction. This is called *Newton's first law of motion*, even though it was first proposed by the Italian scientist Galileo in 1612. The Englishman Sir Isaac Newton was born in the year Galileo died, and he used Galileo's idea and developed it further.

Momentum

A heavy truck is harder to stop than a car travelling at the same speed. This is because the truck has more momentum. The **momentum** of an object depends on its mass and its speed. It can be calculated using the formula:

$$M = mv$$

where **M** is the momentum, **m** is the mass in kilograms and **v** is the speed of the object in m/s

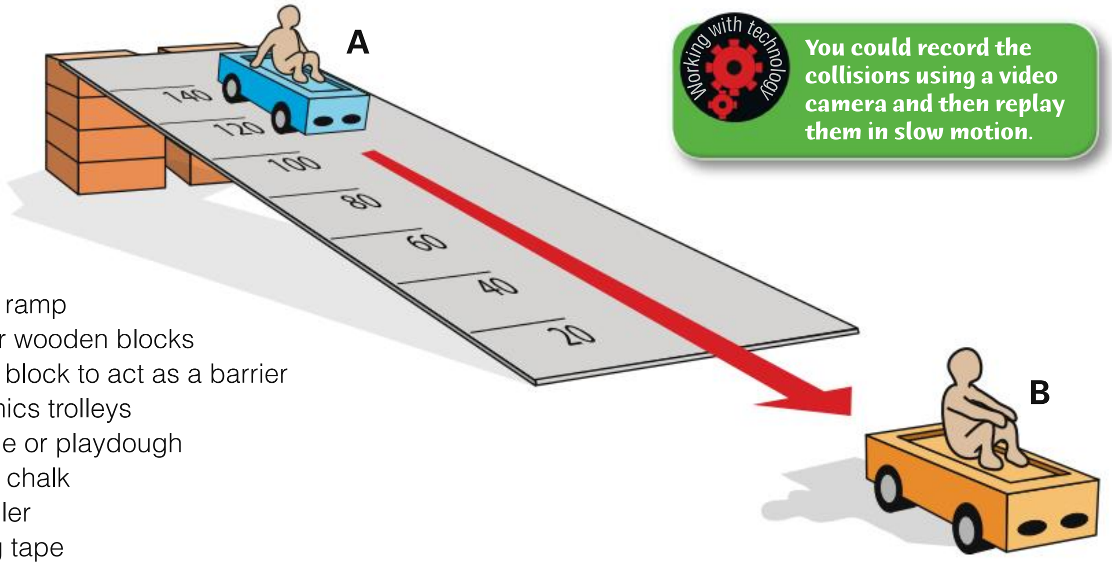
Momentum increases as either the mass or the speed increases. A truck has more momentum than a car moving at the same speed. The larger mass of the truck gives it more momentum. For this reason it will do more damage if it collides with something. Also, a fast-moving car has more momentum than a slow-moving one. Its greater speed gives it more momentum.

In Investigation 5 you can investigate the effects of inertia and momentum in car accidents.

Investigation 5 Car accidents

Aim

To use trolleys and dummies as a model for car accidents.



Working with technology: You could record the collisions using a video camera and then replay them in slow motion.

Materials

- wooden ramp
- bricks or wooden blocks
- wooden block to act as a barrier
- 2 dynamics trolleys
- plasticine or playdough
- piece of chalk
- metre ruler
- masking tape
- talcum or graphite powder
- graph paper

Planning and Safety Check

Read both parts of the investigation carefully.

- What is the aim of each part?
- Design a data table for Part B.

PART A

Method

1. Make two plasticine dummies to represent people in car accidents.
2. Put a dummy on the front of each trolley. (You should powder the bottoms of the dummies to reduce their stickiness.)
3. Mark 20 cm intervals on the ramp, starting from the bottom, as shown.
4. Place trolley B about 40 cm in front of the ramp. Place trolley A at the top of the ramp, directly in line with trolley B.
5. Release trolley A so that it collides with trolley B.

   Observe carefully what happens to the dummies in the collision.
6. Repeat Step 5 two or three times.

Discussion

1. What happened to the dummy on trolley A during the collision? Explain *why* this happened.
2. What happens to the occupants of a moving car when it collides with a stationary car?
3. What design features of cars reduce the risk of injury in this type of collision?
4. What happened to the dummy on trolley B? Explain why this happened.
5. What happens to the occupants of a stationary car hit from behind by another car?
6. What design features reduce the risk of injury in this type of collision?

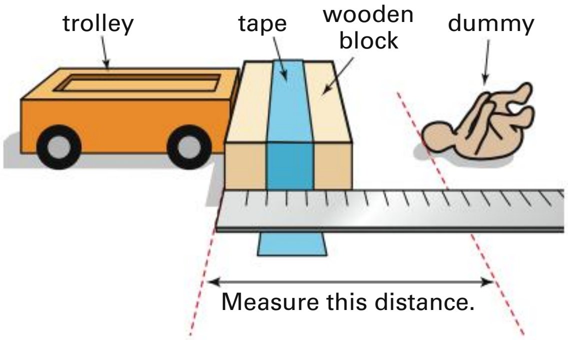
PART B

Method

1 Tape a wooden block firmly to the bench or floor 30 to 40 cm in front of the ramp.

2 Put the plasticine dummy on the trolley and line it up on the 20 cm mark. Release it so that it crashes into the wooden block and observe what happens to the dummy.

Measure the distance from the dummy to the impact side of the wooden block. Measure to the nearest centimetre, and record the result in a data table.



3 Repeat Step 2 at least three times, exactly the same way each time. You will probably get a different result each time. This is because there are variables that are difficult to control. For instance, the trolley may hit the block differently because of small changes in the way it rolls down the ramp.

Find the average of the measurements.

4 Repeat Steps 2 and 3 by placing the trolley at higher positions on the ramp. Record all results.

5 Plot your results on a graph. Try to draw a line of best fit.

Discussion

1 What happens to the impact speed of the trolley as it is released from higher up the ramp?

2 What is the relationship between the impact speed and the distance that the dummy was thrown?

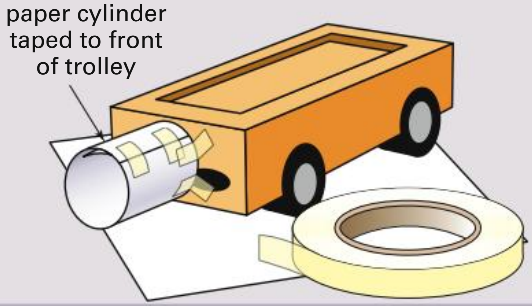
3 Use your graph to predict how far the dummy would be thrown if you released the trolley from one of the marks you have not used. Try it and check your prediction.

4 Could you modify the experiment to get more reliable results? How?

Inquiry

1 Redesign Part A to model what happens in a head-on collision.

2 Experiment with a crumple zone for the trolley, e.g. a cylinder of paper as shown below. You could also experiment with a seatbelt or airbag for the dummy.



The second and third collisions

How can one person walk away from a major collision and another person die in a minor collision? The following true story will help you answer this.

A farmer loaded his truck with eggs and headed for the markets. On the way, he lost control of the truck and crashed into a tree beside the road. The truck was travelling at 60 km/h when it was stopped by the tree. However, due to inertia, the farmer's body continued moving until it collided with the steering wheel and windscreen. There was also a third collision when the farmer's internal organs were slammed against each other and against his skeleton. It was these second and third collisions that seriously injured the farmer.

The eggs in the back of the truck were packed in soft cardboard cartons and stacked in crates.

The crates were also tied down. Some of the crates were thrown from the truck and the eggs smashed, but most of the crates remained in the truck and the eggs were undamaged!

Why was the farmer injured while most of the eggs were safe? Obviously the eggs were carefully packaged, but the farmer was not. Because he was not wearing a seatbelt, he smashed into the steering wheel and was seriously injured. At 60 km/h, the impact of the second collision is like landing face first on the ground after falling from the fifth floor of a building. Worse, it is like falling on a steering wheel sticking up from the ground, or on a glass windscreen or a dashboard!

Inertia and car design

Seatbelts hold car occupants securely in place during a crash and reduce the chance of serious injury and death by about 60%. This is why the wearing of seatbelts is law. Also, babies and young children who are too small for seatbelts must have specially designed child restraints.

Some deaths and serious injuries have been caused when car occupants, whether wearing seatbelts or not, have been struck by loose objects flying forward from the rear seat or parcel shelf. If you and the car come to a complete stop from even a moderate speed, say 40 km/h, loose items will continue travelling at that speed. Imagine being struck in the back of the head by a portable radio or something similar travelling at 40 km/h! Even small light objects can kill at that speed.

Head restraints help to prevent neck damage to occupants, particularly in rear-end collisions. Look at the top part of Fig 6, where there is no head restraint. When the car is struck from behind, the person's body is moved forward by the seat, but the head is left behind because of its inertia. The effect is like that of cracking a whip, and the person can suffer a serious neck injury called whiplash. If the head is supported by a head restraint, both body and head move together.

Modern cars are designed to help you survive serious crashes. In a head-on collision, the engine compartment is designed to crumple and absorb as much energy as possible. The engine is forced

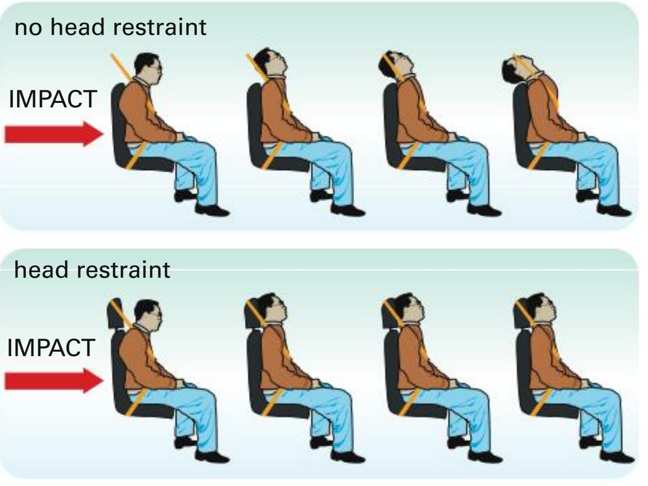


Fig 6 How head restraints work

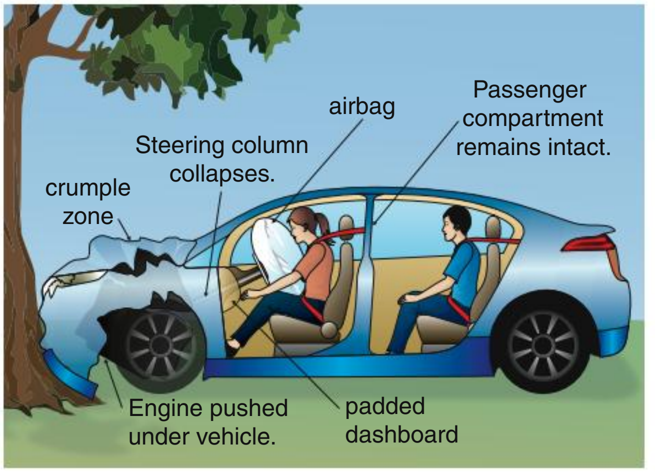
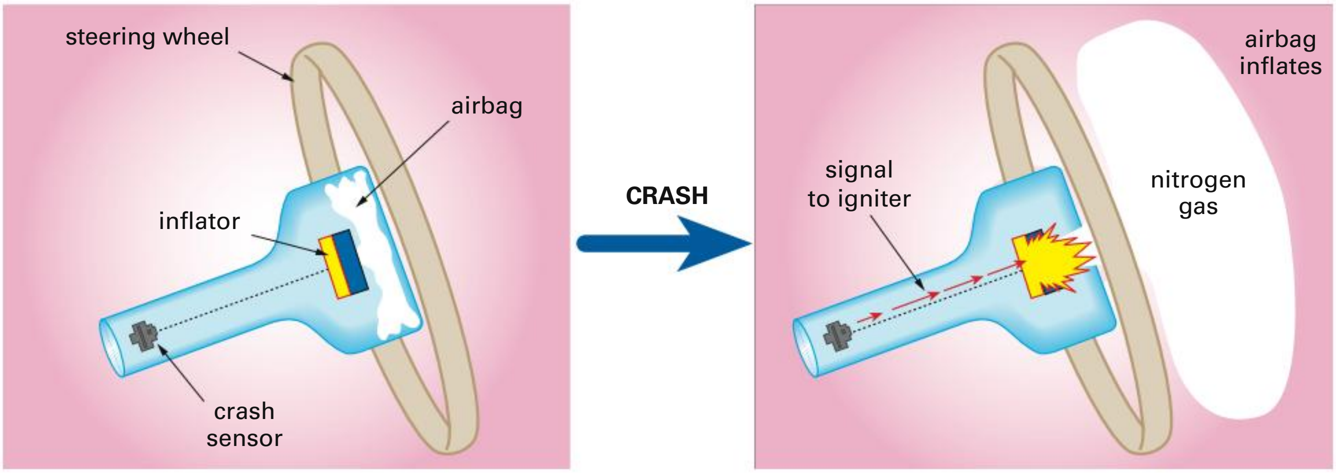


Fig 7 Safety features in a car

under the rigid passenger compartment, and the steering column collapses so that the driver is not speared.

Most new cars are now fitted with front and side *airbags*. These do not replace seatbelts, but are an additional safety device. In a serious crash, belted front occupants may still move forward enough to hit the steering wheel or windscreen. Airbags are designed to inflate in frontal collisions that are comparable to hitting a solid wall at about 25 km/h. Most sensors contain a micromachined accelerometer, which produces an electronic signal when jolted. This sends an electric current to the igniter in the inflator. This



causes the chemical propellant (usually sodium azide) that is sealed in the module to undergo a rapid chemical reaction, which produces nitrogen gas that inflates the bag in about 0.3 seconds. A second later the gas quickly escapes through tiny holes, thus deflating the bag so you can move.

WEBwatch

To find out more about airbags, go to **www.OneStopScience.com.au** and follow the links to **How air bags work**.

OneStopScience

Force, mass and acceleration

We know that force causes acceleration, but Sir Isaac Newton was the first to work out the relationship between the size of a force and the acceleration it causes.

First, the larger the force, the larger the acceleration it causes. For example, if you push an empty shopping trolley very gently, it only moves slowly. If you apply a large force by pushing hard, it moves rapidly. This means that the force and the acceleration produced by the force are directly proportional. To double the acceleration of the trolley you need twice the force. And half the force will produce only half the acceleration.

Second, a force will give a greater acceleration to an object with a small mass than it will to an object with a large mass. If you push an empty shopping trolley with a large force, it will accelerate rapidly. But when you use the same force to push the same trolley filled with groceries, the acceleration is less. This means that for a constant force the acceleration is inversely proportional to the mass of the object being accelerated. In other words, if you double the mass, you halve the acceleration. And if you halve the mass, you double the acceleration.

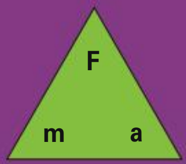
Fig 8 A small push gives an empty shopping trolley a small acceleration. A bigger push gives the empty trolley a large acceleration. But this same push gives a full trolley only a small acceleration.

These two relationships between acceleration, force and mass can be combined as a single mathematical equation:

$$a = \frac{F}{m}$$

where **a** is the acceleration in m/s^2, **F** is the force in newtons and **m** is the mass in kilograms.

The equation can then be rearranged as shown:



$$F = ma$$

This equation is known as Newton's second law of motion.

Crumple zones

Newton's second law of motion is useful in analysing collisions. Using the equation for acceleration, you can rearrange the equation F = ma as follows:

$$F = ma = m\left(\frac{v-u}{t}\right) = \frac{mv - mu}{t}$$

The quantity mv is the momentum of the object, so you can rewrite F = ma as:

$$\text{force} = \frac{\text{final momentum} - \text{initial momentum}}{\text{time taken}} = \frac{\text{change in momentum}}{\text{time taken}}$$

Suppose a car has a mass of 600 kg. It is travelling at 90 km/h (25 m/s) when it collides with a tree and comes to a stop in 0.1 seconds. We can calculate the force exerted on the car as follows. Because the car comes to a stop its final speed is zero.

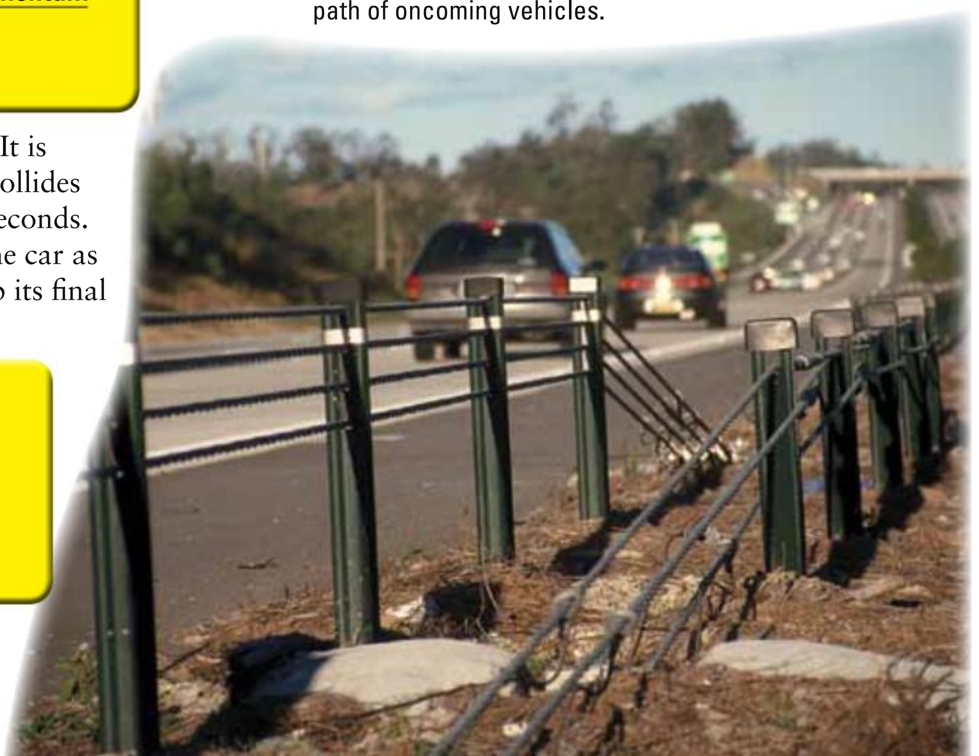
$$\begin{aligned} F &= \frac{mv - mu}{t} \\ &= \frac{(600 \times 0) - (600 \times 25)}{0.1} \\ &= \frac{-15\,000}{0.1} \\ &= -150\,000 \text{ N} \end{aligned}$$

The negative sign means that the force is decelerating the car. Because it is such a large force, the occupants are likely to be seriously injured.

How can the forces during a collision be reduced? Apart from driving more slowly, the most practical method is to lengthen the time from impact to when the car comes to a stop. This can be done by building crumple zones into a vehicle. In a head-on collision it takes some time for the front end to crumple. Although the car is badly damaged, the occupants are less likely to be hurt. Of course, the occupants must be protected in a rigid passenger compartment (see Fig 7) so that they are not crushed. And they must wear seatbelts to stop them colliding with the interior of the car.

Suppose the car in the previous example had a crumple zone so that it stopped in 0.3 seconds instead of 0.1 seconds. The force now would be 50 000 N, only a third of what it was without the crumple zone. If the car had hit a pile of hay bales, it would have stopped in about 1 second. In this case, the force on the car would have been only 15 000 N, a tenth of the force when it hit the tree. This is why some roads have energy-absorbing barriers, to increase the collision time and decrease the force on the car.

Fig 9 These energy-absorbing wire ropes prevent vehicles crossing the median strip into the path of oncoming vehicles.



Conservation of energy

As a car speeds up, its momentum and its kinetic energy increase very quickly. However, if the car collides with an energy-absorbing safety fence and comes to a stop, what has happened to all the energy the car had?

To understand this we can use Newton's cradle, shown in the photo. If you pull out the first ball and let it go, it hits the second ball in the line and comes to a dead stop. But the ball on the other end of the line jumps out the same distance you pulled the first ball out. It then falls back and the whole process is repeated. The balls go on clicking back and forth for a long time, before they eventually stop. If you pull out *two* balls to start with, then two balls jump out the other end. To see an animation of this, use the keyword 'Newton's cradle animation' to search on the internet.

Fig 10 Newton's cradle

What has happened is that the kinetic energy of the first ball has been transferred along the line of balls. The last ball in the line jumps out with the same amount of kinetic energy as the first ball had. As you learnt in *ScienceWorld 8*, energy cannot just disappear. It can be converted from one form to another, but it cannot be created, destroyed or lost. This is the law of **conservation of energy**.

Let's apply the law of conservation of energy to a car involved in a collision. As the engine runs, the stored chemical energy in the petrol is converted into heat energy and then into kinetic energy. As the car moves, there is friction caused by the car's moving parts and by wind resistance. As a result of this friction, some of the kinetic energy is carried away by the air. Suppose a tyre blows. The brakes lock, the tyres smoke and some of the car's kinetic energy is converted to heat energy. Then crash! The car collides with the safety fence. The wire in the fence stretches and absorbs most of the energy. The front of the car is pushed in, and bits of the car fly everywhere. The passengers are thrown forward but are restrained by their seatbelts. Loose objects in the car fly forward.

During the crash, the kinetic energy of the moving car is transferred to the fence and bits of the car, and converted to other forms of energy—sound and heat. There was no energy created, and no energy destroyed or lost. Energy was conserved.

Efficiency

Whenever friction occurs, kinetic energy is converted to heat energy. This heat energy is then of no use. This is why no machine can be 100% efficient. If a machine has moving parts, there will always be friction. This is why the balls in Newton's cradle eventually stop, because friction produces sound and heat as the balls collide.

Scientists have found that in all energy conversions and transfers, some energy is always converted to heat. For example, when petrol is burnt in a car engine, only about 20% of the stored chemical energy is converted into kinetic energy. The other 80% is converted to heat and sound energy.

Energy can be used over and over again, but a bit is converted to heat energy every time it is used. This is why television screens and mobile phones become warm when you use them. In fact, all energy ends up as heat eventually. This heat energy goes into the Earth's atmosphere and is eventually radiated into space.

To harness the energy around us we change its form, or move it from one place to another. Whenever we do this some energy is converted to heat. This means no machine can be 100% efficient, and perpetual motion machines are not possible. To keep things going, you have to keep putting energy in.

Drink driving

It is illegal to drive a motor vehicle if your blood alcohol concentration is more than 0.05, or zero if you are a learner driver or P-plater. *Blood alcohol concentration* is the amount of alcohol per 100 mL of blood in your body at a particular time. It is measured in g/100 mL. So 0.05% means that there is 0.05 g of alcohol in each 100 mL of blood.

On average, a person reaches a blood alcohol concentration of 0.05 after consuming three *standard drinks* in an hour (Fig 11). However, this can vary considerably from person to person. It depends on your weight, whether you are male or female, and whether or not you eat food with the alcohol. As part of its normal functions, the body processes alcohol and gets rid of it. Each hour, blood alcohol concentration falls by about 0.015, equivalent to one standard drink.

Drinking and driving are a deadly combination. The alcohol slows down your reaction time and therefore increases braking distance. As well, your powers of judgment and decision-making are reduced, and you take foolish risks. The more alcohol you consume, the greater the risk of having an accident, as shown in Fig 12. In fact, with a level of 0.05, you are more than twice as likely to have an accident as normal.

Questions

1 What does a blood alcohol concentration of 0.05 mean?

2 Use the graph to calculate the risk of having a crash when the driver has a blood alcohol concentration of 0.08, 0.10 and 0.14.

3 How many 375 mL cans of full-strength beer could an average person drink in an hour before reaching the 0.05 limit? How many cans of light beer?

4 Andrew drank three 375 mL cans of beer. How long will it be before all the alcohol is removed from his body?

5 Lauren, Ben, Stephanie and Michael got together for a few drinks one evening. This is what they drank in three hours.

Lauren: 4 glasses of beer and a vodka and tonic
Ben: 1 can of light beer and a rum and coke
Stephanie: 1 glass of wine and 3 glasses of orange juice
Michael: 5 pots of beer

a How many standard drinks did each have?

b Who was legally fit to drive home? (All have full licences.)

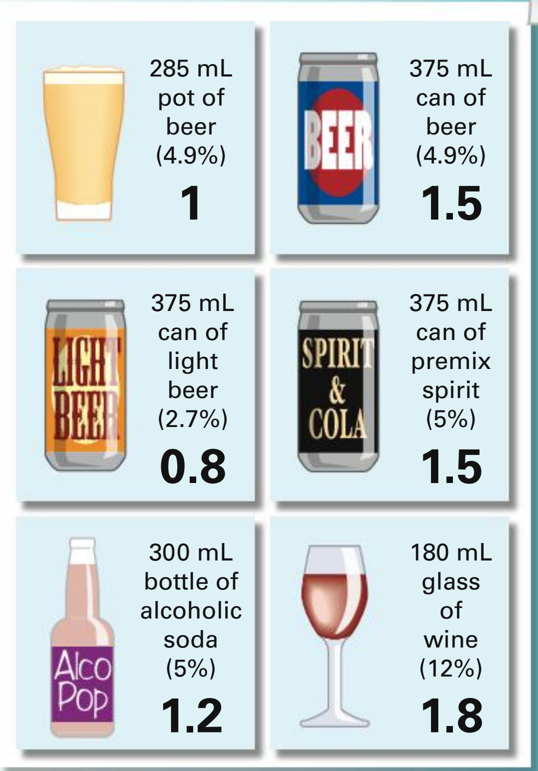


Fig 11 How many standard drinks?

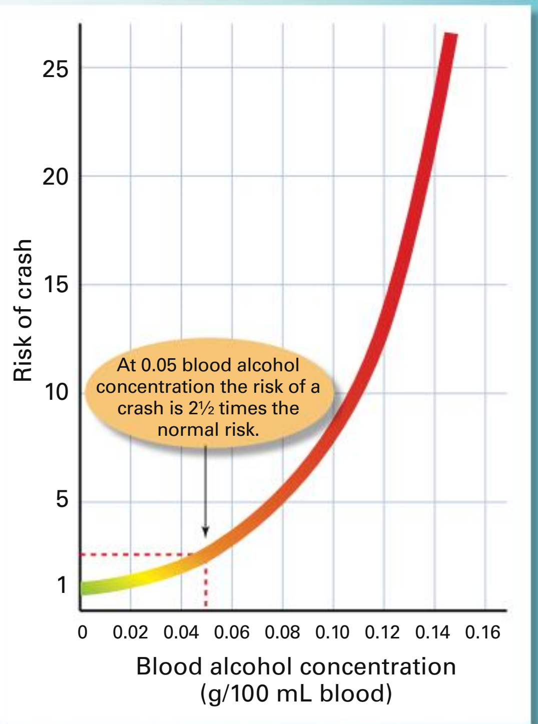


Fig 12 Relative probability of crashing at various blood alcohol concentrations

Check

1 A sports car and a semitrailer are both stationary. Which one has more inertia?

2 List at least five design features that have increased the safety of cars.

3 a Two cars have the same mass but one has an engine three times as powerful as the other. How would the acceleration of the two cars compare?
b Two cars have the same engine but one has a mass one-quarter of the other. How would the acceleration of the two cars compare?

4 Use what you have learnt in this chapter to explain what is likely to happen to a standing train traveller when the train:
a accelerates rapidly
b stops suddenly.

5 State the law of conservation of energy. Illustrate your answer by describing what happens when two cars collide.

6 Copy and complete the following table.

Force acting	Mass of vehicle	Acceleration
?	1000 kg	2 m/s^2
2000 N	500 kg	?
5000 N	?	5 m/s^2
10 N	?	26 m/s^2
?	1500 g	3.5 m/s^2
5 N	200 g	?

7 Put these four objects in order, from the one with the most momentum to the one with the least.
- a 600 kg car travelling at 100 km/h
- a 5 tonne truck travelling at 15 km/h
- a 45 gram golfball in flight at 100 km/h
- a 100 kg person cycling at 40 km/h

8 Suppose you are travelling at 60 km/h. Which of the following accidents is likely to be most serious? Least serious? Explain your answers.
a hitting a wooden fence
b hitting a large tree
c hitting an oncoming vehicle

Challenge

1 When a space rocket takes off, its acceleration increases as it rises. Suggest why this happens.

2 Four-wheel drive vehicles are often fitted with bullbars. What is the purpose of bullbars? Do they protect the occupants of the vehicle in a head-on collision? Explain.

3 How fast would a 25 kg rocket be going if it started from rest and accelerated under the influence of a 350 N force for 6.5 seconds?

4 A spacecraft of mass 2000 kg is moving away from a space station with a speed of 100 m/s. It fires its main engines for 20 seconds. Its speed when it stops accelerating is 400 m/s.
a What is its acceleration?
b What is the force of the rocket engines?

5 What force must your seatbelt be able to withstand if you hit a tree at 60 km/h and stop in 0.08 seconds? (Assume your mass is 70 kg.)

6 A football of mass 0.5 kg reaches a speed of 25 m/s as a result of a kick with an impact time of 0.22 seconds. Find the:
a final momentum of the ball
b average force on the ball
c acceleration of the ball

7 A 5 kg trolley rests on a table. A horizontal force of 10 N acts on the trolley for 5 seconds. (Hint: Use the equations in Extra for experts on page 37, and assume there is no friction.)
a What is the speed at the end of the 5 seconds?
b How far does the trolley move in the 5 seconds?
c If the force ceased to act after 5 seconds, how fast would the trolley be moving after 6 seconds?

8 A 30 tonne semitrailer travelling at 70 km/h brakes suddenly to avoid a collision. What force must the brakes of the semitrailer exert to stop it in 150 m?

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 To find average speed, ______ the distance travelled by the time taken:

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

2 The ______ of a distance–time graph gives the instantaneous speed.

3 Acceleration occurs when an object changes ______.

$$\text{average acceleration} = \frac{\text{change in speed}}{\text{time taken}}$$

4 Stopping distance depends on your ______, the speed of your vehicle, and the condition of the brakes, tyres and road surface.

5 Tyres grip the road by friction. When the wheels ______ the friction is less.

6 Inertia is the tendency of an object to stay at rest or continue its present motion, unless acted on by a ______. The inertia of an object depends on its ______.

7 The momentum of an object depends on its mass (m) and its speed (v). Momentum (M) can be calculated by using the ______ M = mv.

8 In a collision a car stops but the occupants have ______ and continue moving until they collide with some solid object. Seatbelts, head restraints and ______ are designed to protect people in collisions.

9 The ______ of an object is directly proportional to the force acting on it, and ______ proportional to its mass.

$$a = \frac{F}{m} \quad \text{or} \quad F = ma$$

- acceleration
- airbags
- divide
- equation
- force
- inertia
- inversely
- mass
- reaction time
- skid
- slope
- speed

Working with technology

Try doing the Chapter 2 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

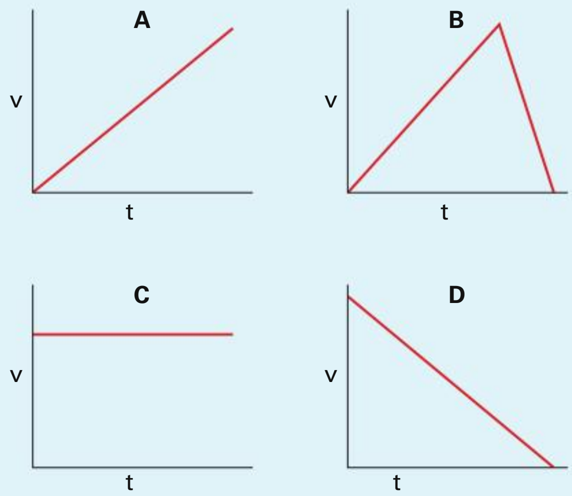
1 The acceleration of a car moving at a constant speed of 30 m/s is:

A 30 m
B 30 m/s
C 15 m/s^2
D 0.

2 A bus driver has a trip of 280 km to complete. If the average speed of the bus is 80 km/h, how long will the trip take?

3 Study the velocity–time graphs on the right. Which was made by an object:

a travelling at constant speed?
b accelerating?
c slowing down?
d speeding up and then slowing down?



4 A sports car and a furniture van are both travelling at a speed of 60 km/h. Which vehicle would require more force to stop it? Why?

5 Scott was driving to the golf course. He braked to avoid a cat. Explain why the golf clubs hit Scott on the head.

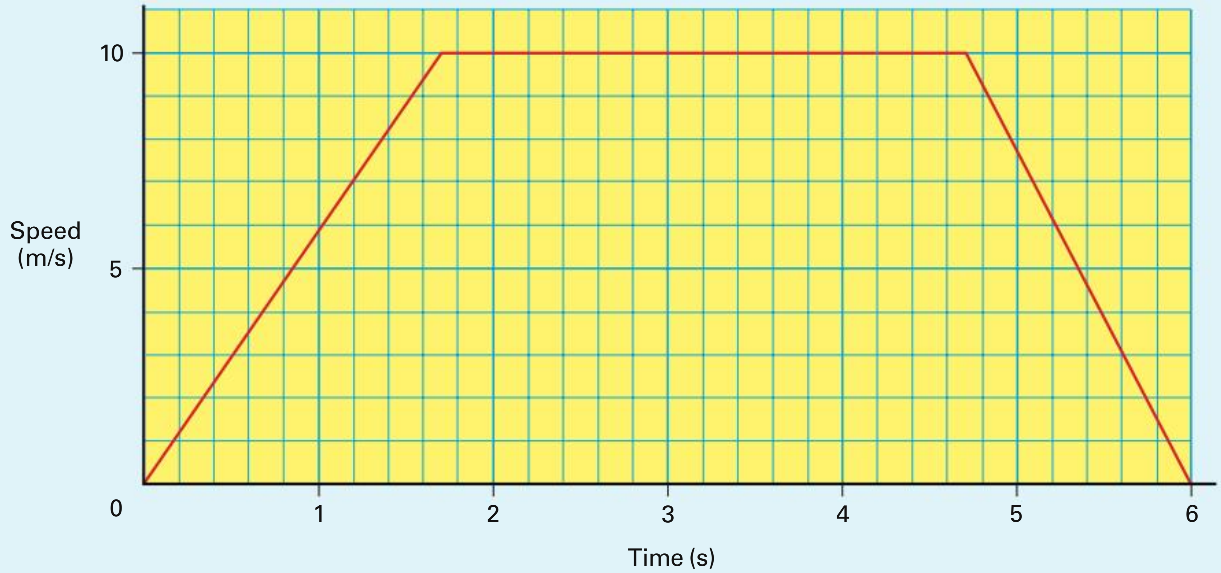
6 The same person drives a motorbike, a car and a semitrailer at 100 km/h. Compare his reaction distances and braking distances for the three vehicles if he has to stop suddenly.

7 A car stopped at traffic lights is hit from behind by another car. Describe what happens to the people in the:
   a stationary car
   b car that hit the stationary car.

8 a What is meant when we say 'the car's brakes locked'?
   b What happens to the car when this occurs?
   c What have car designers done to solve the problem of brakes locking?

9 Tim is riding his bicycle at a uniform speed of 15 m/s. He brakes and comes to a stop in 3 seconds. If he and the bike have a total mass of 80 kg, what force did the brakes apply?

10 The graph below shows the change in speed of a lift as it travels from the ground to the top floor.
   a Explain the shape of the graph.
   b At what rate does the lift accelerate?
   c At what rate does it decelerate?



Check your answers on page 302.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

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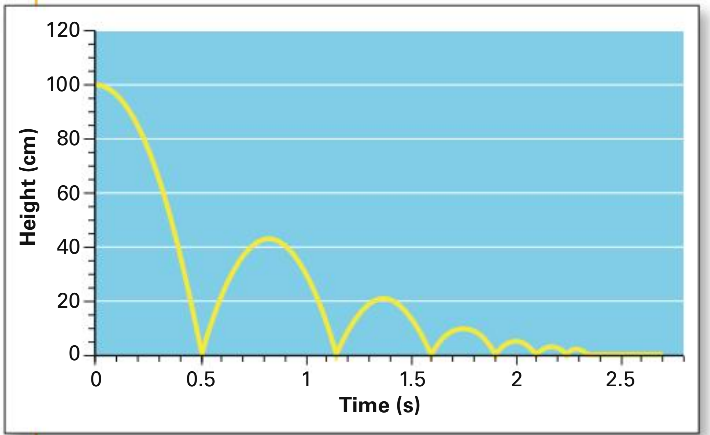
Science Inquiry Skills

Dataloggers

Advances in electronics over the past 50 years have resulted in the development of electronic sensors to measure variables such as temperature, light, pH, sound and movement. These sensors capture data, and are connected to dataloggers that store the data for use at a later time. This data can be analysed using spreadsheet software such as Microsoft Excel. On this page there are seven examples of how dataloggers are used in science and everyday life.

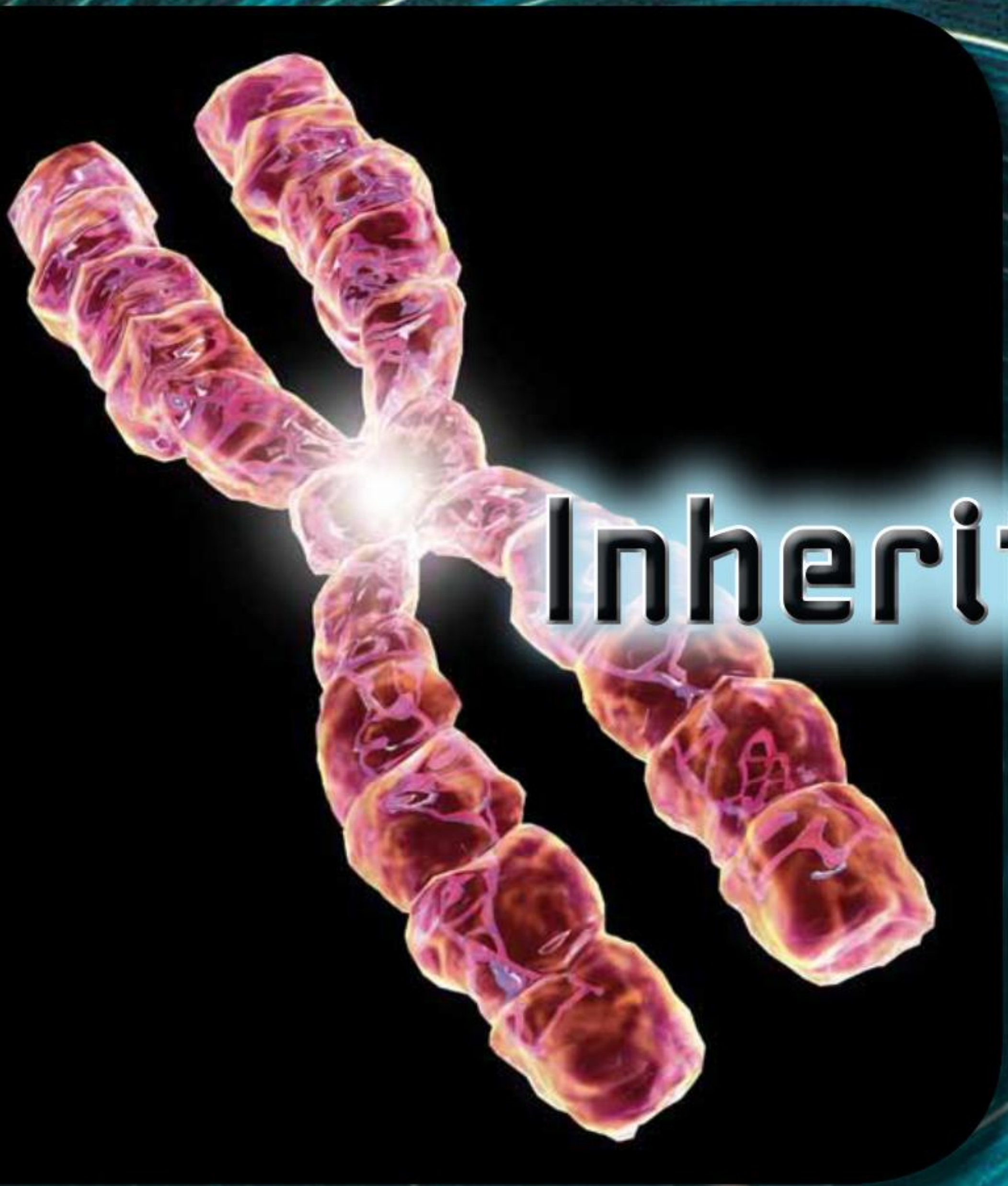
1. In Investigation 4 on pages 32–34 did you use a ticker timer or a datalogger, or both? What advantages do dataloggers have over ticker timers?
2. The students in a Year 10 class used a datalogger to obtain this graph of the motion of a bouncing ball.



   a. How long was it before the ball hit the floor the first time?
   b. What was the height of the ball's first bounce?
   c. How long was it before the ball stopped bouncing?
   d. Would you be able to obtain this graph without a datalogger? Explain.
3. Dataloggers can collect data remotely without needing someone present to take measurements. Suggest places where remote dataloggers would be useful.

4. 'Black box' flight recorders, like the one above retrieved from an Air France airliner off the coast of Brazil in 2009, are a type of datalogger. How do these black boxes work?
5. Dataloggers are used in intensive care units to monitor patients. What sort of data do they record?

6. Some dataloggers have a wireless link to a computer or are linked directly to the internet. What is the advantage of this?
7. How could a datalogger be used in your home to keep energy use and costs to a minimum?



3 Inheritance

In this chapter you will …

Science Understanding

- describe the role of DNA as the blueprint for controlling the characteristics of organisms
- use diagrams to show how sex cells are produced by the process of meiosis
- use a model to show how the bases in DNA code for different amino acids
- use Punnett squares to predict the genotypes and phenotypes in dominant/recessive gene pairs

Science as a Human Endeavour

- discuss issues associated with DNA fingerprinting and testing for genetic diseases
- gain an understanding of how mapping of the human genome has led to better understanding of human diseases

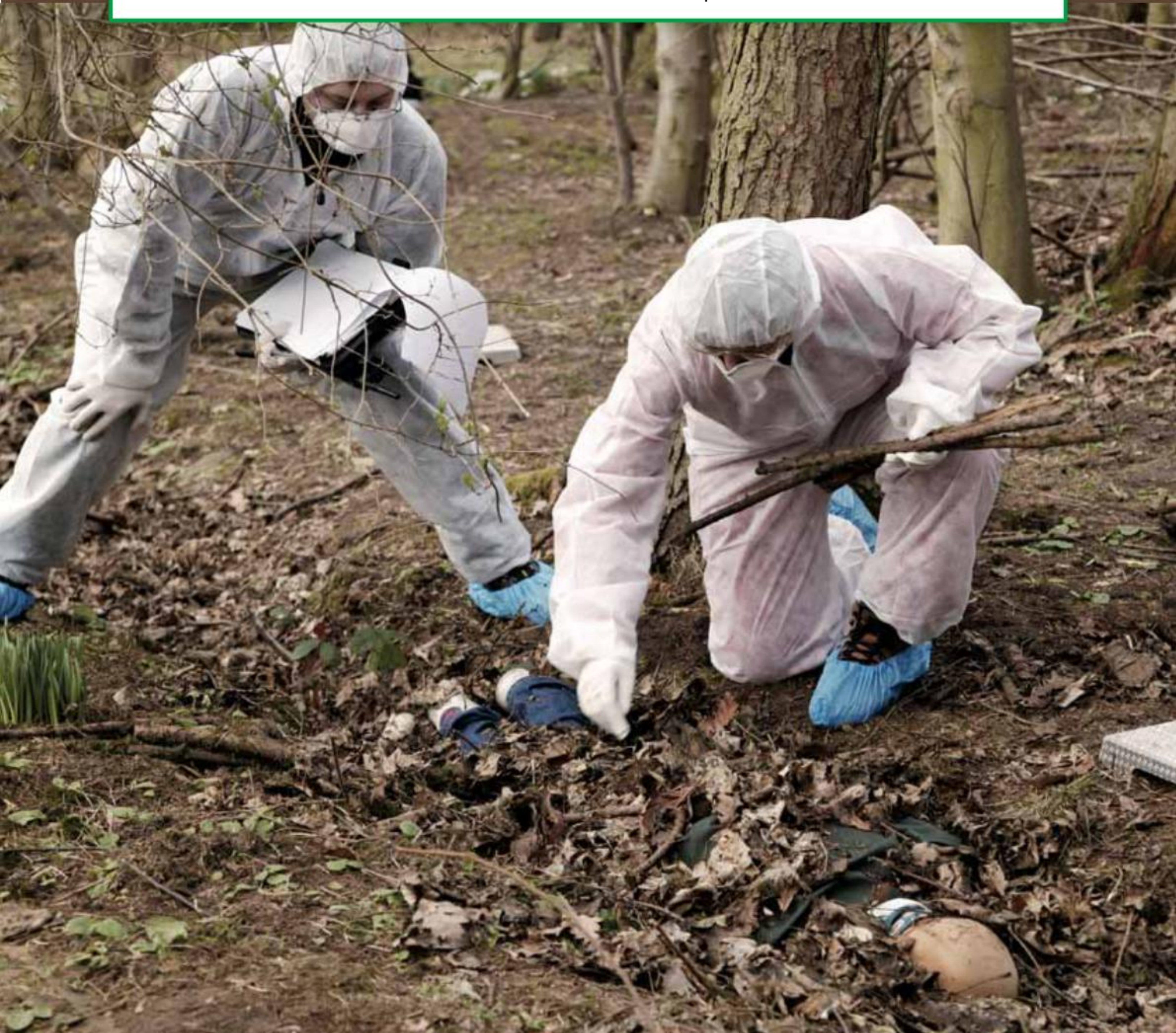
Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Work in a group of three or four and discuss the following questions. Keep your answers for later in the chapter.

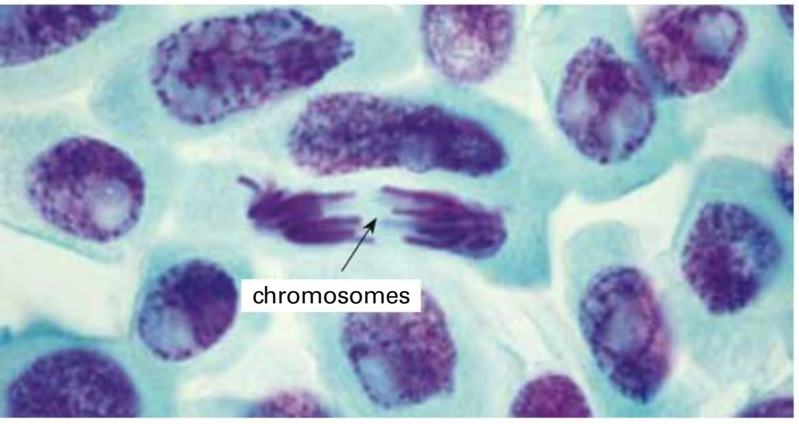
The forensic scientists in the photo are undergoing training by investigating a fake crime scene. They are looking for sources of DNA from the dummy victim and also from the suspect.

1 What is DNA and where is it in your body?
2 What would be good sources of DNA at a crime scene?
3 Suggest how a suspect could be convicted using DNA.
4 If you were a forensic scientist, what other evidence would you gather to help convict the suspect?



3.1 Chromosomes

Around 1900, many scientists wanted to find out what part of an organism's cell was responsible for passing on characteristics from one generation to the next. An American biologist, Walter Sutton, provided one of the earliest clues to the problem. He wondered about the importance of sausage-shaped objects that had been observed in cells undergoing division. He noticed that the rounded nucleus in a cell seemed to change into these sausage-shaped objects just prior to cell division, and each of the new cells contained these objects, which we now call **chromosomes**. These can be seen in the dividing plant cell below.



Mitosis

The process of cell division is called **mitosis** (my-TOE-sis). Mitosis occurs in cells in the regions of the body that are producing new cells for growth or replacement of dead cells. For example, mitosis occurs in the skin where dead cells are constantly being replaced.

Fig 1 shows a simplified version of mitosis. When a cell is not in the process of dividing, the chromosomes cannot be seen because they are tightly coiled up inside the nucleus. At the beginning of the cell division process, the chromosomes become shorter and thicker. They duplicate and the two duplicate chromosomes are joined in the middle. In the doubling process, each chromosome makes an exact copy of itself.

Finally the chromosomes separate, forming two daughter cells that are identical to the original cell.

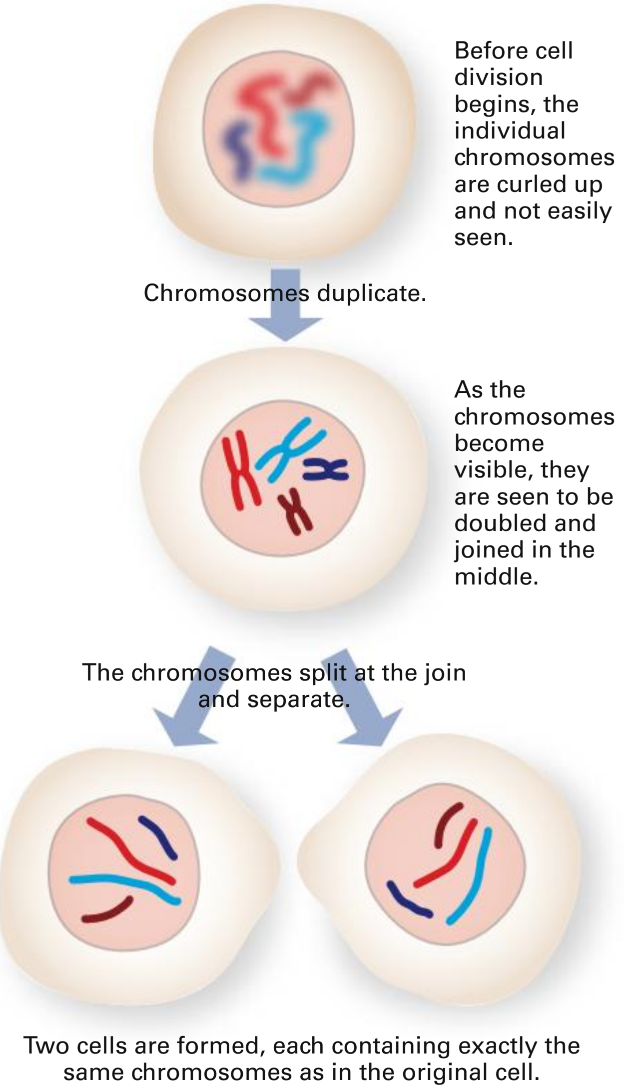


Fig 1 The process of cell division is called mitosis.

Chromosomes in cells

Sutton observed that the same species of organism always had the same number of chromosomes, and that the number of chromosomes was different for different organisms. For example, humans have 46, a fruit fly has 8 and corn has 20.

In the diagram in Fig 2 on the next page, the 46 chromosomes in a human have been placed in pairs from largest to smallest (except the X chromosomes). Notice that each chromosome is roughly an **X** shape. This is because each chromosome is duplicated and the pairs are joined in the middle.

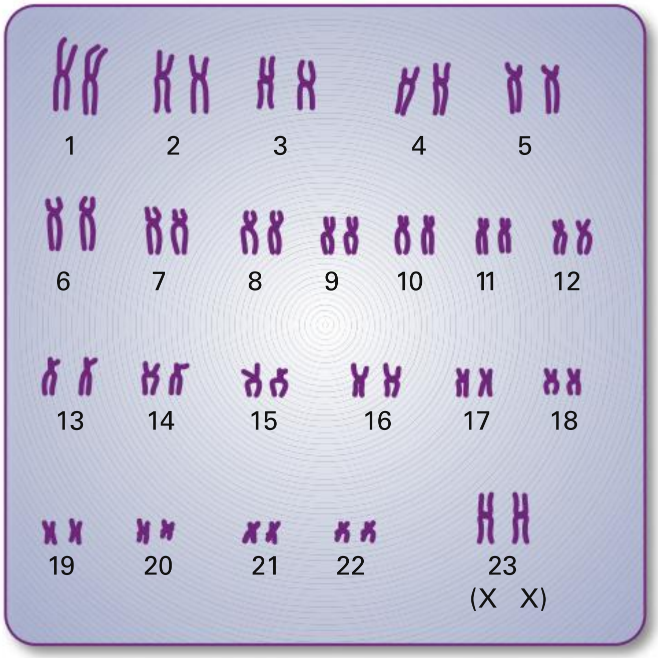
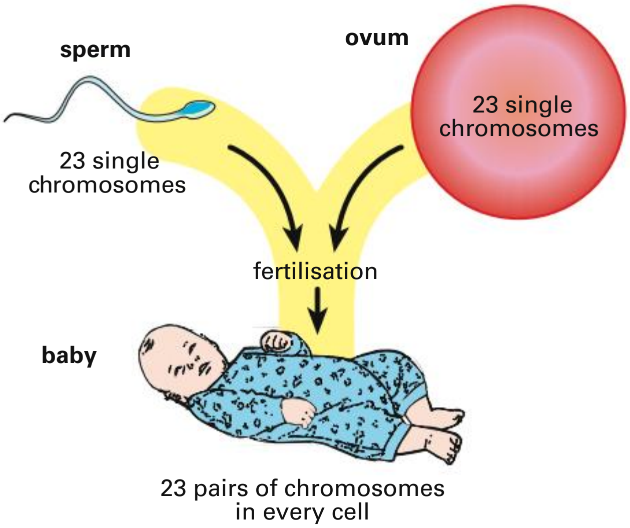


Fig 2 The 46 chromosomes in a human female are arranged in pairs based on size. The pair numbered 23 contains the sex-determining genes.

The nuclei of sex cells (sperm and eggs) contain only *half* as many chromosomes as the nuclei of all other cells. Why is this? The formation of sperm and ova occurs by a special type of cell division during which the chromosome pairs separate. This means that each sex cell receives 23 *single* chromosomes. When the nuclei of the sperm and egg join during fertilisation, the new cell then contains 23 *pairs* of chromosomes.

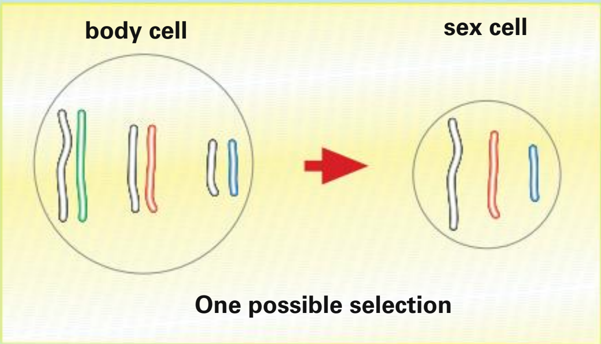


Activity

Chromosomes in sex cells

In this activity pipe cleaners will represent chromosomes. You will need three pairs of pipe cleaners, each pair a different length. One of each pair is white and the other is coloured.

1. Place the pipe cleaners in pairs so that you have a white one and a coloured one in each of the pairs.
2. Draw a circle at the top of a sheet of paper and lie the three pairs of chromosomes in it. This represents a body cell containing three pairs of chromosomes.
3. Your task is to make sex cells. For this, you select one long chromosome, one medium one and one short one. One selection has been done for you.



4. How many different sex cells can you make?

   Use coloured pencils to draw the three single chromosomes in each of the sex cells.

Extra for experts

Formation of sex cells

When your body cells divide, each new cell has the same number of chromosome pairs as the parent cells. In humans this is 23 pairs. These cells are referred to as *diploid* cells: *di* means two and *ploid* refers to the chromosome number. So in your body most of the cells are diploid and have two copies of each chromosome. Earlier you learnt that this type of cell division is called *mitosis*.

When sex cells are formed they have only one chromosome of each pair. These cells are called *haploid* cells. This means the cell division process has to be different from mitosis. The process of sex cell formation is called **meiosis** (my-OH-sis). Meiosis occurs only in special cells in the testes and ovaries in animals, and in the anthers and ovaries in plants.

In mitosis two daughter cells are produced in each division. However, in meiosis four different sex cells are produced, as shown in the diagram on the right and the animation.

Questions

1 Meiosis can be thought of as having two cell divisions. Describe how the first division is different from the second division.

2 There is another way the chromosomes can be arranged in line 3 of the diagram. Using red and blue pens, draw this arrangement. Draw the sex cells this arrangement will produce. How is it different from those in the diagram?

3 Imagine the blue chromosomes originally came from the organism's mother. What is the chance that a sex cell could carry all of the mother's chromosomes? Justify your answer.

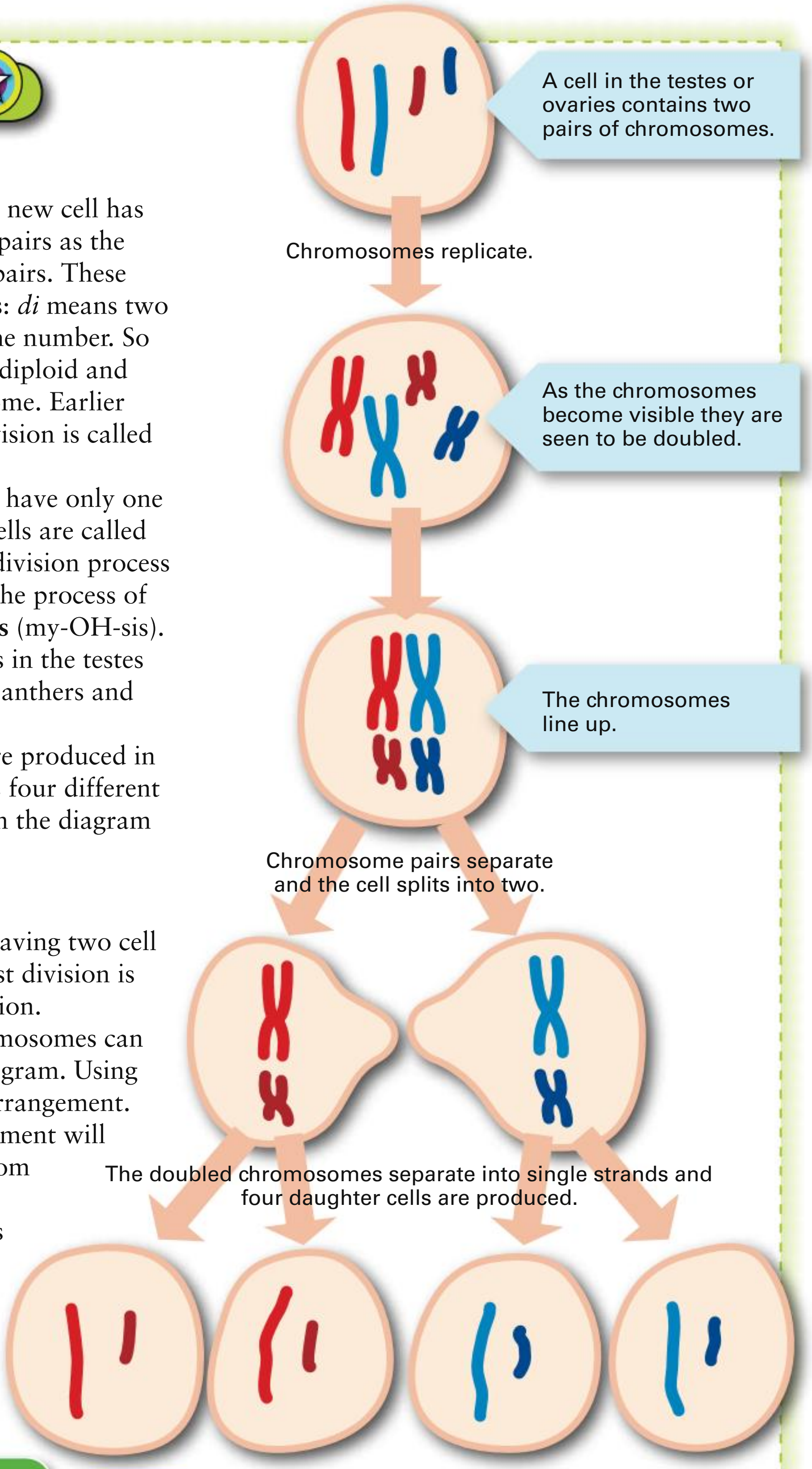


Fig 3 The process of meiosis produces sex cells with half the number of chromosomes of a body cell.

Working with technology

To see an animation of meiosis, open Making sex cells at www.OneStopScience.com.au.

Determining sex

The chromosomes on the right are from a human male. How are they different from the chromosomes in a female in Fig 2 on page 59?

Notice that chromosome pair 23 in the male is different from that in the female—the male has two quite different chromosomes. The larger one is called the X chromosome and the smaller one is the Y chromosome. These chromosomes are called *sex chromosomes* because their genes determine the sex of the offspring.

Sperm cells, which are made in the testes, contain either an X chromosome or a Y chromosome, and 22 other chromosomes. On the other hand, ova, which are made in the ovaries, contain an X chromosome and 22 others.

If you are a boy, you would have received a Y chromosome from your father and an X chromosome from your mother. And if you are a girl, you would have received an X chromosome from each of your parents.

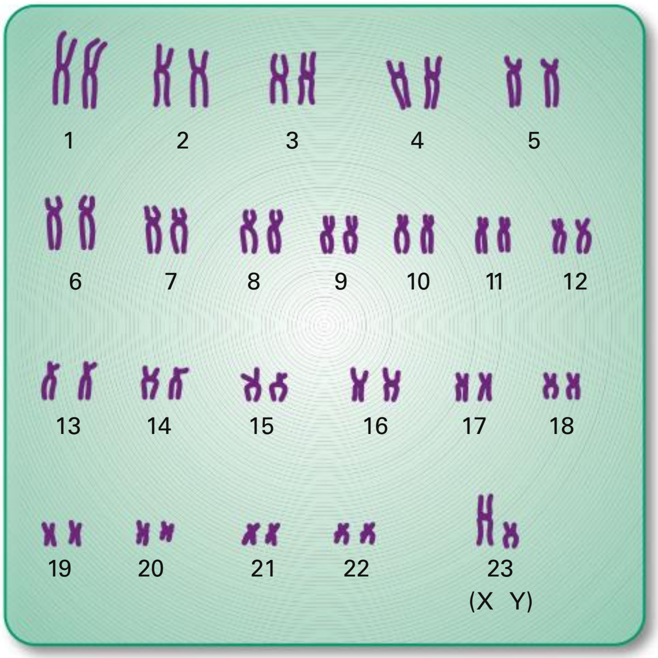


Fig 4 The chromosomes from a human male

Activity

If a couple is having a baby, what are the chances of having a boy? A girl? You can use a model to find out.

You will need eleven small plastic disks for this activity.

1. Use a felt pen to write X on five disks and Y on five others. These ten disks represent sperm.
2. Place all ten disks in a box or bag.
3. Mark the eleventh disk with an X. This represents an ovum.
4. Place the X disk on a piece of paper on the table.
5. Then, without looking, select a sperm disk and place it on the table next to the ovum.

   Record whether the result is a boy or a girl.
6. Replace the disk and repeat for a total of 10 draws.

   Calculate the percentage of boys and girls.
7. Repeat the procedure for a total of 100 draws.

   Calculate the percentages of boys and girls. Suggest why these results are different from the result in Step 6.

   Pool all the class results. Are the results the same as your results?

   In 1 mL of male semen there are about 40 million sperm. How many would be carrying the Y chromosome? What is the chance that a sperm carrying an X chromosome will be the first to fertilise the ovum?

   A couple has five daughters. What is the chance that their next child will be a son?

Check

1 What are chromosomes? When can you see them?

2 In mitosis, the chromosomes in the two daughter cells are identical to those in the original cell. How does this occur?

3 How do the chromosomes in human sperm cells differ from those in ova?

4 In humans most cells contain 23 pairs of chromosomes. In which parts of the body would you find cells with 23 single chromosomes?

5 Cosmo said to his friend, 'I inherited my red hair from my grandmother'. What does he mean by this?

6 The Smiths have three sons. Mrs Smith is pregnant and believes she is having another son. Mr Smith disagrees and says that because they have three sons the next child has a greater chance of being a daughter. Who is correct? Explain your answer.

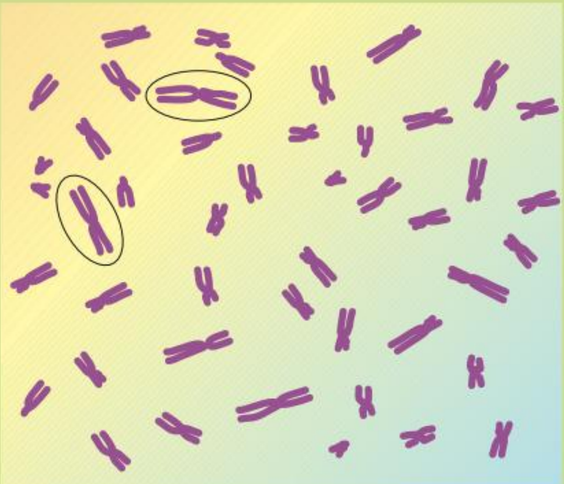
7 Use the table on page 58 to work out how many chromosomes there are in:
  a a fox's ovum.
  b the pollen of a corn plant.

8 The father's sperm determines the sex of the child. Is this statement true or false? Give a reason for your answer.

9 Look at the table of the number of chromosomes in different organisms on page 58. Notice that they are all even numbers. What is the reason for this?

Challenge

1 The diagram below shows the chromosomes of a human female. The chromosomes circled are a pair.
Could both of these chromosomes have come from only one of the parents? Explain.



2 Is it true to say that the most complex organisms have the greatest number of chromosomes? Use the table on page 58 to justify your answer.

3 There are two types of twins in humans—identical twins and fraternal twins.

Fig 5 Identical twins (top) and fraternal twins (bottom)

Identical twins form when an ovum splits into two just after a sperm fertilises it. Fraternal twins form when two ova are fertilised by two different sperm.

a Explain in terms of chromosomes why identical twins are always the same sex, yet fraternal twins can be the same or different sex.
Explain why one member of fraternal twins can have blue eyes while the other has brown eyes, yet identical twins both have the same eye colour.

4 In the formation of sex cells in the testes or ovaries (meiosis), the pairs of chromosomes line up in the middle of the cell. Then each member of the pair separates and moves apart. A new cell membrane forms down the middle and separates the two daughter cells.
Sometimes a pair of chromosomes may not separate, resulting in one sex cell with too many chromosomes and the other with too few. Using X and Y chromosomes only, explain, using diagrams, how a person's cells could contain three sex chromosomes, XXY.

5 The boy in the photo below has Down syndrome, a genetic disorder affecting about one in every 600 births. Children born with this disorder often have a lower than normal immunity to disease. Before antibiotics and other treatments became available, many of these children died when they were very young. People with Down syndrome have one extra chromosome in their cells.

Use the diagram in Fig 6 at the top of the next column and the ones on pages 59 and 61 to work out:

a which chromosome pair is affected

b whether the person whose chromosomes are shown in Fig 6 is a male or a female.

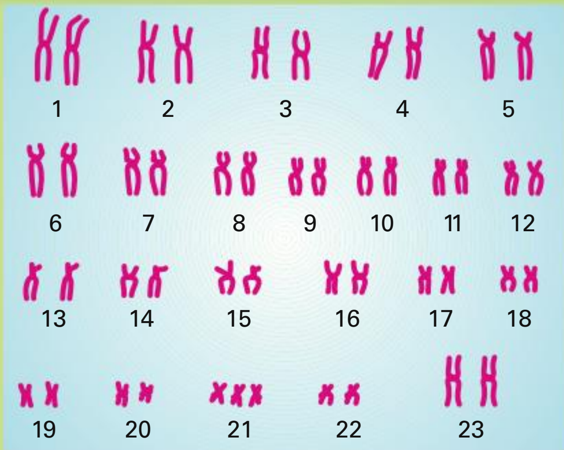


Fig 6 Chromosome map

6 Use the information in Fig 6 and in Question 5 to suggest how a person could be born with Down syndrome.

7 Not all features of organisms are controlled by genes. Some are influenced by factors in the environment experienced when the young organism is growing.

a What environmental factors might affect the features of humans?

b During which part of a human's life would these environmental factors have most influence?

c The blue flowers in the photo below were from a hydrangea plant grown in acidic soil. The red flowers were produced from a cutting of the same plant grown in basic soil.
What other environmental factors might affect the features of a plant?

Fig 7 Hydrangea flowers grown in acidic soil (blue) and basic soil (pink)

3.2 DNA

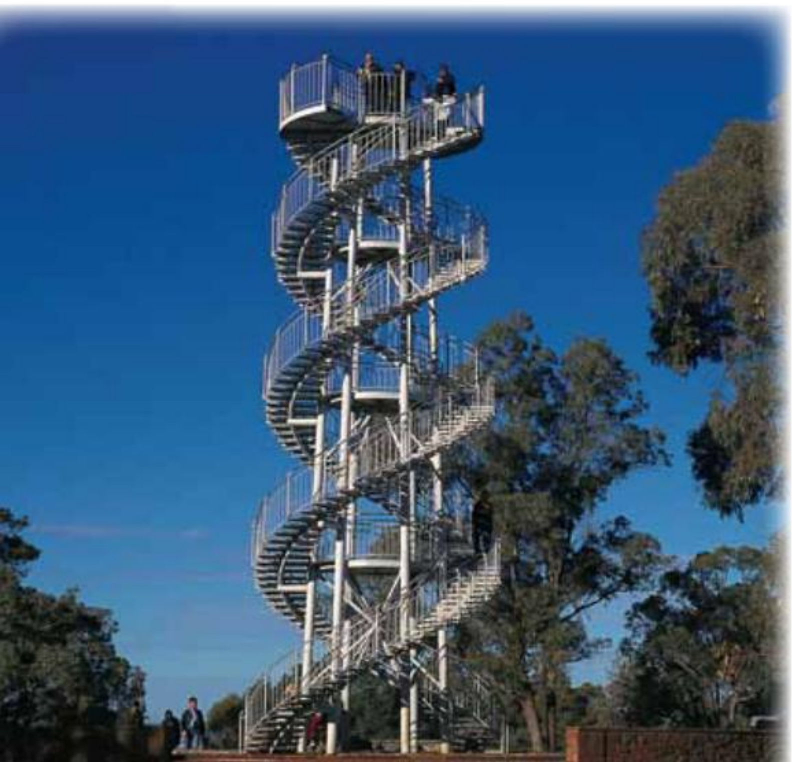
Chromosomes contain a substance called **deoxyribonucleic acid** or **DNA** for short. It is the DNA in the chromosomes that determines your characteristics.

The chemical composition of DNA was first investigated in 1869 when the German chemist Friedrich Miescher found that a substance from cell nuclei was acidic and contained the element phosphorus. Because it was found in the nucleus, this substance was initially called *nuclein* and later called deoxyribonucleic acid.

In the 1950s, James Watson, Francis Crick and Maurice Wilkins proposed that the DNA molecule is shaped like a *double helix*—something like the lookout in King's Park, Perth (see the photo below).

The DNA contains sugars (deoxyribose), phosphates and nitrogen-containing substances called *bases*. There are four types of bases: adenine (A), guanine (G), thymine (T) and cytosine (C). In the DNA molecule, base A on one strand will bond only with T, and C will bond only with G. For this reason A–T and C–G are called *base pairs*.

The DNA molecule is double stranded with each base on one strand weakly bonded to its base pair on the other strand. This bonding makes the two strands lock together to form the double helix shape.



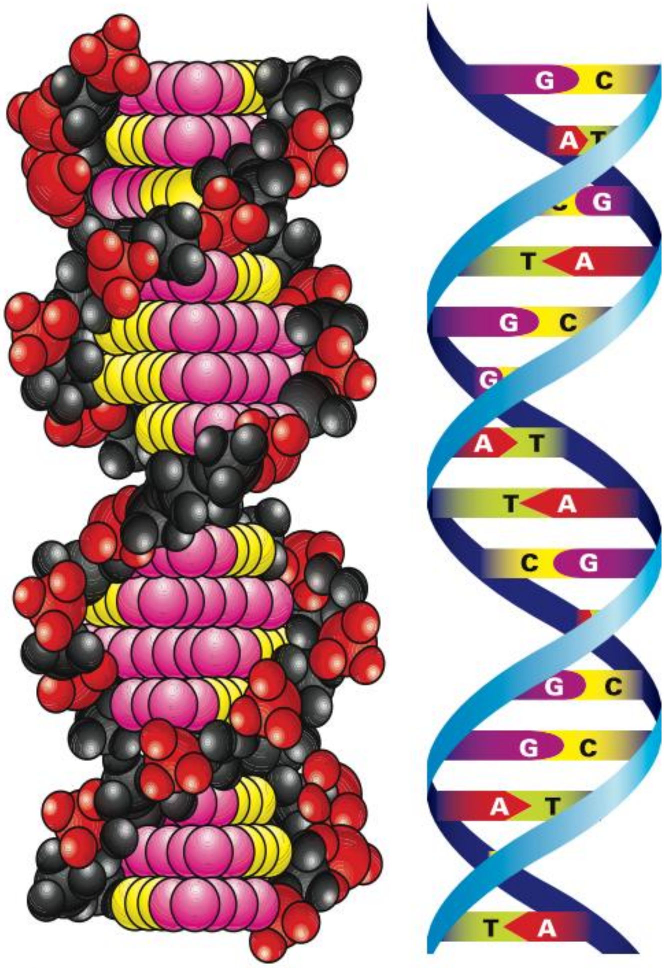


Fig 8 A model of DNA and a simplified structure on the right. The weak bonds between the matching base pairs on each strand hold the DNA molecule in its helical shape.

Genes

Organisms are different because the proteins in their cells are different. It is the DNA that provides information about the types of amino acids that make up proteins. The arrangement of the four different bases in the DNA strand will determine what type of protein will eventually be made. These sections on the DNA containing the bases are called **genes**. A gene is the portion of a chromosome that tells the body what type of protein to make.

Many of the substances in cells are made with the aid of enzymes, and all enzymes are proteins. So by determining the types of enzymes that are produced, the DNA code determines the organism's characteristics.

DNA replication

During cell division the DNA in the chromosomes copies itself. This process is called **replication** because the DNA copy is an exact *replica* of the original DNA.

The DNA is made up of building blocks called *nucleotides* (see Fig 9). The nucleotides are made of three molecules—sugar, phosphate and a base molecule. The nucleotides are linked together in the DNA to form strands.

The two twisted strands of DNA in the double helix are held together by weak bonds between the base pairs on each strand. When replication begins the weak bonds break and the DNA 'untwists', as shown below.

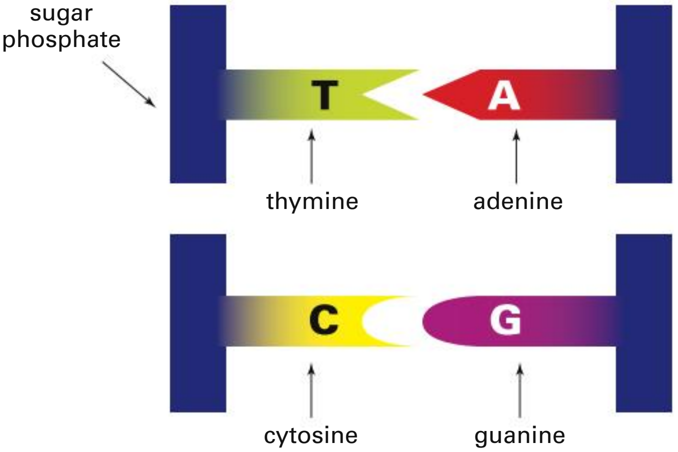


Fig 9 Nucleotides are the building blocks of DNA. They consist of sugar, phosphate and base molecules.

Working with technology

For an animation of this, open **DNA replication** at **www.OneStopScience.com.au**.

OneStopScience

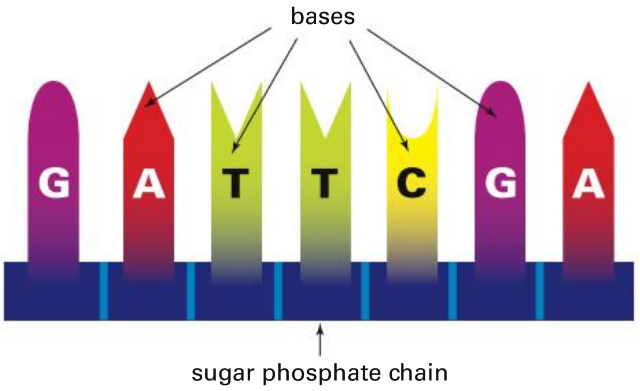
Replication begins as the DNA helix 'untwists'. The strands unzip as the weak bonds between the bases break.

The new strands begin to be built on each strand of the original DNA, using spare nucleotides.

Finally an identical copy of the original DNA is made.

The DNA code

If the two strands in the molecule of DNA separated, part of a single strand would look like the structure in the diagram below. It is the sequence of the bases along the DNA that forms the code.



Any *three* of these bases form a triplet code for one amino acid. For example, GAT will code for one type of amino acid and TCG will code for another. However, with four types of bases you can make $4 \times 4 \times 4 = 64$ different triplets. This is many more than the 20 amino acids, so some amino acids have two or more alternative codes (see the table on the next page).

Different sequences of bases code for different amino acids, which make up different proteins; and the number of amino acids in a protein molecule can vary from less than a dozen to over 50 000. DNA molecules contain millions of bases. Hence, a DNA molecule can code for thousands of proteins.

Mutations

The fawn (baby deer) in the photo on the next page was born without any skin colouring or hair colouring. This characteristic is called *albinism* and the animal is called an *albino*.

This fawn has a gene in its cells that has stopped the production of any pigment. There has been an alteration in the original gene that codes for normal colouring. Alterations to genes are called **mutations**. (See the box on page 68 to learn more about the chemical basis of albinism.)

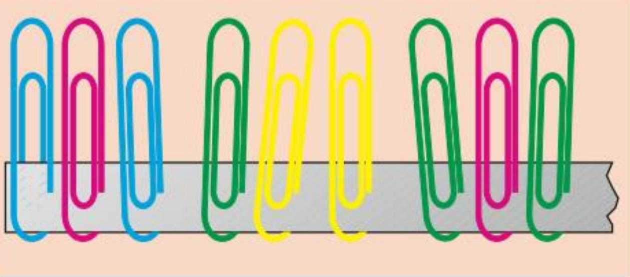
Some mutations can be detrimental to the organism, and most are fatal, causing death.

Activity

Model DNA

You will need some coloured paper clips and a small sheet of cardboard.

1. Choose four colours from the pile of paper clips, and assign a base to each colour. For example, blue = A, red = T, etc.
2. Cut a 12 mm wide strip from the sheet of cardboard. Make it between 20 and 30 cm long. The strip represents the sugar phosphate chain of the DNA molecule.
3. Place 18 paper clips (in any order) along the strip of cardboard. For convenience, group them into threes with a small gap in between.



The table on the next page shows the code for the 20 amino acids that are found in the body. Notice that most amino acids have two or more alternative triplet codes. Notice that there are also codes for STOP and START.

4. Use the table on the next page to find the code for STOP. This indicates the end of the amino acid chain of the protein that is to be made. Add this triplet to the end of your chain.
   - Use the table to work out the amino acid sequence on your model DNA.
   - Swap strips with your partner and work out their amino acid sequence.

Keep your model for the next activity.

Other mutations can be beneficial. For example, humans have benefited from a mutation in wheat that produced high-yielding wheat.

How do mutations cause changes to characteristics? Suppose a small part of a DNA

DNA code	amino acid	DNA code	amino acid	DNA code	amino acid	DNA code	amino acid
TTT	phenylalanine	CTT	leucine	ATT	isoleucine	GTT	valine
TTC		CTC		ATC		GTC	
TTA	leucine	CTA		ATA		GTA	
TTG		CTG		ATG	methionine/ START	GTG	
TCT	serine	CCT	proline	ACT	threonine	GCT	alanine
TCC		CCC		ACC		GCC	
TCA		CCA		ACA		GCA	
TCG		CCG		ACG		GCG	
TAT	tyrosine	CAT	histidine	AAT	asparagine	GAT	aspartic acid
TAC		CAC		AAC		GAC	
TAA	STOP	CAA	glutamine	AAA	lysine	GAA	glutamic acid
TAG		CAG		AAG		GAG	
TGA		CGT	arginine	AGT	serine	GGT	glycine
TGT	cysteine	CGC		AGC		GGC	
TGC		CGA		AGA	arginine	GGA	
TGC	tryptophan	CGG		AGG		GGG	

Fig 10 The triplet codes on DNA and the amino acids they code for—notice that there are alternative triplet codes for almost all of the 20 amino acids, as well as codes for STOP and START.

strand had the following sequence of bases:

AATCAACCTTCA

For convenience, let's separate the triplets.

AAT CAA CCT TCA

Using the table above this would code for the following amino acids:

asparagine glutamine proline serine

If there was a change to one of the bases:

AAT CCA CCT TCA

the new sequence of amino acids would be:

asparagine proline proline serine

This change could produce quite a different protein from the one that was made originally.

Mutations occur naturally, and it has been estimated that 1 in 1 000 000 cells contains a mutation in its DNA. However, the rate of mutations can be increased by exposure to

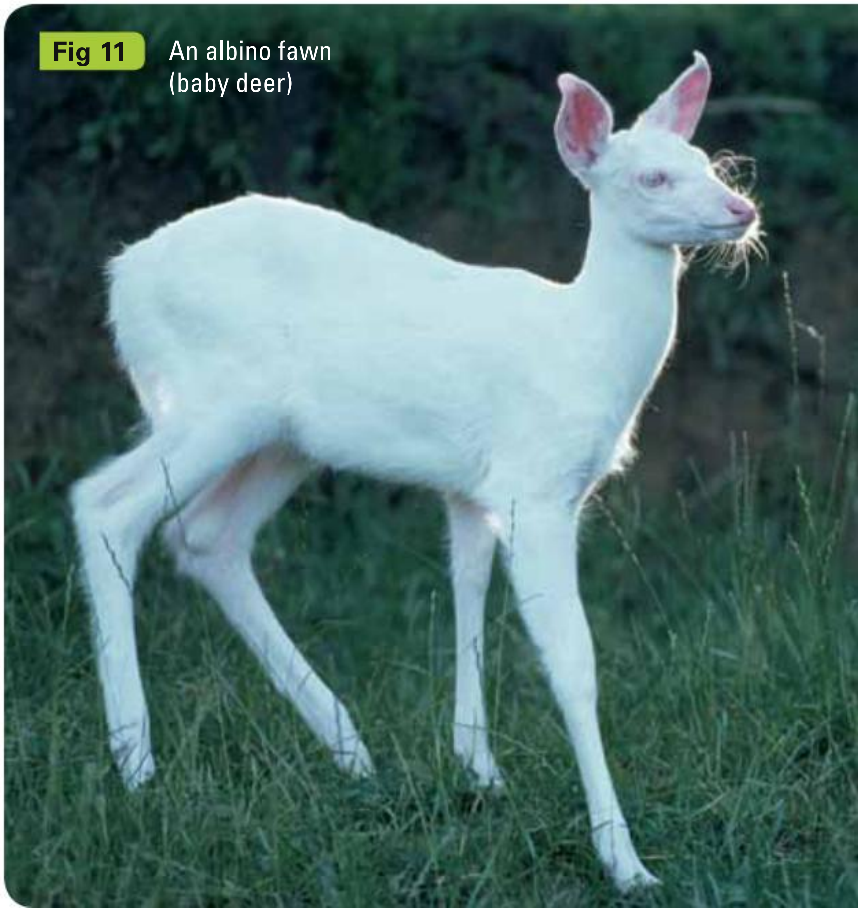


Fig 11 An albino fawn (baby deer)

high energy radiation from X-rays and nuclear radiation, as well as exposure to chemicals such as formalin and certain pesticides.

The UV part of sunlight can also increase mutations in organisms. These mutations can lead to cancer, particularly in skin cells. This is why over-exposure to the sun is dangerous, especially for people with light coloured skin.

Activity

DNA and mutations

You will need the model strand of DNA that you made in the activity on page 66.

Simulate a mutation by selecting one paper clip at random and replacing it with another colour.

- Find the new sequence of amino acids.
- Sometimes a mutation will not change an amino acid in a protein. Work out how you can change a base in your sequence but not change the original amino acid sequence.

Why there are albinos

The colour of your skin, eyes and hair is due mainly to a chemical compound called *melanin*. Melanin is made in special cells called *melanocytes* found at the bottom of the epidermis in your skin. The colour of your skin and hair depends upon the size of the melanin granules in the melanocytes. In black skins, the granules are larger and in white skins they are less obvious.

Melanin is made from tyrosine, a colourless amino acid. Tyrosine is converted to melanin by an enzyme called *tyrosinase*. If a mutation occurs in the gene that codes for the production of tyrosinase, the enzyme is not produced and melanin is not made. This results in an albino with whitish-pink skin, white hair and red eyes.

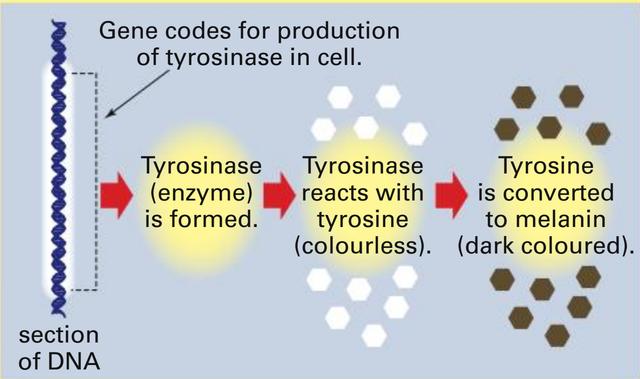


Fig 12 An albino South African boy

WEBwatch

Use your internet browser to find more information about albinism. Search using the following words: *melanin*, *melanocytes*, *albino*, *skin colour*.

Find out why albinos cannot tan in the sun and why an albino's eyes are red. Also try to find out why albino wild budgerigars are yellow.

Genomes

In 1916, after years of experimenting, Walter Sutton inferred that the inherited characteristics of fruit flies were carried on the chromosomes in the cell. In March 2004, scientists who had been experimenting collaboratively for 5 years found there were 250 million bases in the DNA in each fruit fly cell. They also determined the order in which the bases are arranged on the DNA.

The whole of the fruit fly's genetic information is found in these 250 million bases, and is called its **genome**.

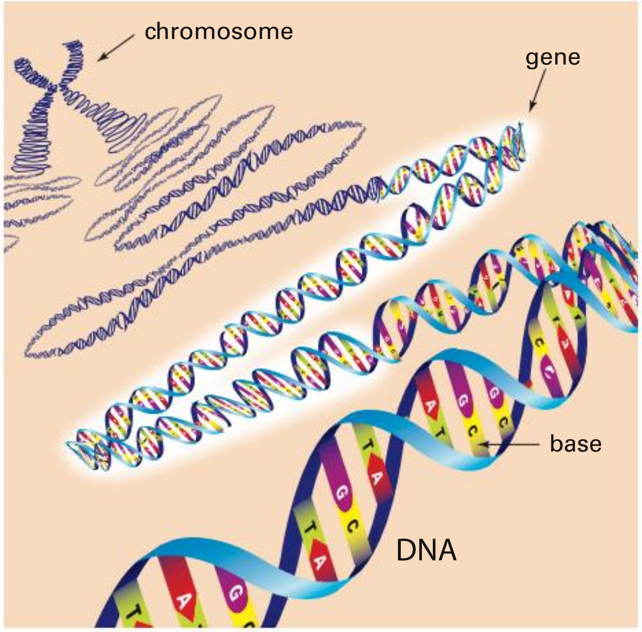


Fig 13 A gene is a section of DNA containing a particular sequence of bases.

What makes up a genome?

The researchers working on the fruit fly genome have also identified 13 601 genes on the DNA. These genes are made up of thousands of bases. The average gene contains about 2000 bases. If you multiply the number of genes by the number of bases an average gene contains, you find that the genes make up less than 20% of the genome.

The larger part of the genome contains sections that control how genes are turned on and off. There are also long sections of bases that are non-coding, and these may influence how the DNA replicates.

The Human Genome Project

The Human Genome Project (HGP), which ran from 1990 to 2003, mapped the position of the genes in the human genome. This massive task was co-ordinated by the United States National Institutes of Health and involved hundreds of scientists from at least 18 countries, including Australia. By the time the HGP had finished it had:

- identified 20,000 protein-coding genes in human DNA, and another 2000 DNA segments that are predicted to be genes
- determined the sequence of the 3 billion bases on human DNA
- stored the information on databases
- addressed ethical, legal and social issues that arose from the project.

The expected benefits of the HGP are:

- improved diagnosis of disease
- treatment of genetic diseases such as cystic fibrosis
- manufacture of custom drugs
- replacement of defective genes
- reduced risk of inheritable mutations
- improved techniques for DNA identification in legal and criminal cases.

HGP—the future?

Although the HGP was coordinated by government departments, one of the project's aims was to transfer all the technologies to private companies. Now much of the HGP follow-up research is being done by private commercial companies, particularly multi-national US-based companies, who expect to earn billions of dollars through sales of new drugs, equipment, technologies and information.

However, will the knowledge of the human genome benefit all humankind? Here are some problems that might arise:

- Will treatment and diagnosis be so expensive that only the rich will benefit?
- Will an individual's genetic file be private and secure, or will it be available to banks, health funds, insurance companies etc?
- Will the large companies patent their drugs so that they control certain treatments?

Activity

Work in a group of three or four people and discuss some of the issues in the statements and questions below. Use the internet, or find material from library books, magazines and newspapers.

1 Getting a man on the moon in 1969 was a massive project involving many scientists. How was this different from the scientific collaboration in the Human Genome Project?

2 Collect as much information as you can on new discoveries, techniques or inventions resulting from the Human Genome Project. Compile a scrapbook or information file and share this with the other groups in the class.

3 Suppose you have no family history of genetic diseases, and are thinking about having children. Should you ask your partner to have a DNA test done to make sure that their genome is disease-free?

4 Some life insurance companies are suggesting that a person's genetic file be submitted when they apply for life insurance, so that the company can assess whether that person is a high-risk case. What do you think? Give reasons for your answer.

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Student Guide to the Human Genome Project

This website has extensive and easy-to-read information on the HGP and links to a large number of other sites.

Frequently asked questions—Human Genome Project

This website answers questions about the HGP.

Educational Kit (HGP)

This National Human Genome Project Institute website has comprehensive information, animation and activities about the HGP.

OneStopScience

DNA detective work

With the completion of the Human Genome Project and advances in computer technology, large segments of DNA or even the whole genome may, in the future, allow precise identification of an individual. This is important in the following situations:

- matching donor organs with recipients in transplant operations
- identifying suspects whose DNA matches evidence left at a crime scene
- exonerating people who are wrongly accused
- identifying victims in major accidents, catastrophes or natural disasters
- establishing paternity of a child.

How is DNA used to identify people?

Detectives and forensic scientists have to gather a number of pieces of evidence together in order to convict a person of a crime. For example, a suspect's blood type and fingerprints are compared with those found at the crime scene, as are pieces of hair or fabric from their clothes and the tread of their shoes. All these pieces of evidence have to prove 'beyond reasonable doubt' that the suspect is the guilty person.

When using DNA to convict people, forensic scientists have to match the sequence of bases in a number of regions of the DNA of the suspect with those of the DNA samples found at the crime scene. Since only 0.1% of your DNA is different from anybody else's, scientists have to match base sequences of the DNA in regions that vary greatly from one person to another.

A court will not convict a person when only one or two of the DNA base sequences match. This is too little evidence. However, when at least five DNA base sequences match, a jury can be confident 'beyond reasonable doubt' that the suspect is the guilty person.

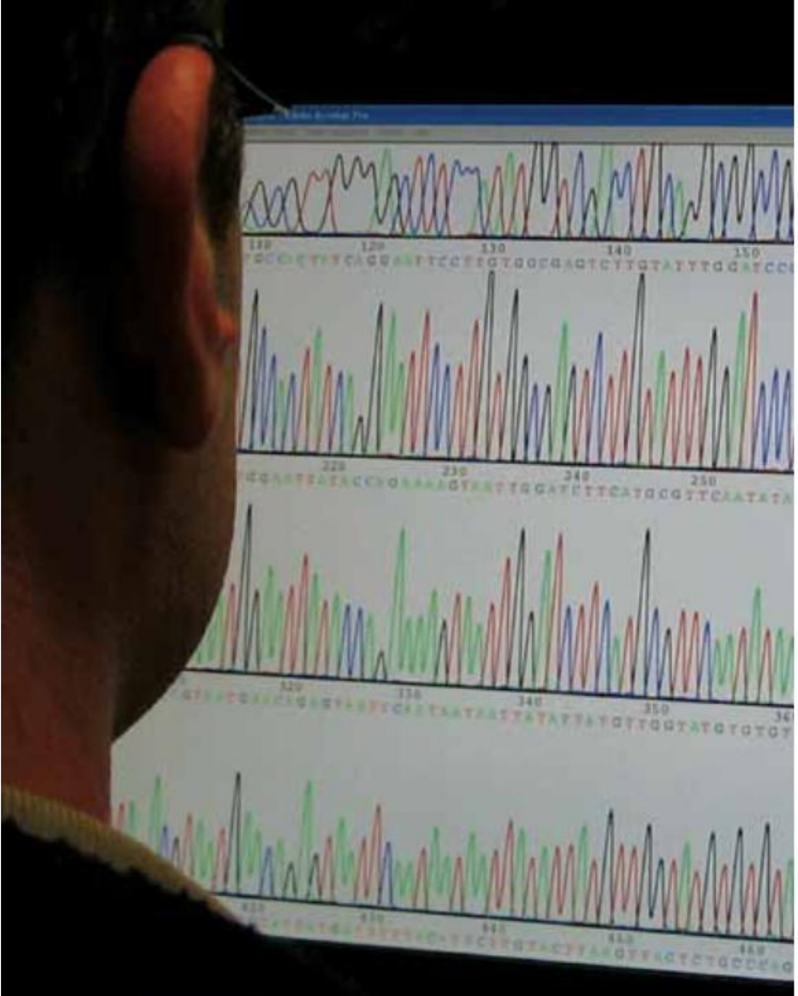


Fig 14 A forensic scientist examines the sequence of bases in sections of DNA.

Solving the French royal mystery

In 1795, Louis-Charles, the young son of King Louis XVI and Marie-Antoinette, supposedly died in a Paris prison. But many people believed he had escaped the brutality and executions of the French Revolution and fled to England.

In April 2000, scientists used DNA-matching technology to try to solve one of history's greatest mysteries. They used some tissue from the young prince's suspected remains and compared the DNA in it with the DNA in hair from his mother, as well as other samples from living and dead members of the royal family.

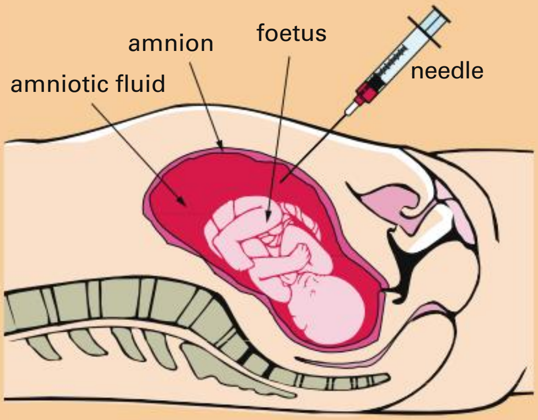
The DNA-matching tests showed that the tissues were from the young prince, but many people are still not convinced. Go to **www.OneStopScience.com.au** and follow the links to **Louis-Charles** for more information about this mysterious case.

Testing the foetus

If parents-to-be know that one or both of them has a family history of genetic disorders, doctors may suggest that the pregnant woman has one or more tests. Doctors also know that children born to women more than 37 years old have a greater chance than normal of having genetic disorders such as Down syndrome.

Doctors will first suggest an *ultrasound* test when the woman is about 11–13 weeks pregnant. In this test reflected sound waves generate a picture of the foetus. If doctors suspect an abnormality, they may recommend other tests.

In a test called *genetic amniocentesis* (AM-nee-oh-sen-TEE-sus), a fine hollow needle is passed through the abdomen of the pregnant woman and into the amnion. This is a fluid-filled sac surrounding and protecting the foetus. A tiny amount of amniotic fluid is withdrawn and tested.



High levels of protein in the fluid may indicate diseases such as spina bifida. DNA in the foetal cells that are found in the fluid are tested to check for Down syndrome and other genetic abnormalities. However, because amniocentesis is an invasive test, there are certain risks. About one in every 200 tests results in a miscarriage.

If the woman is found to be carrying an abnormal foetus she may be given choices of action. She may continue with the pregnancy or she may terminate the pregnancy before the legal limit (28 weeks in most states of Australia).

Check

1 What is DNA, and where is it found in the body?

2 What is a base pair? How do the bases help form the double helix shape?

3 a What is the genetic code?
  b What materials does the genetic code eventually produce?
  c Why are these materials so important in organisms?

4 A small part of a DNA strand contains the following bases: GGATAGCTTAGC
What are the matching bases on the other strand of DNA?

5 Insulin is a relatively small protein, having a total of 51 amino acids in its structure. What is the smallest number of bases on a DNA strand needed to code for insulin?

6 A small segment of DNA has the following sequence of bases:

ACA GGT CAA CCT TCA GGG TAA

Use the table on page 67 to work out the amino acid sequence.

7 Explain, by using the base sequence in the question above and the table on page 67, how mutations alter proteins.

8 Which environmental factors can increase the rate of mutations in organisms?

9 Make a list of the benefits that might be gained and the problems that might arise from the Human Genome Project.

10 The Human Genome Organisation has allocated 3–5% of its budget for the study of the project's ethical, legal and social issues. Make a list of some of these issues. You may want to discuss this with others.

Challenge

1 Biologists estimate that 99.9% of all your genes are similar to the genes of other people. The other 0.1% makes you different. However, about 80% of your genes are the same as those in a cat or dog, and about 60% are the same as in an earthworm. What can you infer from this information?

2 The following amino acids are from a small section of a protein:

leucine–glycine–tyrosine–lysine–lysine–glycine

  a Work out *one* base sequence on the DNA strand that would code for this section of protein.
  b Compare your base sequence with others in the class. How many different sequences did the class make for this section of protein?
  c What is the base sequence on the other strand of the double-stranded DNA?

3 Suppose a mutation occurs in a sperm cell of an animal and a gene is altered. This sex cell fertilises an ovum and an offspring is produced. However, many mutations are fatal and the offspring dies.

Use your knowledge of the materials genes make to suggest why this occurs.

4 A forensic scientist matches the DNA from a suspect with a sample from the crime scene. Explain to someone who doesn't know what DNA or forensic science is how this works. Use the terms *base sequence*, *DNA regions* and *beyond reasonable doubt* in your answer.

5 Man A believes he is the father of a child. The mother believes that man B is the father. How would you use DNA technology to go about solving this problem?

6 Use the internet to find out about other ways to test the health of a foetus. Try looking for chorionic villus sampling (CVS) and the maternal serum test.

WEBwatch

Watson and Crick were awarded the Nobel Prize in Physiology and Medicine in 1962 for their work on DNA structure.

Use the internet to find out more about their work. Also find out about the work of Rosalind Franklin and why she might have shared the Nobel Prize with Watson and Crick.

Then write a feature story about the discovery of the structure of DNA.

3.3 Dominant and recessive

Suppose you have set up an aquarium with two black fish—one male and the other a female. One day, a few months later, you notice eight baby fish. Your two parent fish have bred and had offspring. However, the puzzling thing about the baby fish is there are six black fish and two red ones!

The colour of the fish is controlled by a particular gene. This gene comes in two forms—one that codes for black colour and the other that codes for red colour. Different versions of the same gene are called **alleles** (a-LEELs).

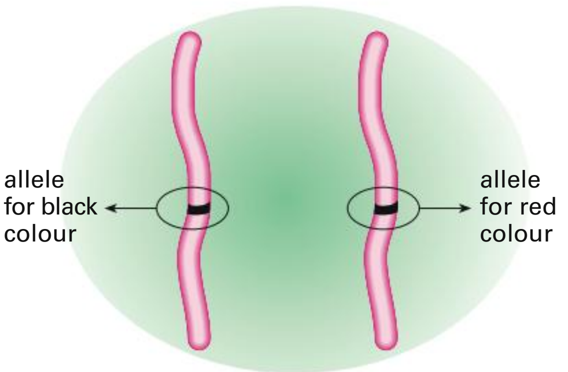


Fig 15 The colour of the fish's skin is controlled by two alleles of the same gene. Each allele is found at the same location on each of the chromosomes in the pair.

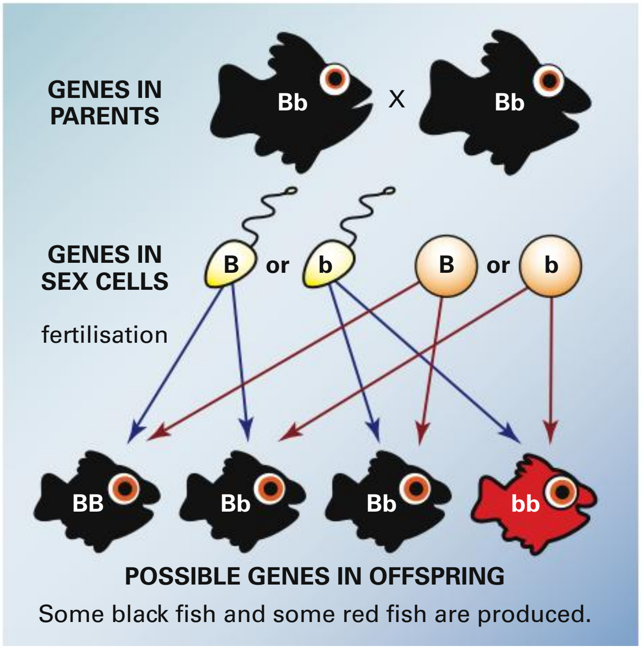
However, if the parents have the genes for black colour as well as red colour, why don't you see any red colour in the parents? This is because the gene for black colour completely masks the gene for red colour. The gene for black colour is said to be the **dominant gene**. The gene for red colour, which is masked by the dominant gene, is called the **recessive gene**.

It is usual to represent the genes by the first letter of the dominant gene. A capital letter is used for the dominant gene, and the lower case of that letter for the recessive gene. In this case, the allele for black colour is **B**, and the allele for red colour is **b** (not **r**).

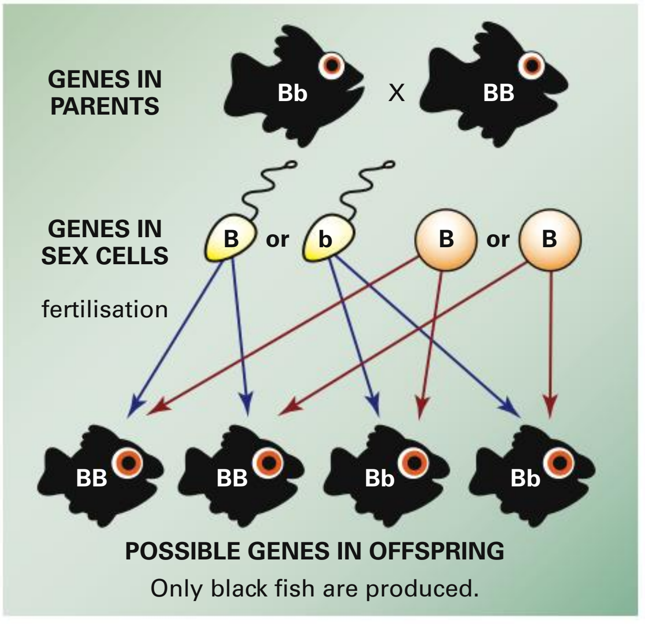
Fish carrying the genes **BB** will be black, and those carrying the genes **bb** will be red. Those fish carrying **Bb** will also be black because **B** is the dominant gene. (The dominant gene is usually written first, ie **Bb** and not **bB**.)

BB = black colour
Bb = black colour
bb = red colour

If the parents have a gene for black colour and one for red colour, they can produce some baby fish with black colour and some with red colour.



If only one of the parents has the gene for red colour, then none of the offspring will be red, as shown in the diagram below.



WEBwatch

Gregor Mendel was a monk and science teacher in a monastery in Austria. In 1866 he published his results of breeding experiments with peas. His meticulous and accurate records showed how characteristics could be passed from generation to generation. Mendel is often called the 'father of genetics'.

Use the internet to answer the following questions. Remember to record the websites where you found the information.

1 What characteristics in peas did Mendel first study? What were his conclusions?

2 Why is Gregor Mendel called the 'father of genetics'?

3 How did Mendel try to explain how characteristics were passed on from generation to generation?

4 It is said that Mendel's work was poorly understood and largely forgotten until after his death. Suggest a reason for this.

Activity

Fish genes model

In the example on pages 73–74, you found that if both parent fish have genes Bb, they will have some black offspring and some red offspring. Let's investigate how many of each colour are produced.

You will need 20 black disks and 20 red disks for this activity. (You can use other colours, or coins, if you wish.)

1 Place 10 black disks and 10 red disks in a small container. These discs represent the ova carrying the colour genes. Label this container 'Female'.

2 Place the remaining disks in another container labelled 'Male'. These disks represent the sperm carrying the colour genes.

3 Without looking, select a disk from the first container and one from the second.

Record the genes and the colour of the offspring. (Remember the gene for black colour is the dominant gene.)

4 Replace the disks and make another selection. Do this 10 times.

Calculate the ratio of black fish to red fish.

5 Make another 10 draws.

Add these results to the first results and again find the ratio of black fish to red fish.

Which results give a more accurate indication of the ratio of black fish to red fish? Why?

Collect the class results and find the ratio. Give your answer as the nearest whole number.

6 Repeat this activity to confirm that parent fish with genes Bb and BB will produce only black fish.

Some genetics terms

The two fish below look the same but have different genes. Biologists use special terms to describe this situation.

black fish
genes = **BB**

black fish
genes = **Bb**

The type of genes in an organism is called its **genotype** (GEN-o-type). What the organism looks like or its physical characteristics is called its **phenotype** (FEE-no-type).

In this example, both fish have the same phenotype but different genotypes.

The fish with genotype **BB** is said to be **homozygous** (HO-mo-ZYE-gus), or a pure breeder, because both the alleles for the skin colour gene are the same. The other fish is said to be **heterozygous** (HET-er-o-ZYE-gus), or *hybrid*, because its two alleles for skin colour gene are different.

So the first fish in the diagram could be described as being a homozygous black fish, while the other one is heterozygous black.

Predicting crosses

In the previous activity you should have found that the ratio of black fish to red fish was about 3:1. It is possible to predict the type of offspring produced when two organisms mate. This mating is called a *cross*. One of the easiest ways of predicting crosses is to use a *Punnett square*.

In the Punnett square below, two heterozygous black fish have been crossed.

Using a Punnett square, you can predict on average that, for each red baby fish, three black baby fish will be produced.

You also found that when a homozygous black fish (**BB**) crosses with a heterozygous black fish (**Bb**), all the offspring are black. Let's use a Punnett square to check this.

Parents = **Bb** x **Bb**

		Parent 2 (**Bb**)	
		Sperm	
		B	**b**
Parent 1 (**Bb**)	Ova **B**	**BB**	**Bb**
	b	**Bb**	**bb**

Expected ratio of phenotypes = 3 black : 1 red

Parents = **BB** x **Bb**

		Parent 2 (**Bb**)	
		Sperm	
		B	**b**
Parent 1 (**BB**)	Ova **B**	**BB**	**Bb**
	B	**BB**	**Bb**

Expected ratio of phenotypes = all black

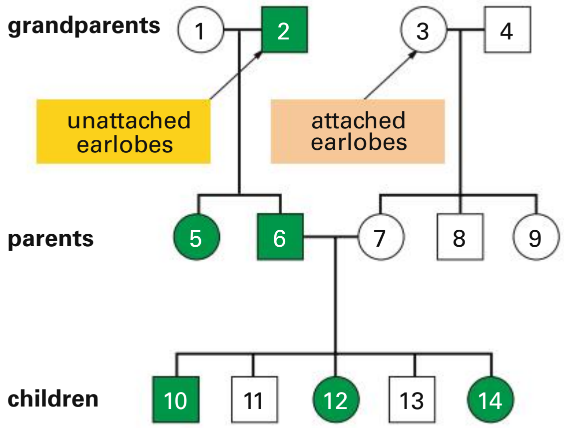
Pedigrees

Earlobe attachment is an inherited characteristic. The gene for unattached earlobes is dominant over the gene for attached earlobes.

Fig 16 Unattached earlobes (left) and attached earlobes (right)

By studying family histories, biologists can build up a pattern of inherited characteristics. This pattern can be seen on diagrams called family trees or **pedigrees**. Pedigrees can show the phenotypes of related individuals over a number of generations.

Look at the pedigree at the top of the page. It traces the history of earlobe attachment through three generations. The circles represent females and the squares represent males. The shaded circles represent females with unattached earlobes, and the shaded squares represent males with unattached earlobes.



Pedigrees can be used to work out the genotypes of the individuals. For example, biologists know that the gene for unattached earlobes is dominant over the gene for attached earlobes. Let's call the gene for unattached earlobes **A**, and the gene for attached earlobes **a**. Using these symbols, you can deduce that:

- grandparents 1, 3 and 4 will be **aa**
- individuals 7, 8, 9, 11 and 13 will be **aa**
- grandparent 2 could be **AA** or **Aa**
- individuals 5, 6, 10, 12 and 14 will be **Aa.**

The pedigree can be rewritten to show the phenotypes and genotypes of the individuals.

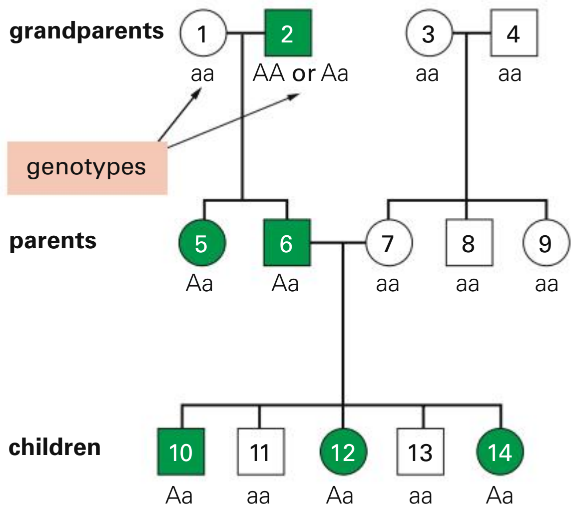


Fig 17 Pedigrees can show the genotypes as well as the phenotypes of individuals.

Not so simple inheritance

Gregor Mendel delivered his scientific paper detailing the results of his breeding experiments with garden peas in 1866. His experiments were well designed and well recorded, and he tested more than 28 000 plants to reduce experimental errors. His success was largely due to the great care he took with his experimental methods. His knowledge of mathematics also helped him interpret his results.

However, Mendel was also very lucky. The seven characteristics he studied in peas were each determined by a single gene. For example, the gene that determines seed pod colour has two alleles. The dominant one codes for green pods, while the recessive one codes for yellow pods.

Single gene inheritance

There are very few characteristics in organisms that are controlled by a single gene. The following are two human characteristics determined by a single gene:

- Earlobe attachment is determined by the presence of the dominant allele.
- *Cystic fibrosis* is a severe disease of the lungs and intestines caused by a recessive gene. A person inheriting the two affected alleles would develop cystic fibrosis. A person with only one affected allele would not develop cystic fibrosis, but would be a 'carrier' for the disease.

Human eye colour

For many years eye colour in humans was thought to have been controlled by a single gene. The allele for brown eyes was dominant over the allele for blue eyes. However, this idea did not explain green eyes or grey eyes or the variation of colours in between.

Biologists currently think that eye colour is controlled by at least three genes and probably others that may control how the coloured pigment is distributed over the iris causing flecks and rings. Eye colour is thought to be controlled by:

- a gene found on chromosome pair 15 that controls brown–blue colours,
- a gene found on chromosome pair 19 that controls green–blue colours, and
- another gene located on chromosome pair 15 that may affect the other two genes.

Eye colour

The colour of eyes is primarily determined by the amount of melanin in them. This dark brown pigment is deposited in the cells on the front surface of the iris. If a lot of melanin is present, your eyes will be brown. If very little or no melanin is present your eyes will be blue.

There is also a brownish-yellow pigment found in people with green eyes. It may also determine whether you have dark brown or light brown eyes.

There is no blue pigment in humans. Blue eyes is the absence of melanin. The cells in the front of the iris scatter the blue light in sunlight more than the red light. So your eyes appear blue just like the sky appears blue.

Blended genes

Budgerigars are native birds that live naturally in woodlands and grasslands throughout inland Australia. There are two purebred forms—yellow birds and blue birds.

Fig 18 The green budgerigar in the middle is the offspring of one parent with blue feathers and the other with yellow feathers.

When a homozygous blue bird mates with a homozygous yellow bird, the offspring are green, not blue or yellow. In this case, the two alleles for feather colour are not dominant or recessive over each other, but instead result in a mixture or blend of characteristics. This is said to be **incomplete dominance**.

There are many examples of incomplete dominance. A red shorthorn bull mates with a white shorthorn cow to produce red and white calves, and red carnations cross with white ones to produce plants with pink flowers.

Suppose a blue male budgerigar mates with a yellow female. All the offspring have green feathers. Let's call the allele for blue feathers **B**. The allele for yellow colour cannot be **b** because it is not recessive. In this case we will call it **Y**, because offspring with alleles **BY** will be green.

The Punnett square at the top of the page shows the results of the cross between a blue budgerigar and a yellow one. When the green offspring are crossed, birds with blue, yellow and green feathers are produced.

Parents = **BB** x **YY**

		Parent 2 (**YY**)	
		Sperm **Y**	**Y**
Parent 1 (**BB**)	**Ova** **B**	**BY**	**BY**
	B	**BY**	**BY**

Expected ratio of phenotypes = all green

Human blood types

There are four main blood types in humans—A, B, AB and O type. ABO blood type is controlled by a gene found on chromosome number 1, and biologists have found that there are three alleles of this gene—**A**, **B** and **o**. A person can have only two of the three alleles, one on one chromosome and the other on its pair. Allele **o** is recessive, while both alleles **A** and **B** are dominant. Therefore, if a person inherits allele **A** from one parent and allele **o** from the other, they will carry **Ao** alleles and will have **A** type blood.

But if a person inherits allele **A** from one parent and allele **B** from the other, the resulting blood type is **AB**. This blood type has features of both **A** type blood and **B** type blood, and not a blend of the two as you would get with incomplete dominance. This type of gene action is called **co-dominance**. The table below shows the relationship between the phenotypes and the genotypes.

Alleles (genotype)	Blood type (phenotype)
AA or Ao	A
BB or Bo	B
AB	AB
oo	O

Activity

There are two parts to this activity. For each part, work in a group of three or four people.

Part A: Determining blood groups

Because there are three different alleles for blood type, it is possible for children of a couple to:

- all have one blood type
- have two different blood types
- have three different blood types
- have four different blood types.

Use the table on the previous page to help you work out the genotypes of the parents and the children in each of the four situations above.

A woman of blood type B claims that a man of blood type A is the father of her two children, who have blood types AB and O. Explain whether her claim is true or false. Does your explanation prove that he is the father of the children?

Part B: Blood transfusions

Carefully read the following extract.

A person requiring a blood transfusion has to be carefully matched to the donor's blood.

The structure of certain molecules on the surface of the cell membrane of a red blood cell determines blood type. There are two types of surface molecules, called A and B, which are controlled by genes. For example, a person with allele A will have red blood cells with A type molecules. A person with allele B produces B type molecules, while alleles A and B together produce both A and B type molecules, and gene o produces no surface molecules. Thus, there are four main blood types in humans.

Now if a person with A type blood is given B type blood, a reaction occurs, resulting in a blood clot. These blood clots can block blood vessels in the heart, brain and other organs, and can be fatal.

The reason the clot forms is due to molecules called antibodies in the blood plasma (the clear part). Antibodies are produced when the body recognises that the surface molecules on cells are foreign. They destroy them by joining to them. This also happens to bacteria and 'foreign' blood.

People with A type blood produce anti-B antibodies. If this person is given B type blood, anti-B antibodies will be produced and will react with the type B blood cells forming a clot.

The table below shows the types of red blood cells and the antibodies that can be produced in the four different blood types.

What are antibodies? Why are they important in the human body?

Draw up a table showing a patient's four possible blood types. Then in another column show the possible blood types that could be given to each patient in a transfusion.

Explain why blood type O can be given to people with any blood type.

Which blood type can receive all the other types of blood?

Blood type	Type of surface molecules on red blood cells	Antibodies found in plasma
A	A	anti-B
B	B	anti-A
AB	A and B	neither
O	neither	both anti-A and anti-B

X-linked genes

In humans, there are a number of genes on the X chromosome that have no equivalent on the smaller Y chromosome. This is because the X is much larger than the Y chromosome. These genes are said to be **X-linked** and the characteristic is said to be sex-linked. Colour vision and blood clotting are two examples.

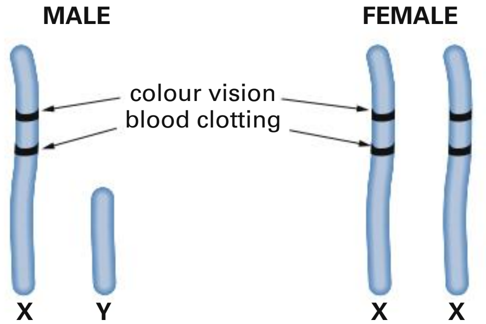
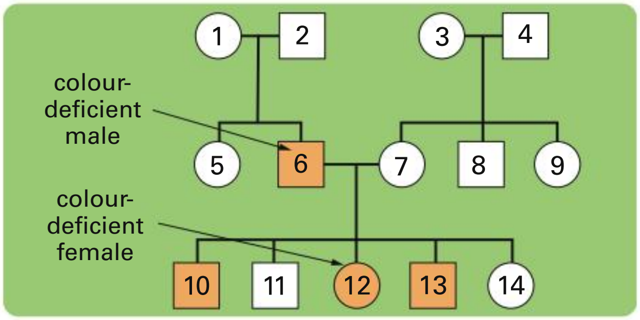


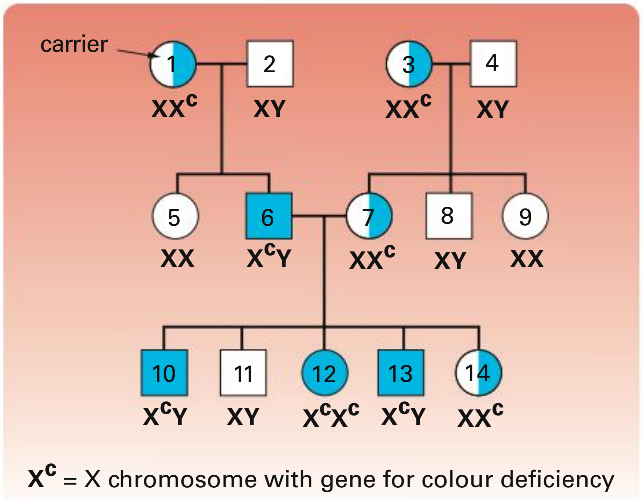
Fig 19 The genes for colour vision and blood clotting are found on the X chromosome. Females have two alleles for each characteristic but males have only one because there are none on the Y chromosome.

The allele for normal colour vision is dominant in humans (as you would expect). Now suppose a male is colour deficient (incorrectly called colour blind). He has an affected gene for colour vision on the X chromosome, but there is no matching allele on the Y chromosome. On the other hand, a female who has an allele for colour-deficient vision on one X chromosome and an allele for normal colour vision on the other, will have normal colour vision. However, she is called a *carrier* because she carries the affected gene for colour-deficient vision.

The pedigree below shows the inheritance of the gene for colour vision.



Male 6 is colour deficient and must have inherited the gene on the X chromosome from female 1 who is a carrier. Males 10 and 13 inherited their genes from female 7, while their colour-deficient sister, 12, got her genes from both her mother, 7, and her father, 6.



Check

1. Explain the differences between these terms:
   a. dominant and recessive genes
   b. heterozygous and homozygous
   c. genotype and phenotype.
2. Suppose a characteristic in humans is represented by the alleles **G** and **g**.
   a. Which one is recessive?
   b. Show two genotypes that produce the same phenotype.
3. If you get half your genes from your mother and half from your father, why don't you have half your mother's features and half your father's?
4. Toby crossed a brown mouse with a white mouse. He discovered that all of the baby mice were brown. What can you infer about the genotypes of the parent mice?
5. Explain the difference between genes that show incomplete dominance and those that are co-dominant.

6 A farmer breeds a black rooster with a white hen. She finds that all the chickens have grey feathers.
   a Use appropriate symbols to show how this happens.
   b What colour feathers should the offspring have if two of the grey-feathered chickens are crossed?

7 Explain in simple language what the following statements mean.
   a The gene for blood clotting is an X-linked gene.
   b Females can be carriers for X-linked genes but males cannot.

8 What would happen if a person with A type blood was injected with B type blood?

Challenge

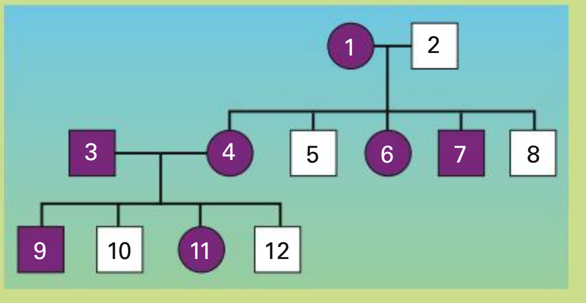
1 Suppose that the allele that controls right-handedness is dominant over the one for left-handedness. A heterozygous right-handed male and a left-handed female have four children, three who are left-handed and one who is right-handed.
   a If the allele for right-handedness is called R, use a Punnett square to calculate the proportion of children who should be right-handed.
   b Suggest a reason for the difference between your result in **a** and the actual proportion of children with this characteristic in this family.

2 When a homozygous hen with black eyes mates with a rooster with red eyes, all the chickens have black eyes.
   a Which allele for eye colour is dominant?
   b What is the genotype of the chickens?
   c Suppose two of the chickens mated when they matured. Use a Punnett square to find the genotypes and phenotypes of the chickens in the next generation.

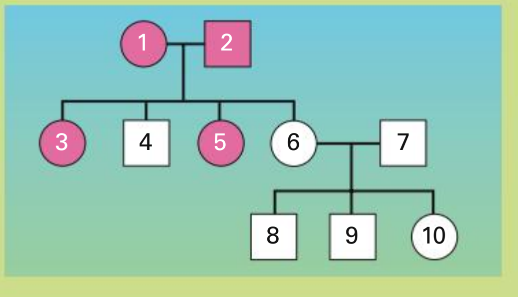
3 In guinea pigs short hair is dominant over long hair. Explain how you could get some long-haired baby guinea pigs if you had a short-haired female and you had to buy a male guinea pig.

4 Muscular dystrophy is an inherited disease caused by an X-linked recessive gene. A man and a woman without the disease have a son with muscular dystrophy.
   a What are the genotypes of the parents?
   b What are the chances that their next son will have the disease?
   c What are the chances that their next female child will have the disease?

5 In humans, the allele for long eyelashes is dominant over the allele for short eyelashes. In the pedigree in the next column the shaded circles and squares show people with long eyelashes.
   a Use appropriate symbols to work out the genotypes of the members in the pedigree.
   b List the individuals who are definitely heterozygous and those who are definitely homozygous. Which ones are in doubt?



6 The ability to roll your tongue into a tube is an inherited characteristic in humans. In the pedigree below, the shaded individuals can roll their tongues. Work out if tongue-rolling is dominant or recessive. Then deduce the genotypes of the individuals.



7 You are a genetic counsellor advising a couple who wish to have a baby. The man tells you that his only sister has had a son and a daughter; the daughter died from Gaucher's disease, a non-X-linked recessive disease of the blood. The woman has no family history of the disease.
   a Use a pedigree to find the chance of the man being a carrier for the disease.
   b What are the chances that the man's children will have the disease?

Science as a Human Endeavour

Genetic counselling

Mrs Van Tronk has just given birth to a baby boy. A few days later she and her husband are asked whether they will permit their baby boy to be tested for the presence of Duchenne muscular dystrophy, or DMD, an X-linked disease which develops mainly in boys and occasionally in girls. It causes the muscles of the lower limbs to weaken and waste away, and eventually control of all muscle movement is lost.

After careful consideration, the Van Tronks give permission for the test to be done. Doctors first test the blood for the presence of a particular enzyme that indicates muscle damage, but this is not a conclusive test for DMD. They find the enzyme in the baby's blood, so a DNA test is done to see whether the baby has the DMD gene. The results of the DNA test show that baby Van Tronk has the mutation that caused DMD. The parents are then counselled by medical and social experts and are made aware of the difficulties of raising a DMD child, and also of the help that is available.

Two years later, Mrs Van Tronk becomes pregnant once more. The Van Tronks know that there is a chance that this baby might also develop DMD. Because the baby is an 'at risk' baby, they make an appointment to see a genetic counsellor. The genetic counsellor explains to them about chromosomes and X-linked genes. They are told that the disease is caused by a gene on one of Mrs Van Tronk's X chromosomes, so that if the developing baby is a boy, he has a 50:50 chance of suffering DMD. The counsellors also discuss how X-linked genetic diseases run in families, and trace her family history with the aid of a pedigree. The counsellors suggest two possible courses of action.

- Test the developing baby's chromosomes to determine the sex of the child and whether it carries the DMD gene. The mother can continue with the pregnancy or terminate it within 28 weeks.
- Have no tests, but be aware that the child may have DMD if it is a boy, and be prepared to care for him.

Fig 20 Duchenne muscular dystrophy is an inherited disease caused by a defective gene on the X chromosome.

Questions

1 Work with two or three other people and draw up a list of options that are available to the Van Tronks.
   a Make a decision on what you would do if you were a Van Tronk. Give reasons for your decision.
   b Suggest what help and support may be necessary for the Van Tronks with each of the options.
2 Should it be compulsory to test all pregnant women to find out if their offspring have genetic abnormalities? Give reasons for your opinion.
3 Under United States law, discrimination based on genetics is banned. At present, this is not so in Australia. How do you think Mrs Van Tronk could be discriminated against if her gene file was known?
4 Go to **www.OneStopScience.com.au** and follow the links to **Gene Testing**. You will find information about gene testing, the pros and cons of the procedures and the current regulations.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 ______ are found in the nuclei of cells. They carry ______, which determine what an organism looks like and how it functions.

2 Body cells contain pairs of chromosomes while ______ contain only single chromosomes. When fertilisation occurs, the single chromosomes form pairs in the cells of the new organism.

3 Sex in humans is determined by sex chromosomes—females have a pair of ______ and males have an X and a ______.

4 Chromosomes are made of ______. The sequence of the ______ on the DNA determines which types of proteins will be made.

5 ______ alter the sequence of bases in cells, and occur spontaneously or from exposure to ______ or certain chemicals.

6 The whole of an organism's genetic information found in its DNA is called its ______.

7 Different versions of a gene, called ______, are found at the same location on a pair of chromosomes.

8 For an inherited characteristic, the ______ form of the gene masks the recessive one.

9 The ______ of an organism is the types of genes it contains, whereas its physical characteristics are called its ______.

alleles
bases
chromosomes
DNA
dominant
genes
genome
genotype
mutations
phenotype
radiation
sex cells
X chromosomes
Y chromosome

Working with technology

Try doing the Chapter 3 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

1 Chromosomes are found in:
A sex cells only
B all cells
C fertilised eggs only
D animal cells only.

2 A gene is:
A a chromosome
B a molecule of DNA
C part of a chromosome that carries a single instruction
D one base on a molecule of DNA.

3 Tongue-rolling in humans is controlled by a single gene. Which one of the following statements is correct?
A Both genes for tongue rolling came from the male parent.
B Both genes came from the female parent.
C One gene came from each parent.
D Two genes came from each parent.

4 Horses have a total of 64 chromosomes in each of their body cells. Male horses have an X and a Y chromosome in their cells.
a How many pairs of chromosomes are found in the body cells of horses?
b How many chromosomes are found in the sperm of a horse?
c Which chromosomes do sperm carry?

5 A strand of DNA contains the bases AAGTC.
a What is the sequence of bases on the other matching strand of DNA?
b How are the two strands of DNA held together in the double helix?

6 A small section of DNA has the following sequence of bases.

TTAAGACTCAAGGGGTCCTCA

a How many amino acids does this section code for?

b Use the table on page 67 to work out the sequence of amino acids in the section of DNA.

c A mutation changes the triplet AAG to GAG. How will this affect your answer to **b**?

d Suppose the section of DNA is part of the gene in humans that makes your blood clot when blood vessels have been damaged. Suggest what might happen if this mutation did occur.

7 The Sloans have just had a baby boy. They also have another son and a daughter. Mrs Sloan is blood type O while her husband is blood type A.

a Which parent is definitely homozygous for blood type?

b If the daughter has O type blood, what blood genotype does Mr Sloan have?

c What are the chances that baby Sloan will have A type blood?

8 In corn plants, there are two types of seeds. The gene for smooth seeds (S) is dominant over the gene for wrinkled seeds (s).

a If a plant is homozygous and has smooth seeds, what are its alleles?

b What is the phenotype of a plant with the alleles Ss? Explain.

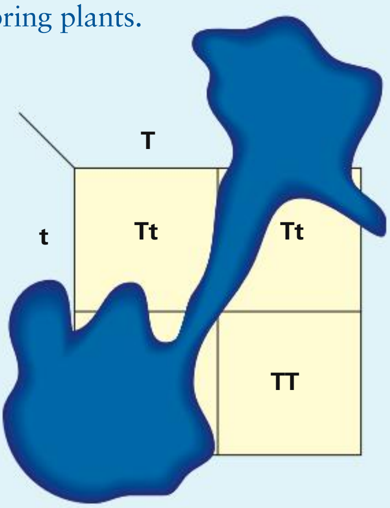
c What is the genotype of a plant with wrinkled seeds?

d Why would a plant with wrinkled seeds have to be homozygous?

9 The gene for height in pea plants has two alleles. The allele for tallness is dominant over the one for shortness. Joshua used a Punnett square to predict the results of a cross between two pea plants. Unfortunately, he spilt some ink over his notebook. From his ink-stained calculations:

a work out the genotypes and phenotypes of the parent plants

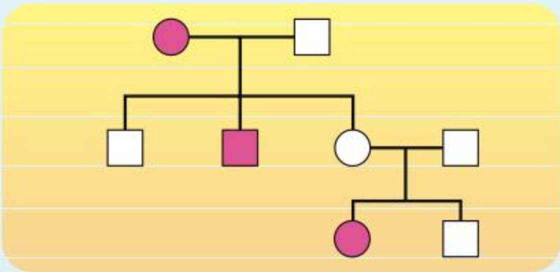
b calculate the ratio of phenotypes in the offspring plants.



10 A couple has four children—three girls and a boy. The father, mother and two of the daughters can roll their tongue, while the other daughter and son cannot. Tongue-rolling is controlled by a single gene. If the allele for tongue-rolling is dominant, use a pedigree to work out the possible genotypes and phenotypes of all the members in the family.

11 Colour-deficiency is an X-linked characteristic. Use pedigrees and the symbols X, X^c and Y to explain why males are much more likely to be colour deficient than females.

12 The people in the pink-shaded shapes in the pedigree below have a particular characteristic. Use the information in the pedigree to work out whether the allele for the characteristic is dominant or recessive.



Check your answers on page 303.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

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Science as a Human Endeavour

DNA testing

Look at the photo on page 71 which shows a DNA profile or 'fingerprint'. Profiles like this can be used to identify people (see *DNA detective work* on page 70).

To make a DNA profile you must first have a sample of a person's DNA—from, for example, blood, hair, saliva, skin or semen. Special enzymes that act as chemical 'scissors' are used to cut the DNA into hundreds of small pieces. These pieces are placed in wells (holes) at one end of a plate of thick gel, as shown in the photo below. An electric current is passed through the gel, giving it a negative charge near the wells. The gel at the other end of the plate is positively charged. Because DNA pieces are negatively charged they are slowly pulled towards the positive end of the plate. The smaller, lighter pieces of DNA move through the gel much faster than the larger pieces, and the pieces become separated. This process is called *electrophoresis* (electro-for-EE-sis). When the separation is complete the gel is stained with dye and each DNA piece is visible as a band, a little like a bar code. This DNA profile can then be compared with the profiles from other individuals.

To match a suspect's DNA profile to a profile of DNA collected at a crime scene, 10 bands in the profiles must match. In a child's DNA profile, some of the bands will match the mother's DNA profile and some will match the father's. To establish parentage, at least four bands must match.

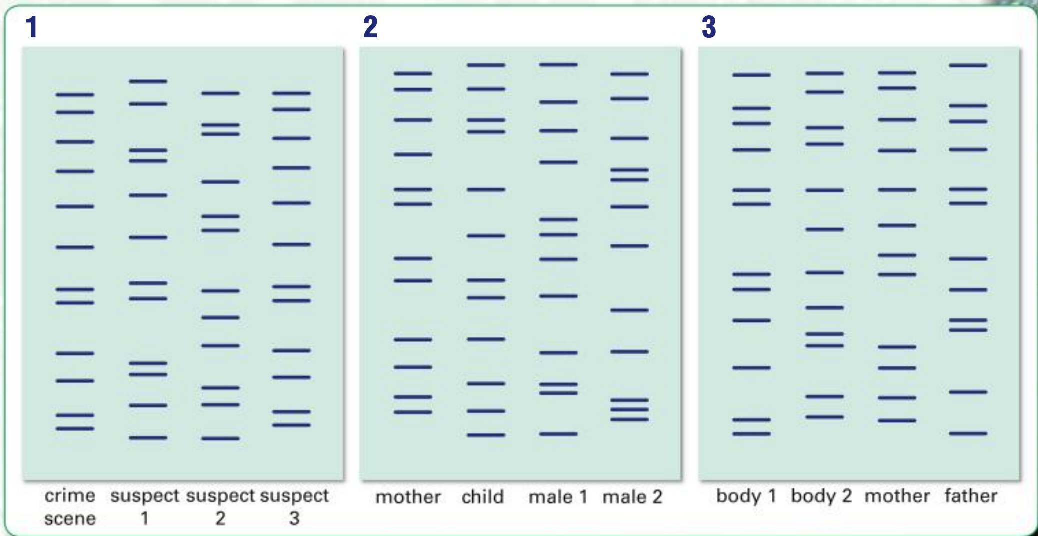
1 Look at the DNA profiles shown in gel 1 above. Do the profiles of any of the three suspects match the crime scene DNA?

2 There is doubt over the parentage of a child. Use the profiles shown in gel 2 below to decide if there is a match to the mother. Which male is the father?

3 Gel 3 below shows the DNA profiles from two bodies recovered from a house fire. Is either of the bodies the missing son of the mother and father tested?

4 Many careers involve DNA testing. Would you be interested in such a career? Why or why not?

Go to **www.OneStopScience.com.au** and follow the links to **Extract your own DNA**.



4 Explaining reactions

In this chapter you will …

Science Understanding

- write chemical formulas for ionic and covalent compounds
- write correctly balanced symbol equations for chemical reactions
- predict the products of a reaction between solutions of two ionic compounds

Science Inquiry Skills

- distinguish between ionic and covalent bonds in terms of the sharing of electrons between atoms
- use the results of chemical tests to draw a conclusion about the product of a chemical reaction
- classify common chemical reactions

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

The photo shows what happened when the teacher mixed two colourless liquids.

- Describe what happened.
- Has there been a chemical reaction? How do you know?
- How could you explain what has happened in terms of atoms?
- Why is it important to understand what happens when chemicals are mixed?

In this chapter you will be able to investigate this reaction for yourself. You will also learn how to explain chemical reactions in terms of atoms, molecules and ions.

4.1 Chemical bonds

Ions

Why is it that salt solution conducts electricity yet sugar solution does not? You can explain this in terms of the particles they contain. Salt solution contains sodium **ions** (EYE-ons) and chloride ions, which can carry an electric current. On the other hand, sugar solution contains uncharged sugar molecules, which cannot carry an electric current.

As you know from previous studies, atoms consist of a nucleus containing positive protons and neutral neutrons, surrounded by negative electrons. The number of electrons is the same as the number of protons, so the atom has no charge. In chemical reactions it is only the outermost electrons that are involved.

Atoms of metals tend to lose electrons. You will find out the reason for this in Chapter 7. For example, a sodium atom can lose one electron to form an ion with a single positive charge Na^+, as shown below. Copper atoms lose two electrons to form Cu^{2+} ions with two positive charges, and aluminium loses three electrons to form Al^{3+}.

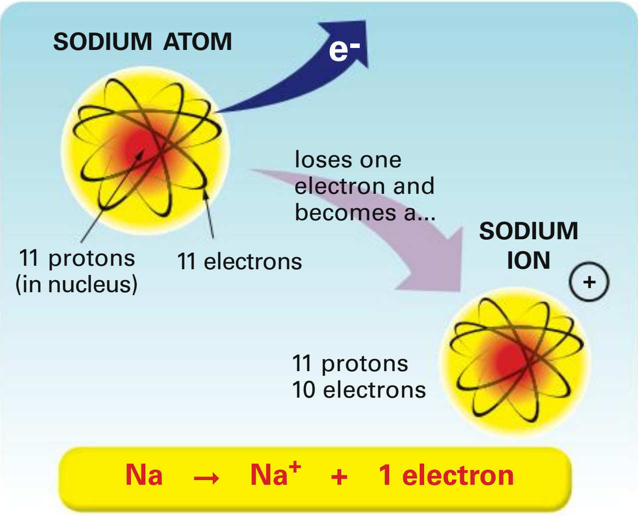


Fig 1 How sodium ions are formed

In contrast to metals, atoms of non-metals tend to form ions by gaining extra electrons. For example, chlorine atoms form negative *chloride* ions Cl^-.

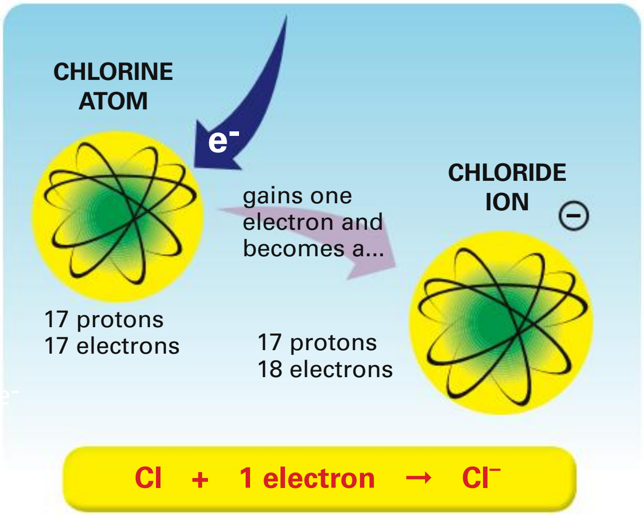


Fig 2 How chloride ions are formed

We can summarise what we have learnt about ions as follows.

METAL ATOMS LOSE ELECTRONS → TO BECOME → POSITIVE IONS

For example:

sodium ($Na \rightarrow Na^+ + 1$ electron)

copper ($Cu \rightarrow Cu^{2+} + 2$ electrons)

aluminium ($Al \rightarrow Al^{3+} + 3$ electrons)

Note: Hydrogen behaves like a metal and loses an electron to form H^+ ions.

NON-METAL ATOMS GAIN ELECTRONS → TO BECOME → NEGATIVE IONS

For example:

chlorine ($Cl + 1$ electron $\rightarrow Cl^-$)

bromine ($Br + 1$ electron $\rightarrow Br^-$)

iodine ($I + 1$ electron $\rightarrow I^-$)

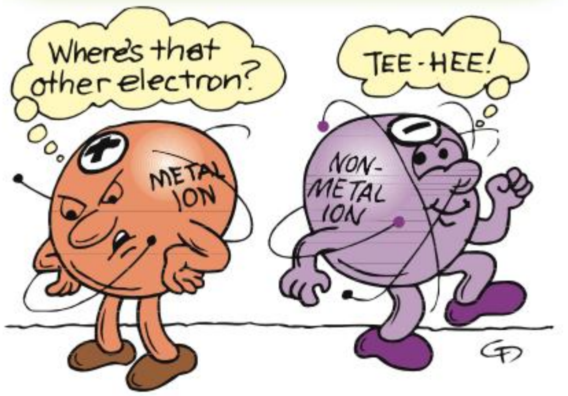
Atoms are not usually found on their own. Rather, atoms join together to form molecules such as water H_2O. The atoms in these molecules are held together by the attractive forces of **chemical bonds**.

There are two main types of chemical bond—ionic and covalent. Both kinds of bond result from the behaviour of the outermost electrons in atoms. Some of these electrons may be lost, some may be gained, or they may be shared. It depends on the kinds of atoms.

Ionic bonds

Metals tend to lose electrons, and non-metals tend to gain electrons. So when a metal reacts with a non-metal, electrons are transferred from the metal to the non-metal, forming positive metal ions and negative non-metal ions.

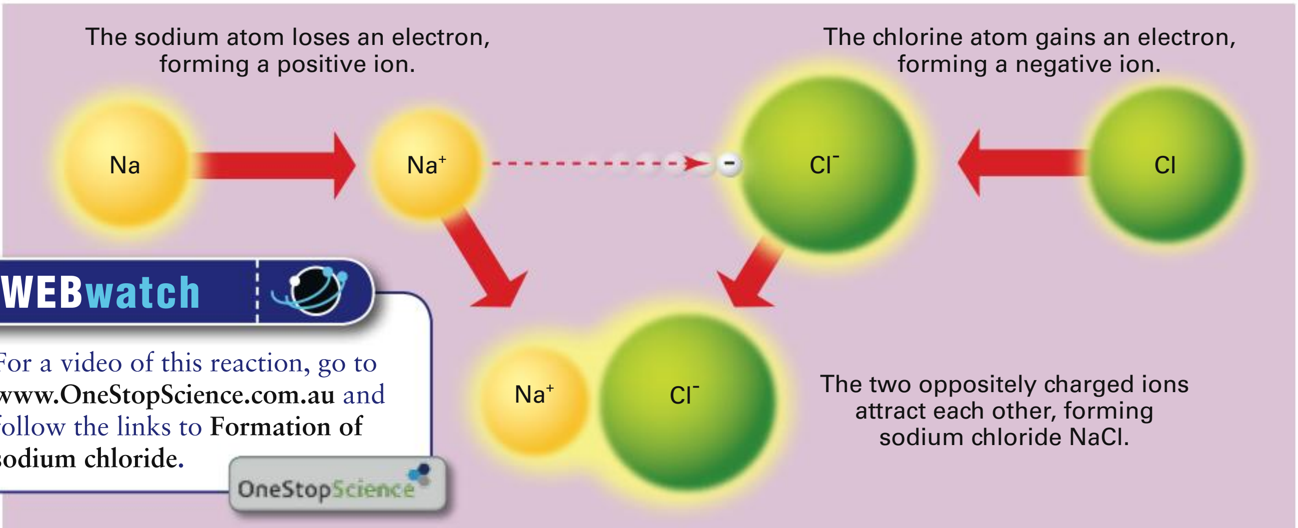
IONIC BOND Ions formed



Ordinary table salt has the chemical name sodium chloride and has the formula NaCl. It is made from the metal sodium and the non-metal chlorine. When sodium and chlorine react, each sodium atom loses one electron to form a positive sodium ion Na^+, and each chlorine atom gains an electron to form a negative chloride ion Cl^-. Opposite charges always attract each other, so the positive sodium ions and the negative chloride ions attract each other. This mutual attraction holds the ions together in what is called an **ionic bond**. See the diagram below.

A salt crystal contains millions and millions of sodium ions and chloride ions, and each ion attracts the oppositely charged ions around it. It is not possible to identify a molecule of sodium chloride because every ion belongs to every other ion surrounding it. There is a regular pattern of positive and negative ions called a *crystal lattice*, as shown in Fig 3 on the next page. If your school has a model of the sodium chloride lattice, notice how the sodium and chloride ions are arranged.

Sodium chloride is called an *ionic compound*. This is because it is made of ions held together by ionic bonds. In solid form, it will not conduct an electric current because the ions are locked into the crystal lattice and cannot move. However, when you dissolve sodium chloride in water, the sodium ions and the chloride ions break apart and spread throughout the water. These ions are free to move and conduct an electric current. The ions carry the electric current through the solution. This is why a salt solution conducts electricity. All ionic compounds conduct electricity when dissolved in water. See Fig 4 on the next page.



WEBwatch

For a video of this reaction, go to **www.OneStopScience.com.au** and follow the links to **Formation of sodium chloride.**

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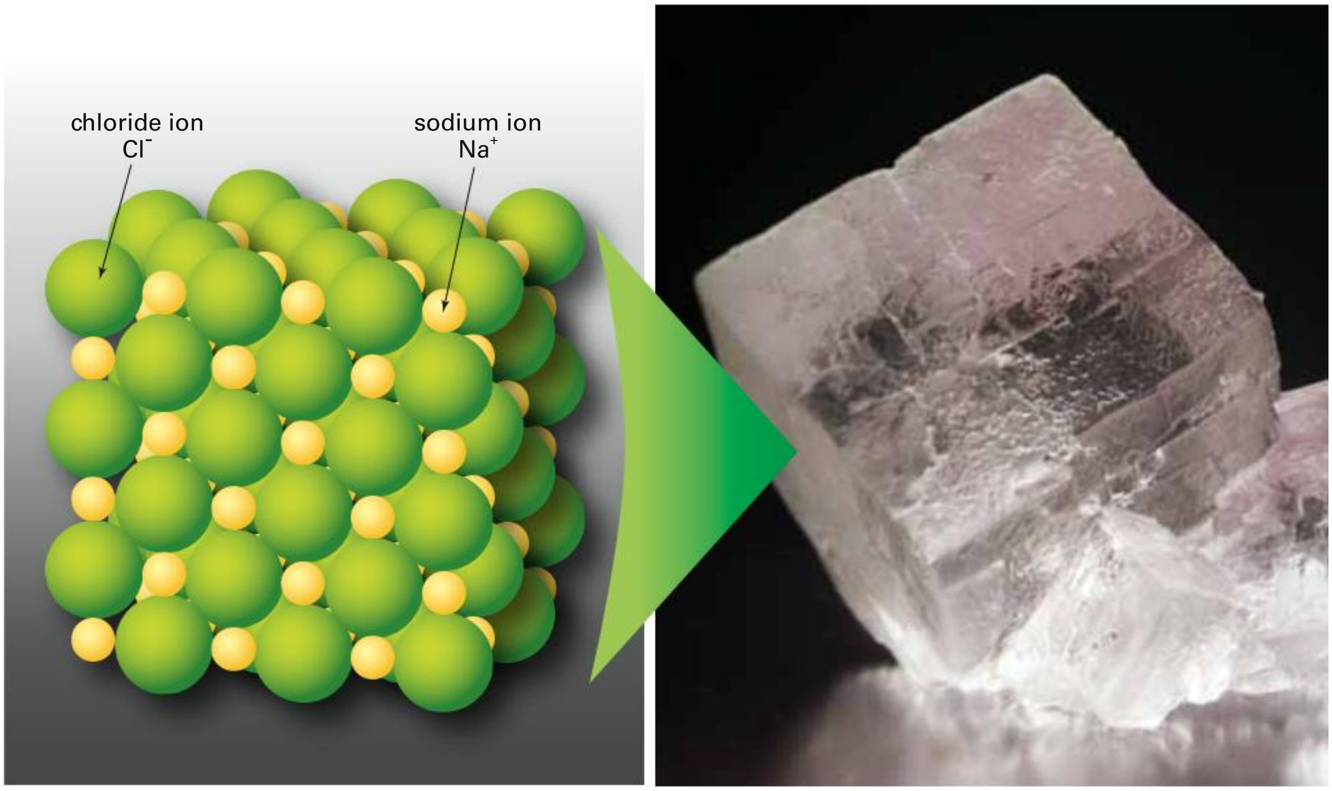


Fig 3 Sodium chloride crystals and their lattice of sodium chloride ions. The positive and negative charges balance each other, so there is no overall charge.

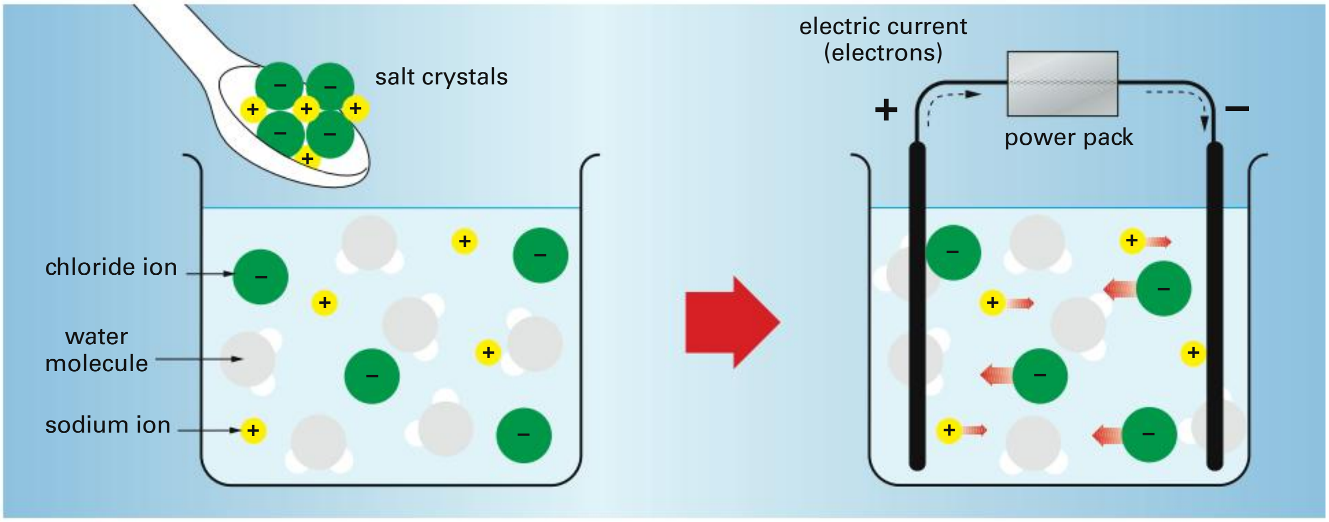


Fig 4 Sodium and chloride ions break apart in the solution. The ions carry the electric current through the solution, and electrons carry it through the wires to and from the power pack.

Individual atoms and ions are of course too small to see. However, you can observe them when there are millions and millions of them together, say in a piece of copper metal. When these copper atoms lose electrons to become copper ions, you can see the results, as in Investigation 6 on the next page.

Investigation 6 Observing copper ions

Aim

To observe the formation of copper ions in a solution.

Materials

- clean strip of copper, approximately 4 cm × 1 cm
- clean strip of copper, brass or bronze mesh, approximately 2 cm × 1 cm
- 10 mL of ammonium sulfate solution ($66\ g$ of $(NH_4)_2SO_4$ in 450 mL water and 50 mL concentrated ammonia)
- petri dish
- 2 connecting wires, with alligator clips
- power pack

Planning and Safety Check

- Your teacher may set up this investigation on an overhead projector so that you can see what happens on a large screen.
- To explain your observations you need to answer the Discussion.

Method

1 Set up the copper strip and copper mesh in a petri dish on a sheet of white paper, as shown. The copper mesh should be about 5 cm from the copper strip. Use clean alligator clips to attach the strip and mesh to the side of the dish.

2 Connect the set-up to the power pack, making sure the copper mesh is connected to the positive (+) DC terminal of the power pack.

3 Half fill the petri dish with the ammonium sulfate solution. Then turn on the power pack to 6 volts DC.

Record your observations of what happens in the next few minutes.

Discussion

1 Towards which terminal (positive or negative) did the blue colour move?

2 Suppose the blue colour is due to copper ions. Which charge would these ions have—positive or negative? Why?

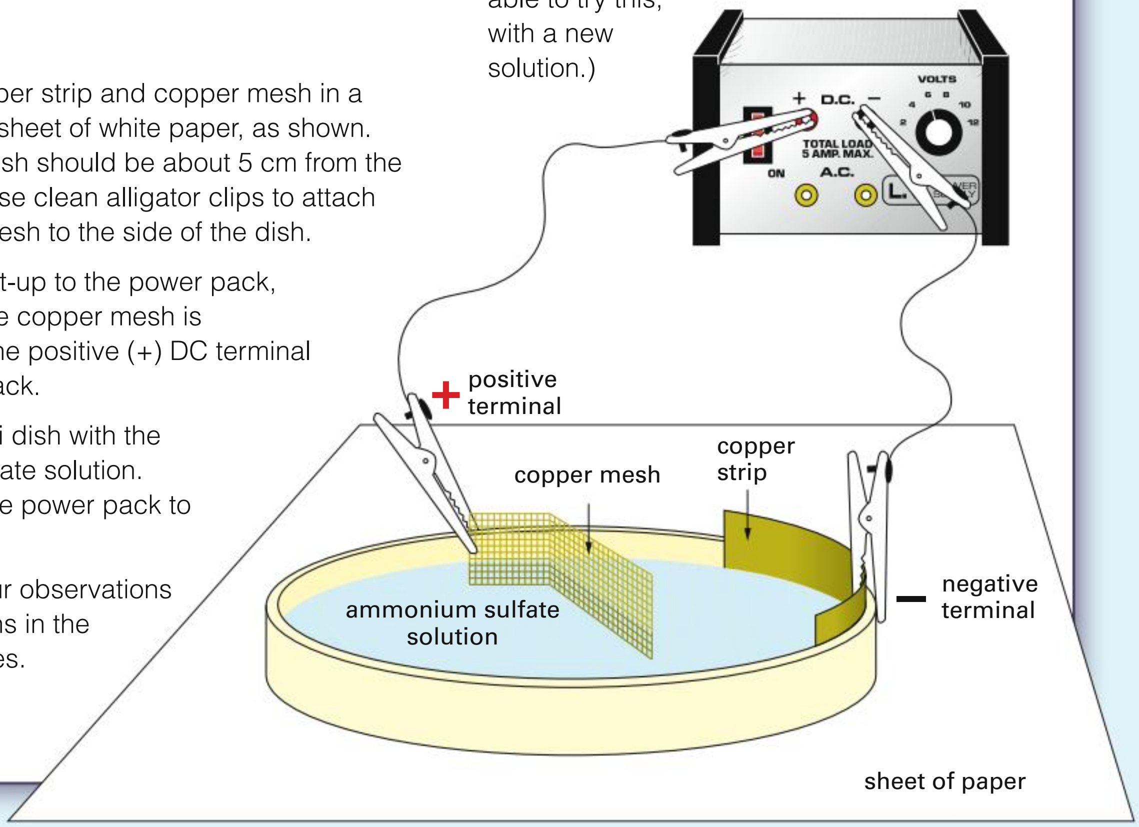
3 Infer where the copper ions came from.

4 In forming ions, did the copper atoms lose electrons or gain electrons? Write an equation for this (see page 88).

5 Although some blue colour was formed on the other side of the copper mesh, it didn't form streaks. Try to explain this.

6 Suppose you added a second copper strip on the other side of the mesh, and then connected both it and the other strip to the negative terminal of the power pack. What do you predict would happen? Explain.

7 Predict what would happen if you reversed the connections to the power pack. (You may be able to try this, with a new solution.)



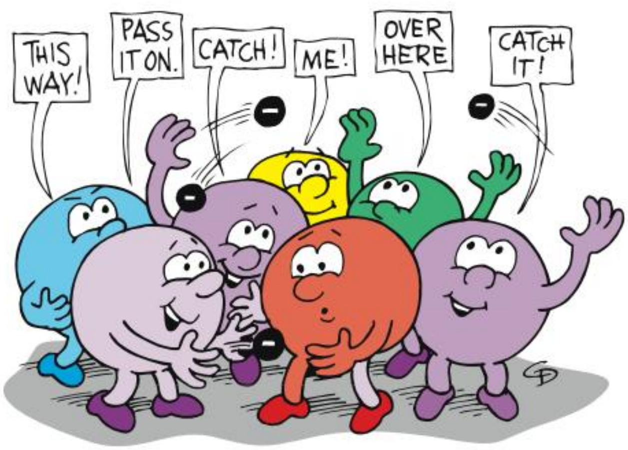
Extra for experts

Metallic bonds

Pure metals such as copper, gold and iron are elements and contain only one type of atom. The outermost electrons around these atoms are very weakly held, and they are easily lost. As a result, inside any piece of metal there are a lot of positively charged metal ions that have lost one or more electrons. These positive metal ions are surrounded by a 'sea' of electrons that belong to no particular atom and are juggled about rapidly.

The positively charged metal ions and the negatively charged electrons attract each other, and this mutual attraction is called a *metallic bond*. It is because of these freely moving electrons that metals are such good conductors of electricity and heat.

METALLIC BOND
Free electrons



Questions

1 Copper atoms have two weakly held electrons. Draw a two-dimensional diagram of a tiny piece of copper that contains ten copper atoms. How many free electrons are there?

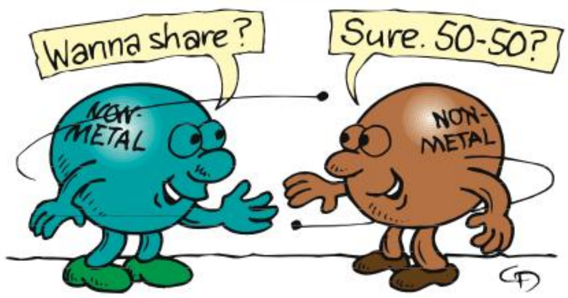
2 Use your diagram to explain why metals are such good conductors of electricity.

Covalent bonds

Non-metal atoms tend to gain electrons. So when two non-metal atoms come together they will both tend to gain electrons, without either of them losing electrons. They can do this by *sharing* electrons to form a **covalent bond**.

When two hydrogen atoms form a molecule of hydrogen H_2, one electron from each atom is shared by the other. Similarly, two chlorine atoms share an electron pair to form a molecule of chlorine gas Cl_2. So, a covalent bond is a shared electron pair holding two atoms together.

COVALENT BOND
Electrons shared



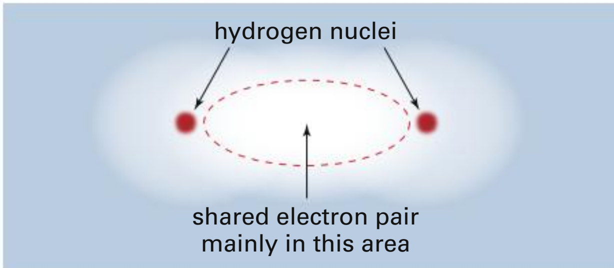


Fig 5 In a hydrogen molecule the hydrogen atoms share electrons equally.

Some non-metal atoms can form more than one bond. For example, oxygen can form bonds with two hydrogen atoms to form water H_2O. Nitrogen can form bonds with three hydrogen atoms to form ammonia NH_3. And carbon can form bonds with four hydrogen atoms to form methane CH_4. It can also form bonds with other carbon atoms (see Fig 7 on page 93). Compounds containing covalent bonds are called *covalent compounds*.

Sugar is a covalent compound containing carbon, hydrogen and oxygen. It consists of large molecules with the formula $C_{12}H_{22}O_{11}$. When you dissolve sugar in water, these molecules separate and spread throughout the solution. However, because the molecules do not form ions, the solution does not conduct an electric current. Similarly all covalent compounds are non-conductors of electricity.

Sometimes non-metals don't share their electrons equally. For example, in the covalent bonds between hydrogen and oxygen in water molecules, the oxygen atom tends to get more than its share of electrons because it is 'greedier' for electrons than hydrogen is. As a result, the oxygen atom has a slight negative charge and the hydrogen atoms have a slight positive charge. So the molecule has one positive end or pole, and two negative ends or poles. For this reason, the bond is called a *polar* covalent bond.

POLAR COVALENT BOND
Unequal sharing of electrons

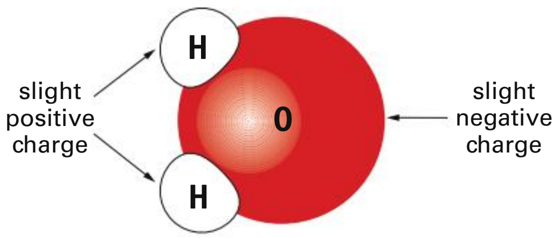


Fig 6 Water molecules are polar because the bonding electrons are pulled slightly towards the oxygen atom. The positive and negative charges balance each other, so the molecule has no overall charge.

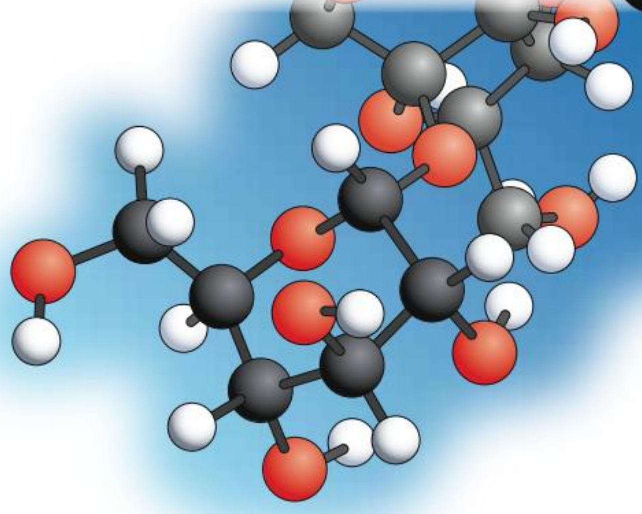
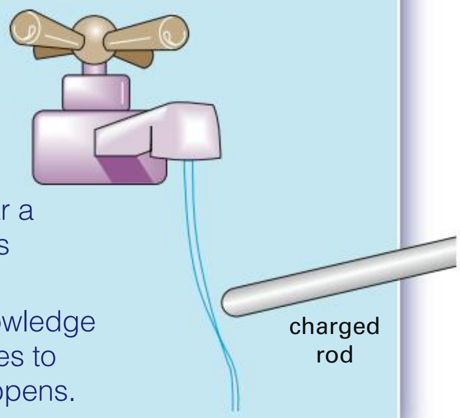


Fig 7 Sucrose (cane sugar) is a covalent compound with the formula $C_{12}H_{22}O_{11}$. In this model carbon atoms are black, hydrogen white and oxygen red.

Bonds between different non-metals are always polar, since no two non-metals are equally greedy for electrons. On the other hand, bonds between atoms of the same non-metal are non-polar; for example, the two oxygen atoms in an oxygen molecule. In this case there is equal sharing of the electrons.

Activity

You can demonstrate the polarity of water by bringing a charged rod near a trickle of water as shown.



Use your knowledge of electric charges to explain what happens.

WEBwatch

For a summary of the different types of bonds, go to **www.OneStopScience.com.au** and follow the links to **Dog bone bonds.**

Check

1 Copy and complete the following sentences
- a An ion is a charged ______.
- b Metal atoms form ______ ions.
- c Non-metal atoms form ______ ions.
- d Compounds formed from positive and negative ions are called ______ compounds.
- e Covalent compounds form when a non-metal atom combines with a ______ atom.
- f Covalent bonds occur when electrons are ______ between atoms.

2 A magnesium atom has 12 protons in its nucleus. It loses two electrons to form a magnesium ion.
- a How many electrons does a magnesium atom have?
- b How many electrons does a magnesium ion have?
- c How many protons are there in the nucleus of a magnesium ion?
- d What charge does an electron have?
- e What charge does a proton have?
- f What charge does a magnesium ion have?
- g Explain why a magnesium ion has this charge.

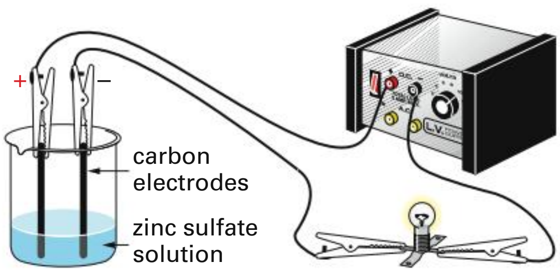
3 The symbol for a silver ion is Ag^+. How many electrons does a silver atom lose to become a silver ion?

4 An aluminium atom Al can lose three electrons. What is the symbol for an aluminium ion?

5 Bromine is a non-metal similar to chlorine. Predict whether bromine atoms tend to lose electrons or gain them. Explain your answer.

6 Magnesium burns in air to form the compound magnesium oxide.
- a Would you expect this compound to be ionic or covalent?
- b Which atoms would be positive and which would be negative?

7 Electricity is passed through a zinc sulfate solution containing zinc ions and sulfate ions.



- a Draw a simple diagram showing what you predict will happen to the zinc and sulfate ions.
- b Predict what will happen if the connections to the power pack are reversed.

Challenge

1 What would need to happen for an oxide ion O^{2-} to become an oxygen atom?

2 Copy and complete this summary of chemical bonding.

Type of bond	Kinds of atoms	Electrons are …	Result
	non-metals		molecules
		lost and gained	

3 Explain why ionic compounds, which consist of electrically charged ions packed together, are electrically neutral. Use sodium chloride as an example.

4 Copper ions are never found on their own. Why is this?

5 Which of the following molecules would you expect to be polar: ammonia (NH_3), chlorine (Cl_2), carbon monoxide (CO), hydrogen bromide (HBr), hydrogen sulfide (H_2S) and nitrogen (N_2)?

6 The red colour of blood is due to iron. Would this colour be due to iron atoms or iron ions? Explain your answer.

7 Why is it wrong to speak of *molecules* of sodium chloride? What should you say instead?

4.2 Chemical shorthand

Chemical formulas

Covalent compounds are formed when atoms join to form molecules; and ionic compounds form when positive and negative ions join together in a crystal lattice. A shorthand way of representing a compound is to use a chemical formula made up from the symbols of the elements in it. For example, the formula for carbon dioxide is CO_2. The 2 after the oxygen shows that there are two atoms of oxygen in a molecule of carbon dioxide. (Note that the 2 is written as a subscript, a little below the line.) There is only one atom of carbon, but the 1 is never written in the formula. Similarly, the formula for water is H_2O (two atoms of hydrogen bonded to one atom of oxygen). Ammonia (NH_3) has three atoms of hydrogen bonded to one atom of nitrogen.

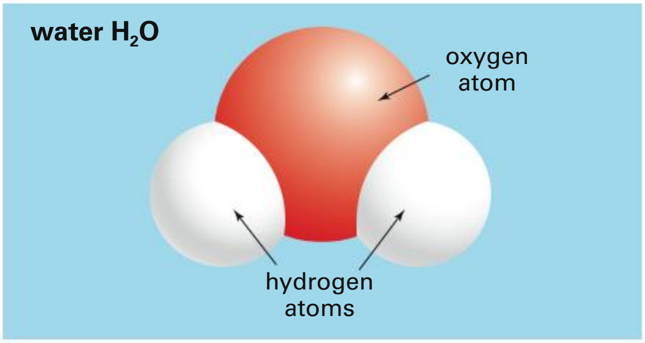
Sodium chloride is an ionic compound consisting of sodium and chloride ions held together by ionic bonds. Its formula is NaCl, which means that the ratio of sodium ions to chloride ions is 1:1. But how do we know that the formula is NaCl, rather than $NaCl_2$ or Na_2Cl or Na_2Cl_3? The answer is that you can tell from the combining powers of the atoms.

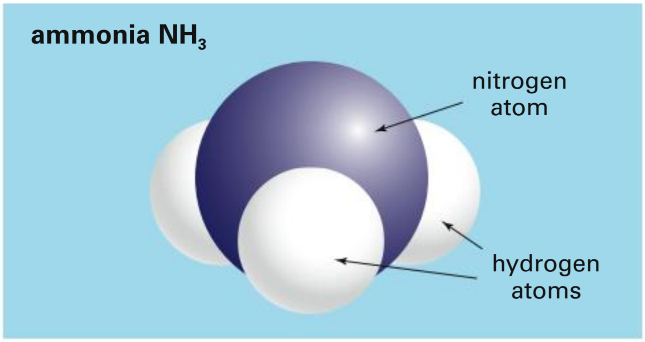
An atom's combining power or **valency** predicts how it will combine with other atoms through the loss, gain or sharing of electrons. For ionic compounds, the valency is the same as the charge on the ion. For example, sodium atoms lose one electron to form Na^+ ions—so sodium has a valency of 1+. Oxygen atoms gain two electrons to form oxide ions O^{2-}—so oxygen has a valency of 2–.

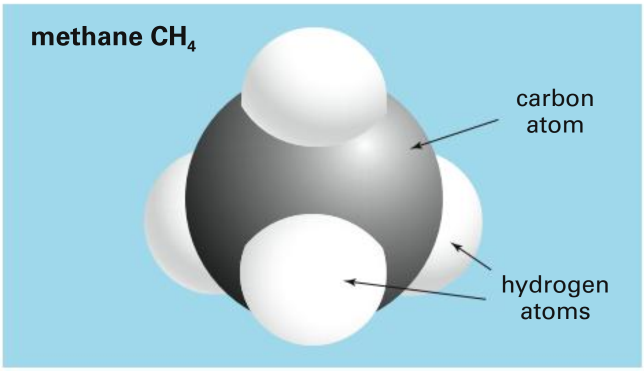
A sodium ion Na^+ can combine with one negative ion that has a valency of 1–, for example Cl^-, to form NaCl. Sodium ions can also combine with oxide ions. However, two Na^+ ions are needed for each O^{2-} ion. Hence the formula for sodium oxide is Na_2O.

sodium Na^+ + chlorine Cl^- → sodium chloride NaCl

sodium Na^+ + oxygen O^{2-} → sodium oxide Na_2O







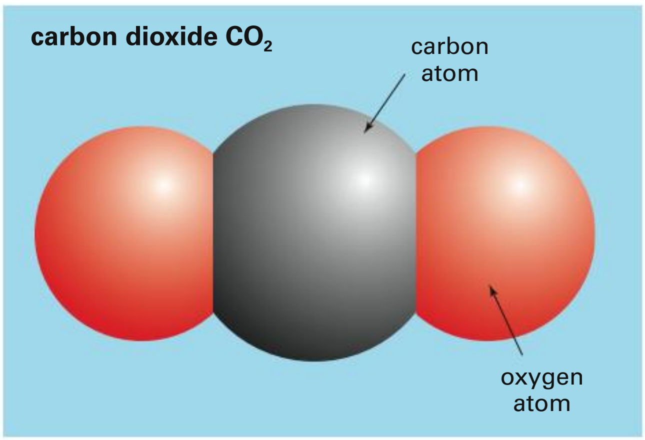


Fig 8 Some common molecules and their formulas

Sometimes the ions consist of groups of atoms called *compound ions*. For example, copper sulfate is made up of copper ions and sulfate ions. Each copper ion (Cu^{2+}) has two positive charges. Each sulfate compound ion (SO_4^{2-}) consists of one sulfur atom covalently bonded to four oxygen atoms, as shown. The five atoms of the sulfate ion usually stay together in chemical reactions.

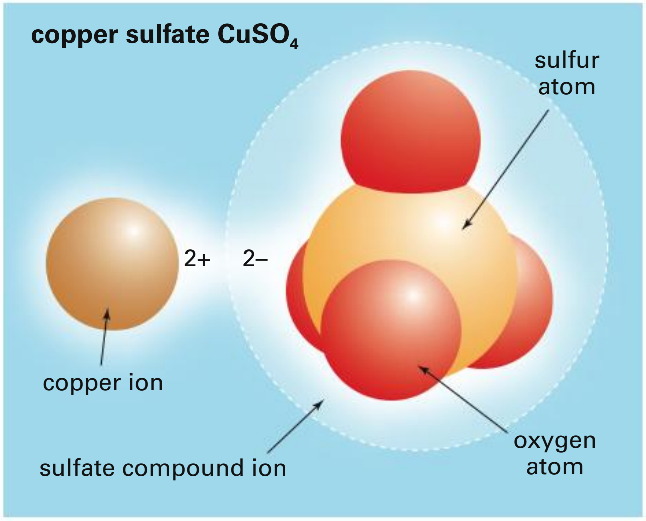


Fig 9 A model of copper sulfate $CuSO_4$. Note that these ions would be arranged in a crystal lattice similar to that for sodium chloride (Fig 3 on page 90).

The sulfate compound ion has two negative charges, which balance the two positive charges on the copper ion. Similarly each unit of copper nitrate $Cu(NO_3)_2$ contains one Cu^{2+} ion and two nitrate NO_3^- compound ions; and each sodium carbonate Na_2CO_3 contains two Na^+ ions and one carbonate CO_3^{2-} compound ion.

The valencies of various ions are listed in the table on the right. There is a pattern in the table that will make sense when you study Chapter 7. Note that some elements have two different valencies. For example, copper loses two electrons to form Cu^{2+} ions; but sometimes it loses only one electron to form Cu^+ ions. Because of this, it forms two different compounds with oxygen. To distinguish between these compounds, you include the valency of the copper ion in the formula, using Roman numerals.

	Ion	Symbol	Valency
	ammonium	NH_4^+	1+
	hydrogen	H^+	1+
Metals	potassium	K^+	1+
Metals	silver	Ag^+	1+
Metals	sodium	Na^+	1+
Metals	calcium	Ca^{2+}	2+
Metals	copper	Cu^{2+}	2+ (or 1+)
Metals	lead	Pb^{2+}	2+ (or 1+)
Metals	magnesium	Mg^{2+}	2+
Metals	zinc	Zn^{2+}	2+
Metals	aluminium	Al^{3+}	3+
Metals	iron	Fe^{3+}	3+ (or 2+)
Non-metals	bromide	Br^-	1–
Non-metals	chloride	Cl^-	1–
Non-metals	hydrogen carbonate	HCO_3^-	1–
Non-metals	hydroxide	OH^-	1–
Non-metals	iodide	I^-	1–
Non-metals	nitrate	NO_3^-	1–
Non-metals	carbonate	CO_3^{2-}	2–
Non-metals	oxide	O^{2-}	2–
Non-metals	sulfate	SO_4^{2-}	2–
Non-metals	sulfide	S^{2-}	2-
Non-metals	sulfite	SO_3^{2-}	2–
Non-metals	phosphate	PO_4^{3-}	3–

This means the copper has a valency of 1.

copper(I) oxide Cu_2O

copper(II) oxide CuO

This means the copper has a valency of 2.

Writing ionic formulas

To write the formula for an ionic compound, follow these rules.

Example 1

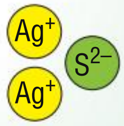
1 Write down the symbols of the ions. Note that the positive ion (usually a metal) goes first. Write the valencies above the symbols.

silver sulfide
1+ 2–
Ag S

2 Crisscross the valencies to get correct subscripts. Leave out the + and – signs.

1+ 2–
Ag 2 S 1

Ag_2S

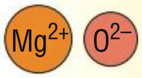


3 Write the correct formula with subscripts, leaving out the 1. Note that the charges are balanced. You need two Ag^+ ions to balance one S^{2-} ion.

Example 2

magnesium oxide
2+ 2–
Mg 2 O 2

MgO

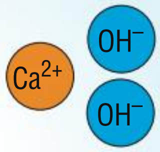


In this example you simplify Mg_2O_2 to MgO since the magnesium and oxygen are in the ratio 1:1.

Example 3

calcium hydroxide
2+ 1–
Ca 1 (OH) 2

$Ca(OH)_2$

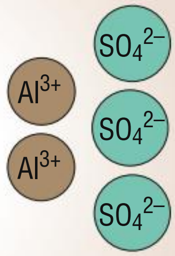


In this example, you put the compound ion in brackets to indicate that it acts as a single unit. The subscript 2 refers to everything inside the brackets. In other words, there are two oxygen atoms and two hydrogen atoms. Where there is only one unit of the compound ion, you can drop the brackets, e.g. NaOH rather than Na(OH).

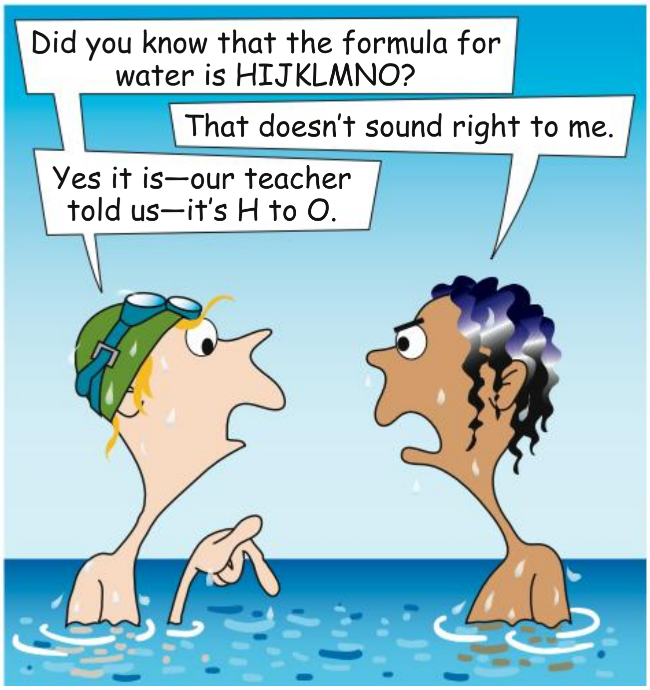
Example 4

aluminium sulfate
+3 –2
Al 2 (SO_4) 3

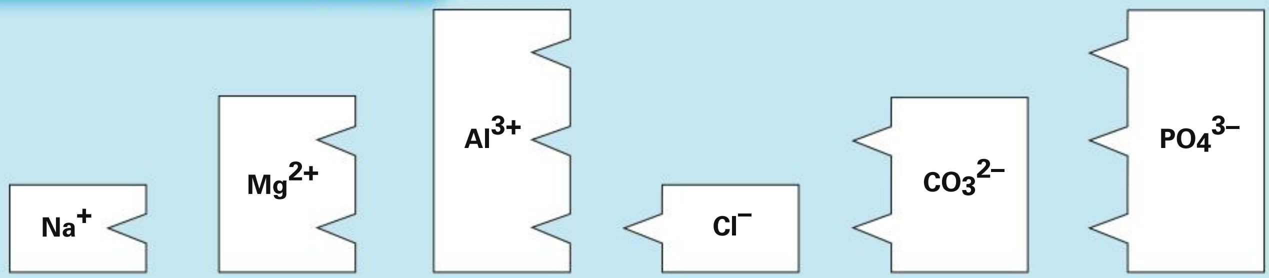
$Al_2(SO_4)_3$



Two 3+ charges balance three 2– charges.



Activity



You can use paper or cardboard cut-outs to make models of various compounds. Look at the models above for various ions. Notches represent electrons lost to form positive ions. One notch indicates one positive charge or a valency of 1, two notches indicate a valency of 2, and three notches indicate a valency of 3. Similarly, spikes represent electrons gained to form negative ions. Work in a group so you can share the work.

1. Your teacher will give you copies of the models—six of each. Colour each type of ion a different colour, e.g. sodium ions yellow, chloride ions green.
2. Use scissors to cut out the models.
3. Use your cut-outs to make a model of sodium chloride. Glue the model compound into your notebook and write its formula under it.
4. Make models of the following compounds:
   - sodium carbonate
   - sodium phosphate
   - magnesium chloride
   - magnesium carbonate
   - magnesium phosphate
   - aluminium chloride
   - aluminium carbonate
   - aluminium phosphate.
5. For each compound you make, count the number of positive charges and the number of negative charges to make sure they are equal. Then write the formula under the model.

Covalent compounds

You can also use valencies to write the formulas for covalent compounds. For example:

carbon	oxide
4	2
C_2	O_4

CO_2

Instead of calling this compound carbon oxide, it is usually called carbon dioxide. The *di* comes from the Greek word for 'two' since two oxygen atoms bond to one carbon atom. Similarly, CO is carbon monoxide, and SO_3 is sulfur trioxide.

Some elements form molecules containing a pair of atoms. These are called *diatomic* molecules, e.g. hydrogen H_2, oxygen O_2, nitrogen N_2, chlorine Cl_2 and iodine I_2. It is best to remember these formulas.

Chemical equations

A chemical equation is a shorthand way of writing down what happens in a chemical reaction. To write an equation you must know the names of the reactants and the products. If you don't know these, you cannot write the equation. Sometimes, however, you can predict what the products might be if you know the reactants.

Work through the following three examples step by step.

Equation 1

Zinc metal reacts with hydrochloric acid to produce hydrogen gas and a solution of an ionic compound called zinc chloride.

Step 1: Writing the word equation

zinc + hydrochloric acid → zinc chloride + hydrogen

Step 2: Writing the formulas

You next write down the formulas of the reactants and products. For most elements the atoms exist on their own, so you simply write the symbol for the element, in this case zinc Zn. It is best to remember that the formula for hydrochloric acid is HCl. For zinc chloride you can work it out using valencies from the table on page 96. In hydrogen gas, however, the molecules are diatomic (H_2).

$$Zn + HCl \rightarrow ZnCl_2 + H_2$$

Step 3: Balancing the equation

In a chemical reaction the atoms are rearranged, but you end up with the same number of atoms as you started with. (This is the law of conservation of mass.) So the final step in writing an equation is to make sure that the numbers of atoms of each element are the same on both sides of the equation. This is called *balancing the equation*.

In this case, there is one zinc atom on each side of the equation. So the zinc atoms are balanced. There are two hydrogen atoms on the right-hand side, but only one on the left. So you can balance the hydrogen atoms by putting a 2 in front of the HCl on the left-hand side. This means 2 molecules of HCl.

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

The 2 refers to every atom in the formula. So 2HCl means that there are two atoms of H and two atoms of Cl. So the chlorine atoms are balanced. *Never change the number in a formula to balance an equation.* The balancing numbers always go in front of the formulas.

Symbols are usually added to tell you whether the reactants are solids (s), liquids (l), gases (g) or dissolved in water (aq—short for aqueous). For example:

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

Equation 2

Ammonia is a very important gas used in industry to make nitric acid, fertilisers, drugs, dyes and plastics. It is made by the Haber process, in which nitrogen and hydrogen react at a high temperature in the presence of a catalyst.

nitrogen + hydrogen → ammonia

You need to know the formulas for nitrogen, hydrogen and ammonia.

$$N_2 + H_2 \rightarrow NH_3$$

To balance the nitrogen atoms you have to add a 2 in front of NH_3.

$$N_2 + H_2 \rightarrow 2NH_3$$

This makes 6 atoms of hydrogen on the right-hand side. So to balance the hydrogens you have to add a 3 in front of H_2 on the left-hand side.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

As a final check on the balancing you can write down the numbers of atoms on each side of the equation, as shown.

	LEFT		RIGHT
N	2	N	2
H	3 × 2 = 6	H	2 × 3 = 6

Equation 3

Iron rusts when it reacts with oxygen in the air to produce iron(III) oxide.

iron + oxygen → iron oxide

$$Fe + O_2 \rightarrow Fe_2O_3$$

To balance the iron atoms, put a 2 in front of Fe.

$$2Fe + O_2 \rightarrow Fe_2O_3$$

To balance the oxygen atoms you need a 3 in front of O_2 and a 2 in front of Fe_2O_3. You may need to work this out by trial and error.

$$2Fe + 3O_2 \rightarrow 2Fe_2O_3$$

Finally, you need to balance the iron atoms again.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

	LEFT		RIGHT
Fe	4	Fe	2 × 2 = 4
O	3 × 2 = 6	H	2 × 3 = 6

Note that the balancing numbers you use should be the smallest possible. For instance, the equation $8Fe + 6O_2 \rightarrow 4Fe_2O_3$ is balanced, but can be simplified to $4Fe + 3O_2 \rightarrow 2Fe_2O_3$.

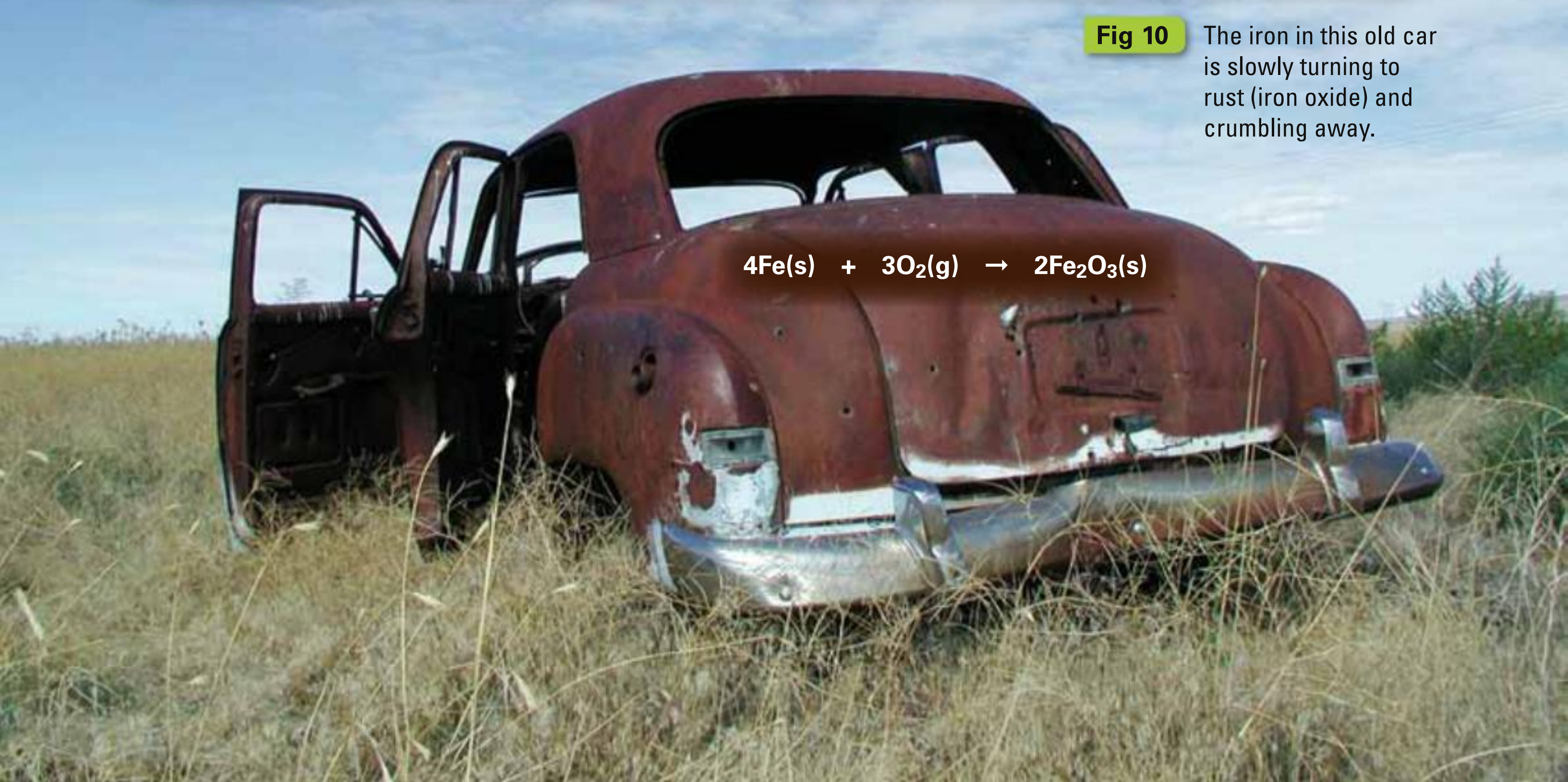
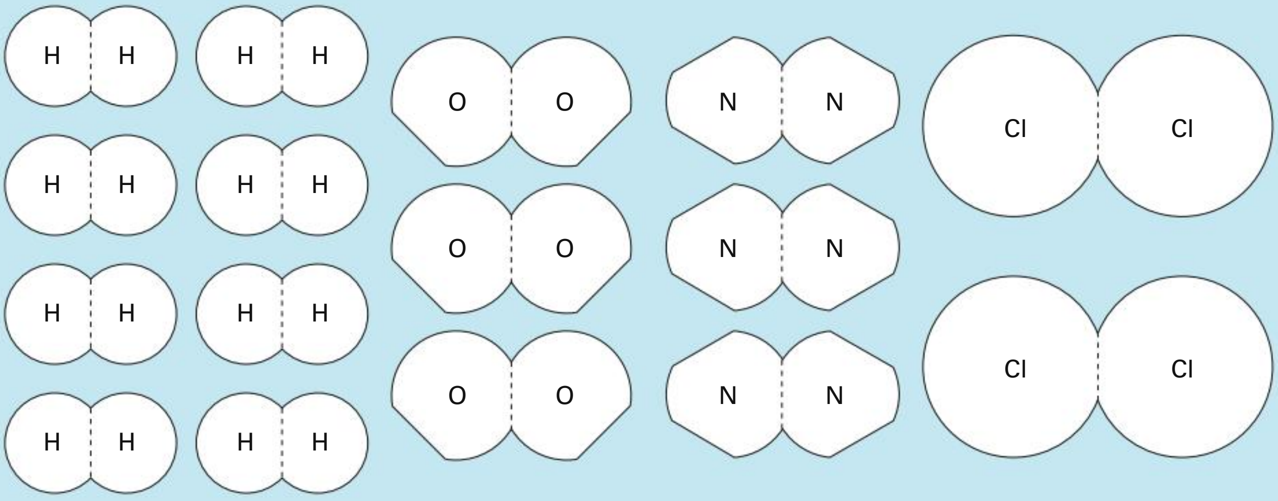


Fig 10 The iron in this old car is slowly turning to rust (iron oxide) and crumbling away.

Activity

hydrogen (valency = 1) | oxygen (valency = 2) | nitrogen (valency = 3) | chlorine (valency = 1)



As you did on page 21, you can use paper or cardboard cut-outs to make models of chemical reactions. The cut-outs above represent some diatomic molecules.

1 Photocopy or trace the molecular models above and label the atoms. Colour the atoms different colours, e.g. white for hydrogen, red for oxygen, blue for nitrogen and green for chlorine.

2 The example below shows how the models can be used to represent the reaction between hydrogen and oxygen to form water.

3 Use the models to represent the following reactions:

hydrogen + chlorine → hydrogen chloride

nitrogen + hydrogen → ammonia

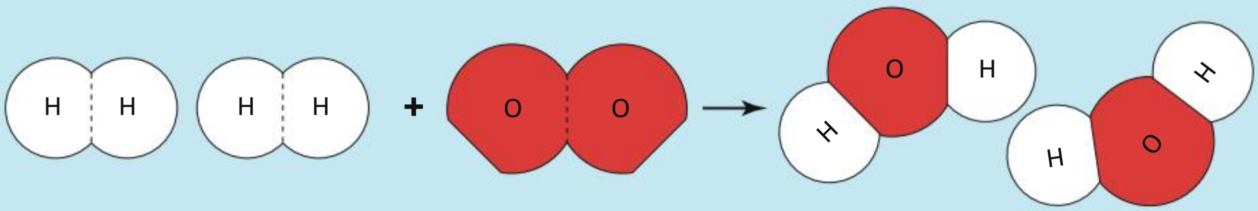
nitrogen + oxygen → nitrogen dioxide

You will need to break the molecules into their atoms by cutting along the dotted lines. Unless you do this, the 'reaction' cannot occur.

4 Glue the models into your notebook and write the balanced equations under them.

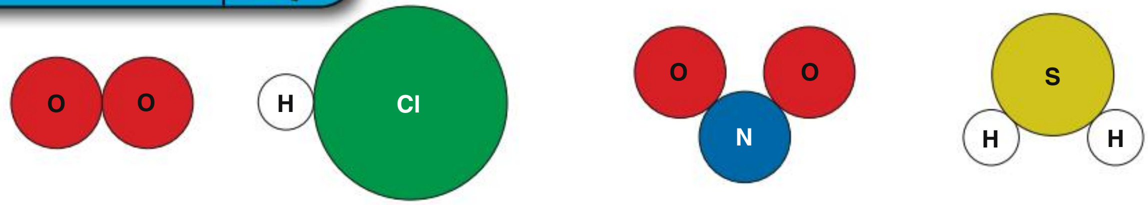
5 If you have a molecular models kit, you can make three-dimensional models.

hydrogen + oxygen → water



$$2H_2 + O_2 \rightarrow 2H_2O$$

Check



1 Look at the models of the four molecules above, and write the chemical formula for each of them.

2 Sulfuric acid contains hydrogen, sulfur and oxygen in the ratio 2:1:4. What is its formula?

3 One of the substances in superphosphate fertiliser has the formula $Ca(H_2PO_4)_2$. How many atoms of calcium, hydrogen, phosphorus and oxygen are represented by this formula?

4 Use the table on page 96 to write the correct formula (with its electric charge) for each of the following compound ions.

- a ammonium
- b carbonate
- c hydrogen carbonate
- d hydroxide
- e nitrate
- f phosphate
- g sulfate
- h sulfite

5 Name the following compounds.

- a KCl
- b $NaNO_3$
- c MgO
- d $FeCl_3$
- e $Al(OH)_3$
- f $(NH_4)_3PO_4$
- g HCl
- h $NaHCO_3$

6 Copy this table and complete the formulas.

	chloride	sulfate	phosphate
calcium			
iron(III)			
sodium			

7 Write down the formulas of the following compounds.

- a sodium hydroxide
- b ammonium sulfate
- c hydrogen sulfide
- d sodium sulfite
- e calcium hydrogen carbonate
- f magnesium sulfate
- g calcium phosphate
- h copper(II) hydroxide
- i iron(II) oxide

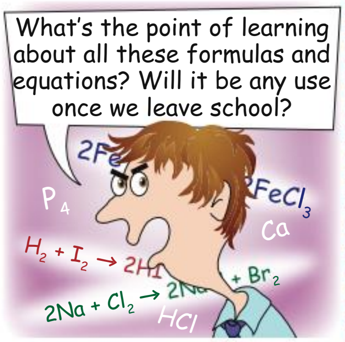
8 Carlos heated some blue copper(II) nitrate in a test tube. A brown gas (nitrogen dioxide) and a colourless gas (oxygen) were produced and black copper(II) oxide was left in the test tube.

- a List the reactants and products.
- b Write a word equation for the reaction.

9 Copy these equations into your notebook and balance them where necessary. The formulas are all correct and must not be changed.

- a $NaBr + Cl_2 \rightarrow NaCl + Br_2$
- b $Fe + Cl_2 \rightarrow FeCl_3$
- c $Ba(NO_3)_2 + H_2SO_4 \rightarrow BaSO_4 + HNO_3$
- d $CaCO_3 \rightarrow CaO + CO_2$
- e $H_2 + I_2 \rightarrow HI$
- f $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$
- g $NaOH + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$
- h $P_4 + O_2 \rightarrow P_2O_5$
- i $CH_4 + Cl_2 \rightarrow CCl_4 + HCl$
- j $Pb(NO_3)_2 \rightarrow PbO + NO_2 + O_2$

10 Michael can't see the point of learning about chemical formulas and equations. In a group discuss how you could answer him.



Challenge

1 Look at this balanced equation:

$2Mg + O_2 \rightarrow 2MgO$

a How many atoms of magnesium react with one molecule of oxygen?

b How many atoms of magnesium react with 5 million molecules of oxygen?

2 Each of the following equations is incorrect. Rewrite them correctly and balance them.

a $H + Cl \rightarrow HCl$

b $H_2O_2 \rightarrow H_2O + O$

c $Cu + O_2 \rightarrow CuO_2$

d $Pb(NO_3)_2 + KI \rightarrow PbI + K(NO_3)_2$

e $Na + H_2O \rightarrow NaOH + H$

3 Write balanced equations for the following reactions.

a Zinc reacts with hydrochloric acid to produce zinc chloride and hydrogen.

b Sulfur dioxide (SO_2) burns in oxygen to produce sulfur trioxide (SO_3).

c Copper(II) carbonate reacts with hydrochloric acid to produce copper(II) chloride, water and carbon dioxide.

d During cooking, sodium hydrogen carbonate (baking soda) decomposes to sodium carbonate, carbon dioxide and water.

e When heated, cane sugar ($C_{12}H_{22}O_{11}$) decomposes to give carbon and water.

f During respiration, glucose ($C_6H_{12}O_6$) reacts with oxygen to give carbon dioxide and water.

4 Elements X and Y form compounds with carbon with the formulas CX_4 and CY_2. Predict the formula of a compound of X and Y. Explain how you worked it out.

5 A metal M forms a sulfate with the formula $M_2(SO_4)_3$. Given this information, which of the following formulas is correct?

a M_2O

b $M_2(CO_3)_3$

c $M(OH)_3$

d M_2Cl_3

e MPO_4

f M_3S_2

6 Challenge yourself by trying to balance these three equations.

a $Al(NO_3)_3 + K_2Cr_2O_7 \rightarrow Al_2(Cr_2O_7)_3 + KNO_3$

b $FeCl_2 + HNO_3 + HCl \rightarrow FeCl_3 + NO + H_2O$

c $Cu + HNO_3 \rightarrow Cu(NO_3)_2 + H_2O + NO$

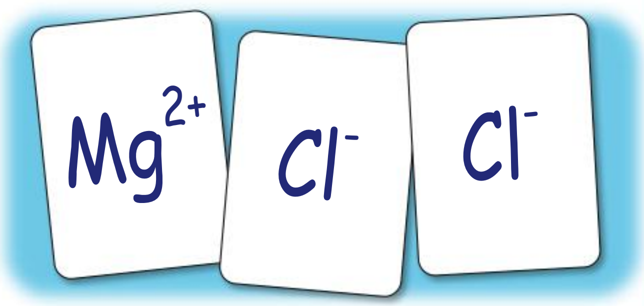
TRY THIS

For this activity you will need playing cards with the names and valencies of positive and negative ions. Use all the ions listed on page 96 and make four identical cards for each one. You will need a total of 96 cards. (Use the 2+ valency for Cu, Fe and Pb.)

Play the game in a group of four or five. The aim of the game is to combine cards to make compounds with correct formulas; for example, one magnesium Mg^{2+} card goes with two chloride Cl^- cards to give $MgCl_2$.

The dealer shuffles the cards and gives each player seven cards. When it is your turn, try to make a compound using the cards in your hand. If you use two cards to make the compound, then you pick up two cards to replace them, and so on. If you can't make a compound, then pick up another card. You can also choose to pick up another card instead of making a compound.

The game continues until all the cards are used up. The winner is the player who has made the most compounds with the correct formulas.



4.3 Predicting a reaction

In a chemical reaction, substances react to form new substances. But what happens to the atoms, molecules and ions in the reactants? To answer this, consider the reaction between potassium iodide and lead nitrate solutions.

Potassium iodide is an ionic compound with the formula KI. It consists of K^+ ions and I^- ions. In solid potassium iodide, the ions are packed closely in a crystal lattice, like the sodium chloride lattice (Fig 3 on page 90). When the solid dissolves in water, the positive and negative ions break apart and spread throughout the solution.

$$KI \rightarrow K^+ + I^-$$

Similarly, lead nitrate $Pb(NO_3)_2$ breaks up to form lead ions Pb^{2+} and nitrate ions NO_3^- in solution.

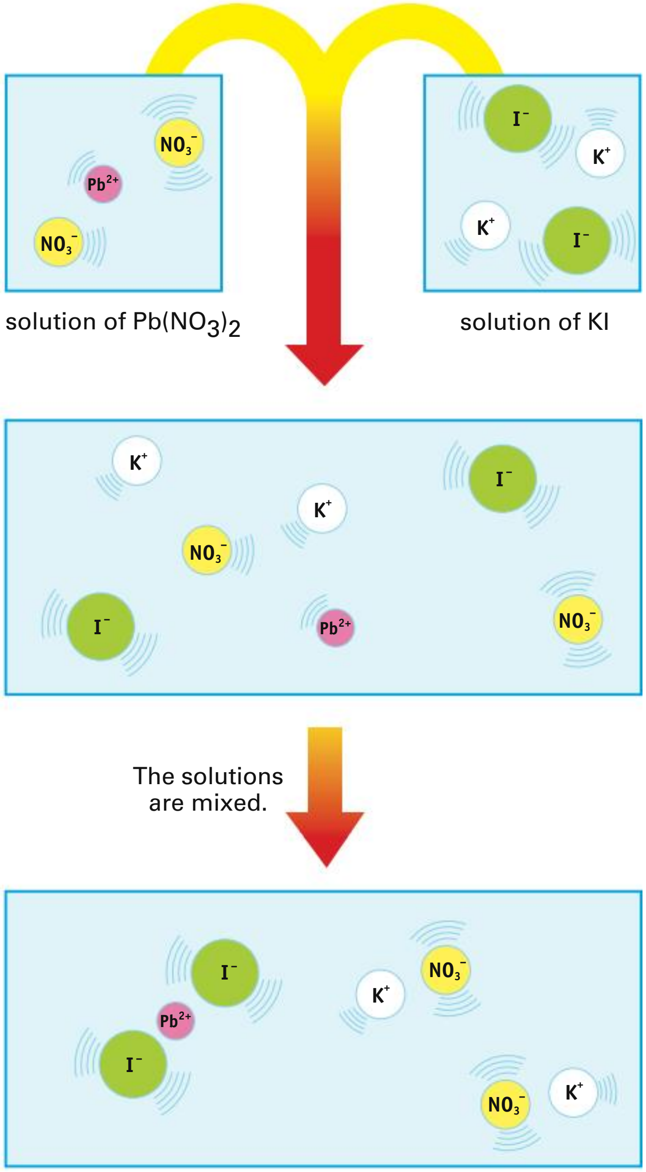
$$Pb(NO_3)_2 \rightarrow Pb^{2+} + 2NO_3^-$$

You can now try to predict what might happen when potassium iodide and lead nitrate solutions react. You can use spheres of different sizes and colours, as shown on the right, to represent the various ions.

When the two solutions are mixed, the four ions also mix. (This is like putting all the spheres in a box and shaking it.) The ions are constantly moving, and there is a good chance that they will bump into each other and possibly combine.

Lead ions can bump into nitrate ions or iodide ions, but are not likely to bump into potassium ions. This is because lead ions and potassium ions both have the same charge, and like charges repel. Similarly, potassium ions can bump into nitrate ions and iodide ions.

So, there is a possibility that the ions could change partners. Lead ions could combine with iodide ions to form lead iodide. Similarly, potassium ions could combine with nitrate ions to form potassium nitrate.



Prediction: the ions can change partners and form new substances.

So, you can predict that when lead nitrate and potassium iodide are mixed, two new substances (lead iodide and potassium nitrate) could be formed. The word equation for the reaction is shown below. You can test this prediction in Investigation 7.

lead nitrate + potassium iodide → lead iodide + potassium nitrate

Investigation 7 What is the precipitate?

Aim

To investigate the precipitate that forms when lead nitrate and potassium iodide solutions are mixed.

PART A Forming the precipitate

Materials

- 2 test tubes
- test tube rack
- **lead nitrate** solution (0.1 M)
- **potassium iodide** solution (0.1 M)
- piece of filter paper
- filter funnel
- stand and ring clamp
- small beaker
- wash bottle containing water
- watch glass
- disposable gloves (optional)

Planning and Safety Check

Read both parts of the investigation carefully.

- What is the aim of Part B?

Lead and all lead compounds are toxic. So be very careful not to get them on your hands or clothing. **Wash your hands well after using these chemicals.** You must follow the method and safety precautions closely.

- How will you dispose of the lead and lead compounds?

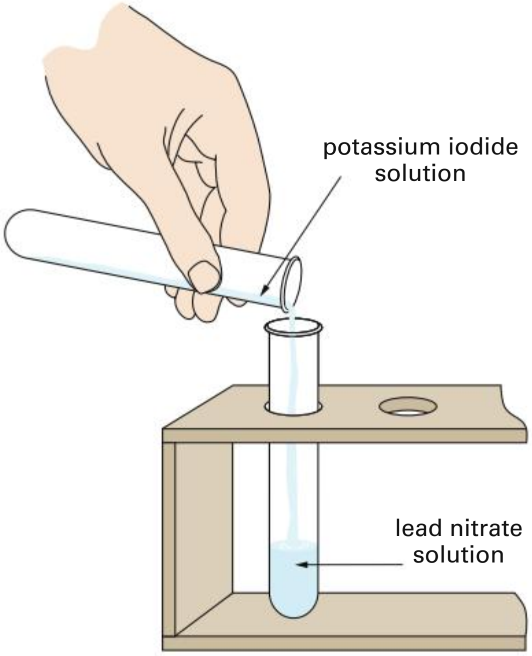
Since iodine fumes are produced in Part B, Step 2 should be done in a fume cupboard.

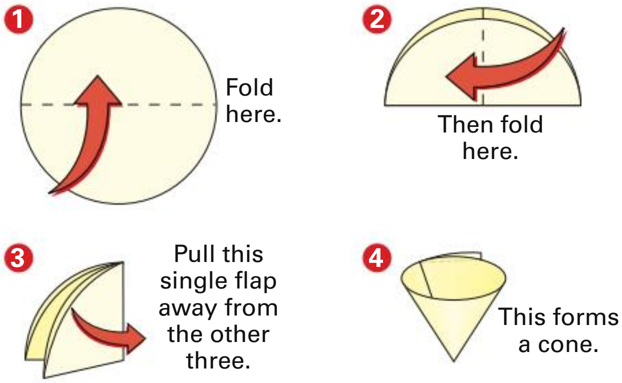
Method

1 Quarter fill one test tube with lead nitrate solution, and the other with potassium iodide solution.

2 Pour the potassium iodide solution into the lead nitrate solution.

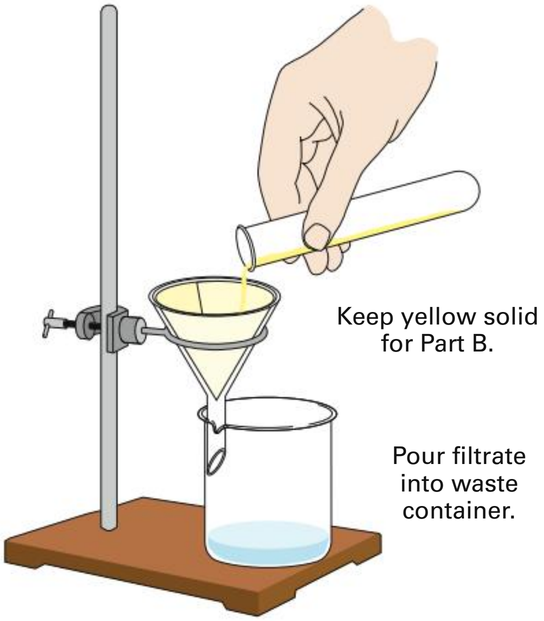
Describe in your own words what happens.





3 Fold a filter paper and open it out into a cone, as shown. You can also use fluted filter paper.

4 Place the cone into the filter funnel and use the wash bottle to wet the paper to hold it in place. Carefully pour the contents of the test tube into the funnel and collect the filtrate in the beaker. Pour this into a special waste container.



5 Lift out the paper cone, spread it out on a watch glass and leave the yellow solid to dry, overnight if possible. You may be able to use a drying oven.
Keep the yellow solid for Part B where you will test to see which ions it contains.

Discussion

1 The yellow solid is called a precipitate. Could it be lead nitrate or potassium iodide? Explain.
2 According to the equation at the bottom of page 104, which two substances could the precipitate be?
3 How could you test that the filtrate contains something besides water?

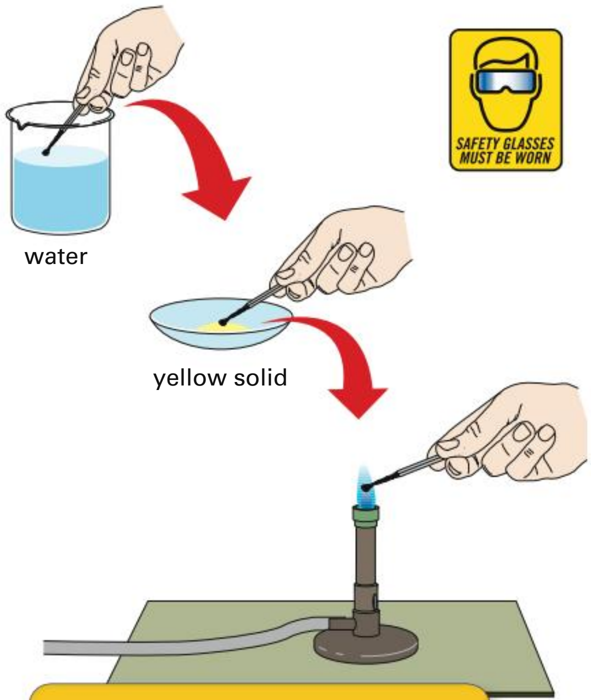
PART B Testing the precipitate

Materials

- yellow solid from Part A
- 2 small test tubes
- test tube holder
- spatula (narrow type)
- burner and heatproof mat
- matches
- cotton wool
- white tile

Method

1 Light a burner in the fume cupboard and adjust it so that you have a very small blue flame.
2 Use the spatula to put about half of the yellow solid into a test tube. Place a loose plug of cotton wool in the mouth of the tube (to prevent iodine fumes from escaping). Heat the test tube over the burner flame. If the solid produces purple iodine gas, it contains iodide ions.
3 Light a match and let it burn briefly. The black, charred end is mainly carbon.
4 Dip the charred end into water, then into some of the yellow solid. (The water is to help the yellow solid stick to the match.)



Warning: Remember to wash your hands when you have finished.

5 Hold the tip of the match just in the burner flame for a few seconds. Watch carefully what happens. If tiny drops of silvery lead form, then the yellow solid contains lead ions. Put the match on a white tile and look for any signs of lead. A simple test is to rub it on paper. Lead leaves a black mark.
6 Place any remaining yellow solid (and the test tube from Step 2) in a special waste container.

Discussion

1 Which ions does the yellow solid contain?

2 Suggest a name for the yellow solid. Write down its chemical formula.

3 Write a balanced equation for the reaction that occurred in Part A.

4 The yellow solid was once used as a paint pigment, but it is not used any more. Suggest a reason for this.

5 When you heated lead iodide in Part B, the products were iodine gas (I_2) and lead. Write a balanced equation for this reaction.

6 When you heated lead iodide on a charred match, it reacted with oxygen in the air to form lead(II) oxide and iodine gas. The lead oxide then reacted with the carbon in the match to form lead and carbon dioxide. Write balanced equations for these two reactions.

Explaining the reaction

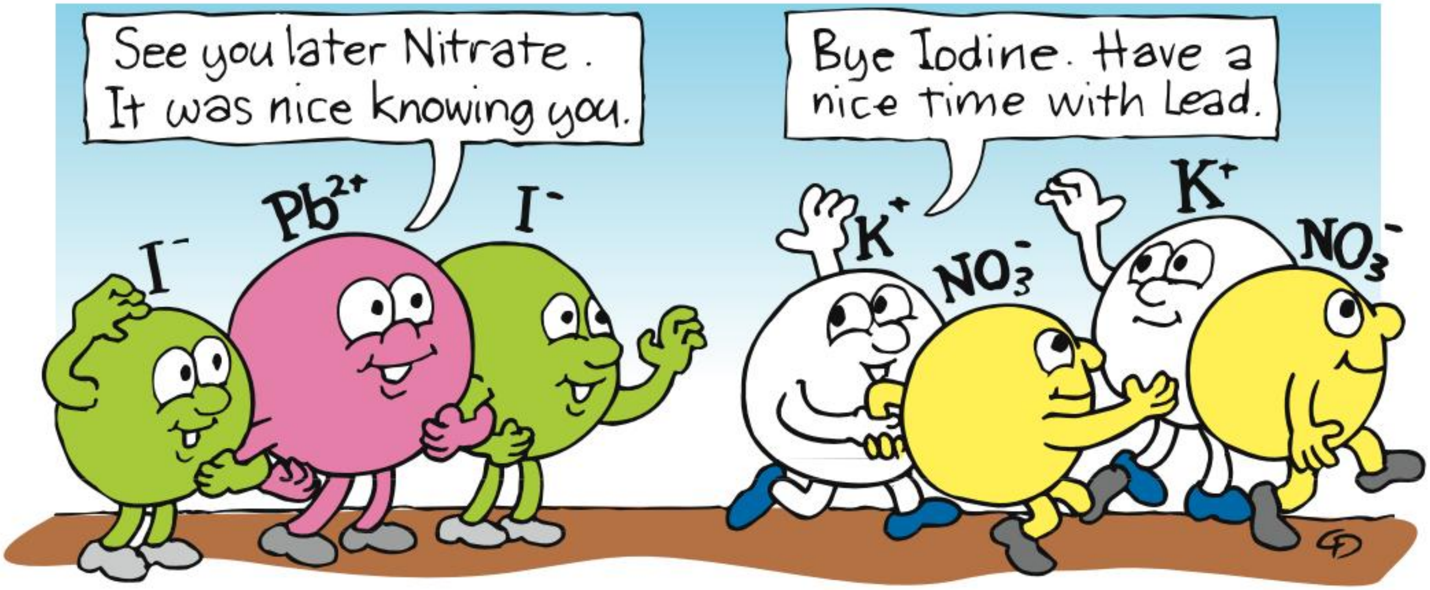
When lead nitrate and potassium iodide are mixed, there are four different ions in the solution. See the diagram on page 104. The reason the lead ions combine with the iodide ions is that lead iodide is very insoluble in water. Each lead ion Pb^{2+} combines with two iodide ions I^- to form a precipitate of lead iodide PbI_2. Hence the equation for the reaction is as follows. (Check the equation you wrote in Discussion question 3 above.)

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

This equation can be written more simply by showing only the ions that form the precipitate. This is called an *ionic equation*. Because the K^+ and NO_3^- ions do not take part in the reaction they are called *spectator ions*.

$$Pb^{2+} + 2I^- \rightarrow PbI_2$$

Fig 11 When lead nitrate and potassium iodide are mixed, the lead ions are more strongly attracted to iodide ions than they are to nitrate ions. So the ions change partners.



For an animation of the formation of lead iodide, open **Changing partners** at www.OneStopScience.com.au.

Check

1 Imagine you are agent 006 and have been captured by Havoc agents. They have left you at a site in the desert formerly used to manufacture poisons. They have left two identical containers—one containing water and the other a colourless, odourless solution of toxic lead nitrate. You must drink soon or die of thirst. How could you find out which container holds the water? (There is a chemistry laboratory on the site.)

2 The table below gives the solubilities of various ionic compounds. The lower the solubility, the more likely it is that the substance will form a precipitate. Silver chloride, which has a solubility of 0.0002 g/100 mL, is virtually insoluble and forms a precipitate, whereas magnesium nitrate, which has a solubility of 70 g/100 mL, is very soluble and would not form a precipitate.

a What is the solubility of:
- lead nitrate?
- magnesium carbonate?

Solubilities in g/100 mL water

	lead	magnesium	silver
carbonate	0.0002	0.01	0.002
chloride	1.0	55	0.0002
iodide	0.07	140	0.0000002
nitrate	55	70	220
sulfate	0.004	33	0.8

b Which of the compounds in the table is the most soluble in water? Which is the least soluble?

c Which group of compounds is the most soluble—the carbonates, chlorides, iodides, nitrates or sulfates?

d Which metal—lead, magnesium or silver—forms the most soluble compounds?

e Use the table to predict what will happen when you mix the following:
- lead nitrate and magnesium sulfate
- silver nitrate and magnesium iodide
- magnesium chloride and sodium carbonate.

Write a balanced equation for each reaction.

f Which compounds would you need to mix to form a precipitate of silver chloride?

3 Write ionic equations to show what happens when the following ionic compounds dissolve in water. (See page 104.)

a sodium chloride

b copper sulfate

c magnesium nitrate

d sodium phosphate

Challenge

1 Lead nitrate and potassium iodide will not react unless they are dissolved in water. Write an inference to explain this.

2 In the reaction $PbI_2 \rightarrow Pb + I_2$ one element gains electrons and the other loses electrons. Explain how this happens.

3 Write a correctly balanced equation for each of the following reactions.

a Magnesium carbonate powder reacts with hydrochloric acid to produce a solution of magnesium chloride, carbon dioxide and water.

b Copper reacts with concentrated sulfuric acid (H_2SO_4) to produce a solution of copper(II) sulfate, sulfur dioxide and water.

c Lead(II) nitrate solution reacts with potassium chromate K_2CrO_4 to produce a yellow precipitate of lead chromate.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 Atoms have no net charge. However, if they lose or gain ______, they become charged. They are then called ______.

2 Metals tend to ______ electrons to form positively charged ions. Non-metals tend to gain electrons to form ______ charged ions.

3 ______ bonds result from the attraction between ______ charged ions when metallic atoms transfer electrons to non-metallic atoms.

4 When an ionic compound ______ in water, the ions in the crystal lattice break apart and spread throughout the solution.

5 ______ bonds result from the sharing of electrons between non-metallic atoms.

6 The ______ or combining power of an atom tells you how it will combine with other atoms by losing, gaining or sharing electrons.

7 Chemical formulas can be used to write equations that represent reactions. These equations have to be ______ to give equal numbers of each type of atom on each side of the equation.

8 Atoms, molecules and ions are rearranged in chemical ______ to form new substances.

balanced
covalent
dissolves
electrons
ionic
ions
lose
negatively
oppositely
reactions
valency

Working with technology

Try doing the Chapter 4 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

1 What is the charge on an atom if it:
  a loses one electron?
  b gains two electrons?

2 a Which of the following are elements? How do you know?
  A C_2H_6O
  B NH_3
  C Cu
  D F^-
  E H_2
  F NO_3^-
  b Which represent compounds?
  c Which represent ions?
  d Which represent molecules?

3 What is the formula for a substance containing magnesium ions Mg^{2+} and hydroxide ions OH^-?
  A $MgOH_2$
  B $Mg(OH)_2$
  C MgOH
  D Mg_2OH

4 The formula for copper sulfate is $CuSO_4$.
  a How many different elements are there in copper sulfate?
  b What ions are formed when copper sulfate dissolves in water?
  c Is copper sulfate an ionic or a covalent compound?

5 What holds atoms together in:
- **a** an ionic compound?
- **b** a covalent compound?

6 Balance the following equations.
- **a** $C + Br_2 \rightarrow CBr_4$
- **b** $Fe_2O_3 + C \rightarrow Fe + CO$
- **c** $P_4 + H_2 \rightarrow PH_3$
- **d** $C_4H_8 + O_2 \rightarrow CO_2 + H_2O$
- **e** $Al_2(SO_4)_3 + Pb(NO_3)_2 \rightarrow PbSO_4 + Al(NO_3)_3$

7 Magnesium sulfate solution $MgSO_4$ is mixed with potassium hydroxide KOH.
- **a** What ions would be in the mixture?
- **b** Predict what new substances would be formed.
- **c** Write a balanced equation for the reaction you predict.

8 Why is it that copper sulfate solution conducts electricity but distilled water does not?

Fig 12 An iron nail in copper sulfate solution

9 The elements X, Y, Z and H form the following compounds: HX, YX_2 and YZ. Assuming H has a valency of 1+, what are the valencies of X, Y and Z?

10 **a** When nitric acid (HNO_3) is added to copper reaction occurs and a blue solution is formed. Why is this so?
- **b** A brown gas called nitrogen dioxide is also formed. Infer whether the atoms in this gas come from the copper or the nitric acid. Explain your answer.

11 Kai placed an iron nail in some blue copper sulfate solution. The next day she noticed that the nail was partly dissolved and there were grains of copper on the bottom of the beaker. The solution had lost some of its blue colour. (See the photo below.)
- **a** Write an inference to explain why the solution lost some of its blue colour.
- **b** Use what you have learnt in Section 4.3 about ions changing partners to write a balanced equation for the reaction that occurred.

Check your answers on page 304.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science Inquiry Skills

Classifying chemical reactions

You use patterns in everyday life so that you don't have to remember everything. You depend on these patterns to predict what is likely to happen. Examples are your school timetable and bus and train timetables. It is almost impossible to know every chemical reaction, but if you know some patterns you can often predict what sort of chemical reaction will occur. Below are six common types of chemical reactions.

1 Combination

In combination reactions two or more reactants combine to form at least one new substance. The pattern for these reactions is:

$$X + Y \rightarrow XY$$

For example, when you heat iron filings and sulfur the compound iron sulfide is formed.

$$Fe(s) + S(s) \rightarrow FeS(s)$$

Photosynthesis is a very important combination reaction in which plants use sunlight to combine carbon dioxide from the air with water to form glucose (plant food) and oxygen.

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$$

2 Combustion

Combustion is a special type of combination reaction in which a substance reacts rapidly with oxygen, producing heat and light. When you burn natural gas in a stove, methane reacts with oxygen in the air to form carbon dioxide and water.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

3 Decomposition

Decomposition reactions are the opposite of combustion reactions. The reactant breaks down to form two or more products:

$$XY \rightarrow X + Y$$

A decomposition reaction occurs when you pass electricity through water.

$$H_2O \rightarrow H_2(g) + O_2(g)$$

Another decomposition reaction saves lives every day. Inside airbags in cars a chemical called sodium azide decomposes explosively when triggered. Nitrogen gas inflates the airbag in a fraction of a second.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

4 Precipitation

Precipitation reactions result in formation of an insoluble solid (precipitate) when two clear solutions are mixed.

soluble salt A + soluble salt B → insoluble salt C + soluble salt D

See the photo on page 87 and Section 4.3.

5 Acid reactions

In *ScienceWorld 9* you learnt the following general equations:

metal + dilute acid → salt + hydrogen

carbonate + acid → salt + water + carbon dioxide

6 Neutralisation

The general equation for neutralisation is:

acid + base → salt + water

This is what happens when you take an antacid tablet to relieve indigestion caused by excess stomach acid.

Questions

1 Classify the following reactions.
- a Hydrogen peroxide (H_2O_2) breaks down into hydrogen and oxygen gas.
- b Sulfur burns in air to produce sulfur dioxide gas.
- c Sodium hydroxide reacts with nitric acid to form sodium nitrate.
- d Hydrogen gas reacts with chlorine gas to form hydrogen chloride.
- e Magnesium reacts with dilute sulfuric acid to form magnesium sulfate and hydrogen gas.

2 Write balanced equations for at least two of the reactions listed in question 1.

Solar panels,
University of Queensland

5 Our energy future

In this chapter you will …

Science Understanding

- define renewable and non-renewable energy systems and give examples of each

Science as a Human Endeavour

- suggest ways of saving energy at home and for transport
- discuss the work of Dave Irvine-Halliday in developing inexpensive lighting systems for developing countries
- investigate whether it is a good idea to install solar panels on your roof

Science Inquiry Skills

- research energy supply alternatives, using the internet and library
- design a model house to test the effectiveness of insulation

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Working in small groups, decide whether each of the following is true or false. Afterwards you may be able to hold a class forum to discuss any questions where groups did not agree on the answers.

1. Coal, oil and natural gas are renewable resources.
2. Australia's coal reserves are predicted to last hundreds of years.
3. The Middle East has about two-thirds of the world's oil reserves.
4. Developing countries have about 50% of the world's population, but consume only about 10% of the world's energy.
5. Nuclear power stations do not produce greenhouse gases.
6. The reason there are no nuclear power stations in Australia is because we have no reserves of uranium.
7. Solar cells are almost 100% efficient.
8. Solar cells are 100 times cheaper than they were 25 years ago.
9. There are many wind generators connected to state electricity grids.
10. It is possible to generate electricity from the methane produced at rubbish dumps.
11. A small car uses less energy per person per kilometre than walking.
12. Electric cars are not as efficient as normal cars.
13. Fluorescent tubes use more energy than ordinary light bulbs.
14. Building a house with the living areas facing north can reduce heating costs.
15. It is possible for cars to run on hydrogen gas.

5.1 Energy today

How much energy do we use?

Imagine how much electrical energy you would use if you ran seven 1000 watt bar heaters continuously throughout the year. The energy used would be about 219 billion joules (219×10^9 J). This might seem an enormous amount, but it is the average energy each person in Australia uses each year. It is three times the world average, and nine times more than our neighbours in Indonesia use.

How do we use energy?

In Australia we use 33% of our energy in industry, 35% in transport, 18% in homes and shops, and 14% in mines and farms. Much of this is in the form of electricity, but we also use large amounts of petrol and diesel for transport and industry, and gas for heating in our homes.

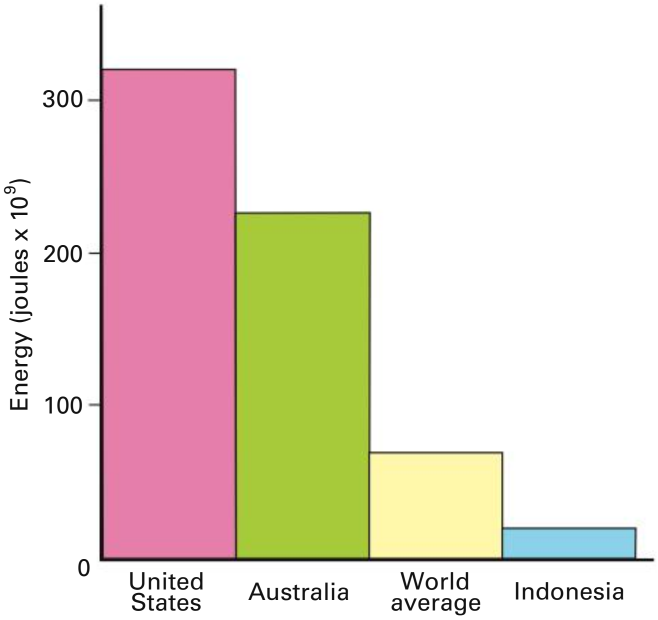


Fig 1 Energy used per person per year in selected countries, based on data from *BP Statistical Review of World Energy*, June 2011

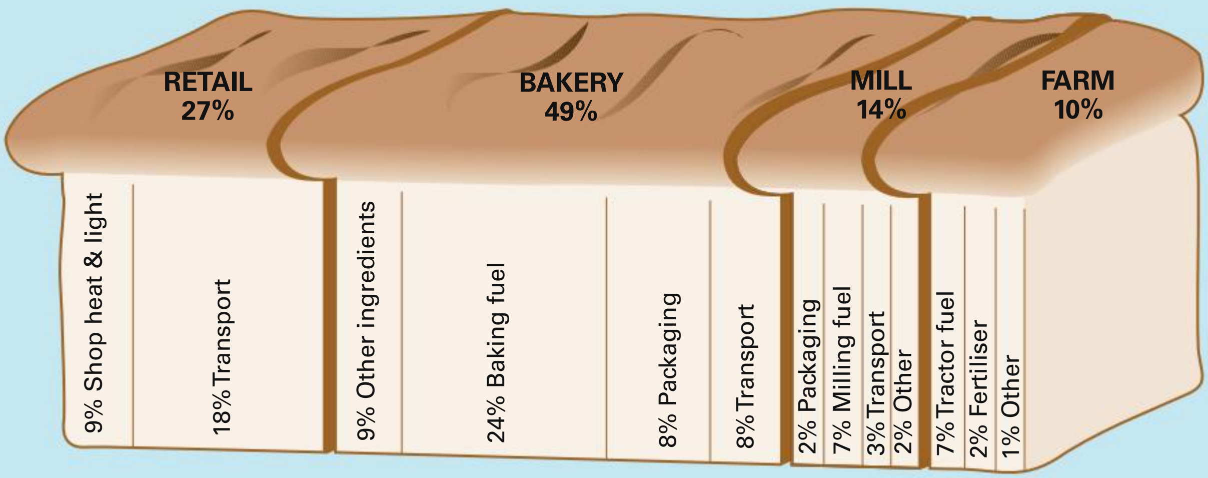
Activity

The diagram below shows how much energy is used to make a loaf of bread.

What percentage of the energy needed to produce a loaf of bread is used to produce the wheat?

What percentage of the energy needed to produce the loaf is used in transport?

Do you think the amount of energy used to produce the loaf of bread could be reduced? How?



Activity

Energy reserves	'Lifetimes' of world reserves from 2010 (in years)	Known Australian reserves in 2010 ($\times 10^{18}$ joules)	Annual Australian production ($\times 10^{18}$ joules)
oil	46	17	1.2
natural gas	59	110	1.9
coal	118	1589	10
uranium	65	241	1 (all exported)

Source: *BP Statistical Review of World Energy*, June 2011, and data from Australian Uranium Association

Use the data in the table above to answer the questions below.

1 Which is Australia's largest energy reserve?

2 Use the equation below to calculate how long Australia's oil, gas, coal and uranium reserves will last at their present rate of use.

$$\text{lifetime} = \frac{\text{proven reserves}}{\text{annual production}}$$

Australia's production and consumption of oil (in thousands of barrels per day)		
Year	**Production**	**Consumption**
1987	628	625
1990	651	694
1993	572	720
1996	619	794
1999	625	843
2002	730	846
2005	580	886
2008	556	936
2010	562	941

Source: *BP Statistical Review of World Energy*, June 2011

3 Compare the lifetimes for the Australian reserves with the lifetimes of the world reserves. What do you notice?

4 Use the data in the table bottom left to plot a graph showing how Australia's production and consumption of oil have changed between 1987 and 2010.

   a Summarise in one or two sentences what the graph tells you.

   b Is Australia a net importer or exporter of oil?

   c Has our consumption of oil ever fallen? When?

   d Was Australia ever self-sufficient (relying on its own oil without importing any)? When?

   e Suggest reasons for the rises and falls in production.

   f In which year did we import most oil? How much?

   g If Australia's population was 22.4 million in 2010, how many litres of oil did each person use each day in that year, on average? (1 barrel = 159 L)

5 Oil makes up less than 1% of our energy reserves but 35% of our energy consumption. What does this mean for our future?

6 Why are we not using our reserves of uranium?

Problems with fossil fuels

From Fig 2 you can see that in Australia we obtain 94% of our energy from fossil fuels—coal, oil and gas. These are **non-renewable energy** sources. Once used they are not replaced, or replaced only very slowly, by natural processes. Alternatively, hydro-electricity, solar, wind, tides and waves are **renewable energy** sources. 'Renewable' means that they are always available or can be replaced as they are used. Provided they are properly managed, they should not run out.

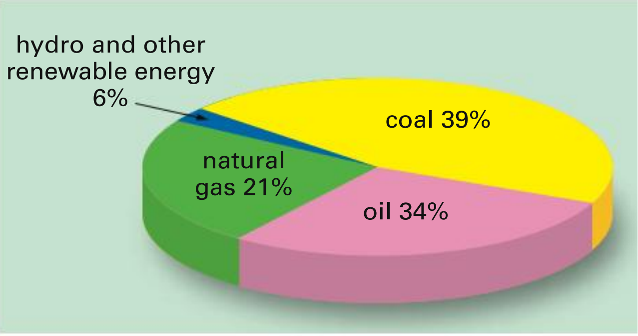


Fig 2 Australia's energy consumption (2009)

Oil is widely used in industry and transport, but Australia has limited reserves of it. The pie chart below shows that some countries have more oil reserves than others. In 2010 Australia produced only 60% of its own oil, and this percentage will decrease as our reserves are used up. Much of our oil will have to be imported from the Middle East, an area of the world that has been politically unstable.

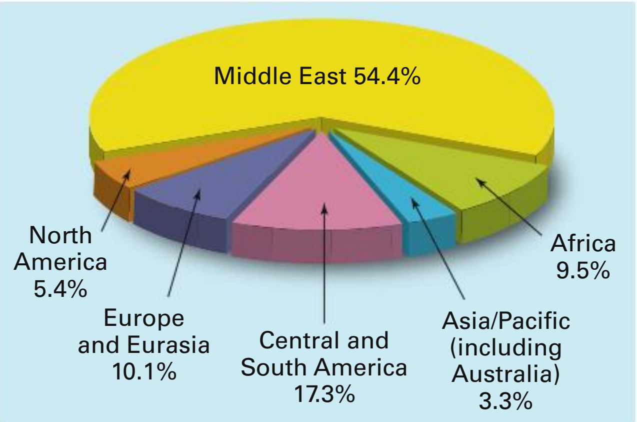


Fig 3 World oil reserves in 2010

The other problem is that the burning of fossil fuels releases gases into our atmosphere. Increasing levels of carbon dioxide are likely to lead to continuing global warming and climate change; and other gases can lead to pollution problems such as acid rain and photochemical smog.

We use almost all our oil as a fuel, but it may be wiser to use more of it to make other materials. For example, you might be surprised to learn that the oil needed to make 100 litres of petrol (about two tankfuls) could provide the raw materials and energy to make a large number of useful items; for example, about 20 polyester shirts, six garbage bags, 20 acrylic jumpers, a car tyre, 20 bicycle tubes and 500 pairs of pantihose!

The nuclear alternative

In contrast to fossil fuel power stations, nuclear power stations do not usually cause air pollution. The use of nuclear fuel not only conserves valuable fossil fuels, but also reduces greenhouse gas emissions and reduces the problem of acid rain. However, there are two major problems with the use of nuclear power: the disposal of highly radioactive wastes, and the risk of serious accidents occurring in nuclear reactors.

A nuclear power station uses the process of **nuclear fission**, and typically produces 25 tonnes of spent fuel each year (Stage 5 of the nuclear fuel cycle on the next page). Most of this spent fuel is uranium and plutonium, which can be recycled (Stage 7), but there is almost 1 tonne of unused, highly radioactive material produced each year. These wastes can be solids, liquids or gases.

The first step in handling radioactive wastes is simply to let them sit for several months in shielded containers. The **half-life** of a radioactive substance is the time it takes for its radioactivity to halve. Substances with short half-lives decay enough to become safe during that time. However, substances with longer half-lives must be stored for hundreds, perhaps thousands, of years and not be allowed to escape into the environment.

For many years, low-level wastes were cast into concrete, put into drums and then dumped at sea. This method of disposal has now been banned, because some drums started to leak. High-level wastes are at present stored in large concrete ponds. The water stops radiation escaping and removes the heat produced by the radioactivity (Stage 6 below).

Scientists are investigating various methods for long-term storage of nuclear wastes. One idea is to solidify the wastes in glass and seal them in stainless steel canisters. These canisters would be stored in deep underground caverns such as old salt mines (Stages 8–9). An Australian scientist, Professor Ted Ringwood, invented an alternative rock-like material called *Synroc* for storing wastes, but this method is still being trialled.

The area where radioactive waste is buried must be free from earthquakes. Also, there are a number of questions about long-term storage, which we simply cannot answer. For example, can we be absolutely sure of what will happen to the wastes over the next thousand years?

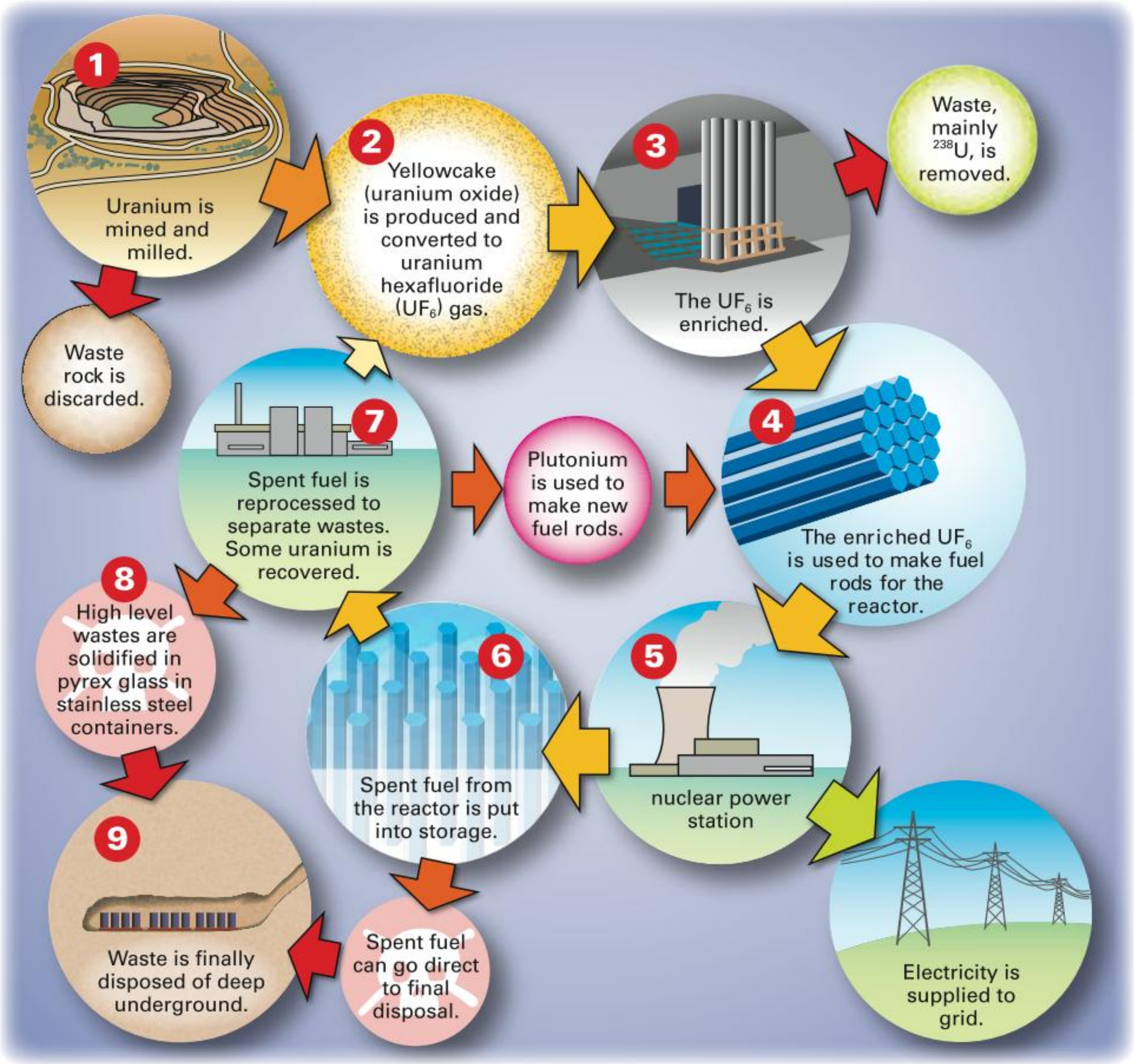
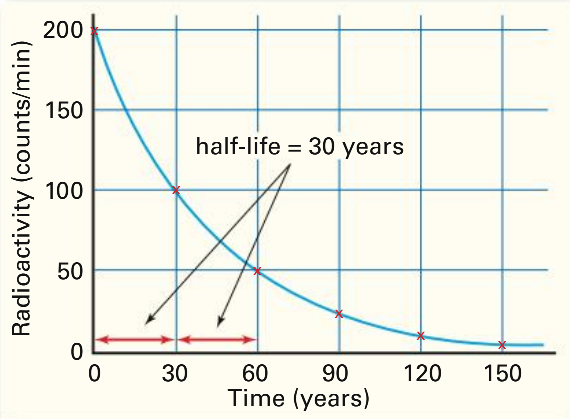


Fig 4 The nuclear fuel cycle

Extra for experts

The half-life of a radioactive substance is the time it takes for its radioactivity to halve, or the time taken for half the atoms in a sample to decay. Suppose a substance has a half-life of 30 years. If the radioactivity is 200 counts per minute to start with, then in 30 years time it will be only 100 counts per minute. After 60 years it will be 50, and after 90 years it will be 25 counts/min. This information can be displayed on a graph.



While nuclear reactors normally release only small amounts of radioactivity, there have been a number of serious accidents; for example, at Chernobyl in Ukraine in 1986 and at Fukushima in Japan in 2011.

The world's reserves of uranium are estimated at 3000×10^{18} joules, enough for about 65 years at current consumption rates. Australia has about 30% of these known reserves, but all of the uranium mined in Australia is exported. At present there are 438 nuclear reactors in 29 countries around the world, generating 14% of the world's electricity, but producing about 400 tonnes of highly radioactive waste each year. There are no plans to build nuclear power stations in Australia, although some people are starting to think about it. There is a small experimental reactor at Lucas Heights in Sydney. However, it is not used to produce electricity. It is used only for research and the production of radioactive substances such as technetium-99 for use in medicine.

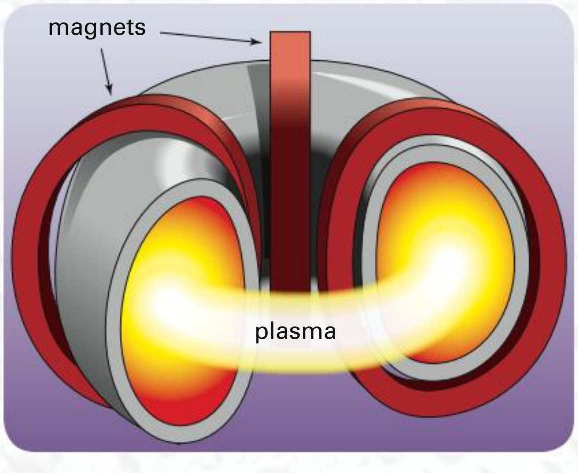
Science as a Human Endeavour

Nuclear fusion

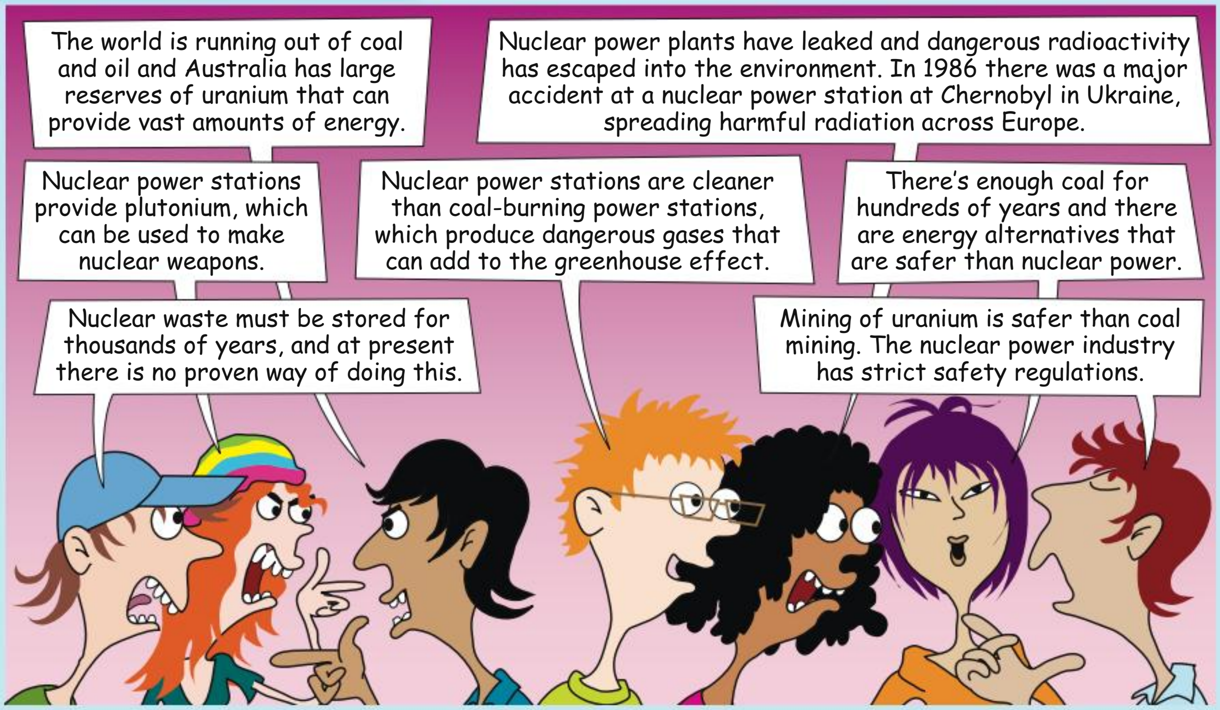
Current nuclear reactors use nuclear fission, where large atoms of uranium are split to produce large amounts of energy. In **nuclear fusion** energy is produced when two small atoms join together to form a larger atom. For example, hydrogen atoms fuse to form helium atoms and neutrons. It's the same type of nuclear reaction that powers the sun. For an animation of nuclear fusion, go to **www.OneStopScience.com.au** and follow the links to **How nuclear fusion reactors work**.

The good thing about nuclear fusion is that it produces less radioactive waste than nuclear fission. Also, the fuel needed is almost unlimited. Deuterium, a form of hydrogen, is found in seawater. There are several experimental fusion reactors around the world, but no working reactors producing electricity.

To produce nuclear fusion, you need a temperature of 100 million degrees Celsius—about six times hotter than the core of the sun! At that temperature the hydrogen is a **plasma**, not a gas. You also need to squeeze the hydrogen atoms together using intense magnetic fields. Microwaves, electricity and particle beams from accelerators heat a stream of hydrogen gas, turning it into a plasma. This plasma is contained inside a doughnut-shaped magnetic field. The fast-moving neutrons that are released heat up a liquid, which is then used to produce steam.



Activity



The debate about nuclear power has been going on for years. Since nuclear power stations were first built, many people have vigorously opposed them. Others are just as strongly in favour of them. The main arguments for and against uranium mining and the use of nuclear power are summarised in the cartoon.

Postbox activity

On your own, answer each of the six questions opposite. Write each answer on a separate piece of paper and put them in numbered boxes.

Form groups of about four, go through all the answers in one of the boxes and decide what is the correct answer. Report your answer to the class.

For extra information go to www.OneStopScience.com.au and follow the links to these two websites. One is pro-nuclear and one anti-nuclear.

World Nuclear Association

ANAWA Anti-Nuclear Alliance

1. What are the details of the nuclear accident at Chernobyl in 1986?
2. How many nuclear power stations are there in other countries? What percentage of the total electricity produced in these countries is nuclear?
3. Which produces cheaper electricity—a coal-burning power station or a nuclear power station?
4. Where in Australia is uranium mined? To which countries is it exported?
5. How does exposure to radioactivity affect people?
6. What is presently done with radioactive wastes? What future plans are there?

Here are some other things you could do:

- Have a debate for and against nuclear power.
- Role-play an inquiry that has been set up to decide whether or not a nuclear power station should be built near your home.
- Write a letter to the editor of a newspaper for or against nuclear power.

Check

1 What is the difference between a non-renewable and a renewable energy source? Give an example of each.

2 a List reasons for looking for energy alternatives other than fossil fuels.
b Why is finding a replacement for oil and gas more urgent than finding a replacement for coal?

3 Compare and contrast nuclear power stations and coal-burning power stations.

4 About 100 years ago the Russian chemist Dmitri Mendeleev said that burning petroleum 'would be akin to firing up a kitchen stove with banknotes'. Why do you think he believed petroleum was too valuable to burn?

5 Energy is used to produce the many foods we take for granted; for example, a loaf of bread (page 114). Think of a food and list the ways in which energy is used to provide the finished wrapped product ready for you to eat.

6 Suppose there is a leak in a nuclear reactor and highly reactive strontium-90 is released into the surrounding countryside, which is used for dairy farming. Two months later breastfed babies are found to have small amounts of strontium-90 in their bodies. Explain how this could have happened.

7 Use the internet to find out what oil shale is, where it is found in Australia, and how it can be converted to oil.

Challenge

1 The table below shows the total nuclear energy produced in the world from 1978 to 2010.
a Display the data on a line graph. (You will be predicting up to the year 2020, so think carefully about the units for the axes.)
b Do you think nuclear energy production was affected by the Chernobyl disaster in 1986? Explain.
c Use your graph to predict the nuclear energy production in 2015 and 2020.
d Which one of your predictions is likely to be more accurate? Explain.

Year	Nuclear energy production (million tonnes of oil equivalent)
1978	140
1982	207
1986	361
1990	453
1994	504
1998	550
2002	611
2006	635
2010	626

e Compare your predictions with those of other people. How much variation is there? Mark the range of predictions for 2020 on your graph.
f List factors that you think may increase the use of nuclear energy over the next 20 years. Also list factors that may decrease its use.

2 Use the nuclear fuel cycle on page 117 to answer these questions.
a Which stages in the cycle produce wastes?
b What happens at Stage 7?
c Which is the longest stage?

3 You have 64 grams of a radioactive substance with a half-life of 5 days. How much of this substance will be left after 5 days? After 10 days? How many days will it take for the mass to decrease to 1 gram? Show this information on a graph.

4 Given that the world is so short of oil, do you think that oil exploration should be allowed in environmentally sensitive areas such as the Great Barrier Reef? You could have a debate.

5 Use the internet to find answers to these questions.
a What is the enhanced greenhouse effect?
b What is the Kyoto Protocol?
c What is carbon emissions trading?

5.2 Renewable energy

At present we obtain about 94% of our energy from fossil fuels. However, some time in the near future these non-renewable resources will run out. We will then have to rely on renewable energy sources.

The largest energy source available to us is the sun, and most of the renewable energy sources described in this section involve the sun's energy—either directly, for example in solar water heaters, or indirectly, for example in plants grown by photosynthesis using the sun's energy. Not all the renewable energy sources described are economically viable at present. However, as the prices of existing fossil fuels increase, the use of renewable resources will become more economical.

It is important that you have some knowledge of the range of energy alternatives described on the following pages.

Solar energy

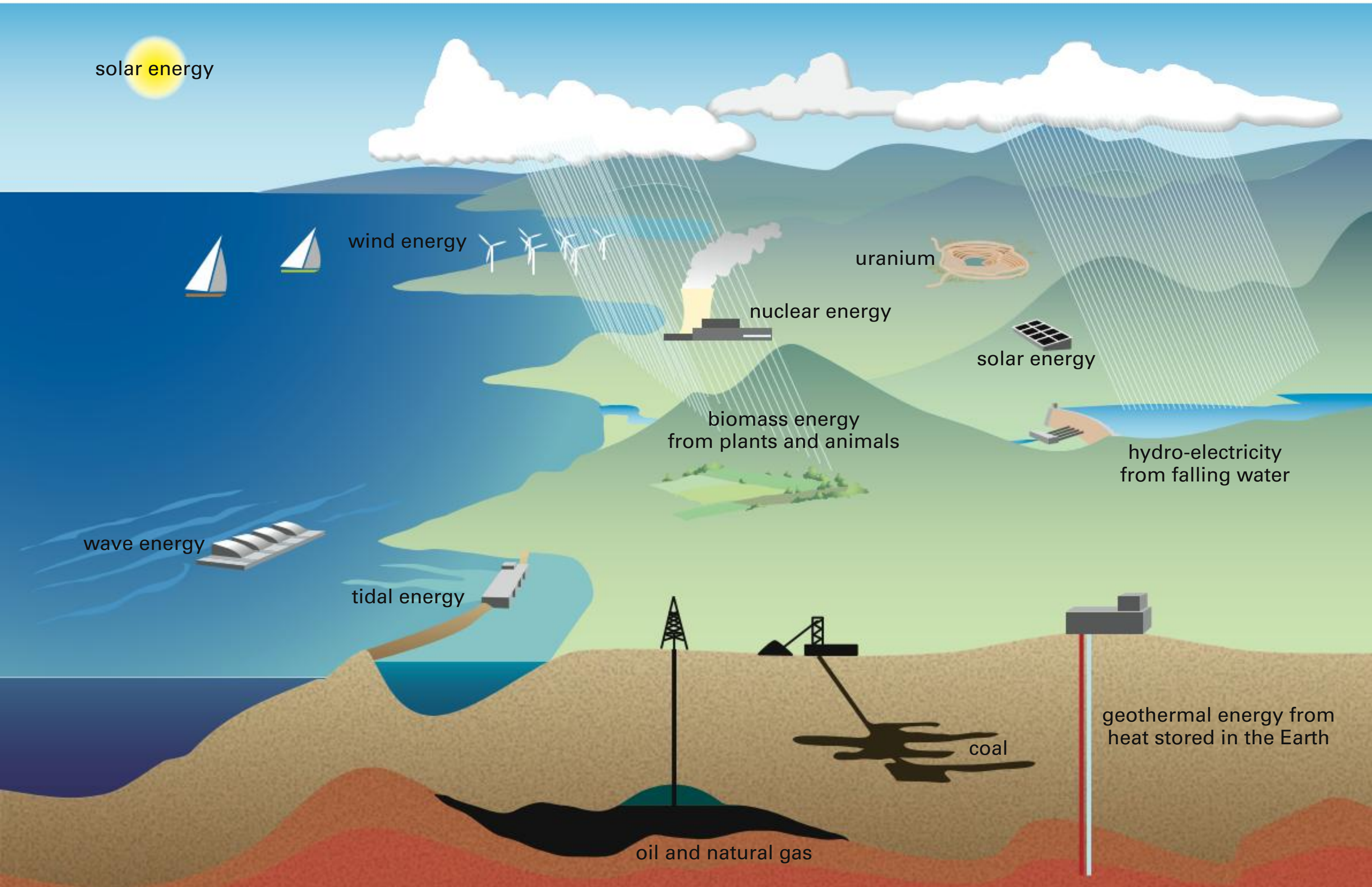
The solar energy striking the Earth every minute is enough to supply the world's energy needs for a year! Most of this solar energy is transformed to heat on the Earth's surface, where it produces winds and waves. A smaller amount of solar energy is absorbed by plants during photosynthesis.

Solar energy can be harnessed in two main ways: for the production of electricity and for heating, for example in solar water heaters.

Solar cells

The Mars Pathfinder rover that landed on Mars in July 1997 was powered by **solar cells** (photovoltaic cells). These can convert light energy into electricity. The first solar cells were only 6% efficient, but efficiencies of more than 40% are now possible.

Fig 5 Which of these energy resources are renewable and which are non-renewable?



The use of solar cells has become widespread in devices such as watches and calculators. They are also used to provide power to homes in remote areas, to pump water and to operate roadside signs and street lighting systems.

There are three disadvantages of generating electricity using solar cells. First, they are expensive. Second, they are less effective in cloudy weather and do not operate at night. Third, large areas of land are needed for collection areas due to their relatively low efficiency. However, as the cost of solar cells decreases and their efficiency increases, they will almost certainly become more widely used. They are already 100 times cheaper than they were 25 years ago!

Fig 6 The Mars *Pathfinder* rover

Working with technology

For an animation on of how a solar cell works, open Photovoltaic energy at www.OneStopScience.com.au.

OneStopScience

Green power

Each year the Australia Prize is awarded in an area of science and technology promoting human welfare. In 1999 it was awarded to Martin Green and Stuart Wenham from the University of New South Wales for their pioneering work with solar cells. For almost 20 years they held the world record for the most efficient solar cells. These cells were used by the winning car in the 1999 World Solar Challenge.

Green and Wenham worked with an Australian company called Pacific Solar (now CSG Solar). They worked out a way of depositing thin layers of silicon onto glass sheets, instead of using expensive silicon wafers. This cut the cost of solar power by two-thirds. Eight modules of these solar cells mounted on your roof will generate 1.5 kilowatts, about a third of the electricity you need. In doing so, they will reduce greenhouse gases by almost 2 tonnes every year.

The modules can be fitted together like Lego blocks. They convert DC electricity to AC suitable for running lights and appliances in homes and offices. Any surplus electricity is automatically fed back into the electricity grid through the meter box, giving the owner a credit on their bill. See page 141.

Fig 7 These solar panels generate electricity directly from sunlight.

Investigation 8 Solar cells

Aim

To investigate the efficiency of a solar cell or solar panel.

Materials

- solar cell or panel of solar cells
- small electric motor plus propeller
- variable resistor or a range of resistors
- milliammeter or multimeter
- voltmeter or multimeter
- connecting wires

Planning and Safety Check

Read through the investigation and design a data table to record your results.

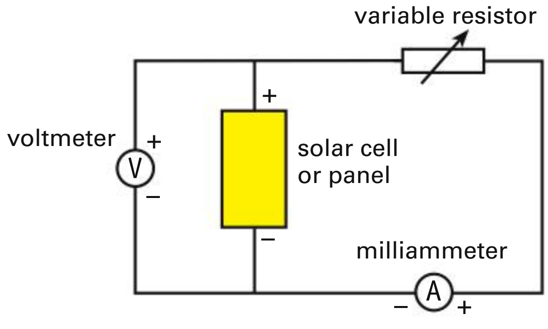
Method

1 Connect the solar cell or panel to a small electric motor (preferably fitted with a propeller). Put the cell in bright sunlight and observe how fast the motor turns.

What is the effect of placing your hand over the cell?

Is the angle of the cell in relation to the sun important? Which angle is best?

2 Set up the electrical circuit as shown in the diagram.



3 Place the solar cell or panel so that sunlight falls directly onto it.

4 Set the variable resistor to zero resistance and measure the current and voltage.

Record these values in your data table.

5 Increase the resistance in steps, recording the voltage and current each time. Stop when further increases in resistance have little effect on the current or voltage.

Discussion

1 For each value of the resistance, calculate the power output of the cell or panel using the following formula:

power (watts) = voltage (volts) × current (amps)

or $P = VI$

Add the power values to the data table.

2 Draw a graph of power versus resistance.

What is the maximum power of your cell or panel? At what resistance does this occur?

3 How many solar cells like yours would be needed to power a 60 watt light bulb?

4 If the maximum power required by a household during the day is 3000 watts, calculate the number of solar cells like yours you would need, assuming sunny conditions.

5 What is the efficiency of the solar cell, assuming the average available power of sunlight is about 1000 watts per square metre?

You will need to measure the surface area of the solar cell to find the maximum power *per square metre*.

$$\text{efficiency} = \frac{\text{power of cell}}{\text{power of sunlight}} \times 100$$

Inquiry

- How does the angle at which the cell or panel is positioned affect its output?
- How does the light intensity affect the power output? (Use a light meter.)
- How does cloud cover affect the output? (To simulate cloud cover you could hold sheets of translucent material over the cell.)

Solar power stations

At Liddell near Muswellbrook in New South Wales, a solar power system is being built beside the coal-burning power station. It consists of a giant array of flat mirrors, which will eventually cover an area the size of four football fields. The mirrors track the sun and concentrate its heat onto what is in effect a huge solar hot water system. The heated water is pumped into the solar power system where it is heated further to produce high-pressure steam to drive turbines and generate electricity. This solar power system will cut down on the amount of coal needed to produce our electricity.

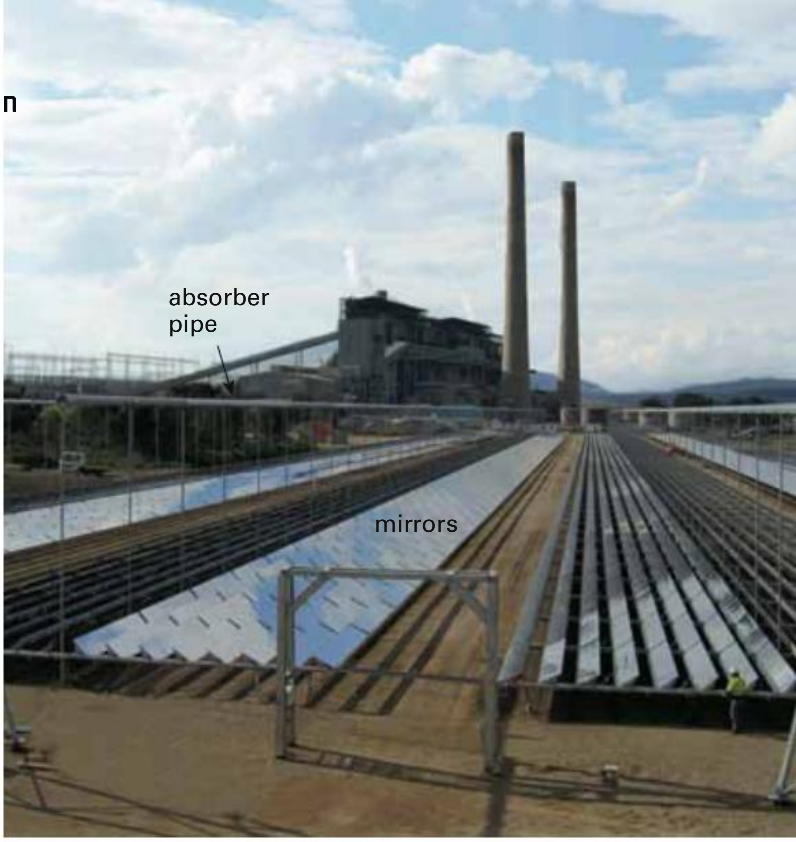


Fig 8 The Liddell Power Station

Wind energy

Windmills have been used in Australia for many years to pump water. Only recently have wind generators been used to produce electricity.

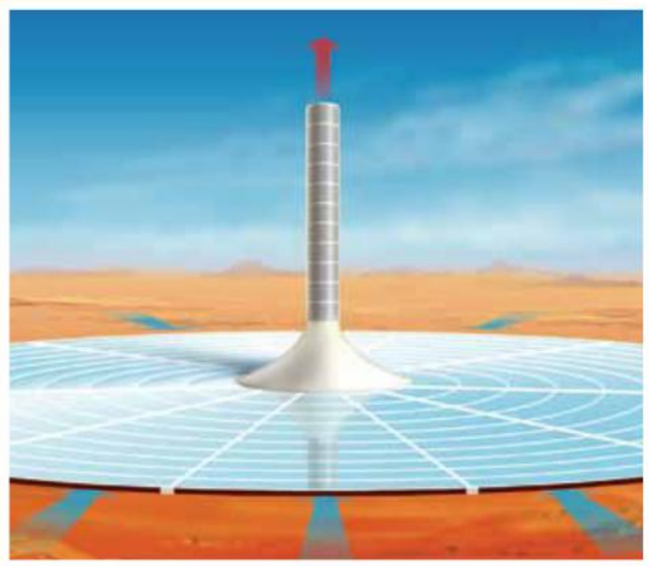
A small wind generator can produce 40–50 kilowatts, enough electricity for a single house. A huge generator whose blades sweep a circle 80 metres in diameter can produce 1.65 megawatts of electricity. A normal coal-burning power station generates about 2000 megawatts, so you need 1200 wind generators to produce the same amount of electricity as a single power station!

Australia's largest wind farm is at Hallett, 220 km north of Adelaide. It has 142 wind turbines and generates enough electricity to supply 170 000 homes. Each turbine is 80 metres tall and the blades are 44 metres long. Other large wind farms are at Waubra near Ballarat in Victoria and Capital near Queanbeyan in New South Wales.

Solar power tower

A Melbourne-based renewable energy developer called EnviroMission has plans to develop Solar Tower power stations in Australia, the United States and China. Solar Towers will combine innovative design with the sun's energy in a unique way to make clean electricity. The design features a tall hollow tower up to 1000 metres tall positioned at the centre of a vast translucent circular canopy with a radius up to 2.5 km. Air inside the canopy is heated by the sun to make a thermal wind. As the hot wind rises up the hollow tower at 35–50 km/h, it passes through 32 turbines located around the base of the tower. These turbines will then generate up to 200 MW of pollution-free electricity. A 200 MW Solar Tower power station will generate enough clean electricity for up to 300 000 average households. No water is used in this electricity generation method.

A report from CSIRO scientists estimates that a 35 km^2 area with plenty of sunlight and little cloud could produce all Australia's electricity using solar power systems like Solar Towers and the Liddell Power Station.



Extra for experts

Wind generators

The power output of two different-sized wind generators was measured at different wind speeds, and the results were recorded.

Fig 9 Waubra wind farm in in central Victoria

Wind speed (m/s)	Power output (watts)	
	Rotor blade diameter 3 m	Rotor blade diameter 6 m
2	15	60
4	120	475
7	400	1 600
9	950	3 600
11	1 840	7 360
13	3 180	12 760

1 Plot two line graphs on the same axes to show how power output varies with wind strength. Label the graphs carefully.

2 Write two generalisations about the power output of wind generators.

3 Use the data to work out what happens to the power output when the wind speed doubles.

4 A phone company wants to power outback telecommunication equipment that needs 1.5 kW to operate. Wind speeds in the area vary from 7 m/s to 11 m/s.
   - a Which generator would be more suitable—the one with 3 m blades or the more expensive one with 6 m blades?
   - b Would the generator you chose still be suitable in an area where the wind speed varies from 6 to 10 m/s? Explain.

5 The power that can be obtained from a wind generator operating at 50% efficiency can be calculated as follows:

power (watts) = 0.3 × A × v^3
where A = area in m^2 swept by the blades
and v = wind speed in m/s.

   - a Calculate the power produced by a wind generator with 10 m diameter blades operating in a 10 m/s wind.
   - b Use the equation to work out what happens to the power when the:
     - wind speed doubles
     - diameter of the blades is doubled.
   - c Are the wind generators in the table operating at 50% efficiency? Explain.

Biomass

Biomass is plant and animal material used as a source of renewable energy. It may be wood from forests, residues from agriculture and industry, or human and animal wastes.

In Australia we throw away over 10 million tonnes of household rubbish every year. Much of this is biomass and contains about the same energy as 3 million tonnes of coal. This rubbish can be used to produce electricity, as shown in Fig 10. When it is dumped and covered with soil, biodegradable materials break down to produce *biogas*, which is mainly methane. PVC pipes that have a porous outer surface are partly buried in the rubbish, and pumps draw the biogas into these pipes. The gas is then burnt and used to generate electricity.

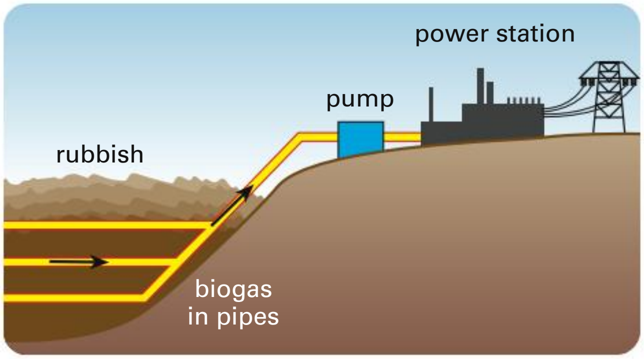


Fig 10 How a biogas power station works

Some processed-food manufacturers are using waste peelings to produce biogas. This solves a waste disposal problem as well as producing useful heat energy for the factory. Some sewage treatment plants, such as the one at Cronulla in Sydney, use biogas to produce electricity to power the plant. As well as using a renewable energy source, such power plants use up methane, which is one of the gases thought to be contributing to global warming.

Hydro-electricity

In Australia about 3% of our total electricity is produced from falling water in hydro-electric power stations. However, hydro-electric power stations can only be built in mountainous areas, and there are few suitable sites remaining. Also, the building of storage dams can cause serious damage to the environment by flooding unique habitats. This is why a dam proposed for the Gordon River downstream from the Franklin River in Tasmania was never built.

An advantage of hydro-electric power generation is the ease with which generators can be started up and shut down. It thus provides a convenient and cheap way to supply the additional power needed during peak periods of use. Look at Fig 11. Water from the upper reservoir can be used to produce power during the day when demand is high, and at night when demand is low, the water can be pumped back into the upper reservoir for re-use.

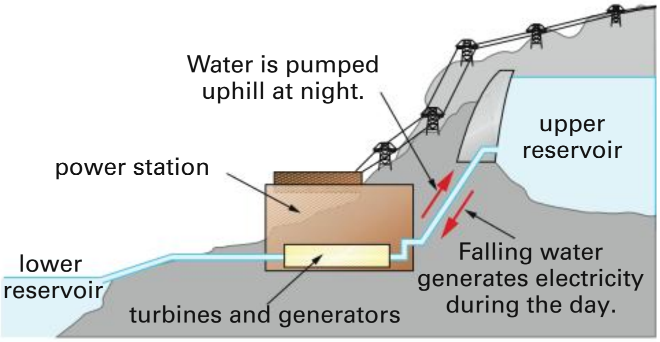


Fig 11 A pumped storage hydro-electric system

Tidal and wave energy

The tides of the oceans contain vast amounts of energy, if only we could harness it. To harness the tides, you need to dam off a bay. As the tide comes in, water flows into a reservoir, driving turbines, which generate electricity. As the tide goes out, water flows through the turbines in the opposite direction, generating more electricity. However, for this process to work effectively, you need large tides and these occur only in a few places.

The north-west coast of Australia is ideal for power generation because of the large tidal range there. A tidal power station is proposed for near Derby, with dams across two arms of a tidal creek and a canal between them. With this design it is possible to generate electricity continuously. However, some people feel that damming the creek will damage the local environment.

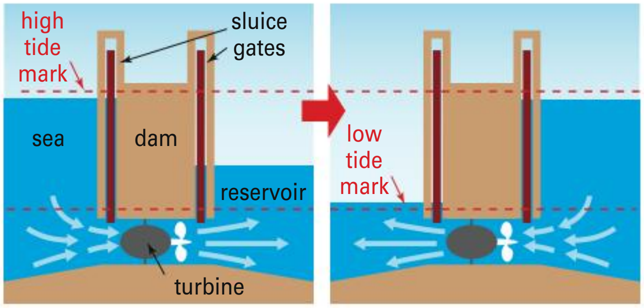


Fig 12 In a tidal power station the turbine can be driven by water flowing either way—from the sea to the reservoir as the tide comes in, and from the reservoir to the sea as the tide goes out.

Ocean waves also have a large amount of energy, as you will know if you have been 'dumped' by a wave. It is possible to use the up and down movement of waves to generate electricity, and scientists have suggested several different ways of doing this. One idea that has been shown to work is illustrated below. Another idea is to use floats, which bob up and down on the waves. These floats would be expensive to build, but may be a possibility in the future. For an animation of these floats, go to **www.OneStopScience.com.au** and follow the links to **The Salter duck**.

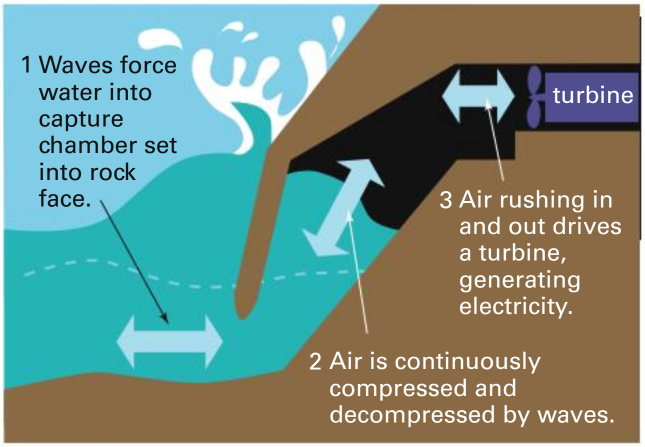


Fig 13 One design for a wave power station

Geothermal energy

Geothermal power stations make use of the heat inside the Earth. In some parts of the world, there is a great deal of volcanic action and hot water and steam reaches the surface. New Zealand, Italy, Iceland and the United States have all built geothermal power stations that use this steam to turn turbines and generate electricity. There are no such areas in Australia. However, if holes are drilled down several kilometres, hot granite rocks are found.

This granite contains radioactive elements such as uranium and thorium, which release heat as they decay. Suitable hot rocks have been found near Innamincka in north-eastern South Australia. The rocks are at a temperature of around 250°C and extend over an area of 1000 km^2. The sedimentary rocks on top of the granite act like a blanket, keeping in the heat. There is another smaller region of hot rock near Muswellbrook in New South Wales.

Water is injected into the central borehole and circulated through the hot cracked granite. The heated water is returned to the surface through the outside boreholes. It can then be passed through a heat exchanger where most of its heat can be removed and used to generate electricity. The water can then be returned to the first borehole and used again.

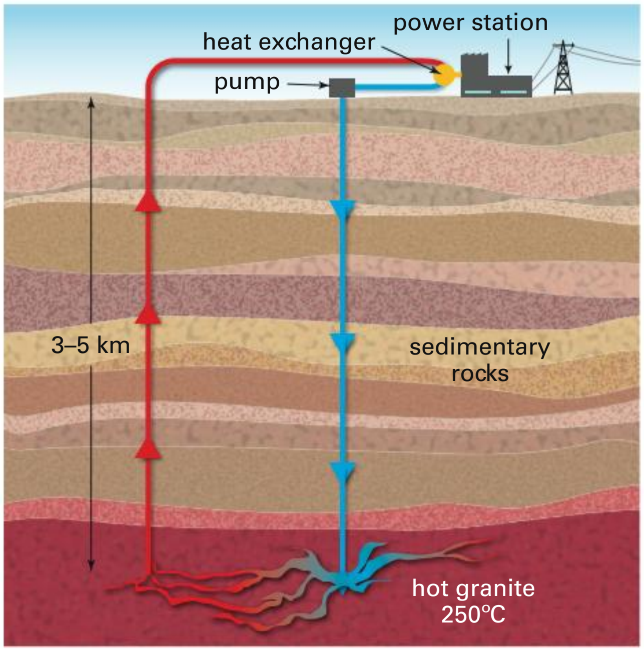


Fig 14 How electricity can be generated from hot rocks. For an animation go to **www.OneStopScience.com.au** and follow the links to **HDR geothermal energy**.

Activity

Energy supply proposal

Suppose a mine is to be developed on the Nullarbor Plain in South Australia. Your task is to prepare a proposal for the supply of energy. You will work in small groups, each group representing a different company responding to the notice on the right.

Step 1: Select an energy system

Research all the energy alternatives available. Use the information on pages 121–127, but look for more detailed information by going to www.OneStopScience.com.au and following the links to these websites.

Future energy needs (NOVA)
Sustainability Victoria
Renewable energy (NSW)

To summarise your findings, draw up a table giving advantages, disadvantages and notes for each source.

Step 2: Collect information

Collect detailed information on your chosen energy system. Identify the strengths and weaknesses of your energy system, and suggest ways of overcoming any problems (as part of your proposal).

Step 3: Prepare proposal

Decide on a name for your energy supply company, and a title for your proposal. Then prepare the proposal for presentation to the group.

Step 4: Presentation

Present your proposal (5–10 minutes) on your energy supply system, including arguments for its use. You could prepare a PowerPoint presentation. Other students will ask questions about your proposal and try to identify weaknesses in your arguments.

Step 5: Discussion

To finish, have a general discussion of the difficulties of energy supply systems on the Nullarbor Plain. Compare the Nullarbor with your local situation.

Nullarbor Mine

Tender for supply of energy system

Manufacturers and suppliers of energy systems are invited to register their interest in tendering for the supply of energy to the proposed uranium mine at Nullarbor. Potential suppliers will be required to provide a general description of their proposed method of energy supply. The proposed method should be cost-effective and suited to the area. The estimated energy requirement for the mine and settlement is 500 megawatts. All proposals must include an environmental impact study.

The Nullarbor mine is approximately 650 km west of Adelaide. The settlement is close to the main highway and about 125 km south of the railway, but it is very expensive to bring in fuel by road, rail or air.

No coal, oil or gas has been found in the area. It hardly ever rains and there are few cloudy days. There are no trees and no streams, but water can be obtained from underground bores.

Nullarbor is close to the ocean, at the top of 80-metre-high cliffs. The average difference between high tide and low tide is 1.5 metres. The average wind speed is 8 km/h in summer and 25 km/h in winter, from the west.

Check

1 What energy change takes place in a:
  a solar cell?
  b solar water heater?

2 What is biogas? What can it be used for?

3 An experimental wave generator can extract 50% of the energy carried in waves. If many similar generators were placed in a 25 km line in front of waves with a power of 80 kW/m, what would the total power output be?

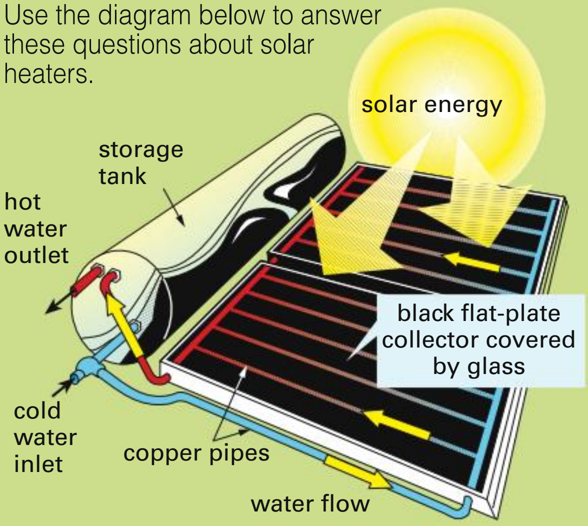
4 What are the similarities and differences between a hydro-electric power station and a tidal power station?

5 A solar water heater costs about $2500 more than an electric or gas hot water system. However, there is a government rebate of $1000. If a solar heater saves 75% of water heating bills, calculate how long it would take for the solar heater to pay for itself. (Assume electric or gas water heating costs are about $350 per year.)

6 Draw a diagram to show how you could generate and collect biogas from household rubbish. What kinds of rubbish would work best?

Challenge

1 Use the diagram below to answer these questions about solar heaters.



  a Why is the collector covered with a glass plate?
  b Would there be any advantage in using a plastic cover instead of a glass one?
  c Why is the collector black?
  d Why does the water move in a cycle from the storage tank to the collector and back to the storage tank?
  e Why is the storage tank insulated?
  f What advantage would there be in having the storage tank inside the house instead of on the roof?
  g Why is the solar heater positioned on the roof so as to face in a northerly direction?

2 A coal-burning power station has a maximum generating capacity of 2640 MW. The average daily rate at which this area receives solar energy is 1000 W/m^2.
  a What area of solar cells, operating at 15% efficiency, would produce the same amount of power as the power station?
  b If a typical residential block of land in the city has an area of 750 m^2, how many of these blocks does your answer in **a** represent?

3 In 2010 Australia used 150 million litres of oil per day. Crude oil contains about 12% petrol.
  a Calculate the quantity of petrol used every day in Australia in 2010.
  b Alcohol is an excellent fuel that can be produced from sugarcane and other plants. Petrol containing up to 10% ethanol (gasohol) can be used in cars without any engine modifications being required. Find the quantity of crude oil that could be saved if all the petrol in Australia was converted to gasohol.
  c If we were to use gasohol instead of petrol, we would need to use half our present farmland to grow energy crops like sugarcane. This means new farmland would have to be made by clearing forests. Discuss the pros and cons of this course of action.
  d Suggest why alcohol is not used as a fuel in Australia at present.

4 Explain why the energy in wind and waves is sometimes called ‘second-hand solar energy’.

5 We presently pay about 20.2 cents per kWh for electricity that is produced mainly in coal-burning power stations. Create a table of costs between now and the year 2020, assuming this cost increases by 5% per year. Then create a table of costs for electricity from solar cells, assuming it costs 50 cents per kWh now and *decreases* by 10% each year.

Plot the two sets of data on the same graph, and predict when solar electricity will be cheaper than power station electricity.

6 Use what you have learnt in this section to decide which type of power generation would be most suitable for a small town of 500 people in each of the following locations. In each case explain your choice.

a an Antarctic base

b a small Pacific island

c a valley in the mountains of Nepal

7 Is there any energy source that can be used without any environmental impact? Discuss this in a group.

TRY THIS

Your task is to design and construct one of the following:

- a solar water heater that will increase the temperature of about 4 litres of cold water by at least 20°C after standing in sunlight for 1 hour, or
- a wind or wave generator that will generate a small electric current.

Use these steps in your construction:

1. Use the diagrams on the right for ideas. Search for other ideas in the library or on the internet, and discuss the task with other people.
2. Draw a plan of your device before you start. List the materials and equipment you will need. You may need to ask your teacher for help.
3. Build a prototype—your first experimental model.
4. Test your prototype and make any necessary modifications. Then test your modified model.
5. Demonstrate your design to the rest of the class. Then prepare a written report, saying what you did and how successful your model was, and giving suggestions for improvements. (Your model may be good enough to enter in a science contest.)

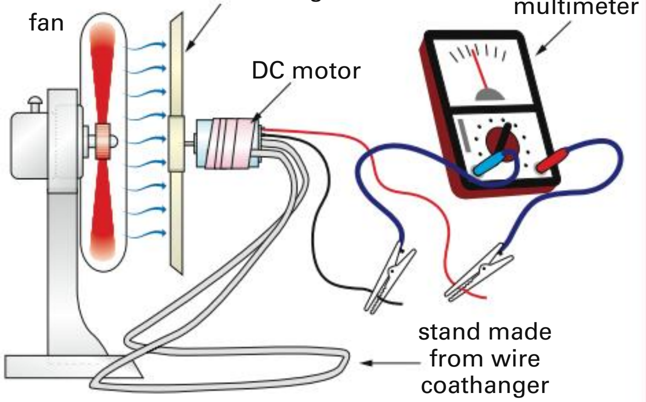
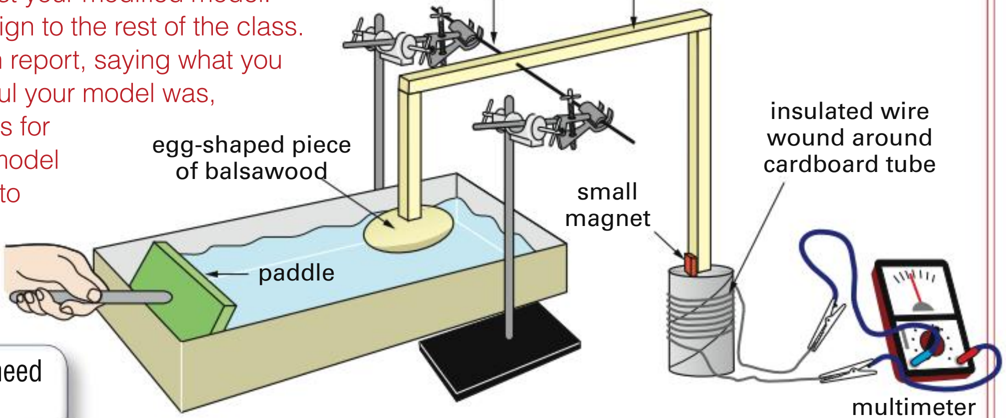


Fig 15 A wind generator

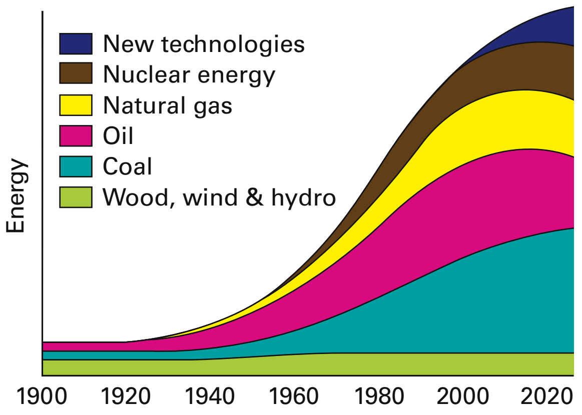
Fig 16 A wave generator



Teacher note: You will need to do this outdoors.

5.3 Managing energy

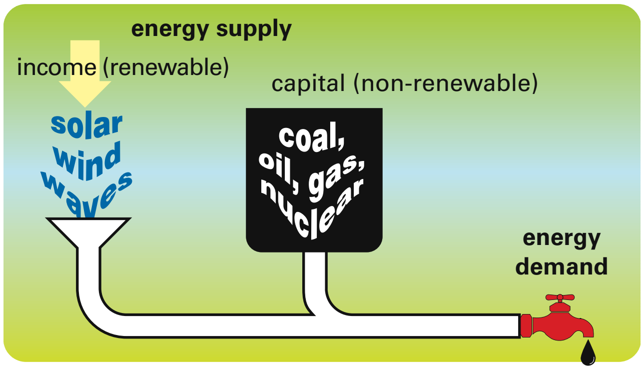
As the graph below shows, the world's use of energy has changed greatly over time. Combustion of wood was the main method of obtaining energy before 1900. Wood supplies once seemed inexhaustible and, like fossil fuels, satisfied most of the demands of the time. The clearing of forests and an increasing demand for a cheaper and more convenient fuel to operate machines led to the change from wood to coal and oil as sources of energy.



Non-renewable fossil fuels are our *energy capital*—like money in the bank waiting to be used. But once used, these resources are gone forever. On the other hand, the sun's energy is supplied continuously. So is the energy of the wind and tides. These renewable resources will always be available. They are our *energy income*—like money from a permanent job.

Almost half of the world's energy needs are presently met by oil, but world oil supplies are predicted to run out in about 40 years time. This is like having a large tank of fuel that you keep using. Eventually the tank will become empty! For our energy use to be **sustainable**, demand cannot be greater than supply for any great length of time. Our energy capital is shrinking and cannot be renewed. However, we can decrease our energy demand by using less of our energy capital, and we can use more of our renewable energy income. At present, most of this renewable energy is not used.

We do not yet know the best mix of energy resources for the future. However, it is clear that to slow down global warming and to reduce air pollution, there must be a significant reduction in fossil fuel combustion. Obviously we need to save energy where possible, and use energy more efficiently. We also need to make greater use of renewable energy sources.



Saving energy

There are many ways in which you as an individual can cut down on energy wastage. Below are a few ideas. For more ideas go to **www.OneStopScience.com.au** and follow the links to **Global Warming—Cool It**.

Transport

About 40% of the energy used in Australia is used for transportation. So if we are to cut down on our usage of energy, we must cut down on the use of petrol for cars, diesel for trucks and kerosene for aircraft.

To get from one place to another requires energy. The table lists the amounts of energy needed for various methods of transport. Cycling and walking are by far the most efficient ways of travelling; travelling by car or by plane is very inefficient in terms of energy use.

Energy needed per person per kilometre ($\times 10^6$ joules)	
cycling	39
walking	54
by train	390
by bus	480
by car	1350
by plane	1890

Many people prefer to travel to work or school by car. However, large numbers of cars in cities use huge amounts of petrol and also cause air pollution. For this reason, people are being encouraged to use public transport. For example, you can travel by car or bicycle to the nearest railway station, and then travel into the city by train.

Our present petrol cars are only about 25% efficient. In other words, for every 100 joules of petrol you put in the tank, you get only about 25 joules of kinetic energy (Fig 17). However, there are other ways of powering cars. One of the most likely possibilities so far is the electric car. It is quiet, produces very little pollution, and has an efficiency of about 70%. The electricity for electric cars would probably come from coal, thus cutting down our use of oil.

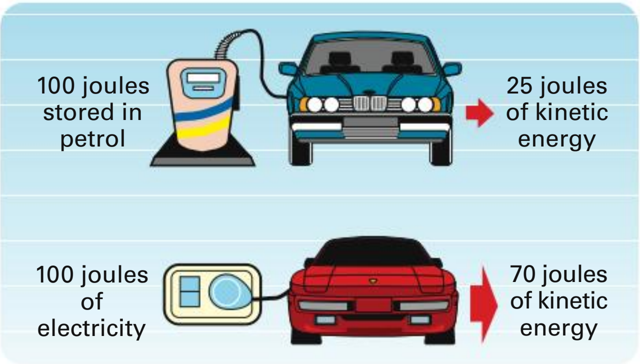


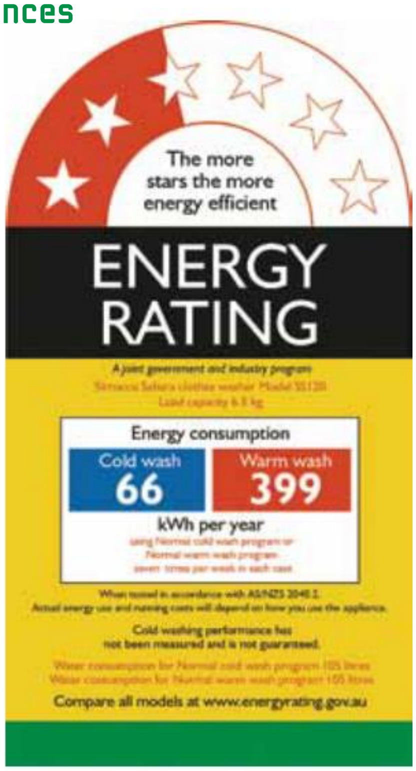
Fig 17 Battery-powered electric cars are more efficient than petrol-powered cars.

At present electric vehicles have a limited range. This means you cannot go far without recharging the batteries. What is needed is a better battery than the present lead storage battery, and much research is being done on this. However, hybrid electric vehicles are already available in Australia; for example, Honda's Civic and Toyota's Prius and Camry. They have a petrol engine *and* an electric motor.

There are things that can be done to conserve petrol. Here are some of them:

- If possible, use a small car.
- Reduce your cruising speed. Reducing speed from 110 km/h to 90 km/h cuts fuel consumption by up to 25%.
- Share a car with a friend.
- Keep the engine properly tuned, e.g. check spark plugs regularly.
- Use good tyres, properly inflated.
- Keep well behind other cars, so that you do not need to brake when they do.

Electrical appliances



In prehistoric times the only energy available to humans came from the stored energy in the food they ate, and from their fires. We now have many electrical appliances to make life easier. Many of these have an energy label, which tells you how efficient they are and how much energy they use.

You could probably do without some electrical appliances. There are also many things you can do to cut down on the energy used by the appliances you do have. Here are some suggestions:

- Turn lights off when you don't need them.
- Use low-energy light bulbs.
- If you have an airconditioner, set the thermostat no higher than 21°C during winter and no lower than 23°C in summer.
- Use the sun to dry your clothes, rather than a clothes drier.
- Switch off the television when nobody is watching it.
- Keep the refrigerator door shut as much as possible.
- Use an extra blanket or doona instead of an electric blanket.
- Use only small amounts of water when cooking.

- Fix dripping hot-water taps quickly.
- Do not iron sheets and other items that do not really need it.

Fig 18 Low-energy light bulbs cost more but use less energy and last longer.

House design

In Australia about 15% of our total energy use is in the home. The amount of energy used for lighting, cooking and appliances is much the same throughout Australia, but the amount used for heating and cooling varies with the climate.

Activity

In a group discuss the suggestions on this page and the previous page for saving energy at home and when travelling.

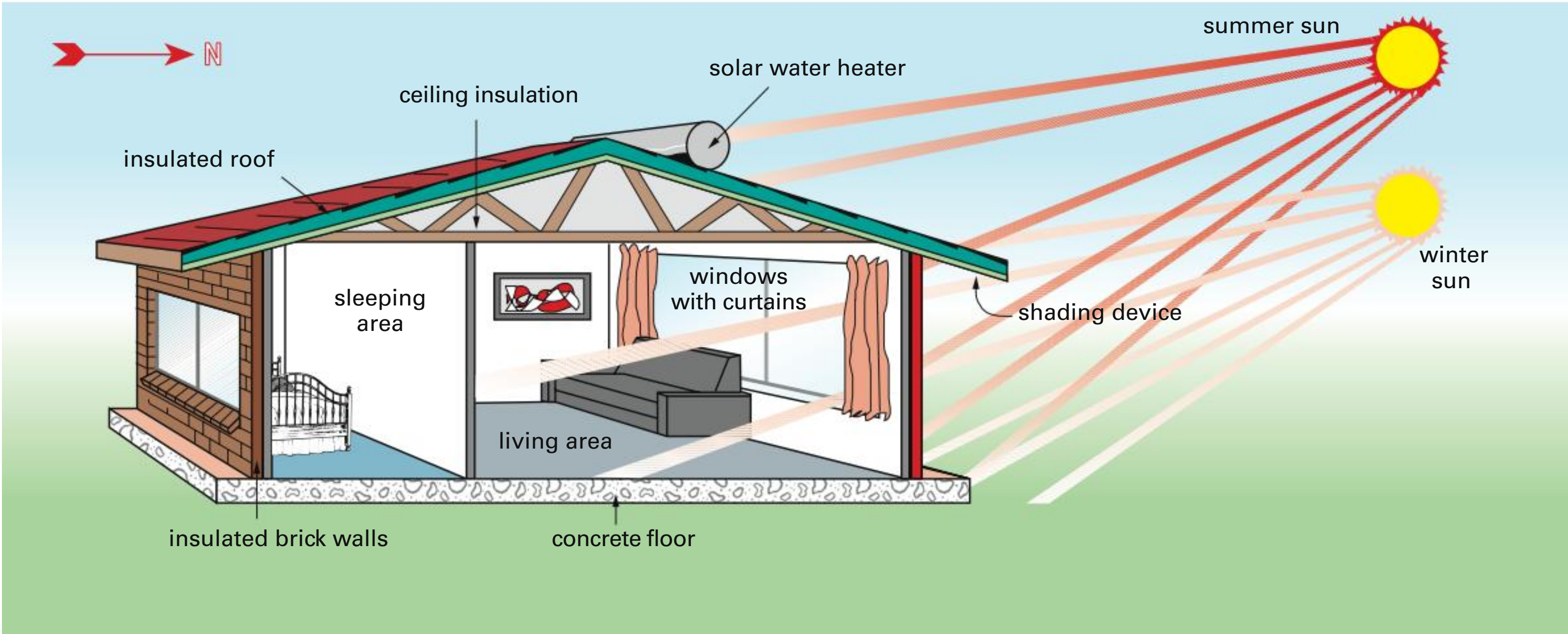
- Which of the things suggested are you already doing?
- Brainstorm other things you could do to save energy.
- What factors might prevent you from implementing some of these energy-saving ideas? (For example, why don't you change to a solar hot water system?)

The energy used in heating and cooling can be reduced by the design of the house and by insulation.

In Australia the sun moves across the northern sky and is lower in winter than in summer. For this reason it is suggested that homes be built with the living areas facing north, so that the sun will warm them in winter, thus reducing heating costs. Shading devices are needed in summer to stop the sunlight from reaching the windows. Deciduous trees planted close to the house also block the heat from the sun in summer.

Insulation in the walls reduces heat loss during winter and heat gain during summer.

Fig 19 A house designed to reduce heating and cooling costs



Experiment 4 A model house

Your task

To design a model house to test the effectiveness of insulation.

Planning and Safety Check

Read through the Method ideas and work out a plan for your experiment. If you are going to do it over 24 hours, you will need a safe place to leave the equipment set up.

Materials

- shoebox or similar box with lid
- scissors
- clear plastic (for windows)
- 2 thermometers or temperature probes and datalogger
- insulation materials, e.g. corrugated cardboard, styrofoam, aluminium foil, woollen cloth

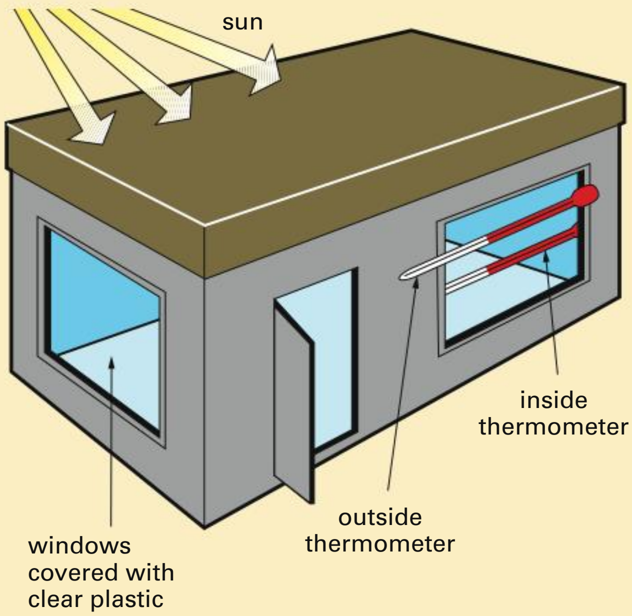
Method ideas

1 Use the shoebox (or other box) to make a model house similar to the one in the diagram. Make sure the house has:
   - a window covered in clear plastic in each wall, and a door
   - a well-fitting roof
   - one thermometer on the outside and one on the inside that can be read without removing the roof.

2 To heat the house, place it in the sun or near an electric heater or high-wattage light bulb.

   How often should you record temperatures?

3 To test the effectiveness of insulation, you will need to do the experiment with and without insulation and compare the results.



Discussion

1 Which are the independent and dependent variables in this experiment? Which variables did you control?

2 Write a brief report on the effectiveness of insulating the model house.

3 Compare your results with those of other groups. Which is the best insulating material?

4 Suggest reasons for any unusual results.

5 Evaluate your experiment and suggest ways of improving it.

Inquiry

You could extend your experiment into a project by investigating some of these questions:

- How quickly does the house cool after the sun sets?
- Does the thickness of the insulation make any difference?
- Do curtains on the windows make any difference?
- What effect does an overhang (eaves) on the roof have?
- What difference does altering the number of windows and their position have?
- Does the type of roofing material make any difference?

The electricity grid

Electricity is a convenient form of energy because it can be transmitted from one place to another, it can be switched on and off, and it can be used as a source of power for many different appliances. In Australia and in most countries, our lifestyle has come to depend on electricity.

Power stations produce this electricity, which is transmitted to our homes and to industry via a vast network of mostly overhead cables called the *electricity grid*. All the power stations in the state are inter-connected, and if there is not enough electricity in one part of the grid it can be obtained from another part. Similarly, excess electricity can be fed into the grid and used elsewhere. Electricity generated from renewable energy sources such as solar, wind and biomass can also be fed into the grid.

Instead of connecting to the electricity grid, it is possible to be self-sufficient in energy, using a system called remote area power supply (RAPS). In a typical RAPS system, electricity is generated by solar cells and a wind generator. There is also a back-up generator and batteries to store electricity.

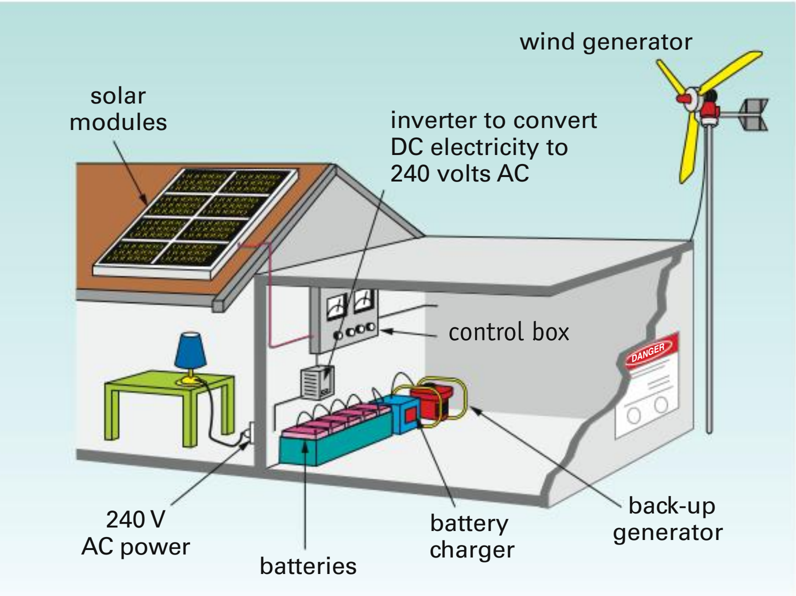


Fig 20 A remote area power supply (RAPS) can be used in towns and cities, as well as in remote areas where it is not possible to be connected to the electricity grid.

Hydrogen—fuel of the future

Take an imaginary journey into the future.

It is the year 2100, in the middle of a busy city. The traffic is remarkably quiet and there are no smelly exhaust fumes. Most of the cars, trucks and buses are using hydrogen fuel and produce little more than harmless water vapour. There are no electric power lines and no chimneys spewing tonnes of harmful gases into the atmosphere. As you move into the industrial area, you notice a row of large storage tanks. These store liquid hydrogen, which is piped into the city and used for transportation, heating, cooling and electricity. You travel to the country and find huge solar panels and wind farms generating electricity to produce the hydrogen.

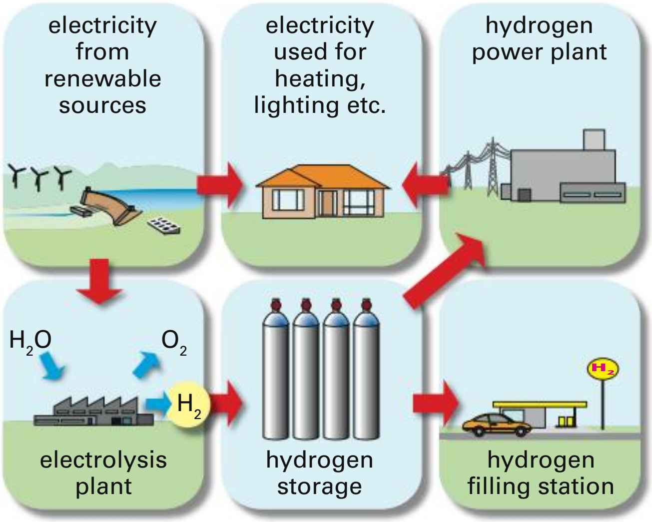


Fig 21 A possible hydrogen energy system—for an animation of this, go to **www.OneStopScience.com.au** and follow the links to **miniHydrogen**.

This science fiction may come true in the future. Most of the technology already exists, but there are many obstacles to be overcome—mainly cost. Hydrogen is an ideal fuel. It can be made from water by **electrolysis** (ee-lek-TROL-e-sis)—passing an electric current through it.

$$2H_2O + \text{energy} \rightarrow 2H_2 + O_2$$

Making hydrogen this way uses up more energy than the gas gives up when it burns in oxygen. However, this problem could be overcome by making the hydrogen using renewable energy sources such as solar cells. Scientists are also experimenting with other ways of making hydrogen. For example, certain photosynthetic microbes produce hydrogen using light energy. The hydrogen can be used directly as a fuel or it can be used to generate electricity using fuel cells.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{energy}$$

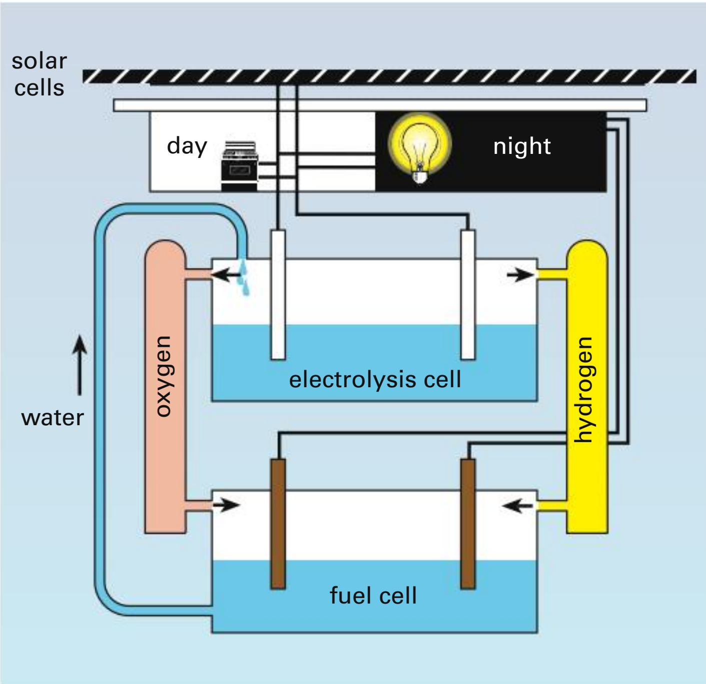


Fig 22 This system overcomes the problem of solar cells only producing electricity during the day. Some of the electricity generated during the day by solar cells is used to electrolyse water into hydrogen and oxygen. At night the hydrogen and oxygen are recombined in a fuel cell to produce electricity.

Two big advantages of hydrogen are that it can store energy and it is easily transportable. It can be liquefied and used as a motor fuel in the same way that LPG is used now. One problem with hydrogen is that it is flammable. This problem can be overcome by using a storage tank containing fine particles of a metal alloy that absorbs hydrogen like a sponge, forming a compound known as a metal hydride. Heating the tank releases the hydrogen gas slowly and safely.

Our energy future

We seem to use energy as though it were unlimited. We buy more and more electrical gadgets; high-rise office blocks are airconditioned all year round, with windows that do not open; city lights blaze all night; we drive to the corner shop instead of walking; and so on. We just seem to take energy for granted. However, our energy reserves are very limited—especially oil, from which we get petrol for our cars. Fossil fuels will one day be exhausted, and alternative energy sources will have to be developed to replace them.

Many alternative sources such as wind and solar are being used to supplement our power needs, and scientists and engineers will no doubt develop new ways of harnessing energy. But *science cannot provide all the answers*. Before we use new energy sources, we must consider any possible environmental problems they might cause. Different sources of energy have different problems, and no energy source is trouble free. We must choose wisely from the alternatives. Energy is a very valuable resource. Without it, we could not live as we do now.

Activity

Electricity from renewable sources such as solar, wind and biomass is at present more expensive than electricity from non-renewable sources such as coal-burning power stations. Most energy supply companies will buy renewable energy if you pay them \$5–\$6 extra per week. This not only conserves our reserves of non-renewable energy but also cuts down on greenhouse gas emissions.

- Suggest why energy from renewable sources is called *green power*.
- Do you think you would pay extra for green power? Explain.
- At present only 10% of people are paying extra for green power. What would need to be done to get more people to switch to green power?

Science as a Human Endeavour

Light up the world

Dave Irvine-Halliday is an electrical engineer at the University of Calgary in Canada. In 1997 he was trekking in Nepal when he saw a sign outside a schoolhouse in a small village inviting people to stop and help teach the children. He went inside and was shocked to find the students working in semi-darkness. His first thought was *Gosh, it's dark in here*, followed by *I wonder if I can help them?*

As Dave travelled back to Canada, he was thinking about the challenge of lighting homes in remote villages around the world. He realised that he would have to come up with a system that was extremely cheap and reliable. He had an important thought—*Why light a whole house, when you only need light in certain areas?* He decided to investigate light-emitting diodes. These were invented in the 1960s and were gradually becoming brighter and more efficient. They could also last for 30 or 40 years. However, because they emitted only coloured light, they were unsuitable for domestic lighting.

After a year trying to develop his own white LEDs, Dave was surfing the web when he found that a Japanese company called Nichia had already solved the problem. When he got hold of one of these new white LEDs, he exclaimed to his assistant *Good God, John. A child could read by the light of a single diode!* So he set up a foundation called 'Light up the World' and began developing a multi-diode lamp to light homes in Nepal. He also developed a simple pedal generator and a small wind turbine to power the lamps. He returned to Nepal in 2000, where he teamed up with another engineer, Stewart Craine, from the University of Melbourne, who had been working with Australian Volunteers International.

Today Dave's lamps can provide limited lighting for a Nepalese village of 60 households for the same amount of energy as a single 100-watt lightbulb in one room of an Australian home. The lamps have also spread to India, Sri Lanka, Africa and South America. A father of five in a Sri Lankan village said, *This is the first time in the lives of my children that they have been able to read at night*.

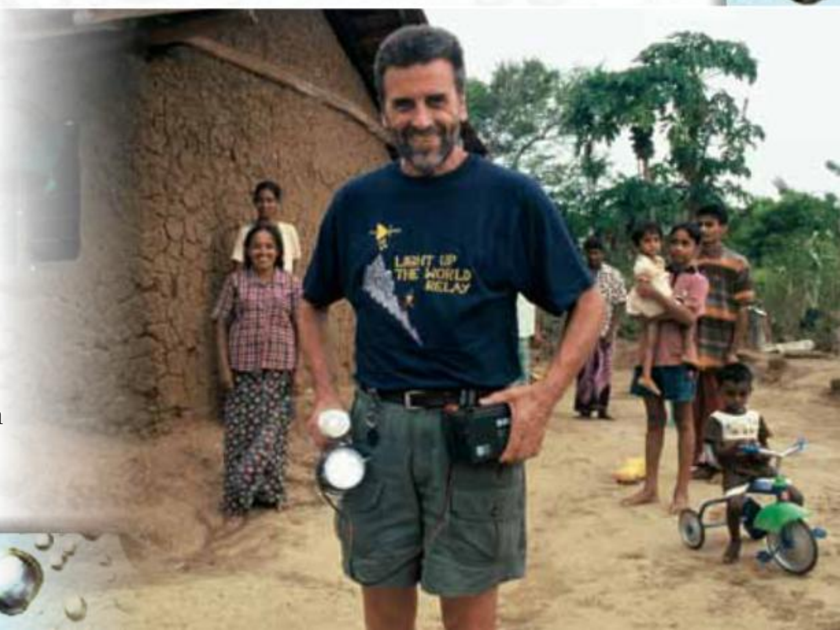
Dave set up a company called Pico Power Nepal in Kathmandu. It manufactures lighting systems and sells them at affordable prices to the villagers. Nepalese households spend half their \$330 annual income on batteries for torches and kerosene for lamps. So with the new lamps, they don't need as much kerosene, and the use of rechargeable batteries means fewer used batteries are thrown away.

For the first five years the Light up the World Foundation was funded entirely by Dave and his wife, but lately people around the world have supported the foundation with donations.

Questions

1. Why can't normal lights be used in Nepalese villages?
2. What was the scientific breakthrough that enabled Dave to fulfil his dream to 'light up the world'?
3. What provided the power for Dave's white LED lamps?
4. In what way is the white LED lamp good for the environment of developing countries like Nepal?
5. What lessons can we, in Australia, learn from this story?

Fig 23 Dave Irvine-Halliday with his lamps, outside a village in Sri Lanka. Photograph kindly used with permission from Rolex Awards/ Xavier Lecoultre.



Check

1 Answer the true–false questions in the Getting started on page 113 again. Have any of your answers changed?

2 How do the following help conserve energy and reduce greenhouse gas emissions?
  a wearing a jumper inside the house on cool nights
  b using lids on pots when cooking vegetables
  c using public transport instead of your own car
  d recycling cans, bottles and paper
  e using only small amounts of water when cooking
  f repairing things that break down instead of replacing them

3 In a group, discuss the advantages and disadvantages of the RAPS system in Fig 20 on page 135.

4 This sign was painted on the side of an experimental vehicle that used an alternative fuel: $2H_2 + O_2 = \text{No Smog}$
  a Suggest what the fuel was.
  b Explain what you think the sign means.

5 Write down a list of electrical appliances that you use that you feel are:
  a essential to your present lifestyle
  b not essential to your present lifestyle.

6 Assuming that each kilowatt-hour of electricity produces about 1.2 kg of carbon dioxide, check your family's electricity bills and determine how much carbon dioxide your family produces each year.

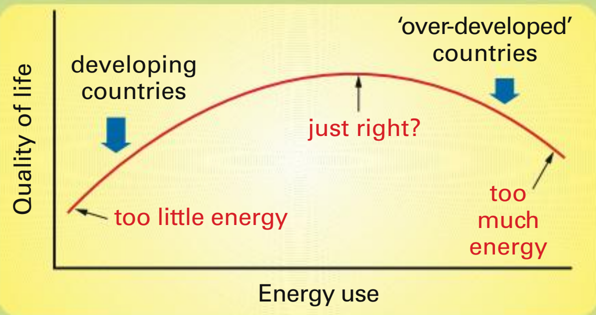
7 Use the internet to research fuel cells and hydrogen cars.

Challenge

1 Use the graph on page 131 to answer these questions.
  a Calculate the proportion that each energy source contributes to the world's present energy use.
  b How are these proportions expected to change by the year 2020?
  c Which energy source would you expect to make up the greatest proportion in the year 2050? Explain your answer.
  d Use the graph to predict when the world reserves of oil will run out.

2 Write a story describing what could happen if we don't manage our energy resources wisely.

3 The graph on the right relates quality of life to the amount of energy used by different countries.
  a What does 'quality of life' on the vertical axis mean?
  b Give an example of a developing country.
  c Would you say that Australia is an 'over-developed' country? Explain.
  d Explain what the graph tells you.



4 You are trying to decide which type of lights to put in your new home. The table gives technical data for three different types of household lights that produce about the same amount of light.

Type of lighting	Unit cost	Lifetime (hours)	Power (watts)
compact fluorescent	$8	6000	15
halogen energy saver	$5	3000	35
LED	$40	30 000	7

If the cost of electricity is 20 cents/kWh, which type of lighting would be the cheapest to run over 8000 hours? (Hint: Take into account the running costs and cost of replacement lights.)

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

accidents
biomass
electricity
greenhouse gas
heat
insulate
non-renewable
oil
public transport
radioactive
renewable

1. Most of our present energy sources (coal, ______ and natural gas) are ______ and will be used up in the near future.
2. Nuclear reactors do not cause air pollution, but have two major problems: the possibility of reactor ______ and the disposal of ______ wastes.
3. Solar energy can be converted to electricity in solar cells and to ______ in solar water heaters and solar power stations.
4. Some ______ sources of energy are solar, hydro-electricity, wind, tides, waves, geothermal and ______.
5. Renewable energy sources will have to be used more widely to keep up with the world demand for energy and to reduce ______ emissions.
6. Some ways in which we can save energy are:
   - use smaller cars or share cars
   - use ______ rather than private cars
   - ______ our homes
   - reduce our use of ______ wherever possible.

Working with technology

Try doing the Chapter 5 crossword at www.OneStopScience.com.au.

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REVIEW

1 Which one of the following is a non-renewable energy source?
A solar energy
B tidal energy
C coal
D wood

2 The main advantage of solar energy over other energy sources is that it:
A is unlimited
B can be converted into heat energy
C can be converted into electrical energy
D can be used only during the day.

3 At a particular place at midday, the power of the sunlight is about 500 W/m^2. This energy can be converted to electricity by using solar cells, which are about 10% efficient.

To run a 1 kW electric motor, the area of solar cells required (square metres) would be:
A 2
B 20
C 50
D 500.

4 Each of the following generates electricity from a source of energy.
a solar cell
b coal-burning power station
c wind generator
d hydro-electric power station
e geothermal power station

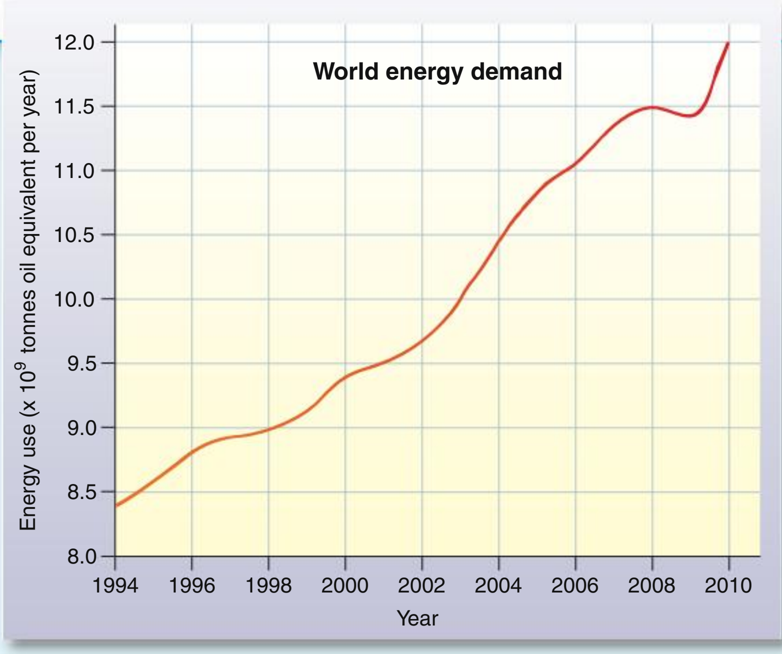
For each generator, select the appropriate source from the following:
- heat energy
- chemical energy
- kinetic energy
- potential energy
- light energy
- nuclear energy

5 The graph on the right shows world usage of energy from 1994 to 2010.

a How much energy was used during 2005?

b In which year did energy use first exceed 10×10^9 tonnes of oil equivalent?

c Why is it difficult to use this graph to predict our energy use in 2015?



6 The Australian government's greenhouse program suggests we try to cut down our use of energy. How would this reduce global warming?

7 The graph below is a forecast of energy supply and demand for Bananaland.

a What is meant by *energy demand*? What is *energy supply*?

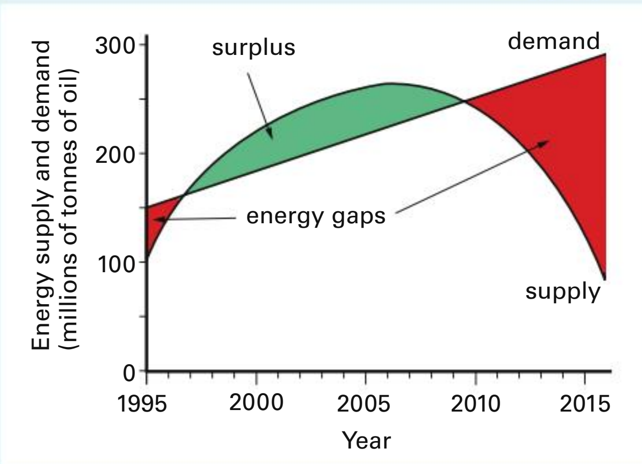
b Suggest how the energy gap on the left of the graph was filled.

c The middle of the graph shows an energy surplus. What is meant by this?

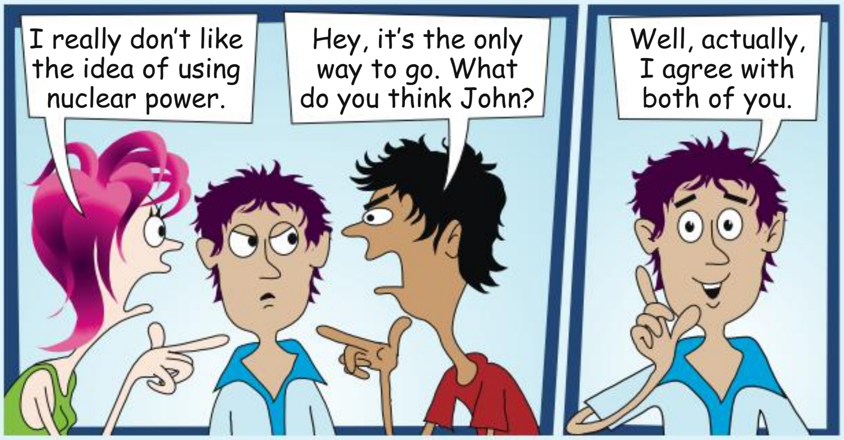
d When does the graph predict the surplus will end?

e How big is the energy gap predicted to be in 2015?

f Suggest at least three ways of filling Bananaland's future energy gap.



8 A nuclear power company placed the cartoon advertisement below in a magazine. What is the advertisement trying to say? Do you agree with it?



9 Why can energy sources such as wind power, geothermal and tidal power contribute only a small amount to our energy needs in the future?

10 Imagine that you are an architect designing a holiday home. The home is to be built in the mountains where you cannot connect to the electricity grid. Describe how you would supply the home with electricity, hot water and heating.

Check your answers on page 305.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

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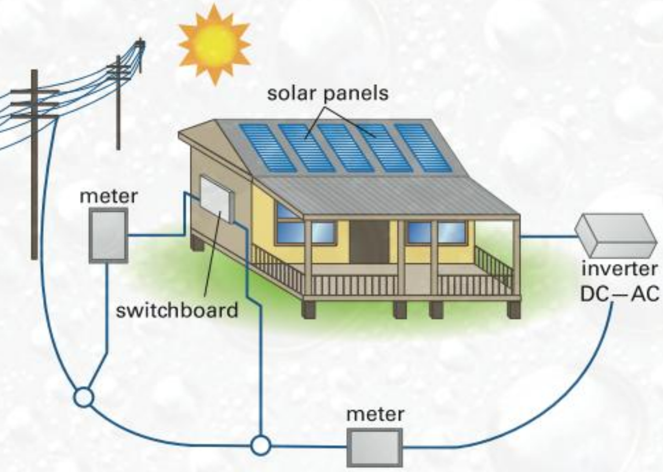
Science as a Human Endeavour

Your own solar power station

You have probably heard on the TV or read in the newspaper about the importance of saving electricity to reduce our use of non-renewable resources, and to reduce our greenhouse gas emissions. Australian companies are selling solar panels like the one shown on page 122. Also, the government is offering rebates to encourage people to install their own solar power stations to make use of the free energy from the sun. But how do these systems work, and are they good for your pocket as well as good for the environment?



The diagram above shows a solar power system for a typical home connected to the electricity grid. The north-facing solar panels on the roof consist of many photovoltaic cells connected in series. They convert light energy from the sun directly into DC electricity. An inverter converts the DC electricity to 240 volts AC—the same type of power currently supplied to homes. The power you generate is measured by a meter. This solar-generated power is either used in the home or sent to the electricity grid if more is produced than needed. Any excess power you send to the grid is credited to you at a rate that is usually higher than what you pay for electricity.

The table at the top of the next column shows the various solar electricity packages offered by a solar power company.

Package (kW)	kWh/day	Cost ($)*
1	5	6050
1.5	8	9587
2	10	13 375
3	15	21 750
4	20	30 625
5	25	39 000

* This includes installation and takes into account the government's solar credits scheme.

How much you save by installing a solar power system will depend on which package you buy, and on how much power you use. Let's assume your power bills for the last year are as follows.

Quarter	Electricity used per day (kWh)	Cost ($)
Jan–Mar	17.9	300
Apr–Jun	16.7	271
July–Sept	12.1	208
Oct–Dec	16.9	277

1 Calculate your average electricity use per day in kWh.
2 What percentage of your average electricity usage could be supplied by a 1 kW solar package?
3 Calculate your total electricity cost for 1 year.
4 How much would you save in a year by using a 1 kW package?
5 At this rate, how many years would it take to pay off the initial cost of the package?
6 How would your calculations be affected if the price of electricity increases (as expected) over the coming years?
7 Which package would supply all your electricity needs?
8 Based on your calculations, do you think it is worth installing your own solar power station on your roof? Justify your answer fully.

6 Space science

In this chapter you will ...

Science Understanding

- use Newton's second law (F = ma) to calculate the force of gravity on an object
- apply Newton's third law (action and reaction) to describe the operation of rockets
- identify the forces acting on an object in orbit

Science as a Human Endeavour

- gain an understanding of the problems of living in space

Science Inquiry Skills

- use internet research to find out the latest on a replacement for the space shuttle
- design an experiment to be carried out on the International Space Station

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Form a group of three or four people and discuss the questions below.

1. You are standing in a lift on a set of scales. The scales read 50 kg. Suddenly the lift moves upwards. What happens to the reading on the scales? Why?
2. You tie an object to a piece of string and whirl it around your head. You then let the string go. In which direction will the object travel? Draw diagrams to help your explanation.
3. You drop two objects at the same time from a very high cliff. They are the same size but one is five times as heavy as the other. Which reaches the ground first?
4. You are on a space walk alongside the space shuttle's cargo bay 400 km above the Earth. You let go of the handrail. Will you fall back to Earth? Explain.

6.1 Getting into space

How high can you jump vertically when you stand on the ground with your feet together? Fifty centimetres? The reason why you cannot jump any higher is because the force of gravity attracts you to the Earth. To get into space you have to overcome this force. To do this, rocket engines have to supply a force greater than the downwards force of gravity. When the engines in a rocket ignite, the force generated by the engines accelerates the rocket upwards.

Science as a Human Endeavour

The first rocketeers

The Chinese are credited with the invention of rockets, which were used in warfare and in religious ceremonies. The rockets were made of bamboo tubes filled with gunpowder. In warfare they were attached to arrows, and in ceremonies they were attached to bamboo sticks to help them steer a straight course.

The legend of Wan-hu

Legend has it that Wan-hu, a lowly government official in the Ming Dynasty (early 16th century), was intrigued with rocketry, and he thought rockets could be used for transportation. Wan-hu was also a keen astronomer and dreamed that rockets could take him to the stars.

He built a special chair with 47 rockets and two kites attached to it. At the appointed time, Wan-hu sat in the chair and gave the order for his assistants to light the fuses. Moments later there was a massive explosion. When the smoke and dust cleared, Wan-hu and the rocket chair were gone. The world's first want-to-be astronaut was gone.

Busting the myth of Wan-hu

The *Mythbusters* television team decided to try to recreate the Wan-hu rocket chair using the same sort of materials available to Wan-hu. They used a crash test dummy instead of a human.

The chair exploded on the launch pad and the dummy suffered severe burns. The team then tried modern rockets, but the chair only rose a few metres before going out of control and crashing. The team concluded that rockets cannot supply enough force to lift a rocket chair very far away from the Earth's surface.

WEBwatch

Go to www.**OneStopScience.com.au** and follow the links to the websites below.

Brief history of rockets

An interesting, easy-to-read account of the history of rocketry from early times to the present

Chinese fire-arrows

The story of Wan-hu, and links to the history of rocketry and other sites

The History of Rocket Science

Detailed information on the history of the science of rockets and rocket design

OneStopScience

Force, mass and acceleration

When the engines in a rocket ignite, the force generated by the engines accelerates the rocket upwards. How quickly a rocket lifts off depends on the mass of the rocket and the force generated by its engines.

In Chapter 2 you learnt that the acceleration of an object is directly proportional to the force acting on it and inversely proportional to its mass. That is:

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$

$$a = \frac{F}{m}$$

$$\text{or} \quad F = ma$$

For example, the upwards force produced by a rocket of mass 10 000 kg being accelerated at 10 m/s^2 is:

$$\begin{aligned} F &= ma \\ &= 10\,000 \text{ kg} \times 10 \text{ m/s}^2 \\ &= 100\,000 \text{ N} \end{aligned}$$

Fig 1 The force generated by a rocket's engines accelerates the rocket upwards.

Weight is a force

If you hang an object on a spring balance, the spring stretches. This shows that there is a downwards force. If a larger mass is hung on the balance, the spring stretches further, showing that the force is greater. F = ma can be rewritten as:

$$W = mg$$

where **W** is the weight force and **g** is the acceleration due to gravity

Acceleration due to gravity

When you hang a 1 kg block on a Newton spring balance, the dial reads 9.8 N. This means the weight of the 1 kg block is 9.8 N. If the block is unhooked from the spring balance, it will fall to the ground. The acceleration of the block is:

$$\begin{aligned} g &= \frac{W}{m} \\ &= \frac{9.8 \text{ N}}{1 \text{ kg}} \\ &= 9.8 \text{ m/s}^2 \end{aligned}$$

So the acceleration due to gravity at the Earth's surface is 9.8 m/s^2.

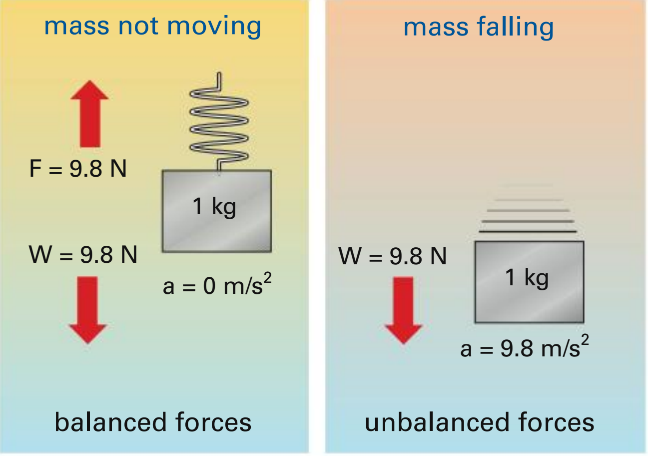


Fig 2 When the mass is hooked on the spring, the forces are balanced (in equilibrium) and there is no motion. When it is unhooked, it falls with an acceleration of 9.8 m/s^2.

What happens if a 2 kg block falls to the ground? When the block is attached to the spring balance, it reads 19.6 N. If the block is unhooked from the balance, the acceleration of the 2 kg block is:

$$g = \frac{19.6\ \text{N}}{2\ \text{kg}}$$
$$= 9.8\ \text{m/s}^2$$

The heavier block still falls with the same acceleration as the lighter one. In general, the acceleration due to gravity is the same for all objects on the Earth's surface. Why then does a tennis ball fall faster than a piece of paper? Falling objects are slowed down by friction due to the air around the Earth, and the amount an object is slowed down depends on its shape. So in real life, different objects do not all fall with the same acceleration.

The acceleration due to gravity is not the same everywhere. It decreases as you move away from the Earth. So when the force of gravity decreases, the acceleration also decreases. This means that if you travel away from the Earth, your weight will decrease. The table below shows how gravity and weight decrease with increasing distance from Earth for a 50 kg person.

Location of 50 kg person	Acceleration (m/s^2)	Weight (N)
On the Earth's surface	9.8	490
100 km above Earth	9.6	480
500 km above Earth	8.3	415
1000 km above Earth	6.8	340

The force of gravity also depends on the mass of the planet or moon. You can investigate the differences in the acceleration due to gravity on different planets in the activity below.

Activity

Suppose you are standing on the surface of planet X and you are curious to find out how the weights of various masses differ from those on Earth.

The table below shows the results for planet X.

Mass (kg)	Weight (N)
2	39.2
4	78.4
6	117.6
8	156.8

- Use the formula W = mg to find the acceleration due to gravity on planet X.
- Suppose you took the four masses in the table back to Earth. Find the weights of the masses on the Earth's surface.
- The acceleration due to gravity on Jupiter is 25.5 m/s^2. Calculate the weights of the 2, 4, 6 and 8 kg masses in the table.
- Write a generalisation about the relationship between weight and gravity.
- If the force of gravity is directly proportional to the mass of the planet, work out which planet (X, Jupiter or Earth) has the smallest mass and which has the greatest.
- How much would you weigh on planet X? How much would you weigh on Jupiter?

Rocket science

The cartoon below illustrates Newton's third law of motion.

When the man fires the gun, the bullets go in one direction and the gun moves in the opposite direction. Newton's third law of motion states:

For every force there is an equal and opposite force.

The two forces in this law are often called the *action* force and the *reaction* force. You can investigate these forces in the activity below.

The action–reaction principle is used in rockets. Rockets shoot out hot exhaust gases from their engines. The force of the exhaust gases shooting out (the action) pushes the rocket forwards (the reaction). This is why rockets are sometimes called *reaction engines*. And the faster the hot exhaust shoots out, the faster the rocket moves in the opposite direction.

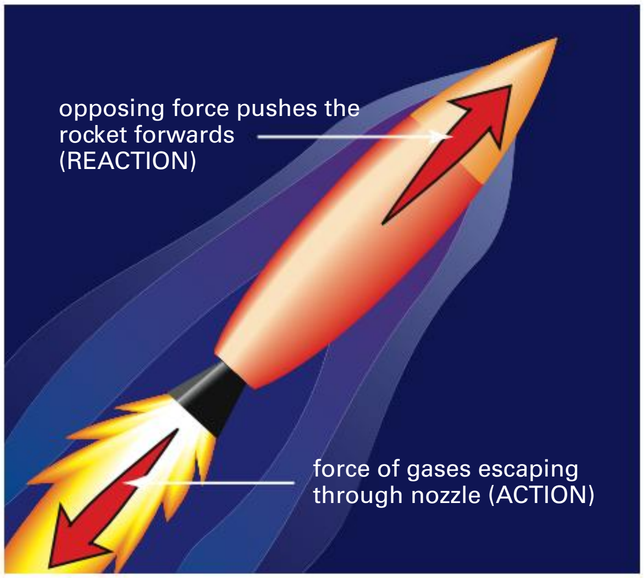


Fig 3 A rocket works on the principle of action and reaction.

All aircraft use the action–reaction principle. The blades on propeller-driven aircraft spin rapidly and push the air backwards (action), thus pushing the aircraft forwards (reaction). The engines on jet aircraft take in air at the front. This is mixed with jet fuel, ignited, and then the hot exhaust gases are forced out of the back of the engine. This pushes the aircraft forwards.

Activity

For this activity you need a heavy ball (medicine ball) and a skateboard or skates.

1 Stand on the skateboard facing the front and hold the medicine ball at chest level.

2 Throw the ball horizontally to another person without bending your legs or pushing the skateboard.
- Describe what happens.
- In what way is this similar to the gun cartoon above?
- Which is the action force and which is the reaction force?

3 Find out what happens when you throw the ball harder.
- Interpret your results.

Experiment 5 Model rockets

Planning and Safety Check

- Carefully read through Part A and Part B. Work in a small group to design the tests for both types of rockets.
- Make a list of the equipment you will need for each part of the experiment.
- Design and draw up data tables for your results.
- Discuss the safety precautions necessary in this experiment. Draw up a risk assessment sheet listing all the safety hazards and the precautions you will need to take.

PART A Balloon rockets

The task

Your task is to design an efficient balloon rocket that will be propelled along a length of nylon fishing line. The efficiency of the rocket will be tested in two ways:

- how far the rocket goes along the nylon fishing line
- how fast the rocket goes in the first 5 metres.

You are to use simple materials in your test—balloons, drinking straws, adhesive tape and nylon fishing line.

Discussion

1 Compile class results of the two tests.

2 Which design features are important in making a balloon rocket?

3 What caused the motion of the rocket?

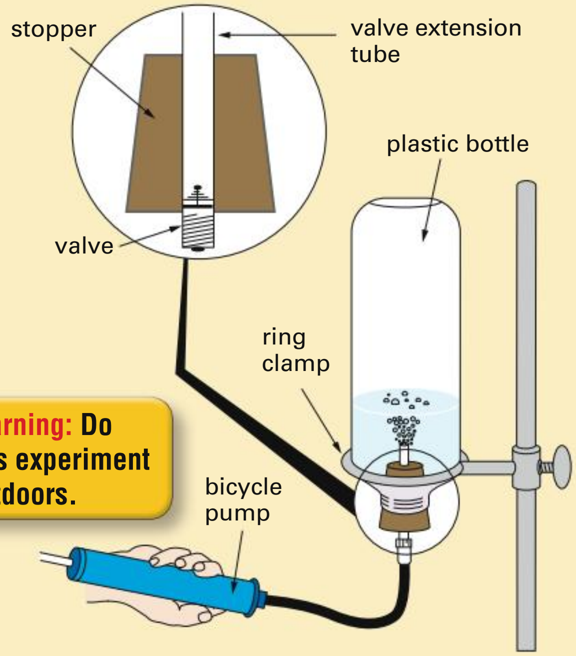
4 How well would your rocket go in space? Explain.

5 How would you design your rocket to test whether altering the size of the jet (where the air comes out of the balloon) has an effect on the speed of the rocket? Try it!

PART B Water rockets

In this part of the experiment, your task is to find out which variables affect the motion of a water rocket.

Use the diagram below to build a water rocket. Your teacher will help you fit a car valve extension tube through a rubber stopper. (You can also purchase commercial water rockets.)



Warning: Do this experiment outdoors.

Experiment with the water rocket to find out how the following variables affect its motion:

- the amount of water in the bottle
- the size and shape of the container.

Discussion

1 Write a report of your findings.

2 Explain in detail what caused the motion of the water rocket. In which ways is this similar to the motion of the balloon rocket? In which ways is it different?

3 Is water necessary for the operation of the water rocket? Test your prediction.

Rocket motion

In Part A of Experiment 5 the balloon rocket moved forwards (the reaction force) because air was forced out of the balloon in the opposite direction (the action force). The water rocket in Part B shot upwards (the reaction force) because the compressed air in the bottle forced water out of the mouth in the other direction (the action force).

In a space rocket, the fuel burns in a combustion chamber. The burning fuel produces hot gases, which are forced out of the nozzle at great speed. The force of the escaping gases produces an equal and opposite reaction, which pushes the rocket upwards. This force is called the **thrust**. Applying Newton's second law of motion (F = ma), the thrust of a rocket is equal to the mass of the escaping gases multiplied by the acceleration of the gases.

The net force accelerating the rocket from its launch pad is the thrust minus the weight of the rocket.

net force = thrust of engines − weight

For example, a 2 000 000 kg rocket has engines that develop a thrust of 69 600 000 N. What is the acceleration of the rocket at lift-off?

Weight of rocket $= 2\,000\,000 \text{ kg} \times 9.8 \text{ m/s}^2$
$= 19\,600\,000 \text{ N}$

Thrust of engines $= 69\,600\,000 \text{ N}$

Net force = thrust − weight of rocket
$= 69\,600\,000 - 19\,600\,000 \text{ N}$
$= 50\,000\,000 \text{ N}$

$$\text{acceleration} = \frac{\text{net force}}{\text{mass of rocket}}$$

$$= \frac{50\,000\,000 \text{ N}}{2\,000\,000 \text{ kg}}$$

$$= 25 \text{ m/s}^2$$

Space engineers design engines that develop as much thrust as possible, while at the same time they try to reduce the weight of the rocket.

Rocket engines

All rocket engines work on the same principle: they burn fuel to produce fast-moving exhaust gases that push the rocket forwards.

As well as the fuel, space rockets have to carry a source of oxygen because there is no air in space in which to burn the fuel. There are two types of rocket engine—the *solid-fuel engine* and the *liquid-fuel engine*.

The solid-fuel engine uses a solid fuel mixed with an *oxidiser* much like a fireworks skyrocket. A spark ignites the mixture and the explosive reaction produces gases that are forced out of the engine's nozzle. The solid-fuel engine is very simple in construction and very powerful for its weight, and is used mainly in booster rockets to lift heavy payloads into space. However, like the skyrocket, it suffers one major disadvantage—once ignited it cannot be extinguished until the fuel has been used up.

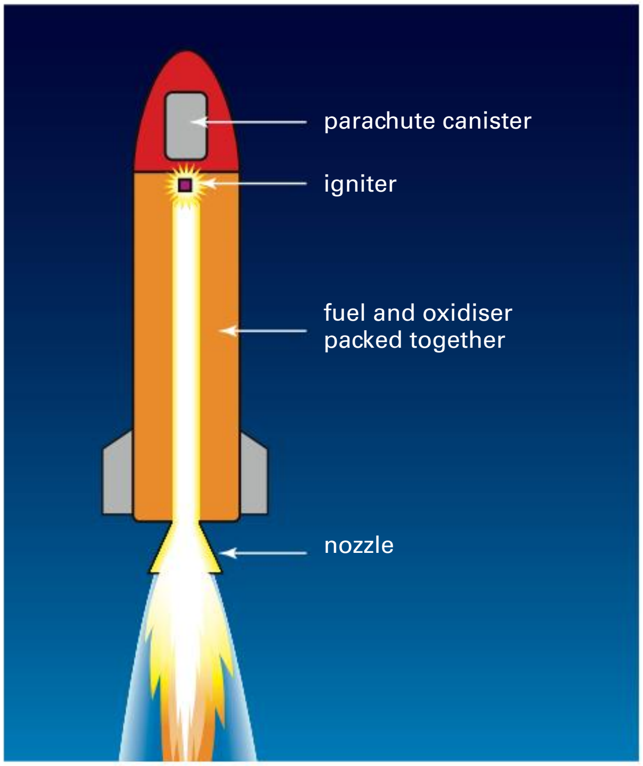


Fig 4 A solid-fuel rocket engine has solid fuel and oxidiser packed together. When ignited, the fuel burns, sending high-speed gases out through the nozzle. The parachute enables the rocket to be recovered for re-use.

The liquid-fuel engine needs complicated pipework and pumps to force the liquid hydrogen fuel and the oxidiser (liquid oxygen) into the combustion chamber. Here they are ignited and burn explosively. The advantage of this type of engine is that it can be throttled back, or turned on and off, to control the rocket's speed.

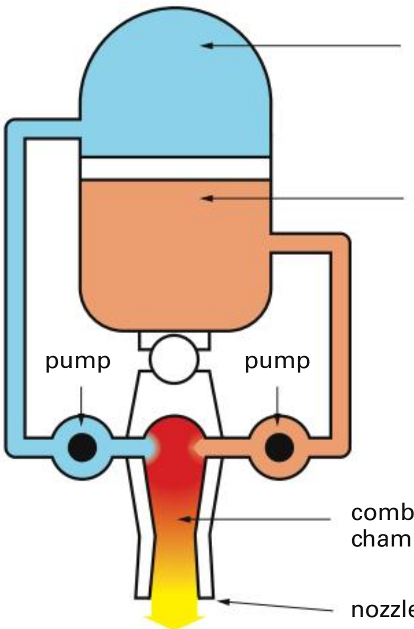


Fig 5 A liquid-fuel rocket engine. This engine is more complicated and expensive to build than the solid-fuel engine, but its thrust can be controlled.

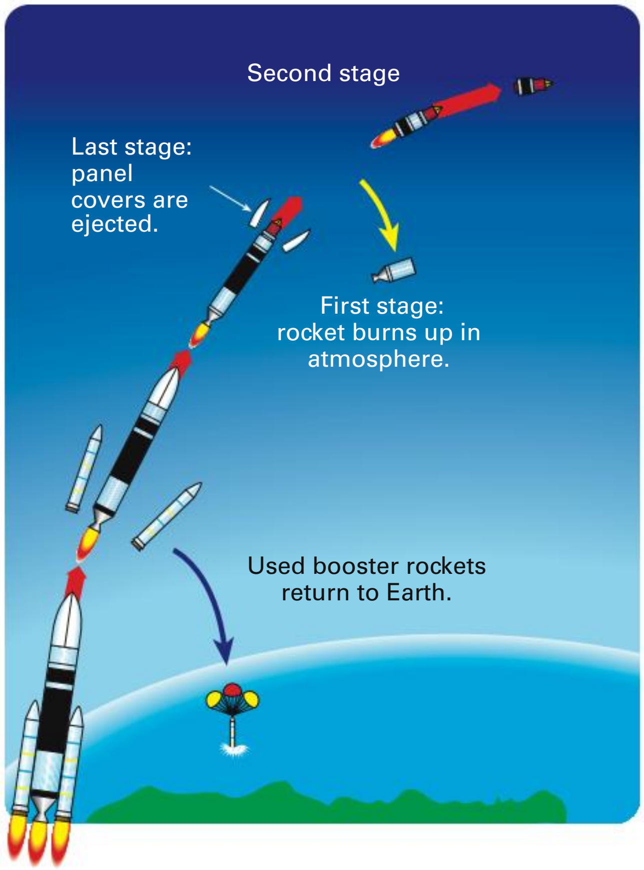


Fig 6 Sections of a multistage rocket detach and fall away after use. This helps to keep the mass of the rocket as small as possible while gaining maximum acceleration.

Rocket designs

Since gravity is greatest at the Earth's surface, the most powerful engines in a rocket have to be used at lift-off. Space rockets usually use two to four solid-fuel booster engines alongside the main liquid-fuel engine. However, two minutes after lift-off the solid-fuel boosters have used up all their fuel. To reduce the mass of the rocket, engineers design parts of the rocket to fall away when they are no longer needed. Most rockets have this design and are called multistage rockets.

About 10 minutes after lift-off, the main rocket engines also run out of fuel. This first stage, which is the largest part, then detaches and burns up in the atmosphere as it falls to Earth. Engines in the second stage then ignite and carry the rocket further into space.

Check

1. a You simultaneously drop a 2 kg rock and a 10 kg rock from a high cliff. Why should they hit the ground at the same time?
   b You then drop a piece of paper and a small pebble from the cliff at the same time. Will they hit the ground at the same time? Explain.
2. How does Newton's third law of motion explain how a rocket moves?
3. A bag of sand is attached to a spring balance. The dial reads 147 N. What is the mass of the bag of sand?

4 Look at question 1 in the Getting started section.
   a What is the mass of the person?
   b How much does this person weigh?
   c Suggest why weighing scales are graduated in kilograms rather than newtons.
   d Why does the reading on the scales increase when the lift moves upwards?

5 Unlike jet aircraft, space rockets carry a source of oxygen as well as fuel. Explain why.

6 You tell a group of 8-year-old students that you lose weight when you go into space.
   a Suggest how the students might interpret this statement.
   b Write down your explanation of the statement.

7 Look at the photo of the helicopter.
   a Explain in terms of action–reaction how the helicopter can rise vertically from the ground.
   b How does the helicopter move forwards?

8 a Explain the difference between a solid-fuel rocket engine and a liquid-fuel engine.
   b The last stage of a multistage rocket contains a small liquid-fuel engine. Why is the engine small, and why does it use liquid fuel and not a solid fuel?

9 In this chapter and Chapter 2 you have learnt Newton's three laws of motion. In your own words write down these three laws. Check pages 44, 49 and 147.

Challenge

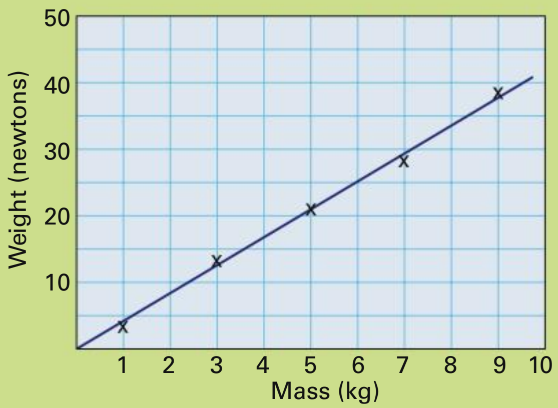
1 A man has a mass of 85 kg. Use the table on page 146 to calculate his weight:
   a on Earth
   b 1000 km above the Earth.

2 The rockets that carried the Apollo missions into space had a thrust-to-weight ratio of 12:1.
   a What does this statement mean?
   b Suggest what would happen to the acceleration of the rocket if the thrust-to-weight ratio was larger.

3 A lunar lander of mass 3000 kg lands on the moon's surface. When they are ready for lift-off, the astronauts fire the lander's rockets, which develop a thrust of 15 300 N. If $g = 1.6\ \text{m/s}^2$ on the moon, calculate the acceleration with which the lander leaves the moon's surface.

4 The space shuttle and the booster rockets pictured on page 144 have a combined mass of 2 200 000 kg. The acceleration on lift-off is maintained at 2.5 g for 50 seconds (g = acceleration due to gravity on Earth).
   a Calculate the net upwards force on the shuttle at lift-off.
   b Find the thrust developed by the engines.

5 The graph below shows a plot of weight versus mass for a number of objects. Use the graph to work out whether the readings were taken on the Moon ($g = 1.6\ \text{m/s}^2$), on Mercury ($g = 4.1\ \text{m/s}^2$) or on Saturn ($g = 10.8\ \text{m/s}^2$). Explain how you arrived at your answer.



6 Leon stands in a lift and hangs a 5 kg bag of potatoes on a spring balance. The dial reads 42.5 N. Describe the motion of the lift. As a challenge, calculate the acceleration of the lift.

6.2 Orbiting the Earth

If you look at the moon on successive nights, you will see that its position in the sky changes. This is because of the Earth's rotation, and also because the moon revolves around the Earth in its orbit. An **orbit** is a path taken by an object as it moves around another object.

Satellites

Objects that orbit planets are called **satellites**. The moon is Earth's natural satellite. The first artificial satellite to orbit the Earth, called *Sputnik 1*, was launched in October 1957 by the then Soviet Union. Since then, more than 4000 artificial satellites have been launched into orbit. Hundreds of communications satellites relay radio and television information between the continents on Earth 24 hours a day.

Fig 7 *Sputnik 1* was the Earth's first artificial satellite. It was relatively small with a mass of 84 kg and a diameter of 53 cm. Its four aerials beamed back information about the temperature and density of the upper atmosphere.

Investigation 9 Orbits

Aim

To use a model to show the forces acting on a body in orbit.

Materials

- 1.5 m length of nylon fishing line
- plastic tubing (about 15 cm long),
- rubber stopper with a hole in it
- brass hanger and some brass masses

Planning and Safety Check

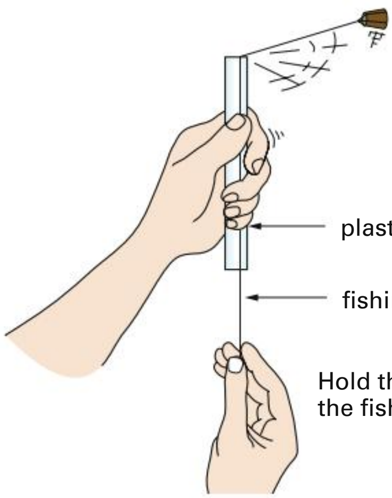
- Carefully read through the investigation. Then tell your partner what you have to do, what you have to record and what safety precautions you have to take.
- It is best to do this investigation outdoors.

Method

1 Tie the rubber stopper to the end of the fishing line. Thread the other end of the fishing line through the plastic tube.

2 Hold the end of the fishing line below the tube and whirl the stopper around in a circle as shown in the diagram below. Now let the fishing line go.

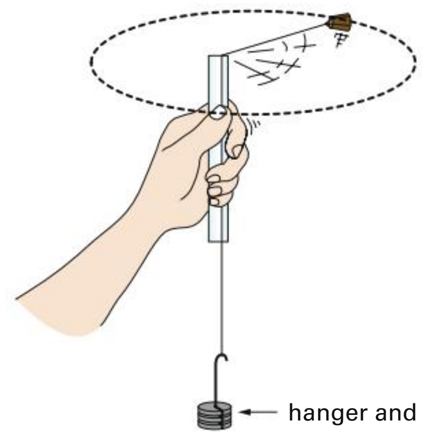
In which direction did the stopper travel? Draw a sketch to show this.



3 Thread the fishing line through the tubing again. Then tie the brass hanger to the free end.

4 Add some masses to the hanger and whirl the stopper so that it orbits at a constant distance and the masses do not move up or down. This may take a little practice.

Record the radius of the orbit.



5 Now speed up the orbiting stopper.

Record what happens to the masses.

6 Add masses to the hanger so that the stopper orbits at the same radius orbit as in Step 4.

7 What will happen if you decrease the speed of the orbiting stopper? Test your prediction.

Discussion

1 Why did the stopper fly off when you let the string go in Step 2?

2 What happens to the rotating stopper when its speed increases? How could you keep it rotating at the same radius of orbit?

3 What keeps a spacecraft in a circular path when it is in orbit?

In the investigation you just did, you should have concluded that the revolving stopper is being pulled towards the centre of the circle by the force along the fishing line. This force keeps changing the *direction* of the stopper's motion. And if this force disappears, the stopper flies off in a straight line. The stopper is not pulled in towards the tubing, because it has sufficient orbital speed (inertia) to keep it in 'orbit'.

In the same way, the gravitational force pulls an orbiting satellite towards the centre of the Earth. The satellite does not fall to Earth, because it has sufficient speed to stay in orbit.

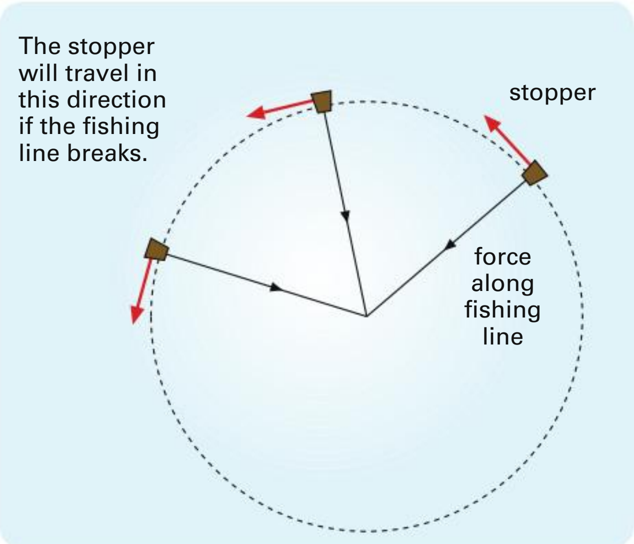


Fig 8 The inwards pulling force along the fishing line constantly changes the direction of the stopper's motion.

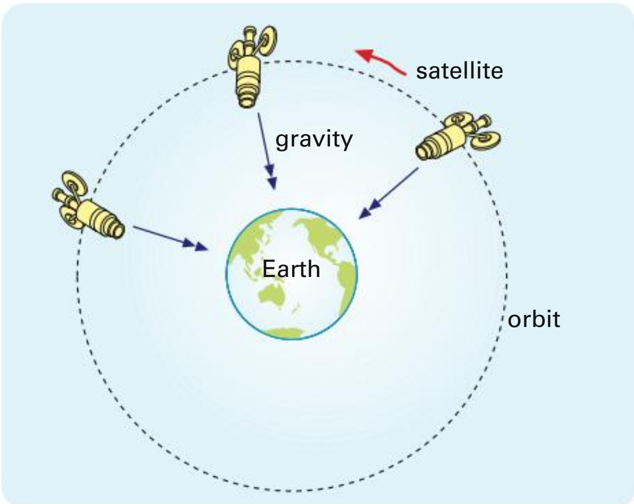


Fig 9 The satellite is being pulled towards Earth by the force of gravity, but its motion (inertia) keeps it in orbit.

Types of orbits

You found out earlier that the Earth's gravity is strongest at the surface and decreases with altitude. (In outer space gravity is zero.) This means that satellites in a low Earth orbit will experience a stronger gravitational pull than satellites in higher orbits. To overcome this problem, satellites in low Earth orbits have to have a greater orbital speed, otherwise they fall back to Earth. In general, the higher the altitude of the satellite, the slower its orbital speed.

Low Earth Orbits

Low Earth Orbits (called LEOs) are usually at altitudes of about 400 km. At this height, 99.9% of the Earth's atmosphere is beneath it, so satellites avoid the problem of friction with the Earth's atmosphere. LEO satellites move at high speeds of about 8000 m/s, and include the Earth-monitoring and 'spy' satellites. Because of their low altitude, LEO satellites can take very clear pictures of objects as small as 3 m across on the Earth's surface. They usually have a much shorter life than other satellites because even the tiny amounts of gases in the upper atmosphere gradually slow them down. As the satellite's speed decreases, it loses altitude and eventually falls to Earth where it burns up in the more dense atmosphere.

LEO satellites can be linked to form information networks in space. For example, 24 LEO satellites have been placed above the Earth to form the Global Positioning System (GPS). Sailors, airline pilots or even motorists driving along central Australian outback roads can find their position on the Earth's surface using a small portable receiver.

Even though LEO satellites have a much shorter life than high altitude ones, placing satellites in the lower orbit is much cheaper. This is because large, powerful and very expensive rockets are needed to launch the high altitude satellites. Sometimes the high altitude satellites are 'parked' in low orbit, before they are boosted into higher more useful altitudes.

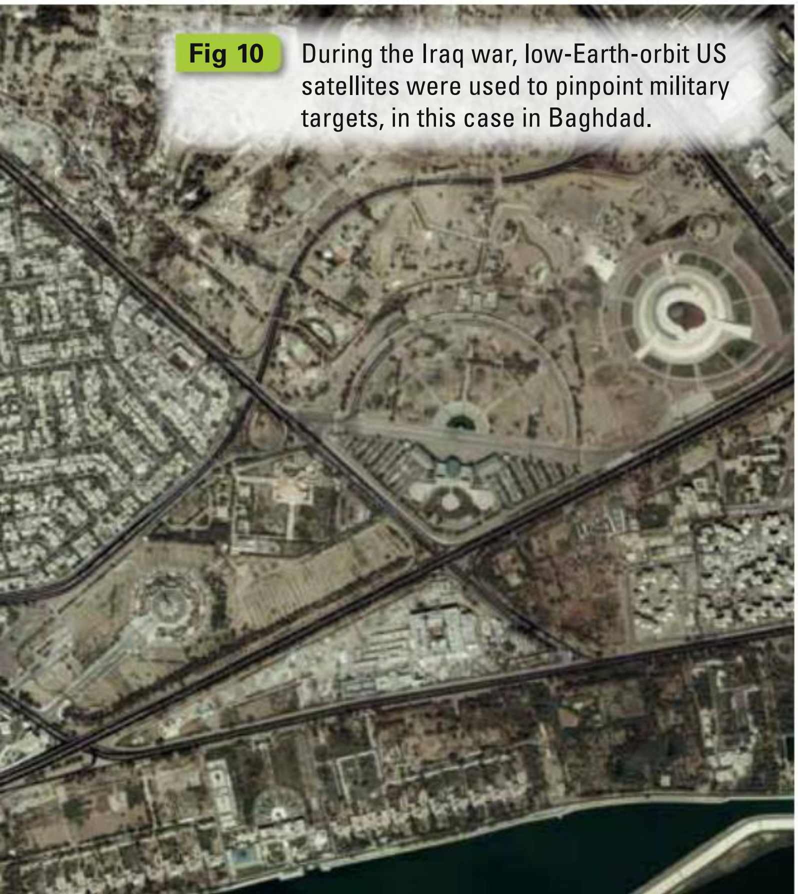


Fig 10 During the Iraq war, low-Earth-orbit US satellites were used to pinpoint military targets, in this case in Baghdad.

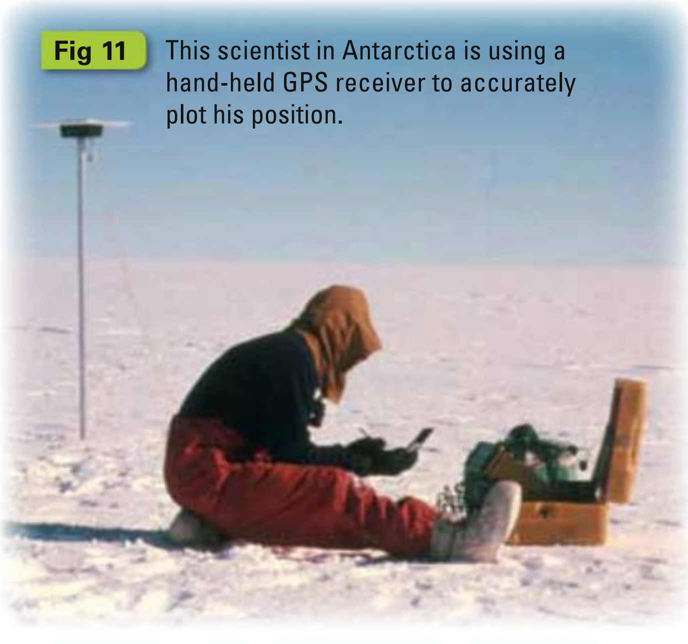


Fig 11 This scientist in Antarctica is using a hand-held GPS receiver to accurately plot his position.

Polar orbiting satellites

Polar orbits are special low Earth orbits that carry satellites in a circle over the North Pole and South Pole. These high-speed satellites complete about 14 revolutions of the planet every 24 hours. As the satellite revolves from pole to pole, the Earth rotates beneath it. In this way, the satellite 'sees' every part of the Earth's surface at relatively close range.

Geostationary orbits

A satellite placed in orbit 36 000 km above the Earth's equator takes exactly one day to complete an orbit. During this time, the Earth also turns once on its axis. This means that the satellite remains over the same point on the Earth's surface. Orbits at this altitude are called **geostationary orbits**, or sometimes geosynchronous orbits. Satellites in this orbit travel at about 3200 m/s, less than half the speed of the LEO satellites.

Geostationary satellites are used to beam everything from commercial radio and television broadcasts to navigational and weather information. However, there are so many satellites in this orbit that its use is now governed by international regulations.

Aussat and Intelsat satellites relay TV channels to subscribers all over Australia. To receive these broadcasts, subscribers have a satellite dish pointing towards a geostationary satellite above the equator.

Fig 12 A satellite dish on this school is used to receive TV channels from geostationary satellites.

The weather information that is continuously beamed down to Australian weather forecasters comes from one of five geostationary satellites that form a network around the equator. The MTSAT Japan satellite is positioned over the equator to the north of Papua New Guinea. This satellite sends information and pictures to forecasters who then send them on to radio and TV stations as well as newspapers.

Fig 13 An image from the MTSAT Japan geostationary satellite positioned in orbit to the north of Australia

WEBwatch

1 Weather satellites

You might like to look at some images from weather satellites. Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Australian Region Satellite Images

The latest satellite images from the Bureau of Meteorology website

Observing the Earth

European Space Agency satellite images of various parts of the Earth's surface

2 Google Earth

Would you like to see a satellite's view of your neighbourhood, or even a close-up of your house? Go to **www.OneStopScience.com.au** and follow the links to **Google Earth.**

You can use this link to download the Google Earth application onto your computer. Then you can scan almost everywhere in the world and zoom in to see details of cities, mountains, lakes and oceans.

OneStopScience

Activity

In 2011 the ageing space shuttle was retired. So what will replace it, and how will astronauts get to the International Space Station and beyond? Apart from the existing Russian *Soyuz* spacecraft, there were three other spacecraft under development in 2011. Your task is to decide which of these three spacecraft, or an alternative, is most likely to replace the space shuttle. Space technology is changing rapidly so you will need to search the internet for the latest development.

1 *Orion*
The *Orion* spacecraft is being developed by Locheed Martin for NASA. It isn't a winged vehicle like the space shuttle, but is a much smaller capsule like the *Apollo* spacecraft. It has a service module for a crew of four, and uses parachutes to land in the sea. The drawing shows *Orion* approaching the International Space Station.

2 *Dream Chaser*
The *Dream Chaser* is being developed by the Sierra Nevada Corporation. It is similar to the space shuttle, but much smaller. It can carry seven astronauts. It is launched on top of an *Atlas V* rocket (see drawing) and can land on a normal runway.

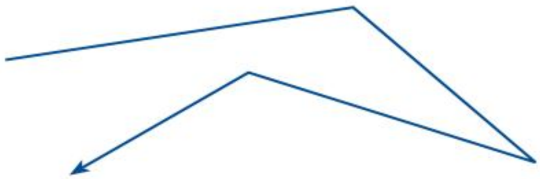
3 *Skylon*
The *Skylon* is being developed by the British company Reaction Engines Limited. It is bigger than the space shuttle and can carry up to 30 astronauts or space tourists. It works like an ordinary jet engine, burning hydrogen or liquid oxygen. It is totally re-usable and can take off and land on a normal runway.

Check

1 Explain in your own words what the words *revolve* and *orbit* mean.

2 a A force can change the speed of an object. What is the other thing a force can do?

b Leon sketched the path taken by a ball rolling over a smooth horizontal surface. The ball started from rest and was struck four times during its movement. Copy the path in your notebook and show, using arrows, the direction of the forces acting on the ball.



3 Mariela whirls a tennis ball attached to a string around her head in a horizontal circle.
  a Explain in terms of force why the tennis ball moves in a circle.
  b What would happen to the ball if the string broke?

4 What is a geostationary satellite? How is it different from other types of satellites?

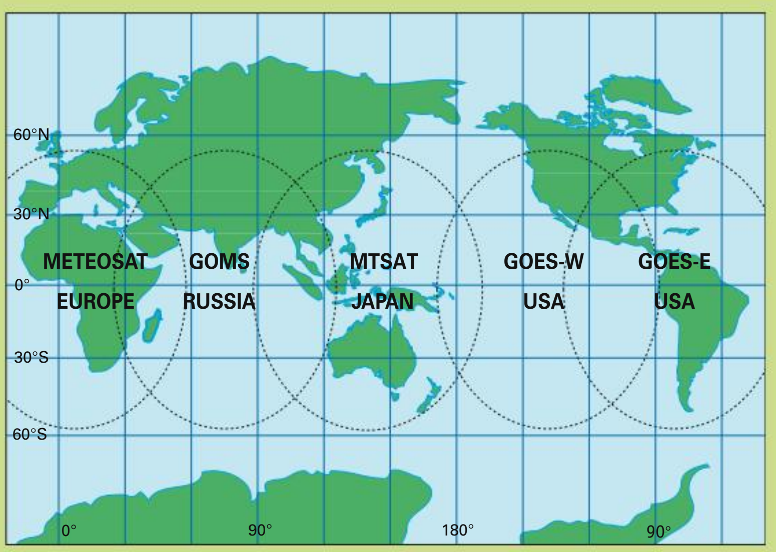
5 a A low Earth orbit (LEO) is usually about 400 km above the Earth's surface but very rarely below this altitude. Why?
  b Why do satellites in LEO have to have high orbital speeds?
  c What is the main advantage of placing a satellite in LEO?

6 How is a polar orbiting satellite different from a geostationary satellite? What are the advantages of placing satellites in polar orbits?

7 What was the purpose of building the space shuttle?

8 a What caused the temperature on the shuttle's surface to rise on re-entry?
  b Which parts of the space shuttle were re-usable, and which had to be replaced before the next launch?

Challenge



1 The map shows the five overlapping areas serviced by the geostationary weather satellites.
  a Which satellite's data would be used to determine the weather patterns for each of the following—Sydney, Perth, New York, Singapore and Hawaii?
  b What is the advantage of a geostationary satellite?
  c Why are these satellites unsuitable for obtaining weather data about Norway or Alaska? Suggest a way of obtaining data about these regions.
  d Geostationary satellites send weather data to Earth 24 hours a day. Suggest how they obtain weather data at night.

2 The tennis ball that Mariela is whirling around her head in Check 3 above does 10 revolutions in 8 seconds.
  a If the string is 2 metres long, how fast is the ball travelling in its circular path?
  b Calculate how long the ball will take to do 10 revolutions if it travels at the same speed but the string is 3 metres long.

3 It is cheaper to launch a satellite-carrying rocket in an easterly direction than in the opposite direction. Suggest why.

4 A satellite is moving with an orbital speed of 8000 m/s in a low Earth orbit at an altitude of 450 km. Assuming the Earth is circular with a radius of 6380 km:
  a calculate the time it takes for the satellite to orbit the Earth
  b find out how many times the satellite orbits the Earth in 24 hours.

5 *Columbia* was the first in NASA's fleet of space shuttles. It was launched on 9 April 1981 and landed again two days later. However, on 1 February 2003, it disintegrated on re-entry and all seven astronauts perished. Use your internet browser to research this space shuttle, and write a short story about its achievements.

6.3 Living in space

As the giant rocket blasts off from the launch pad, the astronauts aboard the space module feel the effects of the tremendous force of the rocket engines. One hour later the space module is in orbit 400 km above the equator. At this altitude the astronauts feel ‘weightless’. Outside the space module, there is no air and no protection from the sun’s radiation. Let’s look at some of the problems of living in space.

Fig 14 An astronaut catches a weightless spoon during a snack on board the Space Shuttle *Atlantis*.

Weightlessness or microgravity

All objects on or near the Earth are attracted to it by the force of gravity. Your weight depends on your mass and the acceleration due to gravity. When an object is in outer space, there is no gravity; that is, the acceleration due to gravity is zero. Therefore objects in outer space are weightless. However, at an altitude of 400 km there is still some gravity. Why then do you feel weightless here?

At an altitude of 400 km the reduced gravity still pulls the spacecraft towards the Earth. However, the spacecraft is moving fast enough to keep it moving in a circular orbit. So the spacecraft and everything inside it is effectively in free fall. This is why astronauts feel weightless when in orbit.

Weightlessness is not really the correct word for this effect. Objects in orbit still have some weight, although very small. **Microgravity** is a more precise word that describes the lack of weight.

Advantages of microgravity

You can move in any direction with just a little push in the opposite direction. You can work upside down without the feeling of blood rushing to your head. And you can sleep horizontally or vertically, although you have to be strapped into your bed to avoid floating away when you move in your sleep.

Disadvantages of microgravity

Astronauts often get space sickness. This is related to the motion sickness some people feel in a rocking boat or when travelling in a car. Space sickness may also be caused by the effects of microgravity on the balancing organs inside the ear.

Eating and going to the toilet also have their problems in space. You have to drink all liquids through a straw from a closed container. In an open cup the liquids form drops and float around the compartment. Food is packed in individual serving pouches on trays that have magnets on them to hold them firmly on a table or wall or wherever you wish to eat.

In the shuttle toilet, air draws the faeces and urine into a bowl underneath the seat. Blades shred the solid wastes, which are then dried when exposed to the vacuum of space. Urine and other waste water is periodically dumped overboard where the material instantly vaporises in space.

Air and water

The air in the crew compartment of the spacecraft is similar to that on Earth. The air pressure is maintained at 1000 hectopascals (1000 hPa)—the same as at sea level.

The composition of the compartment's air is 79% nitrogen and 21% oxygen. Carbon dioxide, given off as a waste product of respiration, is monitored very closely. An excess of CO_2 in the air can make you drowsy and sleepy and this could be dangerous for the crew. Canisters filled with lithium hydroxide absorb the CO_2. The CO_2 reacts with the lithium hydroxide to form lithium carbonate and water vapour. Other canisters filled with activated charcoal absorb odours from the compartment.

Electrical power in the spacecraft is generated by fuel cells. In these devices, oxygen and hydrogen are chemically combined to produce electricity and about 3 litres of water per hour as a by-product. The water is stored and is used for drinking, for the toilet and for the air control system, which maintains the relative humidity at about 55%. Any excess water is dumped overboard where it vaporises and disperses into space.

Maintaining fitness

When you have been in space for a period of time, the microgravity affects your body in a number of ways.

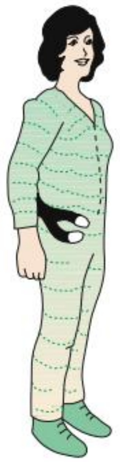
1 One of the most noticeable effects is that the liquids in your body redistribute themselves. The liquids in the upper part of your body increase, causing your face to puff up and some stuffiness in your sinuses.
2 Your posture alters with the low gravity. When you relax, your arms float away from your body, your knees bend and your toes point, making walking difficult. To overcome this, you can wear suction cups on your shoes.
3 The microgravity affects your heart in a similar way to being bedridden for a long period of time. Your heart and pulse rates decrease, as does your blood pressure. To overcome this problem, you have to exercise for at least 30 minutes each day on the treadmill or rowing machine.
4 The most serious problem for space travellers is the demineralisation of bones. Weightbearing bones lose calcium and phosphorus during long periods of microgravity, and this causes a weakening of the bones in the skeleton.
5 Long periods of microgravity also decrease muscle tissue. The Russian cosmonaut Yuri Romanenko lost 15% of the muscle tissue in his legs during an 11-month stay aboard the Mir space station.

Fig 15 Astronaut Shannon Walker exercising on a treadmill on the International Space Station. Why do you think she is wearing a bungee harness?

Heat and radiation

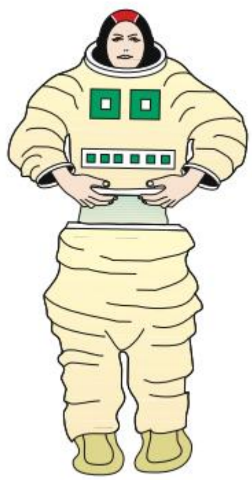
At an altitude of 400 km the temperature in space can be as high as 250°C in the sunlight and as low as –150°C in the shade. The crew compartment of the spacecraft is maintained at a constant temperature and pressure, but any space walks require special clothing. To overcome the extreme temperature changes in space, the undergarments of the spacesuits are equipped with water-cooling and ventilation.

On Earth, the atmosphere absorbs much of the harmful high-energy radiation from the sun, but in space there is no such protection. This radiation can cause cancer and changes to the chromosomes in your sex cells. Spacesuits therefore have to be designed to reflect this dangerous radiation.

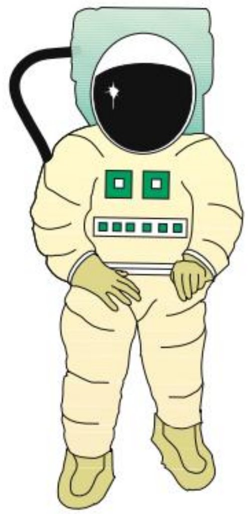


1 The spacesuit's undergarment is made from Spandex mesh with plastic tubing woven into it. The tubing circulates cool water from the life-support backpack.

2 The outer suit comes in two sections and can be put on in less than 5 minutes. The suit contains oxygen-filled pressure bladders that help to keep its shape.



3 When the torso section is put on, the cooling tubes from the undergarment are connected to the tubes that flow to the life-support backpack. The trousers are then joined to the torso section by a rigid aluminium ring.



4 The life-support backpack contains oxygen, water, batteries, and communication equipment. The spacesuit is designed to be re-used and should last 15 years.

Activity

Astronaut's diary

Use the information on pages 158–160 to write a 24-hour diary in the life of an astronaut orbiting the Earth in a space station. For this task, work in a group of three or four people. Use the following ideas in your diary.

- How many hours do you allocate for sleeping, exercising, working and relaxing?
- List the difficulties you face when doing everyday activities in microgravity; for example, washing, cleaning your teeth, eating and drinking, and using the toilet.
- What are the problems of working in a spacesuit and doing jobs in space?
- Describe the experiences at lift-off from Earth and in re-entry.

Space stations

In early 1971 the Russian spacecraft *Salyut 1* became the first space station to be put into Earth orbit. Since that time a number of improvements have been made to make them more liveable for the astronauts who spend an extended period of time in them.

The unmanned *Salyut 6* space station was sent into orbit in 1978. Two months later, two cosmonauts on board a Soyuz spacecraft docked with the Salyut space station and entered it via the docking bay. Three months later they were visited by two other cosmonauts in another Soyuz supply vehicle. This was the first time a space station had been supplied with fresh provisions, and unwanted materials removed.

In 1988 Musa Manarov and Vladimir Titov became the first people to spend more than a full year away from Earth on board the Mir space station. After nearly 15 years in space Mir crashed back to Earth in March 2001.

The International Space Station (ISS)

In 1998 a new space station was born. On 20 November, space scientists from 16 countries throughout the world watched as the Russian Proton rocket carried the first section of the International Space Station (ISS) to an orbit 400 km above the Earth. The ISS is the largest international space project in history.

The ISS is in orbit at an altitude of 360 km, and orbits the Earth every 92 minutes. By September 2011 it had completed over 73 000 orbits since its launch.

In 2006, additional solar panels were installed to increase electrical power, and further modules will be added until it is complete some time in 2012.

Fig 16 (*top*) The International Space Station in orbit 360 km above the Earth's surface
(*middle*) Astronauts in the Zvezda Service Module taking photos
(*bottom*) US astronaut flight engineer Susan Helms looking at Earth from a window in the ISS

Artificial gravity

The one factor that causes most problems for humans in space is the lack of gravity. Serious health problems such as the demineralisation of bones, weakening of the heart and loss of muscle tissue occur when people spend long periods of time in space. Many of the experiments on board the ISS are designed to look at these problems, but they may only be solved if artificial gravity can be created in space stations. How can space stations be designed to create artificial gravity? Try the activity below.

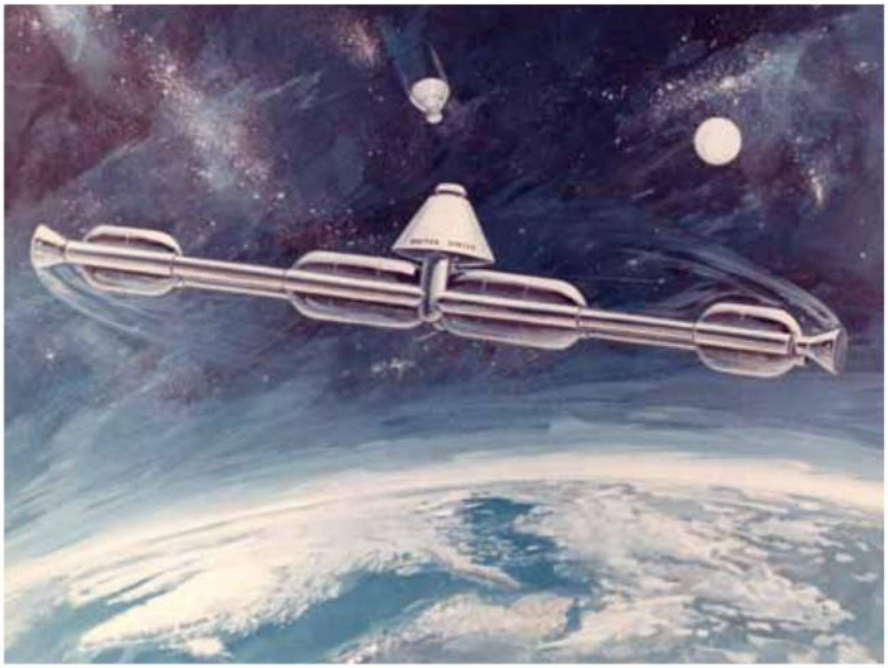


Fig 17 An artist's impression of a space station spinning around a central axis to create artificial gravity

Activity

Your task is to design a space station that will generate artificial gravity and will have facilities for an extended stay by the people on board. Use the internet, books and magazines to help you with this task.

Use the statements below as a guide in your design. As well as describing your design, write a report detailing the various features of the space station and how its inhabitants can survive in space.

- Describe the overall shape of the space station.
- Is it necessary to create artificial gravity in the space station? If not, how will the people on board overcome microgravity problems?
- How will light and electricity be provided for the occupants?
- How will the space station be built? Remember that the present-day shuttle can carry a maximum load of 20 tonnes.
- How will the space station be supplied with food, water, oxygen and fuel, and how will unwanted materials be removed?
- How will the space station be protected from radiation and from meteorites?

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Inside the space station
A video of activities on the ISS

International Space Station (Wikipedia)

Space Station
Comprehensive information about the ISS

Life on the Space Station
YouTube video describing the ISS

International Space Station
NASA's space station site

OneStopScience

Science as a Human Endeavour

Andy Thomas: Australian astronaut

Andy Thomas is the only Australian to have orbited the Earth. He began his training with NASA in 1992 and flew his first flight into space on board the space shuttle *Endeavour* in May 1996.

In 1998 he spent 141 days and 2250 orbits of the Earth aboard the Mir space station and was the last US-trained astronaut to stay on Mir.

He blasted off into space again in 2001 on board the space shuttle *Discovery* along with three other crew, and headed towards the International Space Station. Three Space Station crew on board *Discovery* replaced three others who had been working on the ISS. Andy and fellow astronaut Paul Richards had to walk in space to attach a platform and pump to the outside of one of the modules on the ISS. In 2005 Andy visited the ISS again on board *Discovery*.

For more information about Andy Thomas, go to **www.OneStopScience.com.au** and follow the links to these websites:

Andrew S. W. Thomas
Mission Specialist Andy Thomas

Fig 18 Andy Thomas gathers equipment in the cargo bay of space shuttle *Discovery* at the end of his space walk in March 2001.

Check

1. What is meant by free fall? Where on the Earth's surface could you demonstrate free fall?
2. Explain the term *microgravity*. Are there any places in the solar system that would have zero gravity? Explain.
3. The photo on the right shows an astronaut getting a haircut on the ISS. Suggest reasons for the design of the hair clippers.
4. In which ways is the air in a spacecraft's crew compartment similar to the air on Earth? In which ways is it different?

Fig 19 Getting a haircut on the ISS

5 All items of equipment, including knives and forks, pens and scissors, that are used during a space mission have small velcro pads on them. What is the purpose of these pads?

6 Why is the level of carbon dioxide in the air of the crew compartment monitored carefully?

7 The fuel cells in spacecraft produce electricity when hydrogen and oxygen combine. The two gases would take up a huge amount of space on the spacecraft. Suggest how space engineers have overcome this problem.

8 You have put on your spacesuit and are now ready to go outside into free space to begin repairs to a damaged satellite. Write a short story about how you would get out of the spacecraft, and what it might be like outside in space.

Challenge

1 The manned manoeuvring unit or MMU allows an astronaut to move from a spacecraft to other places, say, another orbiting satellite. The propellant is simply nitrogen gas.

a Suggest how this propellant might move you through space.

b How do you think you would be able to control the speed of the MMU?

2 a How is carbon dioxide removed from the air in a spacecraft?

b Write a word equation for the reaction that occurs when carbon dioxide is removed from the air in the spacecraft using lithium hydroxide.

3 Suggest why the outside temperature at an altitude of 400 km can be as high as 250°C in the sunlight and –150°C in the shade.

4 Electrical power for the space shuttle was produced in fuel cells. Each cell generated 1.2 volts DC and there were 24 cells in each battery. Each cell produced about 20 watts of electrical power.

a What was the total voltage produced by each battery?

b What power (in watts) was produced by each of the shuttle's batteries?

5 Suggest why water vaporises immediately it is released into space from a spacecraft.

6 The International Space Station has cost over \$100 billion to build. The Human Genome Project cost \$45 billion.

a Compare and contrast the benefits of these two science projects to humankind.

b What is your opinion about the statement that these projects are examples of 'scientists spending money on themselves and not on the people who really need it'?

7 Use the internet and other library resources to write a brief history of space stations. Find out how many space stations have been built and put into orbit, what functions they served, and what has happened to them.

8 Before humans went into space, small Rhesus monkeys were placed in orbit for various periods of time. Even recently monkeys have been used in a number of space experiments.

Discuss with others the pros and cons of using animals in space experiments. You might like to organise a debate on this subject.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 There are a number of problems to overcome when living in space: you need a supply of air and water, you need protection from ______ and extremes of temperature, and you have to deal with 'weightlessness' or ______.

2 The weight of an object is a ______ and it is found by multiplying its ______ by the acceleration due to gravity.

3 The acceleration due to ______ on the Earth's surface is 9.8 m/s^2, and it ______ as you move away from Earth.

4 The force or ______ developed by a rocket's engines is due to the exhaust gases moving backwards (the ______) and pushing the rocket forwards with an equal force (the ______).

5 The net force on a rocket at lift-off is equal to the thrust of the engines minus the ______ of the rocket.

6 Gravity pulls a satellite towards the Earth, but its ______ (motion) keeps it in orbit.

7 ______ in low Earth orbits, where the gravity is stronger, have much greater ______ than satellites in higher orbits.

action
decreases
force
gravity
inertia
mass
microgravity
orbital speeds
radiation
reaction
satellites
thrust
weight

Working with technology

Try doing the Chapter 6 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

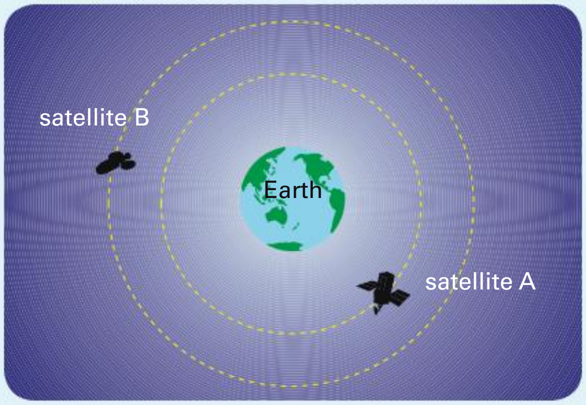
1 You are standing on some scales in a lift. The scales read 60 kg. The lift suddenly accelerates downwards. The reading on the scales will be:
- **A** 60 kg
- **B** less than 60 kg
- **C** more than 60 kg
- **D** 60 × 9.8 kg.

2 In 1975 *Apollo 15* astronaut Scott Irwin dropped a hammer and a feather while standing on the moon's surface.
- **a** Why did they both hit the ground at the same time on the moon but not on the Earth's surface?
- **b** Would the hammer fall faster or slower on the moon than on the Earth? Explain.

3 Jilly stands on ice wearing ice skates. She throws a heavy weight out in front of her.
- **a** In which direction does she move?
- **b** Explain what would have happened if Jilly had thrown the object with more force.

4 Which one of the statements is correct?
- **A** Liquid-fuel rockets are cheap to make and are very simple in construction.
- **B** Solid-fuel rockets have to carry a source of oxygen but liquid-fuel rockets do not.
- **C** Once ignited, solid-fuel rockets cannot be extinguished.
- **D** Most liquid-fuel rockets burn hydrogen and nitrogen gas in the combustion chamber.

5 Two satellites are in orbit around the Earth. Satellite A is at an altitude of 400 km while satellite B is at an altitude of 900 km. Explain why satellite A has to have a greater orbital speed than B.



6 You are in a spacecraft ready for lift-off. The engines that fire for lift-off are solid-fuel engines. The last stage is powered by liquid-fuel engines.

a Why do space rockets have to carry their own source of oxygen as well as the fuel?

b What is the advantage of using solid-fuel engines for lift-off?

c The engine in the spacecraft is a liquid- fuel type. Suggest why this engine is used.

7 Spending long periods of time in microgravity causes problems for the heart, weight-bearing bones and muscle tissues. Describe how microgravity affects these parts of the body.

8 Imagine you were a crew member of shuttle mission STS-120 to the International Space Station. You made the following observations.

a When the shuttle reached the ISS in orbit, you noticed that your face and neck became 'puffy' and you felt a fullness in your head.

b In the ISS crew compartment, you could drink liquids upside down as easily as right-side up.

c Inside the orbiting ISS, you sneezed and you crashed backwards into the compartment wall.

d During re-entry you noticed the tiles on the nose of the orbiter glowed red hot.

Write an inference for each observation.

9 The table gives the acceleration due to gravity for a number of bodies in our solar system.

Solar system body	Acceleration due to gravity (m/s^2)
Mars	4.1
Earth's moon	1.6
Saturn	10.8
Pluto	0.3
Ganymede (moon of Jupiter)	3.9
Uranus	8.9

a On which planet would your weight be about half of what it is on Earth?

b Astronaut Ziro's weight is 88 N on Earth's moon. What is his mass on Mars? What is his weight on Uranus?

c A rocket of mass 75 000 kg blasts off from Ganymede with an acceleration of 5 m/s^2. Calculate the thrust developed by the rocket's engines.

d Will the same rocket be able to lift off from the surface of Uranus? Explain.

10 An astronaut in a manned manoeuvring unit (MMU) or 'space scooter' has a total mass of 110 kg. Each of the 24 jet nozzles around the base of the MMU can produce a thrust of 9 newtons.

a What would the astronaut's weight in newtons be on Earth?

b The astronaut goes for a space walk and fires one jet nozzle. How fast would she accelerate?

c If the astronaut stood on the Earth's surface and fired all the jet nozzles downwards, would the MMU develop enough thrust to lift her off the ground?

d Would the astronaut lift off if she fired all the MMU's jets on the moon?

Check your answers on page 306.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science Inquiry Skills

Space experiment

A major task for the crew of the International Space Station is to conduct experiments in space. School students are sometimes given the opportunity to participate in these experiments.

In 2003, eight Australian orb-weaving spiders were launched into space on board the space shuttle *Columbia*. They were part of an experiment designed by Year 9 students at Glen Waverley Secondary College in Melbourne. The aim of the experiment was to find out whether spiders can spin webs in microgravity. The spiders were in a special box that was kept at a constant temperature in the payload bay of the space shuttle. It contained fruit fly larvae to provide a food supply of flies for the spiders. The students controlled their space experiment by having a second spider habitat at school, identical to the one in space except for gravity. The spiders were monitored by video and data was available to everyone on Earth via an internet site. The spiders were able to spin webs in space, but they were not as neat as on Earth. Tragically, *Columbia* broke up as it re-entered Earth's atmosphere and all seven astronauts were killed. None of the spiders survived.

The researchers at RMIT University and Melbourne Zoo who supervised the 'Spiders in space' experiment are now working with NASA to take bees into space. If humans are to live on Mars, then they will need to cultivate crops in greenhouses. However, until now astronauts have had to pollinate plants by hand. Bees are excellent pollinators, but could they live in space? The 'Bees in space' project is developing an inflatable greenhouse to contain the plants and the bees. Project organisers are working with schools to develop experiments to find the bee species best suited to space. The 'Bees in space' project will include building a test greenhouse in the South Australian desert and a teleconference with astronauts aboard the International Space Station. Researchers think Australian stingless bees, for example the teddy bear bees in the photo, would be the best to use.

Activity

Design an experiment to be carried out on the International Space Station. First, think of something that would behave differently in the microgravity of space. Then devise a plan to carry out your experiment on the space station. The equipment you use must be compact and light, and the experiment needs to be simple and easily performed by the space station crew. You could search the internet under 'International Space Station experiments' for ideas.

Write a detailed outline of your experiment, with diagrams of the equipment needed. Include a paragraph predicting how the findings of your experiment using the space station technology could improve our knowledge of science and lead to benefits for people.

7 Periodic table

In this chapter you will …

Science Understanding

- recognise that elements in the same group of the periodic table have similar properties
- use diagrams to describe the structure of atoms in terms of electron shells
- understand how the electronic structure of an atom determines its properties and its position in the periodic table
- test the chemical properties of metals and arrange them in order of their chemical activity

Science as a Human Endeavour

- predict the impact of future applications of buckyballs and carbon nanotubes on people's lives

Science Inquiry Skills

- carefully follow a series of steps to extract copper from an ore, and evaluate your method

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Use the table below to answer these questions about the physical properties of metals.

1. Which is the strongest metal?
2. Which is more dense—iron or copper?
3. Which are the two rarest metals listed in the table?
4. Which metals do not melt until the temperature is above 1000°C?
5. Is there a relationship between percentage abundance and cost? Explain your answer.
6. Suggest why bridges are made from steel (iron) rather than aluminium.
7. Which would be the best metal to make a spacecraft to explore the surface of Venus, where the temperature varies from 450°C to 1000°C?

Metal	Symbol	Percentage abundance in Earth's crust	Approximate cost ($/kg)	Density (g/cm^3)	Melting point (°C)	Strength ($\times 10^6$ N/m^2)
aluminium	Al	8.1	3	2.7	660	80
copper	Cu	0.007	10	8.9	1083	150
gold	Au	0.000 0005	27 000	19.3	1063	120
iron	Fe	5.0	0.6	7.9	1535	300
lead	Pb	0.002	1	11.3	327	15
silver	Ag	0.000 0004	500	10.5	961	150
tin	Sn	0.0004	11	7.3	232	30
titanium	Ti	0.6	16	4.5	1668	620
zinc	Zn	0.013	5	7.1	420	150

Periodic table of the elements

International Union of Pure and Applied Chemistry 2011

Key

6 — atomic number
C — symbol
Carbon — name of element

The colour of the name for each element indicates its state at room temperature:

black—solid
blue—liquid
pink—gas
red—synthetic

1	2	3	4	5	6	7	8	9
1 H Hydrogen								
3 Li Lithium	4 Be Beryllium							
11 Na Sodium	12 Mg Magnesium							
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium
55 Cs Caesium	56 Ba Barium		72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium
87 Fr Francium	88 Ra Radium		104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium
			57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium
			89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium

WEBwatch

For a lighthearted look at the periodic table, go to **www.OneStopScience.com.au** and follow the links to **The elements**.

Chemical families

- Alkali metals
- Alkaline earth metals
- Transition metals
- Rare earth metals
- Other metals
- Metalloids
- Other non-metals
- Halogens
- Noble gases

10	11	12	13	14	15	16	17	18
								2 He Helium
			5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
			13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium						

63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
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

7.1 The periodic table

Imagine searching through piles of unsorted CDs looking for the latest album of your favourite artist. Such a task could take days. Fortunately music shops arrange their CDs in separate sections. They then divide each of these groups into smaller groups according to the type of music, e.g. rock, popular, jazz and classical. Artists within each group are then arranged alphabetically.

Scientists have a similar problem to the music store owner. There are over 100 different elements, each with different physical and chemical properties. However, some of these elements have similar properties. For example, fluorine, chlorine, bromine and iodine all react very easily with metals. Groups of elements with similar properties are called *families*. Fluorine, chlorine, bromine and iodine are all in the same family.

Mendeleev's table

Over the years chemists have tried many different ways of classifying the elements. In 1869 Dmitri Mendeleev (MEN-del-LAY-if), a Russian chemist, devised a classification system that, with some changes, is still used today. He made a card for each element, with its name, atomic mass and properties. He placed the cards in a row in order of increasing atomic mass. Hydrogen has the lightest atoms, so it was first. He then took from the row of cards those elements whose properties were similar to others before them in the row and placed these cards in columns under the ones they were similar to. In this way he built up a table like a calendar. On a calendar the days of the month are in order, but the dates for the same day of the week are in the same vertical column. For example, on the calendar below, April 4, 11, 18 and 25 are all Mondays. In Mendeleev's table, elements in the same family were in the same column.

APRIL						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

Look at the left-hand blue column in the table on page 170. This column contains lithium, sodium and potassium, which all have similar properties. The number above each element is its **atomic number**—the number of protons in the nucleus, or the number of electrons surrounding the nucleus. If you begin with lithium Li (atomic number 3) and count eight elements to the right you come back to sodium Na (atomic number 11). Count another eight elements and you come to potassium K. Mendeleev's chart is called the **periodic table** because it shows a periodic (occurring at regular intervals) pattern in the elements.

Mendeleev was so convinced of the periodic properties of the elements that he left a few empty spaces in his table. He felt that none of the elements known at that time had the right properties to belong in those spaces. Instead, he predicted the existence of new elements with the correct properties to fit the empty spaces. Years later, his predictions were found to be correct when these new elements were discovered.

The modern periodic table

Elements that have similar properties appear in the same part of the periodic table. Families of elements are in the same vertical column, called a *group*. For example, lithium, sodium and potassium belong to Group 1. The horizontal rows are called *periods*. The bottom two rows are so long that elements 57 to 71 and 89 to 103 are normally taken out and placed at the bottom so that the table fits on one page.

The elements fall into two main groups—metals and non-metals. Towards the right of the periodic table you will see a red zig-zag line. The elements above and to the right of this line are non-metals. The rest of the elements (about 80% of them) are metals.

The metals on the left become more reactive as you go down a group, and less reactive as you go from left to right across the periods. So the most reactive metal of all is francium (Fr) in the bottom left-hand corner of the table. The non-metals become less reactive as you go down a group, and more reactive as you go from left to right across the periods, except for the noble gases in Group 18. So the most reactive non-metal is fluorine (F) in Group 17.

Elements next to the zig-zag line are neither metals nor non-metals. They are called *metalloids* or *semiconductors*, because they are neither good conductors of electricity nor good insulators. Examples are boron, silicon, germanium and arsenic, which are used to make diodes, transistors and microchips for the electronics industry.

You will notice that hydrogen is shown by itself. This is because it behaves like a Group 1 metal in some situations and like a Group 17 non-metal in other situations.

Electron shells

The electrons moving around the nucleus of an atom are not all the same. They have different amounts of energy. The electrons nearest the nucleus have least energy, while those furthest away have most. Around the nucleus are several different *energy levels* or **electron shells**. The electrons can be anywhere on the surface of these spherical shells. In the smallest atoms, hydrogen and helium, there is just one small shell close to the nucleus. Hydrogen (below) has one electron and helium has two.

WEBwatch

Use the internet to search for *periodic table*. You will find many different periodic tables. With most of these you can click on a particular element to obtain information about it. For one suitable website go to **www.OneStopScience.com.au** and follow the links to:

The Visual Elements Periodic Table

Choose an element and find information on it; for example:

- when and how it was discovered
- its physical and chemical properties
- what it is used for
- how it was named
- what chemical family it belongs to.

OneStopScience

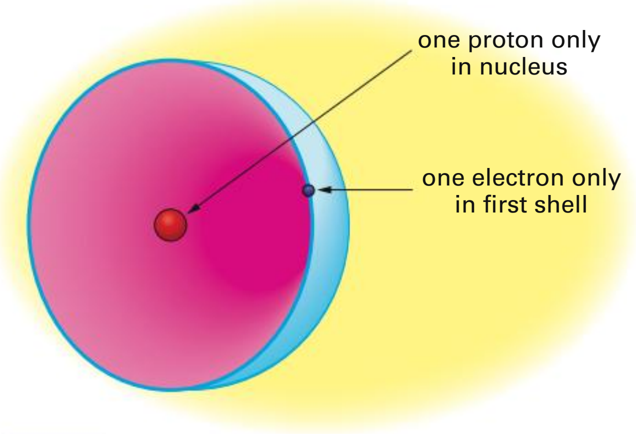


Fig 1 A cutaway view of a hydrogen atom (atomic number = 1), showing its nucleus and spherical electron shell

There is a limit to the number of electrons each shell can hold. In the inner shell, there is room for only two, so if the atom has any more electrons they occupy a second shell, further from the nucleus. This second shell can hold up to eight electrons. The third shell can hold up to 18 electrons.

The electrons in the outer shell of an atom are called the **valence electrons**. These electrons are the most easily removed, and they determine the chemical reactions of the element. Atoms like neon (below), with a full outer shell, are very stable and rarely react with other elements. This is because it takes a lot of energy to add an extra electron or take one away. They form Group 18 in the periodic table—the noble gases.

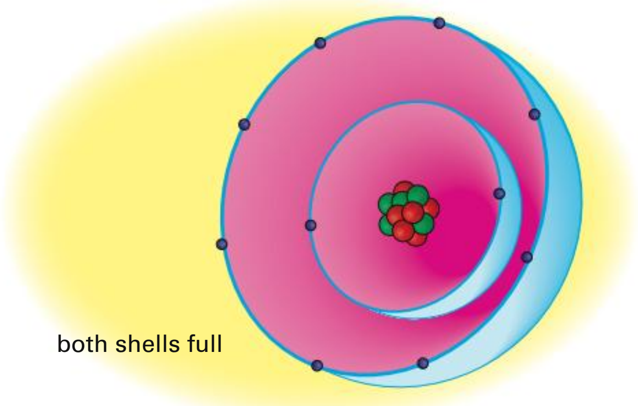


Fig 2 A neon atom (atomic number = 10)

Note that *the periodic table group number is the number of electrons in the outer shell*. For example, Group 18 elements have eight electrons in their outer shell, except for helium, which has two. Atoms like sodium (below), with one electron in their outer shell, are very reactive because this electron is easily removed, leaving the atom with a full outer shell. They form Group 1—the alkali metals. All the metals in this group have a valency of 1+.

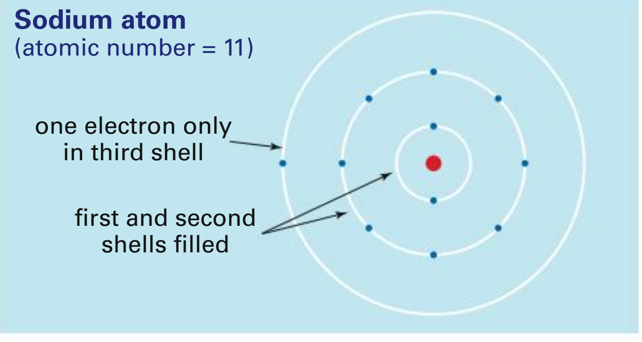


Fig 3 In chemical reactions a sodium atom tends to lose its outer electron to form a Na^+ ion. For simplicity the electron shells have been drawn in two dimensions.

Atoms such as chlorine, which are one electron short of a full outer shell, are also very reactive because they readily accept another electron to fill their outer shell. They form Group 17—the halogens. All the halogens have a valency of 1–.

When sodium reacts with chlorine to form sodium chloride, the sodium atoms lose an electron to form Na^+ ions, and the chlorine atoms gain an electron to form Cl^- ions. In this way, both sodium and chlorine have full outer shells. The mutual attractive force between the positive and negative ions is an ionic bond.

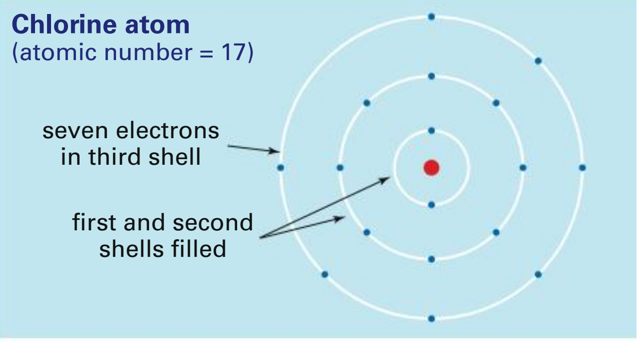


Fig 4 A chlorine atom tends to gain an electron to form a Cl^- ion with a full outer shell.

Carbon (below) has four electrons in its outer shell and therefore has a valency of 4. Rather than losing or gaining electrons to form ions, it *shares* electrons to form covalent bonds. When it reacts with hydrogen, it can form four of these bonds, giving it a full outer shell of eight electrons. Hence the compound CH_4 (methane) is formed.

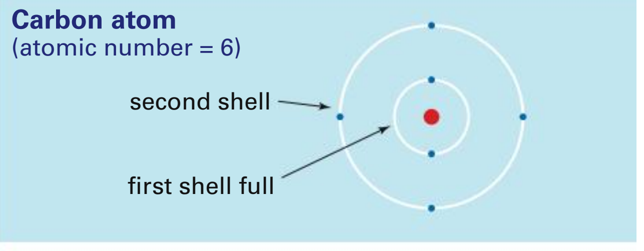


Fig 5 Carbon has 4 electrons in its outer shell and can therefore form 4 covalent bonds.

Working with technology

To see an animation of ionic and covalent bonds, open Chemical bonds at www.OneStopScience.com.au.

OneStopScience

Check

For most of these exercises you will need to refer to the periodic table on pages 170 and 171.

1 What does the atomic number of an element tell you?

2 What is the atomic number of these elements?
a hydrogen
b carbon
c copper
d uranium

3 Roughly sketch the periodic table. On it show where you would find:
a metals and non-metals
b the noble gases, the alkali metals, the halogens and the transition metals.

4 Which of the following elements are metals?

carbon	helium	radium	silicon
sodium	sulfur	titanium	tungsten

5 Use the periodic table to find at least three elements named after countries and at least three named after scientists.

6 Find calcium (atomic number 20) in the periodic table. Name three elements that are in the same family as calcium.

7 At room temperature, which of the non-metals are gases? Which are solids and which are liquids?

8 List the elements from Group 14 in order of atomic number, and state whether each is a metal, non-metal or metalloid.

9 Use the periodic table to decide which three of the following elements have similar properties: aluminium, barium, calcium, chlorine, iron, magnesium, xenon.

10 Explain the difference between a period and a group in the periodic table.

11 What are valence electrons? How can they explain the different chemical properties of the elements?

Challenge

1 Which would be more reactive:
a magnesium or barium?
b sodium or magnesium?
c carbon or oxygen?
d fluorine or chlorine?

2 Write a paragraph explaining how the periodic table is useful to scientists.

3 In 2004 scientists in Japan made a new element with atomic number 113. Predict which elements it is similar to.

4 Imagine that you have to learn the names of the first 10 or 20 elements. Design a mnemonic to help you remember. (A mnemonic is a sentence, sentences or rhyme to help you remember facts: for example My Very Educated Mother Just Served Us Nachos refers to the eight planets in the solar system.)

5 Copy and complete the table on the right for the first 20 elements in the periodic table, showing how the electrons are arranged. For each atom draw the electron shells as on page 174.

Elements	Atomic number	Number of electrons…			
		first shell	second shell	third shell	fourth shell
hydrogen	1	1			
helium	2	2			
lithium	3	2	1		

a Which of the first 20 elements have one electron only in their outer shell? Which group is this in the periodic table?
b Which elements need only one electron to fill their outer shell? Which group is this? What is their valency?
c Which elements have full outer shells? Which group do they belong to?
d How many hydrogen atoms does oxygen need to react with to give it a full outer shell? Write the formula for the compound formed.
e When nitrogen reacts with hydrogen, predict the formula of the compound formed.
f Which two elements have properties similar to beryllium? How do you know?
g Magnesium reacts with chlorine to form magnesium chloride. What is the formula for this compound?

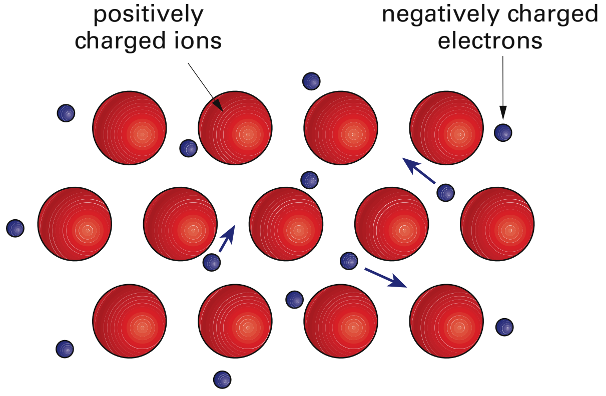
7.2 Chemical families

Metals

Metals have many properties in common. They are all good conductors of heat and electricity. They are *malleable*, meaning they can be pressed or bent into different shapes. For example, silver bars can be hammered into jewellery. Most metals also have what is called a *metallic lustre* or shine. These properties of metals can be explained in terms of their structure.

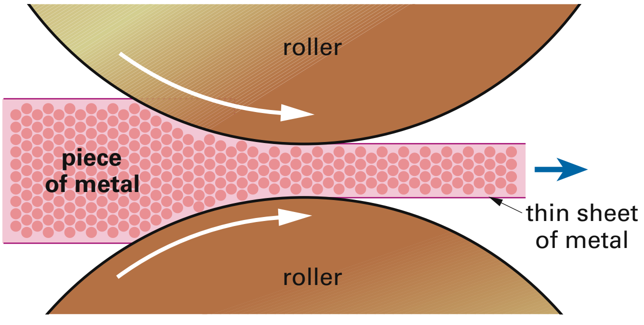
Metals conduct heat and electricity

The atoms in a metal are packed in a regular three-dimensional pattern called a *lattice*. The electrons are not firmly bound to the nuclei and can move freely in the spaces between the atoms. This is why metals conduct heat and electricity.



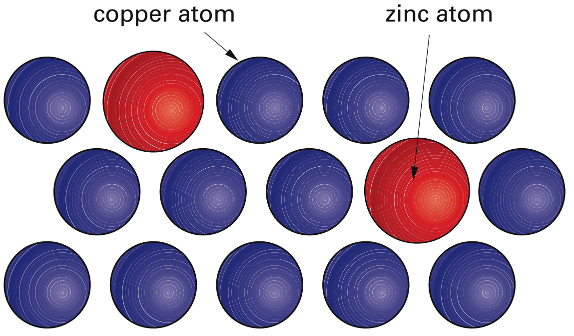
Metals are malleable

Metals can be rolled into thin sheets. This is because the layers of atoms can slide over each other and the free electrons can easily move into new positions.

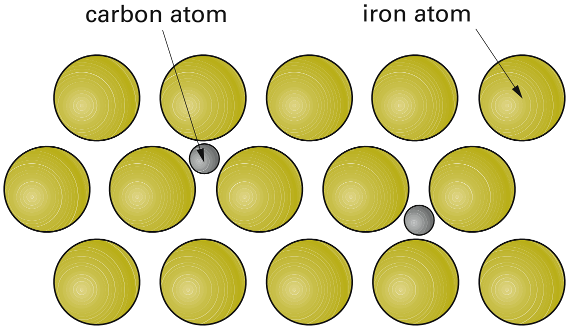


Alloys

An alloy is a mixture of two or more different metals made by mixing the molten metals together, and then allowing them to cool and solidify. For example, 'silver' coins are made from an alloy containing 75% copper and 25% nickel. Brass is an alloy of copper (70%) and zinc (30%). Because the zinc atoms are similar in size to the copper atoms, they can take the place of copper atoms in the lattice.



In some alloys the atoms are different sizes. For example, steel is an alloy of iron and traces of carbon. In this case the carbon atoms are much smaller than the iron atoms and they fit into the gaps in the lattice.



Because gold is a soft metal, other metals such as silver and copper are added to it to make it harder; and the addition of copper produces a more orange colour (rose gold). The proportion of gold is expressed in terms of carats. Most rings and bracelets are 18 carat or 9 carat gold.

Carats	24	22	18	14	9
Percentage gold	100	91.7	75	58.5	37.5

Investigation 10 Metal properties

Aim

To test the chemical properties of metals and arrange them in the order of their chemical activity.

Materials

- small samples of various metals, e.g. aluminium, magnesium, lead, copper, tin, zinc, iron, silver
- steel wool or emery paper
- dilute **hydrochloric acid** (1 M) in a dropper bottle
- test tubes (in test tube rack)
- **zinc sulfate** solution (saturated)
- **copper sulfate** solution (saturated)
- ammeter or multimeter
- power pack
- 4 connecting wires
- switch

Planning and Safety Check

- Do a risk assessment for this investigation. What safety precautions will be necessary?
- Prepare a data table to record all your observations.

Method

Part A: Reactions with acid

1 Observe each of the metal samples. Which are tarnished (not shiny)?

2 Clean each sample with steel wool. Then put the samples in labelled test tubes.

3 Add 5 drops of dilute hydrochloric acid to each metal.

Record the rate at which bubbles of gas are formed; for example, *fast*, *medium*, *slow* or *no reaction*.

4 Clean out the test tubes and wash the remaining metal samples in water. Keep them for Part C.

Part B: Reactions with metal solutions

1 Put about 5 mL of zinc sulfate in each tube.

2 Add a metal sample to each and leave for 3–5 minutes.

Record any reactions that occur. A reaction may be indicated by a dark deposit on the metal. If the metal remains shiny, you can infer there has been no reaction.

3 Wash and clean the metal samples. Then repeat Steps 1 and 2 using *copper sulfate*.

Again record your results.

Discussion

1 What usually happens when you add dilute hydrochloric acid to a metal?

2 Which metals reacted with:

a all three test solutions (hydrochloric acid, zinc sulfate and copper sulfate)?

b two solutions only?

c one solution only?

d none of the solutions?

3 Put the metals in order from the most reactive to the least reactive.

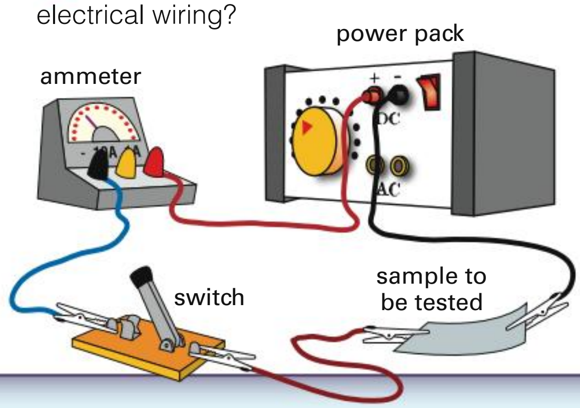
4 Suppose you wanted to make a metal tank to hold copper sulfate solution. Which would be the best metal to use? Why?

Part C: Conductivity

1 To test the electrical conductivity of the samples, set up the electrical circuit shown. Set the power pack on 6 volts DC.

2 For each sample, record the electric current that flows.

Which metal would be best to use in electrical wiring?



Reactive metals

The elements in Group 1 of the periodic table (lithium, sodium, potassium, rubidium, caesium and francium) are metals with similar properties. Because they have a single electron in their outer shell they are very reactive and are never found in nature as elements, only as ionic compounds. They are called **alkali metals** because they react with water to form alkaline solutions. For example, sodium reacts violently with water to form sodium hydroxide and hydrogen.

The **alkaline earth metals** in Group 2 have two electrons in their outer shell. They are reactive, but not as reactive as the alkali metals. They contain two of the most biologically important metals: magnesium is found in chlorophyll, and calcium is found in bones and teeth.

sodium + water → sodium hydroxide + hydrogen

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

Fig 6 Sodium reacts violently with water. Your teacher may demonstrate this.

Investigation 11 Alkaline Earth metals with water

Aim

To investigate the reactions of magnesium and calcium with water.

Materials

- 2 test tubes, test tube holder and rack
- Bunsen burner and heatproof mat
- 5 cm strip of magnesium
- small sample of calcium
- phenolphthalein
- steel wool or emery paper

Planning and Safety Check

- Do a risk assessment for this investigation. What safety precautions will be necessary?

Method

1 Clean the magnesium strip with steel wool and coil it around a pen.

2 Put the coil in a test tube and cover it with water.

3 Watch carefully over the next 5 minutes for any sign of a chemical reaction. If nothing happens, heat the tube gently over a small flame.

4 What happens when you add a drop of phenolphthalein to the test tube?

5 Add a small piece of calcium to the second test tube and cover it with water. Test the gas given off with a lit match. Add a drop of phenolphthalein.

Record your observations.

Discussion

1 Which is more reactive? Magnesium or calcium?

2 What was the gas produced when magnesium and calcium reacted with water?

3 Why did the phenolphthalein change colour?

4 Write balanced equations for the reactions of magnesium and calcium with water. See the sodium reaction above.

Transition metals

The metals in the middle of the periodic table are called **transition metals**. They are hard and have high melting points. The properties of transition metals that are close together in the periodic table are often very similar. This is why they can be mixed to form alloys. Iron, cobalt and nickel, which are in the same period, have similar properties. For example, they are all magnetic. Copper, silver and gold, which are in the same group, also have similar properties. Metals near the top of the table (e.g. aluminium and zinc) are generally more reactive than those towards the bottom of the table (e.g. silver, gold and lead).

Many of the compounds that transition metals form with non-metals are coloured. For example, copper sulfate is blue and iron(II) chloride is green. This is why these compounds are used to colour glass. Copper ions give a blue colour, iron gives a green colour and gold gives a red colour. Hair colour is also determined by the presence of minute amounts of transition metal compounds. Blond hair contains titanium compounds, red hair contains iron compounds, and dark hair contains a mixture of iron, copper and cobalt compounds.

Metals give a characteristic colour to a flame, as you can see in Investigation 12.

Investigation 12 Flame colours

Aim

To observe the characteristic flame colours produced by metal salts.

Materials

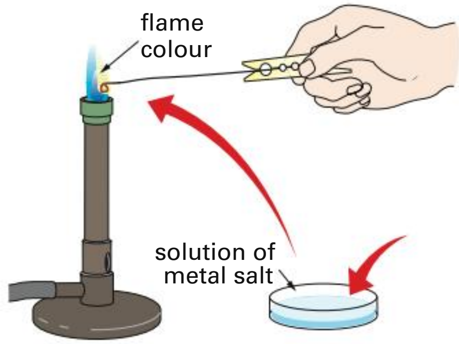
- petri dish
- piece of nichrome wire, about 10 cm long
- wooden peg or test tube holder
- Bunsen burner
- saturated solutions of chlorides or carbonates of the following metals: barium, calcium, copper, potassium, sodium, strontium

Planning and Safety Check

- Read the investigation carefully and do a risk assessment. Because the metal solutions are toxic you should wash your hands thoroughly after doing the investigation.
- Your teacher may set up six different ‘stations’ around the laboratory with the above materials and a different metal salt at each station.
- If the solutions are available in atomiser bottles, you simply spray them into the flame.
- For Step 6 you will need an *unknown* metal salt to test.

Method

1. Bend the end of the nichrome wire to form a small loop. Hold the other end with a peg.
2. Light the burner and adjust to a hot flame.
3. Dip the wire into the solution of the metal salt in a petri dish.
4. Place the wire in the edge of the flame and observe the colour.



5. Move to a new ‘station’ and repeat the procedure with a different metal salt.
   Record the flame colours for the different metals in a data table.
6. Now that you know the colour each metal produces in a flame, your teacher will give you an unknown metal salt. Test it and infer which metal it contains.

Fig 7 The colours of fireworks are due to transition metal compounds.

Non-metals

The non-metals are on the right of the periodic table. Many are gases at room temperature. The elements in Group 17 (fluorine, chlorine, bromine, iodine and astatine) are called the **halogens**. Because they have a vacancy of one in their outer shell they have a valency of 1–. They are very reactive and form salts when they combine with metals. (The word 'halogen' means 'salt former'.) For example, chlorine reacts with sodium metal to form sodium chloride.

sodium + chlorine → sodium chloride

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

The elements in Group 18 have a full outer electron shell. They are called the *inert gases* or **noble gases** because they do not react with other 'common' elements. Helium is used to fill balloons and mixed with oxygen for divers' tanks. Neon is used in neon signs and lasers because it gives a coloured light. Argon is used in light bulbs and in welding to provide an unreactive environment.

The noble gases are so unreactive that they do not even react with themselves. They are said to be *monatomic* because they consist of single atoms. The other non-metal gases form *diatomic* molecules, each consisting of a pair of atoms linked by a covalent bond; for example hydrogen H_2, nitrogen N_2, oxygen O_2, chlorine Cl_2 and fluorine F_2.

Fig 8 The red tubes in this sign contain the noble gas neon. The green, yellow and blue tubes contain argon.

As you move to the left in the periodic table, the non-metals tend to form a greater number of covalent bonds. For example, molecules of white phosphorus (P_4) consist of four phosphorus atoms at the corners of a tetrahedron; and sulfur molecules (S_8) consist of eight atoms in a chair-shaped ring.

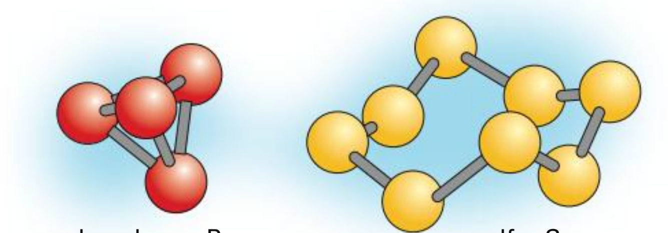
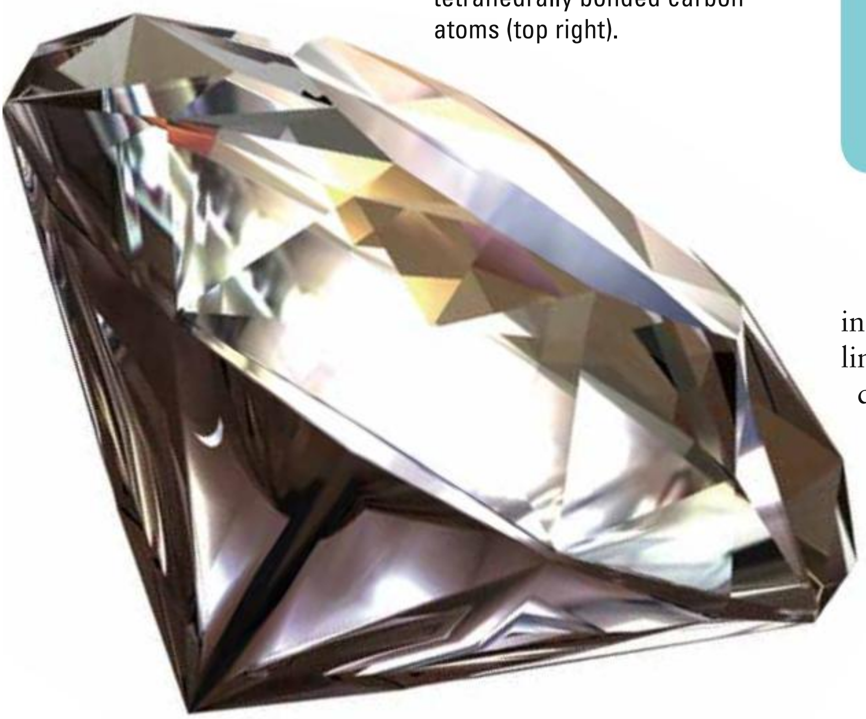


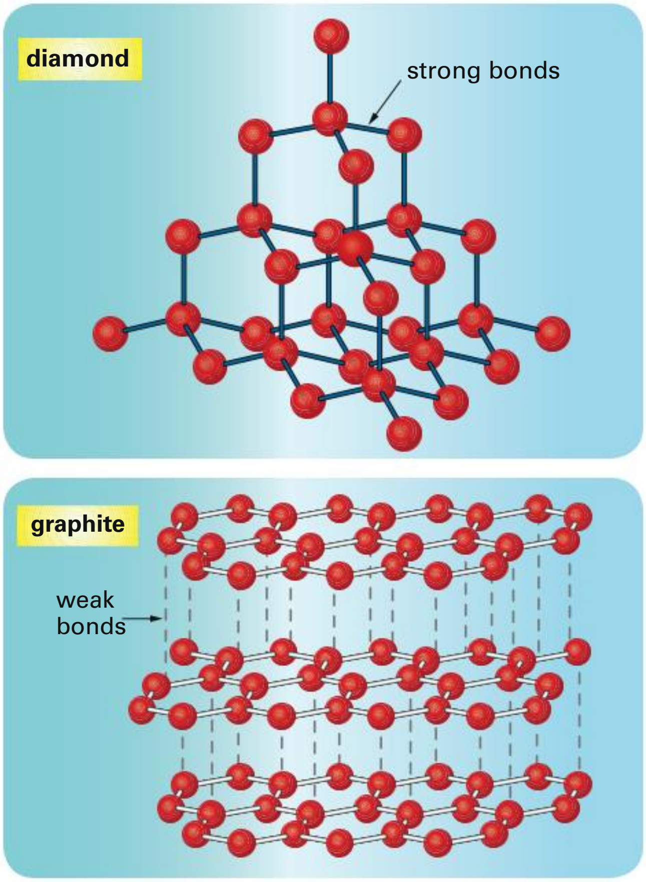
Fig 9 As you move to the left in the periodic table, the non-metals form a greater number of covalent bonds.

Some non-metals exist in different forms called **allotropes**. For example, oxygen can exist as O_2 or as O_3 (ozone), whose properties are quite different from those of O_2. Similarly, carbon can exist as diamond, graphite or charcoal (soot). Diamond is the world's hardest substance—tough, brilliantly clear and sparkling, and unaffected by heat below 700°C. On the other hand, graphite is a soft, grey, flaky material with a greasy feel. It is used as the 'lead' in pencils. Diamond and graphite are both made of carbon atoms, but their structures are different.

Fig 10 Diamond's unique properties are due to its structure of tetrahedrally bonded carbon atoms (top right).



There are no individual molecules in diamond or graphite. Instead they both consist of atoms covalently bonded to each other in a network lattice. In the diamond network each atom is linked to four others in an infinitely interlocking tetrahedral structure. It is this tight structure that makes diamond so hard.



Note: These diagrams show only part of the structure of diamond and graphite.

In graphite, however, the atoms are arranged in layers, like sheets of hexagonal tiles. Each atom links with only three other atoms, not four as in diamond, and there are therefore electrons left over. These unattached electrons drift freely between the layers like the free electrons in a metal. This is why graphite is a conductor of electricity and tends to look metallic.

Graphite can be turned into diamond by squeezing it to push the layers of atoms closer together until they interlock and make diamond. But the pressure needed to make this happen is enormous, and so far only small artificial diamonds have been made this way.

Recently scientists have discovered another allotrope of carbon called *buckyballs* in which the carbon atoms are linked to form single molecules rather than a giant network. The first buckyball to be found contained 60 carbon atoms and is shaped like a soccer ball. (See the activity on the next page.) Other shapes such as buckytubes have also been discovered.

Scientists are searching for uses for buckyballs and buckytubes. For example, it has been suggested that they could be used to make nanomachines like the gears in Fig 11, about a millionth of a millimetre in size. You can find out more about this by going to **www.OneStopScience.com.au** and following the links to **Buckyballs**.

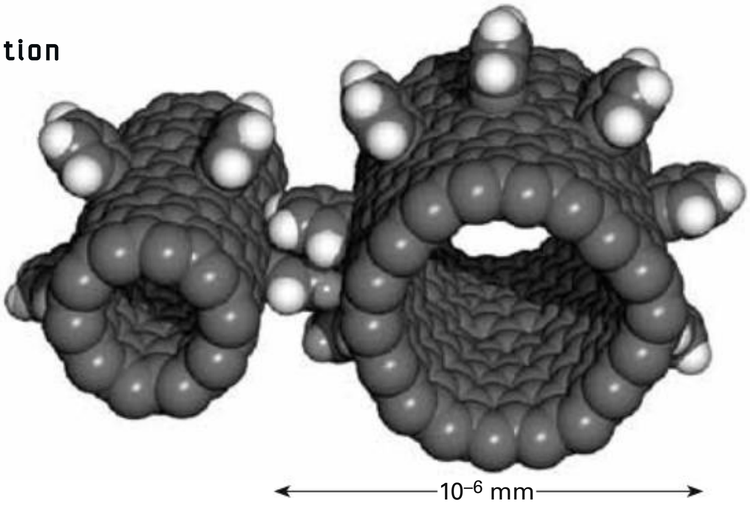


Fig 11 Buckytubes could be used to make gears in nanomachines.

Check

1 List four physical properties of metals.

2 What is the difference between a monatomic and a diatomic gas? Give examples of each.

3 What is an allotrope? What are the names of the four allotropes of carbon?

4 Explain in terms of its structure why graphite is flaky and feels greasy.

5 Toni tested a piece of eggshell, a marble chip and some garden lime. She dissolved each in hydrochloric acid and used the solution for a flame test. In each case she observed the same orange-red flame. What can she conclude from her observations?

Challenge

1 Suggest how buckyballs might be useful as lubricants.

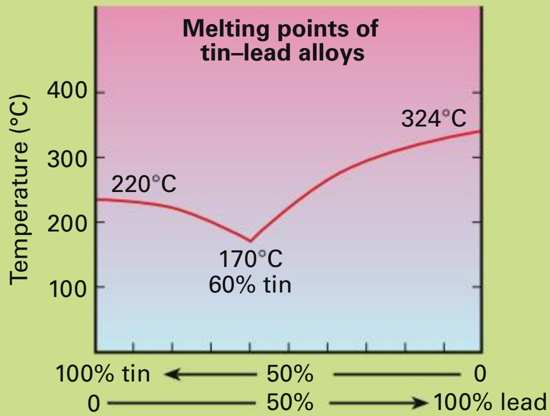
2 Alloying iron with carbon makes it harder. Explain this in terms of the structure of alloys.

3 Explain the following properties of metals in terms of their structure:

- **a** high melting point
- **b** high density
- **c** malleable (can be rolled into sheets)

4 The graph on the right shows how the melting point of solder (a tin–lead mixture) changes as its composition changes. A 60% tin mixture gives the lowest melting point. If the percentage of tin is lower or higher than this, the solder has a higher melting point.

- **a** What would be the approximate melting point of an alloy of composition 25% tin and 75% lead?
- **b** What are the possible compositions for a solder with a melting point of 200°C?



Activity

1 To make a model of a buckyball, photocopy the hexagons below onto stiff paper or light cardboard.

2 Cut out the three strips of hexagons. (Don't cut along the dotted lines.)

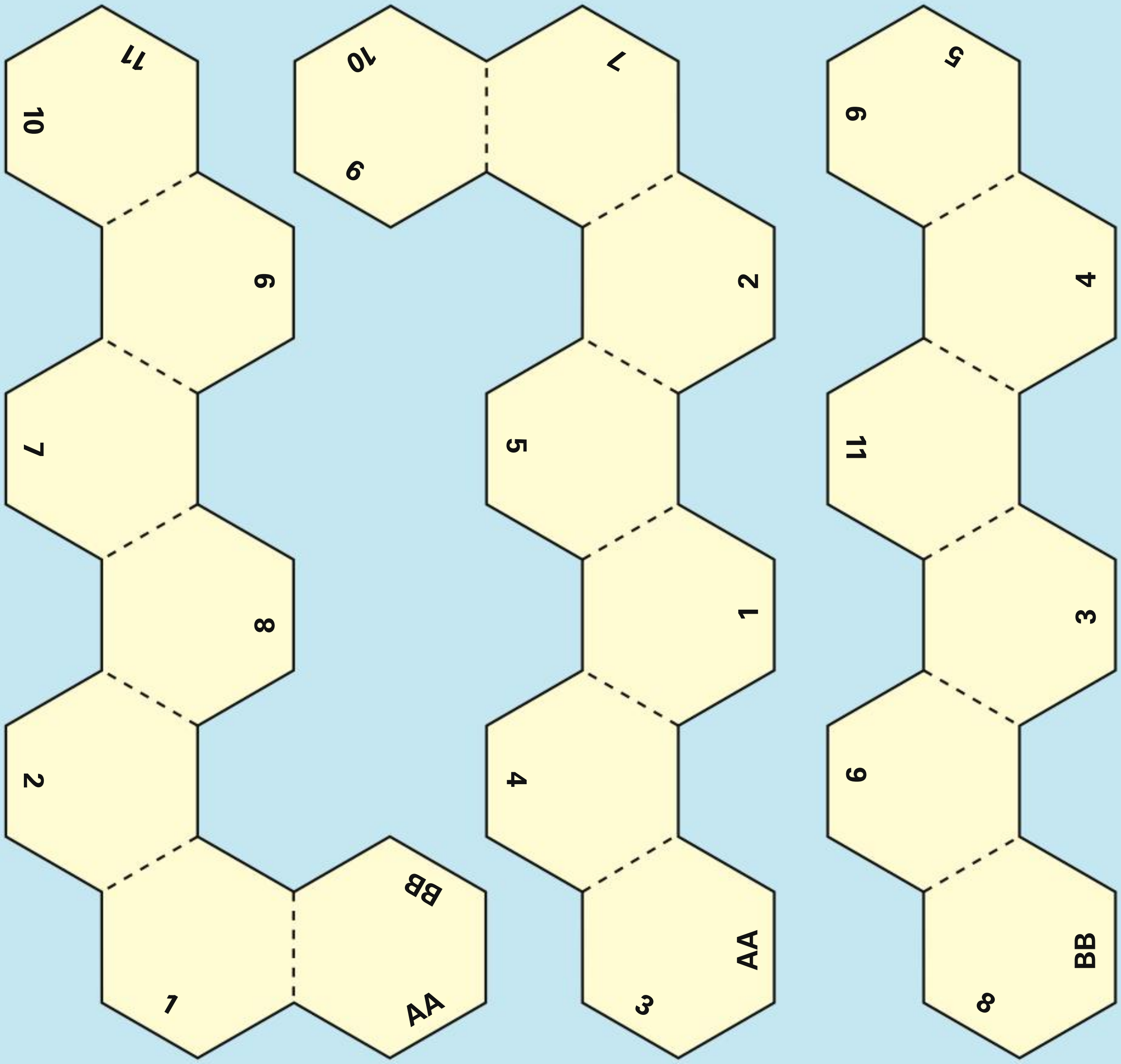
3 Fold the strips along the dotted lines.

4 Tape together the two edges labelled AA and the two edges labelled BB.

5 Tape together the two edges labelled 1. Continue this in order from 1 to 11.

How many hexagons are there in the buckyball? How many pentagons? (In this model the pentagons appear as five-sided holes.)

If each corner represents a carbon atom, what is the molecular formula for your buckyball?



7.3 Extracting metals

The pie chart below shows the main elements found in the Earth's crust. As you can see, the most common elements are the non-metals oxygen and silicon. These two elements are often combined as the compound silicon dioxide (SiO_2), found in sand and in rocks (as quartz).

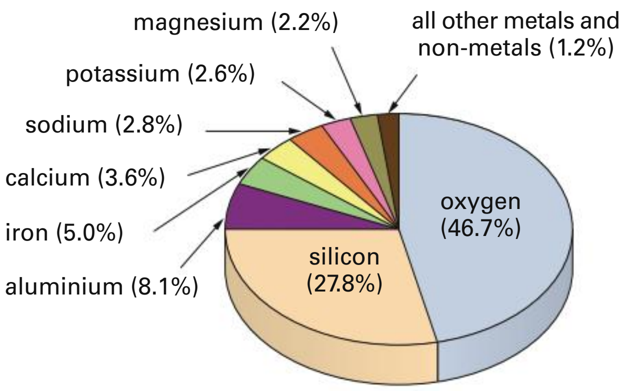


Fig 12 The composition of the Earth's crust

Fig 13 Gold is usually found in its uncombined state. This is the Poseidon Nugget found in central Victoria in 1906. It weighed 27 kilograms.

The metals are usually found as compounds with non-metals, although the unreactive metals such as gold can be found as elements (see Fig 13). Compounds of the reactive metals are fairly abundant; for example, sodium chloride (common salt) and calcium carbonate (limestone). However, compounds of the less reactive metals such as copper, zinc, silver, tin and lead are quite rare. This is why mining companies spend so much money on exploration.

Metal compounds are called **minerals** when found in large amounts in rocks. If these rocks contain enough minerals to make it economical to mine them, they are called **ores**. The table below gives examples of ores commonly mined in Australia.

Ore	Chemical composition	Metal extracted
bauxite	aluminium oxide (Al_2O_3)	aluminium
chalcopyrite	copper iron sulfide ($CuFeS_2$)	copper
galena	lead sulfide (PbS)	lead
gold	found as element (Au)	gold
haematite	iron oxide (Fe_2O_3)	iron
pitchblende	uranium oxide (U_3O_8)	uranium
rutile	titanium oxide (TiO_2)	titanium
sphalerite	zinc sulfide (ZnS)	zinc

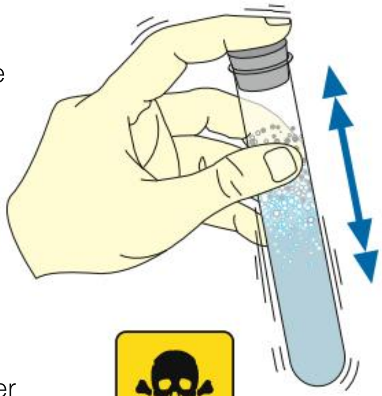
Before a metal can be extracted from its mineral, the impurities in the ore must be removed. One way to do this is by a process called *froth flotation*, which was developed at Broken Hill in Australia. (To see an animation of this, open the **Froth flotation** animation at **www.OneStopScience.com.au**.) The ore is crushed and added to water in a tank. A frothing agent is added and air is bubbled through the mixture. The frothing agent attaches itself to the bits of mineral and rises to the surface as a froth. The froth containing the mineral is then scraped off and the mineral is dried, ready for the next step in the extraction process.

ore $\xrightarrow{\text{removal of impurities}}$ mineral $\xrightarrow{\text{extraction process}}$ metal

Investigation 13 Froth flotation

Aim

To model on a small scale the process of froth flotation.



Materials

- fine sand
- kerosene
- spatula
- liquid detergent
- watch glass
- large test tube with stopper
- powdered **chalcopyrite**, **galena** or **haematite**

Method

1 Mix a spatula of powdered mineral with the same amount of sand in a large test tube. Then half-fill the test tube with water.

2 Put the stopper in the test tube and shake it. Do the sand and the mineral separate?

3 Add 2 mL of detergent and a few drops of kerosene.

4 Shake the test tube again.

5 Use the spatula to scoop off the froth into a watch glass and check that it contains the mineral.

6 Dispose of the sand and mineral in a waste bucket at the front of the class—not down the sink.

Discussion

1 Suggest a method of obtaining dry mineral from the froth in the watch glass.

2 What happened to the sand initially mixed with the mineral?

3 Suggest ways of improving the process.

Smelting

Thousands of years ago humans managed to extract metals without any idea of the chemical reactions involved. The metals were probably first extracted by accident, when rocks containing the ore were thrown on a fire and the new metal was observed the following day. From this, early humans worked out that two things were needed—heat and charcoal (carbon). Many metal ores are oxides, and we now know that when a metal oxide is heated with carbon, the oxide is converted to the metal. At the same time the carbon combines with the oxygen from the oxide to form carbon dioxide. For example, lead is extracted from lead oxide.

$$2PbO(s) + C(s) \rightarrow 2Pb(s) + CO_2(g)$$

This process is called **smelting** and the metal in the ore is said to be *reduced*, because it gains electrons. Hence the extraction of a metal from its ore is called *reduction*. The equation for the reduction of lead ore is:

$$Pb^{2+}(s) + 2e^- \rightarrow Pb(s)$$

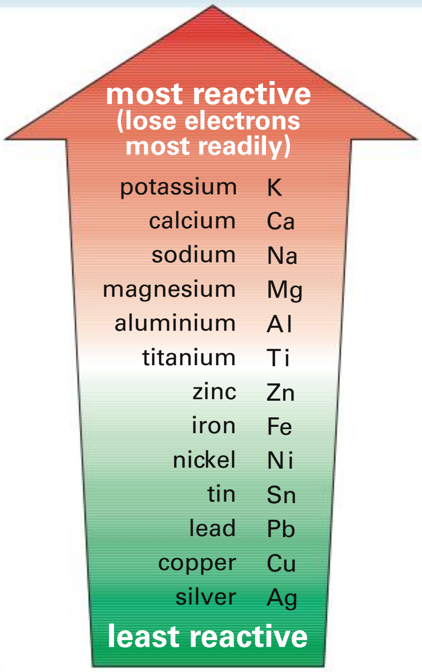


Fig 14 Metals can be listed from the most reactive to the least reactive. This is called the *activity series*. The metals at the top are harder to extract than the ones at the bottom. Do your results from Investigation 10 on page 177 agree with this?

The ore of iron is iron oxide (Fe_2O_3). The iron can be extracted in a *blast furnace*. In Australia there are blast furnaces at Port Kembla in New South Wales, Whyalla in South Australia and Kwinana in Western Australia. A mixture of iron oxide, coke (made from coal) and limestone is fed into the top of the furnace. Very hot air is blasted in near the bottom, causing the coke to burn and form the gas carbon monoxide. The carbon monoxide then reacts with the iron oxide, reducing it to iron.

$$2C(s) + O_2(g) \rightarrow 2CO(g)$$

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$$

The molten iron collects in the bottom of the furnace, where it is tapped off from time to time, as shown in Fig 15 below. Impurities in the ore combine with the limestone to form slag, which floats on the molten metal. The slag is used as a road-surfacing material or in cement manufacture. The molten iron is converted to steel in another furnace.

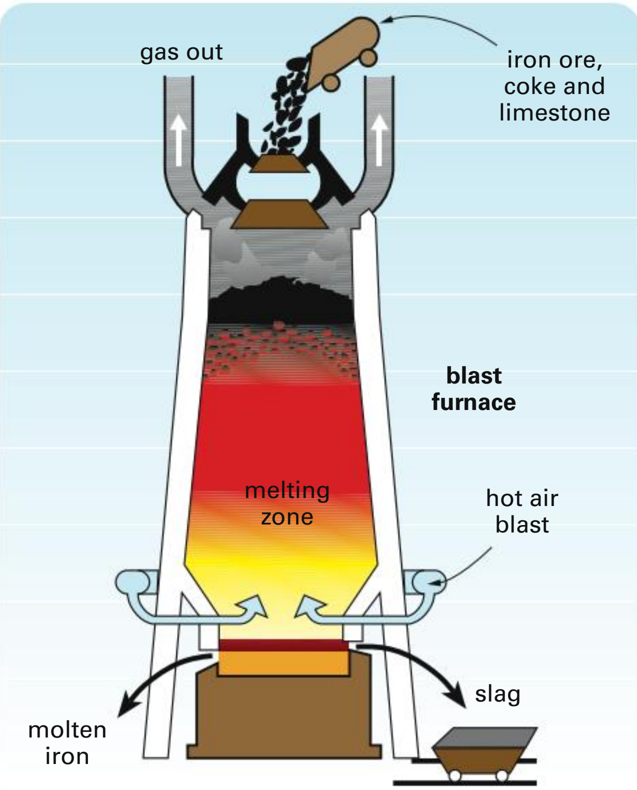


Fig 15 Smelting in a blast furnace

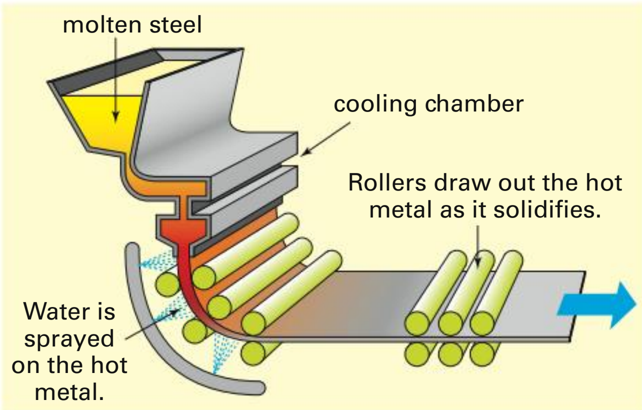


Fig 16 The molten steel is rolled into flat sheets and cut into sheets or rolled up as in the photo.

Copper can be extracted from its ore by 'roasting'. The chalcopyrite $CuFeS_2$ is converted to copper sulfide Cu_2S, which then reacts with oxygen, forming copper metal and the gas sulfur dioxide.

$$Cu_2S(s) + O_2(g) \rightarrow 2Cu(s) + SO_2(g)$$

In the past, copper producers built high chimneys to release the poisonous sulfur dioxide into the atmosphere. The high chimneys were used to avoid producing dangerous levels of the gas at ground level where people could be affected. However, high levels of sulfur dioxide in the atmosphere can lead to acid rain. For this reason environmental laws now require producers to collect the sulfur dioxide and use it to make sulfuric acid or fertiliser.

Electrolysis

The copper from a copper smelter is only about 98% pure, but it can be made 99.9% pure by the process of *electrolysis* (ee-lek-TROL-e-sis), where electricity is used to produce chemical reactions. The impure copper is made into a thick plate, which is connected to the positive terminal of a power source. A thin plate of pure copper is connected to the negative terminal. Both plates are then placed in a bath of copper sulfate solution and sulfuric acid. As the current flows through this solution, the impure copper dissolves and pure copper is deposited on the thin plate in a reduction reaction.

$$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$$

The 'mud' that falls to the bottom of the bath contains less reactive metals such as silver and gold, which can be recovered. The process uses considerable electricity, so the copper refinery must be close to a source of abundant, cheap power. This is why copper produced in the smelter at Mount Isa in Queensland is shipped to Townsville for refining.

More reactive metals such as aluminium and magnesium cannot be extracted by smelting, but can be obtained by electrolysis. For example, to produce aluminium, the ore (aluminium oxide) is melted and electricity passed through it.

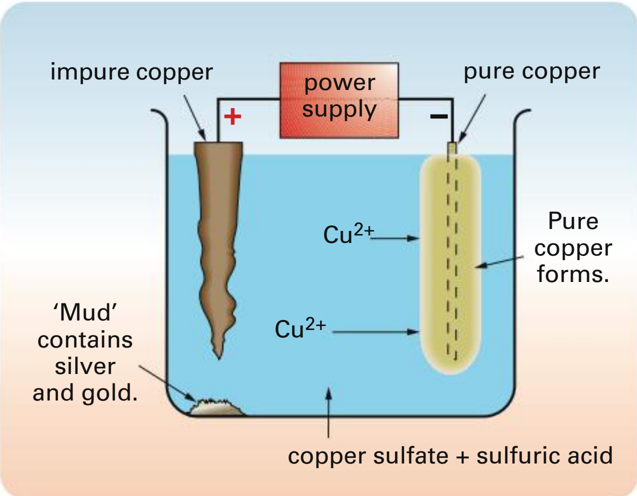


Fig 17 Purifying copper by electrolysis

Displacement

In Investigation 10 Part B (page 177) you put magnesium in a copper sulfate solution. Did you find that copper fell to the bottom of the test tube? This reaction is called *displacement*, because the more reactive magnesium displaced (pushed out) the less reactive copper from the copper sulfate solution. This method is used to extract some metals. For example, titanium is displaced from titanium chloride solution by adding magnesium.

$$TiCl_4(aq) + 2Mg(s) \rightarrow Ti(s) + 2MgCl_2(aq)$$

The titanium and the magnesium swap places. The magnesium metal goes into solution as magnesium chloride, and the titanium comes out of the solution as the metal.

Activity

You will need a test tube and rack, silver nitrate solution, 15–20 cm of copper wire and a pen.

1 Three-quarters fill the test tube with silver nitrate solution. **Be very careful not to spill any as it stains hands, clothing and benches.**

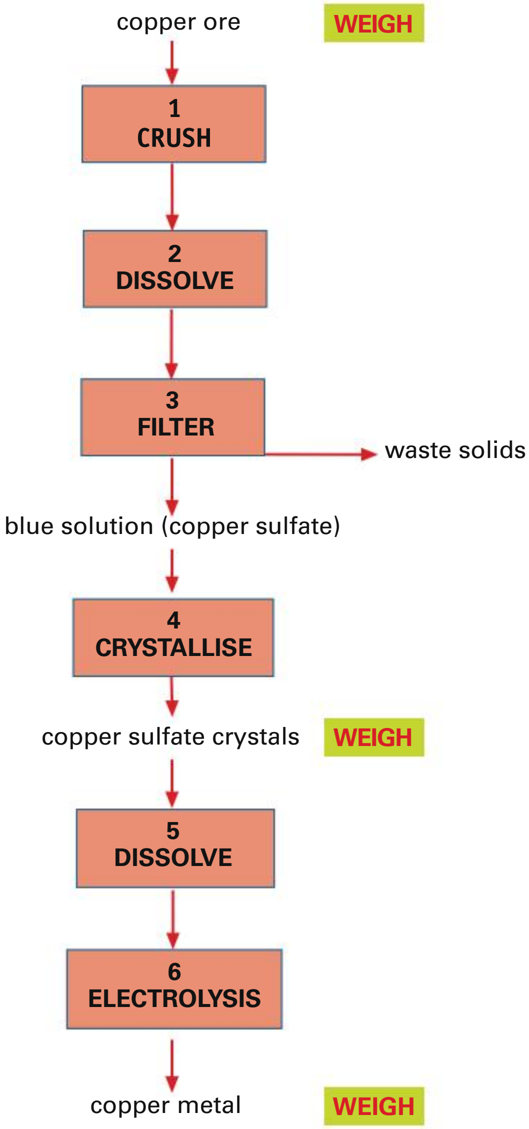
2 Twist the copper wire around a pen to make a spiral, with a bit left over to make a hook. Put it in the test tube, hooking it over the lip of the tube.

3 Leave the test tube in a dark cupboard overnight. In the morning observe what has happened.

What new substances have been formed?

Write a word equation for the reaction that has occurred, then a balanced symbol equation.

Investigation 14 Copper metal from copper ore



Aim

To extract copper sulfate and copper metal from a simulated ore.

Materials

- copper ore made by mixing copper sulfate, sand and plaster of Paris, adding water and allowing to set
- balance
- mortar and pestle
- 2 beakers or conical flasks
- filter funnel and stand
- filter paper
- burner, tripod and gauze
- watch glass
- hand lens
- spatula
- sodium chloride
- stirring rod
- power pack
- strips of lead and copper
- 2 connecting wires
- steel wool

Planning and Safety Check

This is a complex investigation that will take several days. You will need to work carefully so that you don't lose any copper.

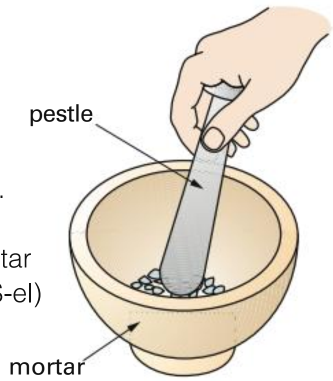
- In a group, describe what you will be doing in each of the six steps shown in the flow diagram on the right.
- When will you need to weigh things?
- What safety precautions will be necessary?

Method

1 CRUSH

a Use a balance to find the mass of the ore to start with.

b Crush the ore thoroughly in a mortar using a pestle (PES-el) until it is a powder.



2 DISSOLVE

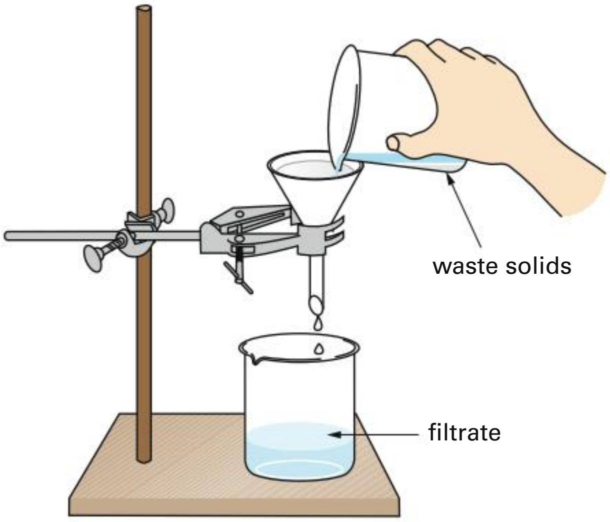
Put the crushed ore in a beaker. Add enough water to dissolve it when you heat it for 5 minutes.

What is the colour of the mixture?

3 FILTER

a Let the mixture cool for a few minutes while the solid settles.

b Decant the mixture through filter paper in a filter funnel. Keep as much of the solid as possible in the beaker because it may clog the filter paper. (Fluted filter paper is faster.)



c Rinse the solid left in the beaker with a further 10 mL of water, and filter this rinse water as well.

What is the colour of the filtrate? What is the filtrate?

What are the solids left in the filter paper? (Discard the filter paper and waste solids into a bin.)

4 CRYSTALLISE

a Boil the copper sulfate filtrate until only a few millilitres remain. Turn off the burner and leave the beaker until the crystals that form are dry.

b Scrape all the crystals onto a watch glass and weigh them.

Describe the copper sulfate crystals. (Use a hand lens.)

c Calculate your percentage yield as follows:

$$\%\ \text{yield} = \frac{\text{mass of copper sulfate}}{\text{mass of ore}} \times 100$$

5 DISSOLVE

a Dissolve the copper sulfate in water. Stir to make sure it is completely dissolved.

b Add a spatula of sodium chloride. This is to help the solution conduct electricity in the next step.

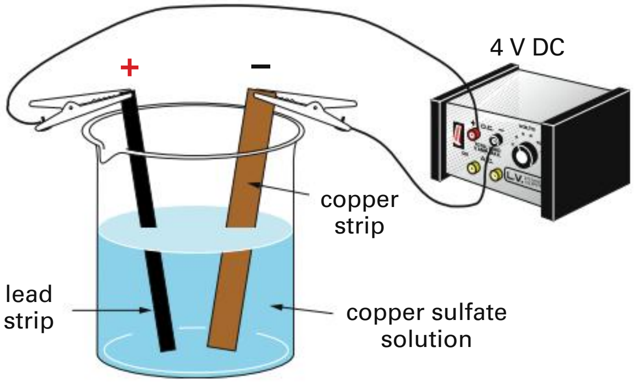
6 ELECTROLYSIS

a Thoroughly clean a strip of lead and a strip of copper with steel wool.

b Weigh the copper strip.

c Set up the electrolysis apparatus as shown below, with the lead connected to positive and the copper to negative.

d Set the power pack to 4 volts DC and turn it on.



At which electrode is copper deposited?

What happens at the other electrode?

What happens to the solution?

e When the solution is clear, or after 15 minutes, switch the power pack off.

f Remove the copper strip, wash it and leave it to dry. Then weigh it again.

Calculate the mass of copper deposited. (If there is any copper in the bottom of the beaker, you need to collect and weigh it too.)

Calculate the percentage of copper in the copper ore you started with.

Discussion

1 Suggest why the ore had to be crushed before any processing was done.

2 Describe how the copper mineral was separated from the worthless material in Steps 2 and 3.

3 Why was the solution boiled in Step 4?

4 In which steps did the process need an input of energy?

5 Suggest a use for the waste solids from Step 3.

6 How accurate do you think your percentage of copper is? Explain.

7 Could you improve your method to get a higher percentage of copper? How?

Fig 18 Pouring molten steel in a steelworks

Check

1 Use the table below to answer these questions.
   a How is copper extracted from its ore?
   b Which elements are in bauxite? Chalcopyrite?
   c Which metal is found as an element rather than as a compound?
   d Why is there a blank space for the method of extracting gold?
   e Which is the most reactive element in the table? (See Fig 14 on page 185.)
   f Infer which is the most difficult metal to extract.
   g Suggest reasons for the order in which the four metals were first extracted.

Metal	Main ore	Method of extraction	First extracted
aluminium	aluminium oxide (bauxite)	electrolysis	19th century
iron	iron oxide (haematite)	smelt with coke (carbon)	1500 BCE
copper	copper iron sulfide (chalcopyrite)	heat ore in air	3000 BCE
gold	found uncombined		5000 BCE or earlier

2 Use the pie chart on page 184 to answer these questions.
   a Which is the most common non-metal in the Earth's crust?
   b Which is the most common metal?
   c What does the pie chart tell you about commonly used metals such as copper, lead, zinc and silver?

3 Aluminium is the most abundant metal in the Earth's crust, but it is not the cheapest. Suggest why.

4 Write a chemical equation for the smelting of copper oxide using carbon. (See page 185.)

5 Would you expect miners to find nuggets (lumps) of magnesium metal? Explain your answer.

6 Four minerals—A, B, C and D—have the following properties:
- A is soluble in acid.
- B is insoluble in acid, and floats in a water frothing agent mixture.
- C is insoluble in water and in acid.
- D is magnetic.

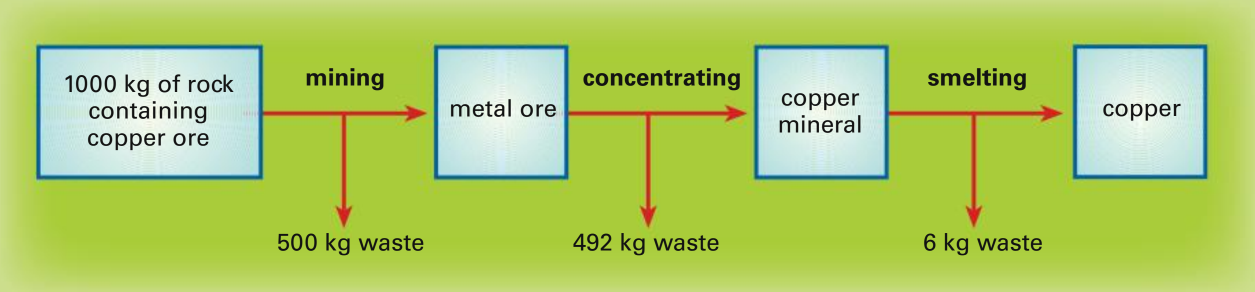
Use this information to work out how you could separate each mineral from a mixture that contains all four.

7 Why is it that one Cu^{2+} ion combines with two electrons?

8 Write down at least three uses for copper.

9 In what ways do the mining of metal ores and the extraction of metals affect the environment?

Challenge



1 The flow chart above shows the extraction of pure copper from rock containing copper ore.

a From each tonne (1000 kg) of rock from the mine, how much of the following do you obtain?

- metal ore
- copper mineral
- copper

b From each tonne of rock mined, how much is waste?

c How would this waste be disposed of?

d What is the average percentage of copper in the mined rock?

e The average percentage of copper in the Earth's crust is 0.005%. Suggest why copper cannot be extracted from ordinary rocks.

2 Which non-metals are commonly found combined with metals in metal ores?

3 When a metal oxide is heated with carbon, a metal is produced. What happens to the oxygen from the oxide? Explain using an example and write an equation.

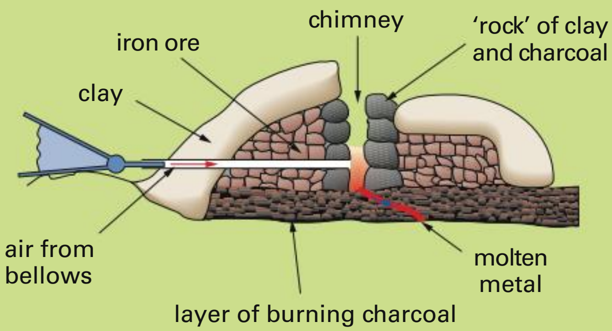
4 a Which ions were present in the blue solution in Step 6 of Investigation 14 (see page 189)? Which ions were attracted towards the negative copper strip?

b Write an equation for the reaction that occurred at the copper strip.

c When you add an iron nail to copper sulfate solution a displacement reaction occurs (see page 187) and the blue colour disappears. Explain what *displacement* is and write an equation for the reaction.

d Objects made of iron exposed to water seeping from copper mines become coated with copper. Explain why this happens.

5 The diagram below shows how iron was extracted from its ore by people in Africa thousands of years ago. How is this similar to the blast furnaces used today? How is it different?



TRY THIS

1 Use the internet or library resources to research a metal of your choice. Make sure you find out:

- where in Australia the metal is found
- what the metal is used for
- the ore from which the metal is extracted
- how and where the metal is refined
- its possible impact on the environment.

Display your findings, for example on a poster.

2 See if you can design a process to extract copper from a mixture of sand and copper oxide, which is insoluble in water.

Check your plan with your teacher, then try it. Record what you do and what happens.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

- atomic number
- electrons
- electrolysis
- gain
- halogens
- non-metals
- ores
- periodic table
- properties
- reactive
- valency

1 Elements can be divided into two groups: metals and ______.

2 The ______ is a way of classifying elements according to their ______. Elements with similar properties are grouped together. It is extremely useful in explaining and predicting the ______ and reactions of elements.

3 The electrons in an atom are arranged in shells around the nucleus. The number of ______ in the outer shell determines the chemical properties of the element.

4 The number of electrons lost or gained by an element determines its ______. For example, alkali metals have a valency of 1+ and ______ have a valency of 1–.

5 All metals conduct heat and are malleable. Some are more ______ than others.

6 Metals can be extracted from their ______ by smelting, ______ or displacement.

7 During the extraction of a metal the positive ions in the mineral ______ electrons to form metal atoms.

Working with technology

Try doing the Chapter 7 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

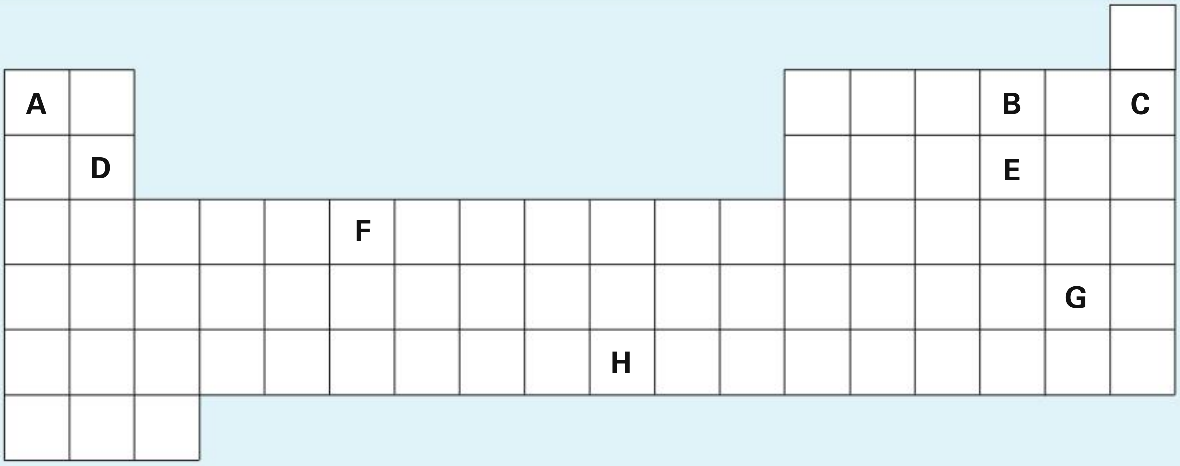
1 In the periodic table, all the gases except hydrogen are:
A in the first period
B in the first group
C in the same family
D on the right-hand side.

2 Use the periodic table on pages 170 and 171 to predict which one of the following elements has properties different from the other three.
A aluminium
B barium
C calcium
D radium

3 A sample of lead could be obtained in the laboratory by:
A heating lead oxide very strongly
B heating lead oxide with carbon
C adding gold to lead nitrate solution
D adding dilute sulfuric acid to lead carbonate.

4 Air Pollution Control finds that a smelter is producing excessive levels of poisonous sulfur dioxide gas. What would you suggest be done?
A Shut down the smelter.
B Convert the sulfur dioxide into useful substances.
C Shift the smelter into the desert.
D Cut down production in the smelter so that less sulfur dioxide is produced.
E Increase the height of the smelter's chimneys.
Say why you rejected the other alternatives.

5 An impure copper sample contains a silver impurity. During electrolytic refining of this sample:
a what happens to the copper?
b what happens to the silver?



6 In the periodic table above, some elements have been replaced by letters. Use the letters to answer these questions. Find:
- **a** the two elements that are in the same group
- **b** two elements that are in the same period
- **c** the two elements that are gases at room temperature
- **d** the elements that are metals
- **e** the two transition metals
- **f** the element that is a noble gas
- **g** the element that is an alkali metal
- **h** the element that is a halogen
- **i** two elements that are likely to react.

7 Platinum exists as an uncombined element in nature. Copper can exist uncombined but more commonly occurs as a compound. Zinc is always found as a compound.
- **a** Arrange the three metals in order from most reactive to least reactive.
- **b** Which metal would be the best to polish and use as a mirror? Why?

8 Imagine that you are searching for two undiscovered elements with atomic numbers 117 and 118. Use the periodic table on pages 170 and 171 to predict the chemical properties of each of these elements.

9 Prepare a flow chart showing the sequence of processes used to convert copper ore (chalcopyrite) to copper metal suitable for electrical wiring.

10 Explain in terms of their chemical structures why copper is a good conductor of electricity and diamond is an insulator.

11
- **a** Copy and complete the table below using the information on pages 173 and 174.
- **b** Which element has six protons in its nucleus?
- **c** Which element has all its electron shells full?
- **d** How many valence electrons does sodium have?
- **e** Which elements are likely to gain or lose one electron?

Element	Symbol	Atomic number	No. of electrons		
			1st shell	2nd shell	3rd shell
hydrogen					
carbon					
neon					
sodium					
chlorine					

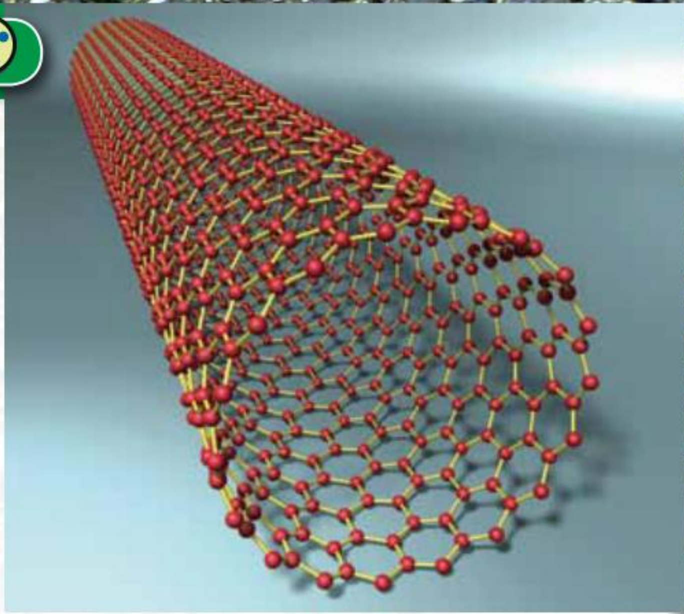
Check your answers on page 307.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science as a Human Endeavour



Nanotubes

Carbon nanotubes or buckytubes (page 182) are flat sheets of carbon atoms arranged in hexagons and rolled into a hollow tube, like rolled-up chicken wire. These nanotubes are 5000 times thinner than a human hair, but can be assembled to create materials six times lighter and 100 times stronger than steel!

Nanotubes were discovered in 1991 but were very difficult to make in large quantities. In 1998 Dr Ying Chen from the Australian National University in Canberra discovered how to make them with technology used by miners to crush rock. Graphite powder is ground into extremely fine particles in a revolving cylinder in which steel balls tumble against each other for hundreds of hours. The fine material is then heated to about 1000°C to produce the nanotubes, which sell for about $900 per gram. Dr Chen has also made nanotubes from boron nitride. These tubes have alternating atoms of boron and nitrogen instead of only carbon atoms.

Nanotubes could be used to make super-light, super-strong nanocars powered by fuel cells using hydrogen. The flammable hydrogen could be safely stored in fuel tanks consisting of arrays of nanotubes that act like a sponge, absorbing hydrogen gas in large quantities. The hydrogen can then be released when required by mild heating.

Nanotubes could be used to make thinner flat-screen TVs, in which electrons are fired at a screen from the tips of nanotubes, giving a sharper and brighter picture. Future computers using nanotube transistors and other electronic devices are expected to be the size of mobile phones, but faster and more powerful than desk-top models. Scientists from CSIRO in Geelong have discovered a way to spin carbon nanotubes into yarn. One use for this would be in bulletproof vests.

In a science-fiction novel written in 1979, Arthur C. Clarke describes the construction in the 22nd century of a 'space elevator'. With the development of super-light, super-strong materials made from nanotubes, this science fiction may become reality. The space elevator would consist of a cable about 47 000 km long yet no more than a few centimetres thick, stretching from Earth into orbit. The top of the cable would be in geostationary orbit, so that it stayed in the same place above Earth's surface. Robotic carriages attached to the cable could take cargo and people into space much more cheaply than by rocket. To better understand this, think of whirling a ball around your head on the end of a string. The whirling ball keeps the string tight.

Questions

1. In a carbon nanotube, how many other carbon atoms is each carbon atom bonded to?
2. From your knowledge of the periodic table, suggest why nanotubes can be made from boron and nitrogen as well as carbon.
3. Would you expect the price of nanotube powder to increase or decrease? Explain your answer.
4. Do you think the space elevator will ever become a reality? Why or why not?
5. Researchers recently injected mice with needle-like carbon nanotube fibres and found they developed the same types of problems as people who have been exposed to asbestos, which causes lung cancer. Should we stop the development of nanotube technology because of this? Justify your answer.
6. Research the internet to find the latest developments in nanotube technology.


Queensland floods 2011

8 Earth systems

In this chapter you will …

Science Understanding

- give examples of how global systems rely on interactions between the biosphere, lithosphere, hydrosphere and atmosphere
- use a model greenhouse to explain how the atmosphere affects the temperature of the Earth
- consider scenarios for future greenhouse gas emissions

Science as a Human Endeavour

- make a group decision about the construction of a freeway through a koala habitat

Science Inquiry Skills

- prepare and present a persuasive speech on an environmental issue
- evaluate scientific data about the possible causes of the rising concentration of CO_2 in our atmosphere

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

The photos on this and the previous page show some of the extreme weather conditions that countries around the world have experienced over the last few years. These disasters and other atmospheric problems have been blamed on such things as:

- emissions from power stations and car engines
- the hole in the ozone layer
- global warming
- increased sunspot activity

1 Form a small group and brainstorm ideas about how each of these factors could be responsible for the extreme weather conditions and other problems such as an increase in skin cancers.

2 Keep your answers for later on in this chapter (page 216).

Cyclonic weather in Australia

Melting sea ice in the Arctic Ocean

8.1 Four spheres

People who study the Earth often think of it as being made up of four spheres.

The **lithosphere** is the Earth's crust and the upper layer of the semi-molten mantle. It is broken into giant tectonic plates that float on the mantle. These plates move a little each year, causing earthquakes and volcanoes. The lithosphere consists of rocks, soil, sand, minerals, coal, oil and natural gas.

Earth's oceans lakes, rivers and creeks make up the **hydrosphere**. The oceans don't form a complete sphere, but they cover two-thirds of the Earth's surface. The hydrosphere also includes groundwater—water that has soaked underground into rocks and soil.

There are living things on the land and in the oceans, lakes and rivers. There are also billions of living things in the soil. Scientists like to think of a web of life right around the planet. They call this the **biosphere**. It also includes part of the atmosphere, since living things can be found up to 10 000 m above the Earth's surface.

Finally, wrapped like a big fluffy doona around the Earth, keeping it warm, is the layer of air we call the **atmosphere**. You will learn more about it in Section 8.3.

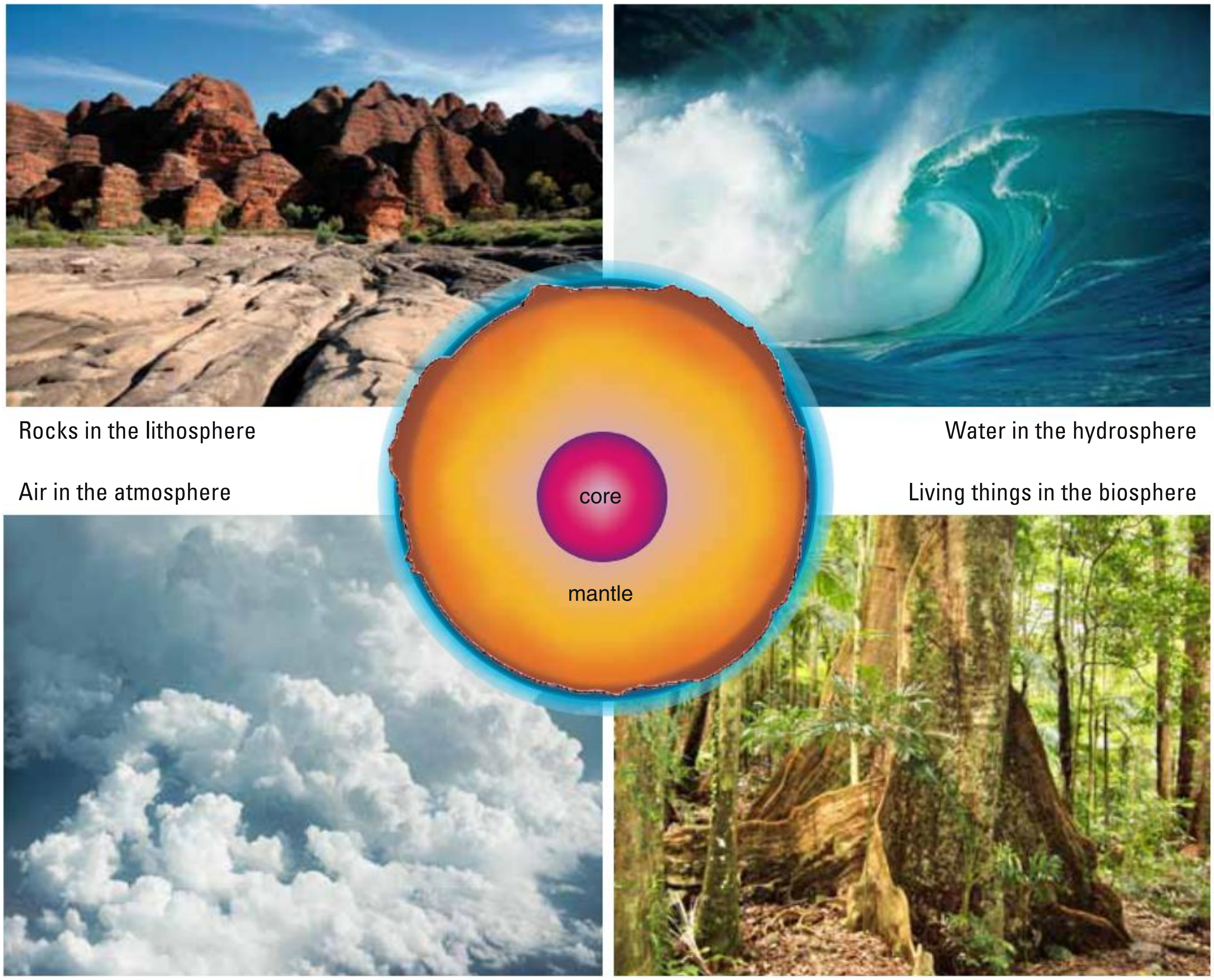


Fig 1 The Earth's four spheres.

The cycling of chemicals

Chemicals are constantly on the move between the lithosphere, hydrosphere, biosphere and atmosphere. Think of a carbon atom that starts out as part of a carbon dioxide molecule (CO_2) in the atmosphere. It is taken in by a plant in the biosphere and converted to plant food (glucose $C_6H_{12}O_6$). The plant is then eaten by an animal, which eventually dies. The remains of the animal are buried in the soil of the lithosphere or washed into a stream of the hydrosphere. As the carbon compounds in the remains decay, they are eventually broken down to CO_2 which returns to the atmosphere. So the carbon atom has gone in a full cycle through the four spheres.

Water also flows freely between the spheres. Most of it is in the hydrosphere, but it is also in clouds in the atmosphere. Rain falling on the Earth soaks into the lithosphere as groundwater, then reappears as springs. Here it may be drunk by animals or soaked up by the roots of plants into the biosphere.

Most of the oxygen (O_2) in the atmosphere is produced during photosynthesis by trees, especially in tropical rainforests, or by **phytoplankton** (FIGHT-oh-plank-ton) floating in the oceans. The word *phytoplankton* comes from two Greek words—*phyton* meaning ‘plant’ and *planktos* meaning ‘drifter’. These microscopic organisms, such as diatoms (see the photo below) are found in vast numbers near the surface of the ocean, where there may be many millions per cubic metre. These phytoplankton are the basis of all aquatic food chains.

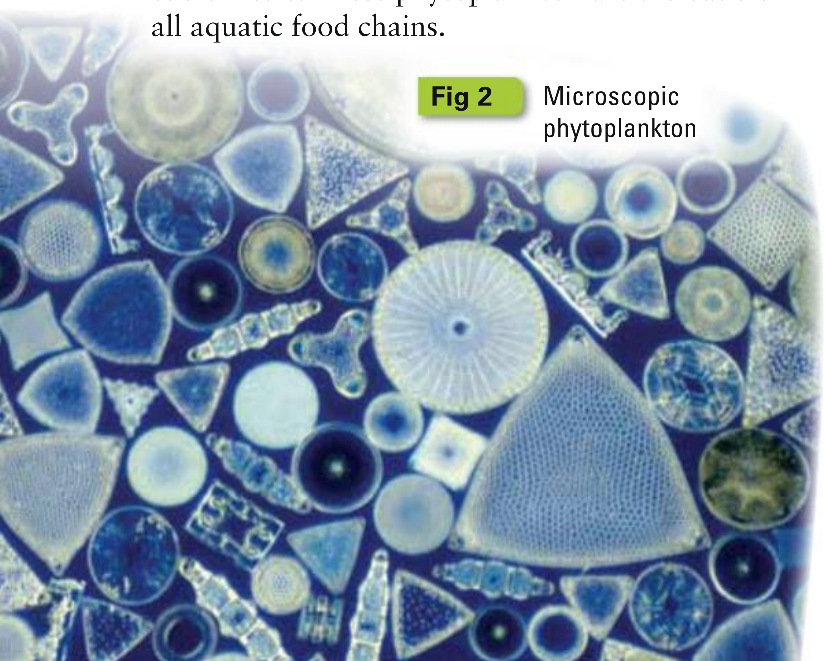


Fig 2 Microscopic phytoplankton

Huge amounts of CO_2 from the atmosphere dissolve in the water of the oceans where it is used by the phytoplankton in photosynthesis. When the CO_2 dissolves it forms carbonic acid. However, with increasing levels of CO_2 in the atmosphere the phytoplankton cannot use up all the dissolved CO_2. As a result the oceans are becoming more acidic. This in turn is affecting organisms in the marine biosphere. For example, in recent years scientists have observed a slowing in the growth of coral on the Great Barrier Reef.

Volcanoes can also cause a flow of matter between spheres. A large volcanic explosion can send enough dust and gases into the atmosphere to affect the weather in other parts of the world, thousands of kilometres away. For example, when a volcano in southern Chile erupted in June 2011, the ash cloud was blown over Australia.

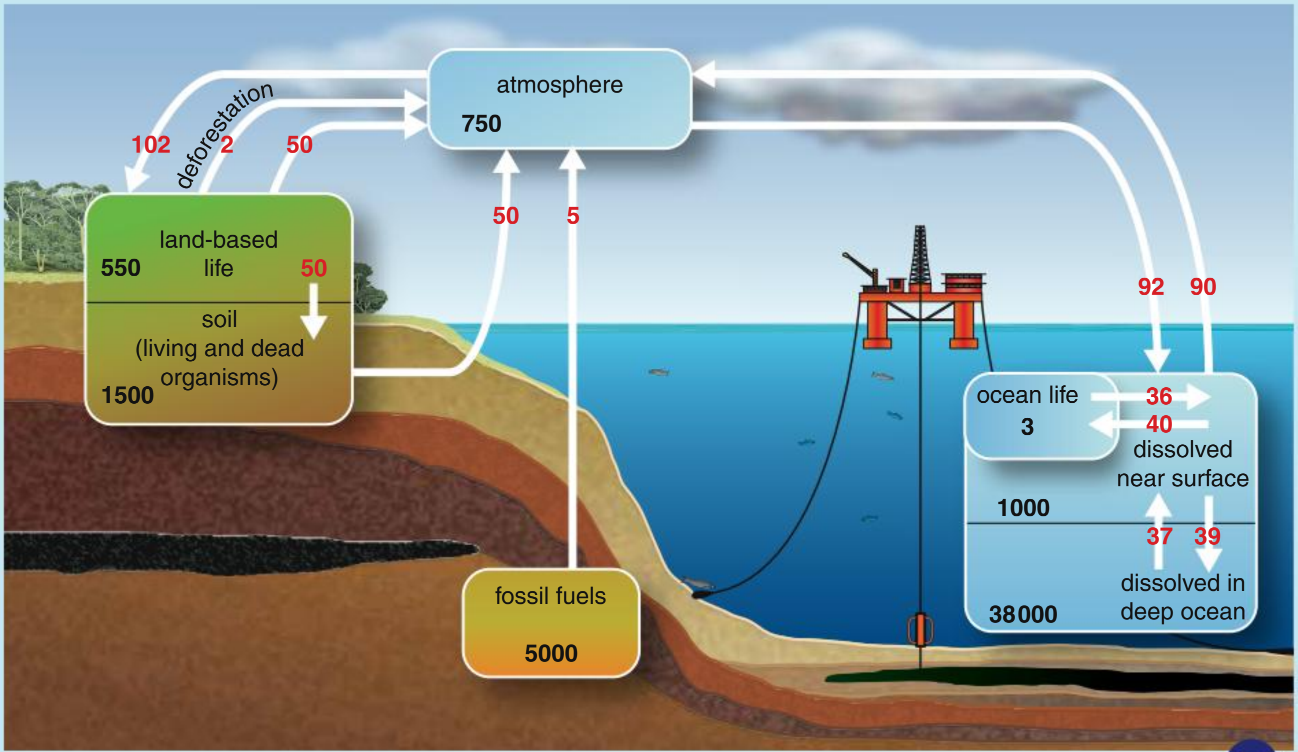
Fig 3 This volcano in Chile erupted in 2011, sending an ash cloud around the world.

Activity

The carbon cycle

In *ScienceWorld 9* you learnt about the carbon cycle, where carbon flows between the atmosphere, the biosphere, the hydrosphere and the lithosphere. In the diagram below the numbers are gigatonnes of carbon, where 1 gigatonne = 1000 million tonnes (10^9 tonnes). The numbers in black are estimates of the total mass of carbon throughout the world. The numbers in red are the estimated flows of carbon *between* the spheres each year. Use the diagram to answer the questions below.

1. Describe where you would find carbon in each of the four spheres.
2. What is the total mass of carbon in each of the four spheres? Which sphere contains the most carbon?
3. Suggest why carbon in fossil fuels is said to be 'locked away'.
4. Suggest why the ocean is often referred to as a 'carbon sink'.
5. What is the total mass of carbon passing into the atmosphere each year?
6. What is the total mass of carbon passing out of the atmosphere each year?
7. In a year, is the mass of carbon in the atmosphere increasing, decreasing or staying the same? If it is changing, by how much each year?
8. What mass of carbon is removed from the atmosphere each year by photosynthesis in land plants?
9. What mass of carbon is *returned* to the atmosphere from living things on land?
10. What is the *net* flow of carbon between the atmosphere and living things on land?
11. Suggest why deforestation (the cutting down of forests) is shown as an arrow from land-based life to the atmosphere.
12. Does the diagram suggest that human activity is affecting the global carbon cycle? Explain your answer.



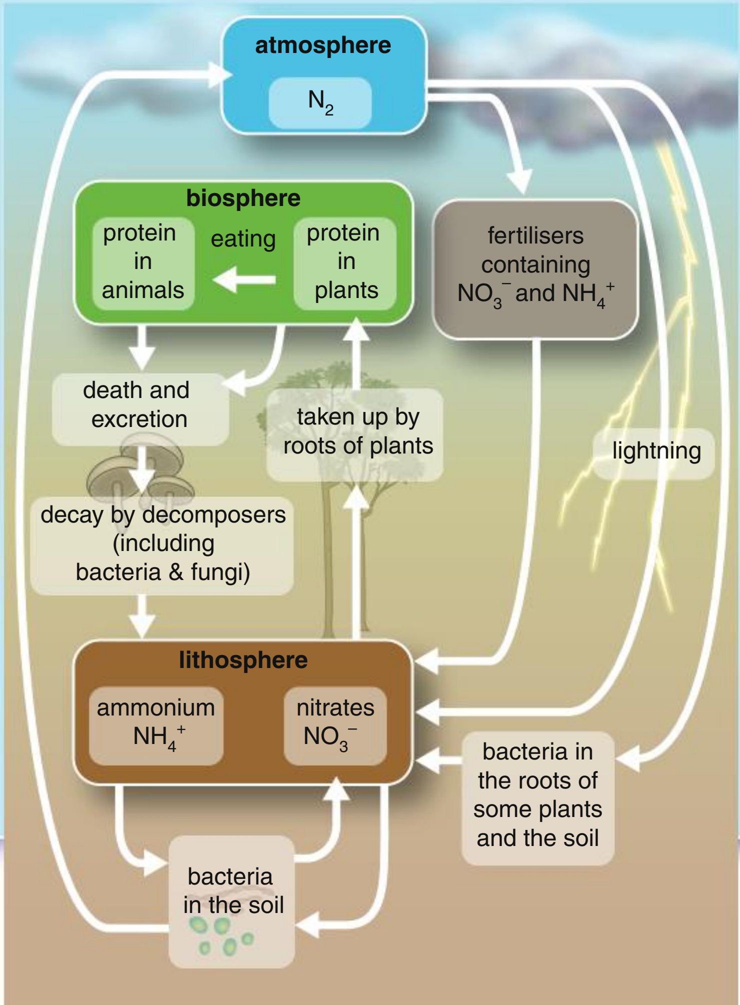
The nitrogen cycle

Nitrogen is needed by living organisms to make proteins. It exists in the atmosphere as a gas (N_2). However, plants cannot use nitrogen directly from the air. Only a few specialised bacteria and algae can convert N_2 gas to nitrate ions (NO_3^-) and ammonium ions (NH_4^+). This process is called *fixing* nitrogen.

The nitrate and ammonium ions are soluble in water, so they can enter the hydrosphere and the lithosphere. They can then be absorbed by plant roots and enter the biosphere. The enormous energy of lightning can also cause nitrogen and oxygen atoms in the atmosphere to combine to form nitrogen oxides, which dissolve in rain to form nitrates.

The growing of crops takes nitrogen from the soil in the form of nitrate ions. This is why farmers and gardeners add fertilisers to the soil to replace the nitrogen used by the crops. The fertilisers are made from ammonia, which is made by the Haber process (see page 100):

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$



As much nitrogen is fixed by industry as is fixed by natural processes. So the manufacture of fertilisers now has a major impact on the nitrogen cycle.

Use the diagram below to answer these questions.

1 How does nitrogen enter the lithosphere?
2 What role do decomposers play in the nitrogen cycle?
3 Which nitrogen substance is taken up by the roots of plants?
4 Why is it that plants can be short of nitrogen when the air is four-fifths nitrogen?
5 Suggest possible consequences of the large-scale fixing of nitrogen by industry, and the use of synthetic nitrogen compounds as fertilisers.

Fig 4 Nitrogen-fixing bacteria are found in root nodules on certain plants like this pea plant.

Extra for experts

You have probably heard about government legislation where power stations and other industries pay a price for every tonne of carbon they release into the atmosphere.

Coal is mainly carbon, with a few impurities. So 1 tonne of coal is effectively 1 tonne of carbon. However, most of the substances in the carbon cycle are carbon *compounds*. For example, when coal is burnt, one carbon atom combines with two oxygen atoms from the air to form a molecule of carbon dioxide, with the formula CO_2. So 1 tonne of carbon produces more than 1 tonne of CO_2.

To work out exactly how much CO_2 is formed, you need to know about *relative atomic mass*. Because atoms are so small, it is very difficult to measure their individual masses.

So chemists compare the mass of one atom to that of another atom. They use carbon as the standard and say it has a relative mass of 12. A titanium atom is four times the mass of a carbon atom, so its relative atomic mass is $12 \times 4 = 48$.

Relative atomic masses	
hydrogen H	1
carbon C	12
nitrogen N	14
oxygen O	16

If you know the formula of a compound, you can calculate its *relative molecular mass*. For example, the relative molecular mass of CO_2 is $12 + (2 \times 16) = 44$. So a CO_2 molecule is 44/12 heavier than a carbon atom. This means that when 1 tonne of carbon burns, it forms 44/12 = 3.7 tonnes of CO_2. To check that you understand how this is done, calculate how much carbon would be in a tonne of methane gas (CH_4).

Check

1 a Which process removes carbon dioxide from the atmosphere?
  b Which processes return carbon dioxide to the atmosphere?

2 What are phytoplankton? What role do they play in ecosystem Earth?

3 Which organisms are responsible for making nitrogen from the air available to plants?

4 Why does soil become less fertile if crops are grown and harvested in the same place year after year?

5 Describe an interaction between the:
  a biosphere and the atmosphere
  b biosphere and the hydrosphere
  c biosphere and the lithosphere
  d atmosphere and the hydrosphere
  e atmosphere and the lithosphere
  f hydrosphere and the lithosphere.

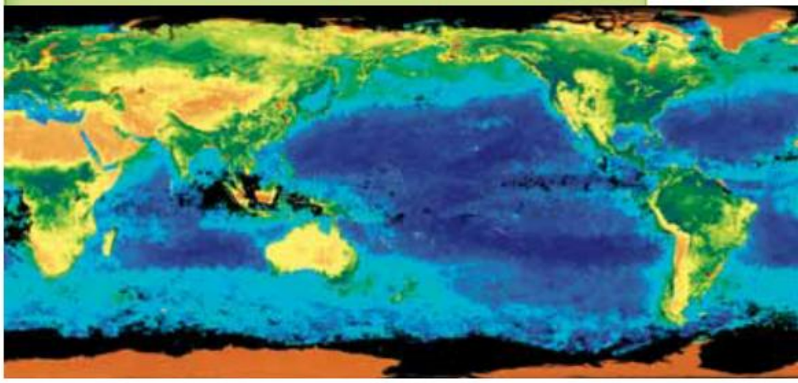
6 Why are the oceans becoming more acidic?

Challenge

This satellite image of the Earth's biosphere shows the distribution of vegetation on land and phytoplankton in the oceans. The colours represent densities of chlorophyll. Colours in the ocean range from red (most dense) through yellow, green and blue to black (least dense). Land colours range from dark green (most) through yellow to dark orange (least).

a How can you explain the variation in the density of chlorophyll on the land?

b Suggest why the density of chlorophyll in the oceans varies.



8.2 Effects of human activity

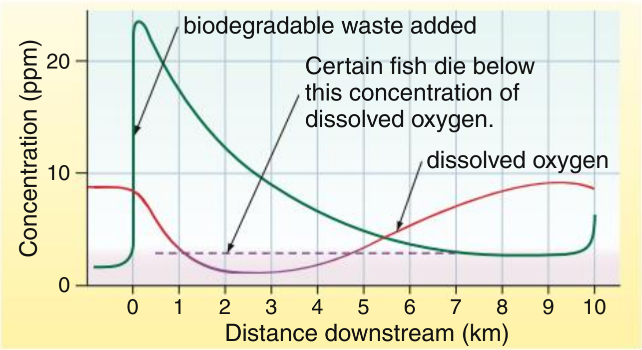
Pollution of the hydrosphere

In Australia each of us uses about 220 litres of clean water every day for drinking, cooking, washing, flushing the toilet and so on; and the many plants and animals around us also rely on water being pure. But our water can become polluted. **Sewage** (SUE-idge) is a common water pollutant—it contains body wastes, food scraps, detergents, grease and dirt. Industries produce wastes that sometimes flow into watercourses, and in country areas pesticides and fertilisers sometimes pollute water in creeks and rivers.

Biodegradable wastes

Biodegradable waste is waste that can be broken down by the micro-organisms (mainly bacteria) in water. Examples of biodegradable waste are sewage, animal wastes, decaying plants and wastes from some industries, e.g. food processing. The micro-organisms degrade the wastes and use up oxygen in the process. However, because water can dissolve only a small amount of oxygen (about 10 milligrams per litre at 15°C), serious oxygen depletion can occur in heavily polluted water.

The graph below shows the concentration of dissolved oxygen in a river when biodegradable wastes are being added to it. In the polluted water much of the dissolved oxygen is used up by bacteria as they reproduce rapidly and feed on the wastes. The fish and other living things in this part of the river will die unless they move to water containing more oxygen. Further downstream, the oxygen level starts to return to normal.



The **biological oxygen demand** (**BOD**) is a measure of the amount of biodegradable material in the water. It measures the quantity of dissolved oxygen required by the bacteria to degrade (oxidise) the organic wastes. As the dissolved oxygen is used up, it is replaced by the slow absorption of more oxygen from the air, but the rate of oxygen absorption is usually much slower than the rate at which it is used up by the bacteria.

Wastes such as sewage and runoff from farms contain *nutrients* (nitrates and phosphates), which can act as plant fertilisers. Algae and other aquatic plants feed on these nutrients and grow in large numbers. When these plants die, bacteria decompose them, using up much of the oxygen in the water. Most living things die through lack of oxygen, and the water turns foul. The whole process is called **eutrophication** (YOU-tro-fi-KAY-shun).

In 1991 excessive nutrients and drought conditions in the Darling River in New South Wales and southern Queensland produced one of the largest recorded outbreaks of blue-green algae in the world. The blue-green algae turn the water an emerald green colour and produce toxins that can cause skin and eye irritation, gastroenteritis and respiratory diseases.

Fig 5 Fish will die if the dissolved oxygen concentration falls below a certain level.

Thermal pollution

All animals are temperature sensitive. For example, humans prefer a constant temperature of about 20–25°C, although they can survive in a much larger range (-15°C to 45°C). Plants grow more rapidly in warmer weather. Fish, being cold-blooded animals, become more active in warm water, and so need more oxygen. Most fish have a narrow tolerance to water temperature, and will die if the temperature exceeds 40°C. In addition, temperature affects their ability to reproduce.

Temperature also affects the amount of oxygen dissolved in the water. The higher the temperature the *less* dissolved oxygen there is. Many power stations and factories use water for cooling. The resulting hot water is usually pumped back into streams and lakes, causing the water temperature to increase and the oxygen concentration to decrease.

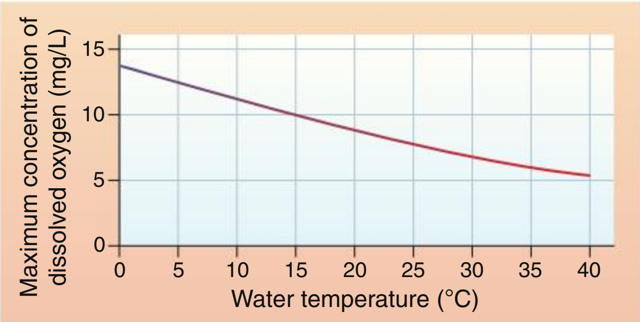


Fig 6 The concentration of dissolved oxygen in water at different temperatures, when the air is in contact with it

Non-biodegradable wastes

Wastes that do not break down or that do so very slowly are said to be *non-biodegradable*. Examples of non-biodegradable pollutants are:

- some insecticides, e.g. DDT
- heavy metals such as lead, mercury and cadmium
- salts such as sodium chloride.

These chemicals are usually released into the environment in only small amounts, but many of them can build up in food chains.

Suppose that a crop in a paddock is sprayed with a non-biodegradable insecticide. One insect might eat 100 plants a day. Then at night one frog might eat 100 of these insects. The next day one kookaburra might eat 10 frogs. So the kookaburra has effectively eaten all the insecticide on 100 000 plants!

The concentration of the pollutant increases as you go up the food chain, by a process called **biomagnification**. Animals at higher feeding levels, like humans, are more likely to be affected by the pollutant than plants or animals at lower feeding levels.

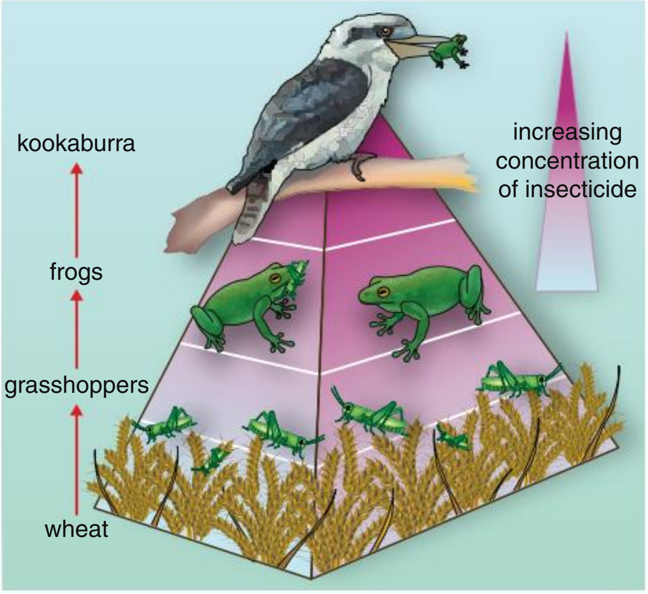


Fig 7 In biomagnification the concentration of a non-biodegradable pollutant increases as you go up a food chain.

Pollutants in groundwater

Groundwater is water that has soaked underground through the soil and permeable rocks of the lithosphere. Pollutants can enter this groundwater in various ways. For example, fertilisers, pesticides and herbicides can soak down through the soil on farms, and toxic wastes can leak from landfill sites. The upper level of the groundwater, below which the soil is saturated with water, is called the *watertable*. If the watertable reaches the surface, it brings any pollutants with it, and in some areas of Australia this process has caused a major problem called *salinity*.

The soil naturally contains salts such as sodium chloride, which dissolve in the groundwater. Trees generally have deep roots and act like pumps, removing water from the soil. Pastures and crops absorb less water than trees, so removing trees and replacing them with pastures and crops changes the water balance in the soil. There is increased stream flow and the watertable rises, bringing dissolved salt with it. This salt is deposited onto the soil surface, killing any vegetation. Irrigation can also cause watertables to rise.

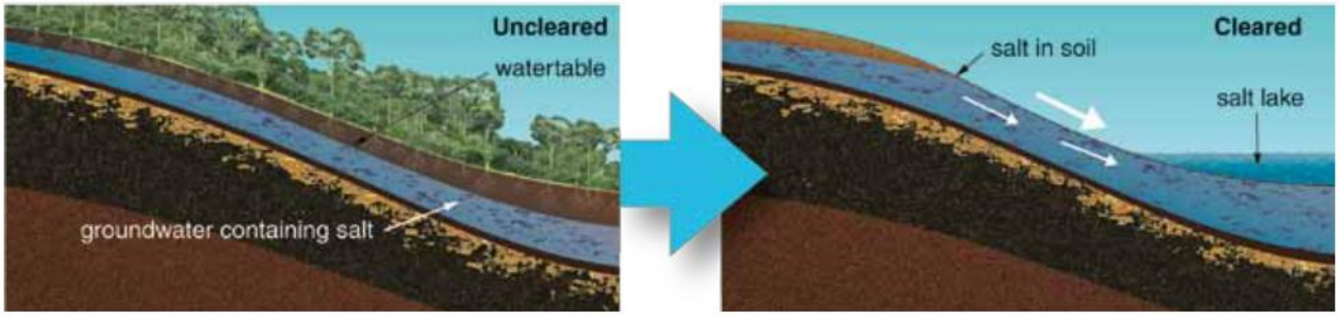
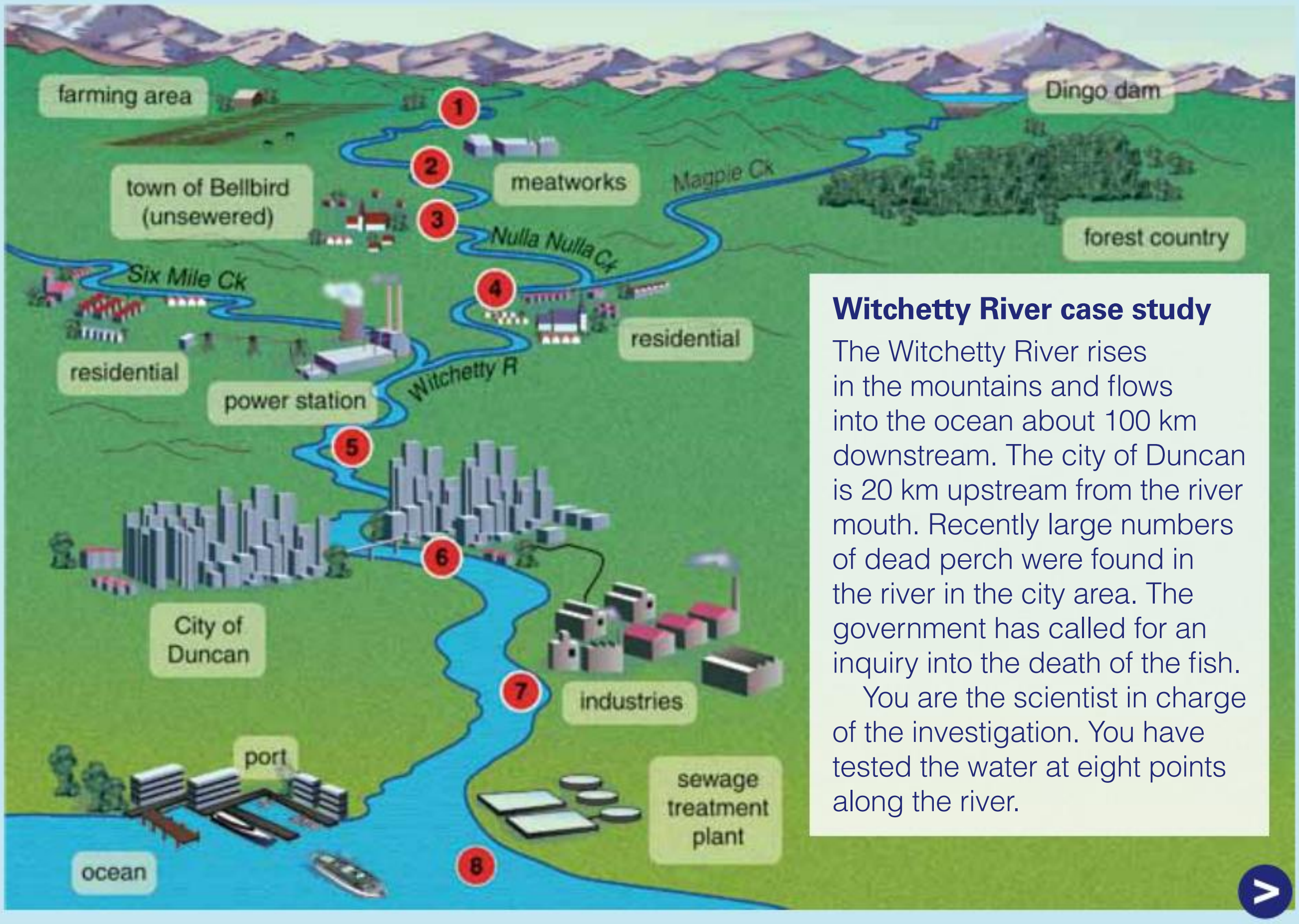


Fig 8 As the watertable rises, it brings salt to the surface.

Activity



Witchetty River case study

The Witchetty River rises in the mountains and flows into the ocean about 100 km downstream. The city of Duncan is 20 km upstream from the river mouth. Recently large numbers of dead perch were found in the river in the city area. The government has called for an inquiry into the death of the fish.

You are the scientist in charge of the investigation. You have tested the water at eight points along the river.

Metals	Concentration ($\times 10^{-2}$ milligrams per litre)			
	Six months ago	Now	Limit for freshwater life	Limit for humans
arsenic	0.03	0.03	44	5
cadmium	0.02	0.01	0.15	1
lead	2.1	1.8	7.4	5
mercury	0.04	0.23	0.41	5

Test 1

Water samples were taken at point 6 to check for four different metals. The results are compared with values obtained six months ago at the same location.

- **a** Which metals have increased in concentration in the last six months? Which have decreased?
- **b** Do you think any of the metals dissolved in the Witchetty River were responsible for the dead fish? Explain your answer.

Test 2

The acidity of the river was tested at four different points. Freshwater fish can only survive in water with a pH between 6.5 and 7.6. The results are shown below.

- **a** At which points is the water acidic?
- **b** Suggest why the acidity of the water varies along the river.
- **c** Was the acidity responsible for the death of the fish?

Sample point	pH of water
1	6.8
4	7.0
6	7.3
8	6.6

Test 3

Water temperatures and dissolved oxygen concentrations were measured at all eight points along the river. It is known that perch need the water temperature below 24°C and the oxygen concentration above 4 mg/L.

Point	Distance along river (km)	Water temperature (°C)	Dissolved oxygen (mg/L)
1	0	18	9.5
2	40	20	9.1
3	50	21	5.0
4	60	22	5.4
5	70	25	4.5
6	80	24	4.0
7	90	23	4.5
8	100	22	4.8

- **a** Draw a graph of temperature versus distance along the river.
- **b** Try to explain the shape of the graph.
- **c** Where was the temperature highest? Suggest a reason for this. Could this have caused the death of the fish?
- **d** Plot the dissolved oxygen levels on the same graph. Use different colours for the two lines and label them.
- **e** Try to explain the shape of the dissolved oxygen graph.
- **f** Where was the dissolved oxygen level lowest? Suggest reasons for this. Could this have caused the death of the fish?

Write your report for the government, saying what killed the fish, and giving recommendations to avoid this happening in the future.

Activity

Biosphere under threat

This activity involves group decision-making to try to find a solution to the problem of freeway construction and koala habitat destruction.

Work in a group of three or four, and read through the following instructions for group decision-making.

Group decision-making

- Be courteous and reasonable in your discussions. Make sure all members contribute.
- Listen to the opinions of others; remember that differences of opinion are useful in clarifying issues.
- If possible, all members must agree with the final decision; avoid taking a vote.
- Do not change your mind simply to avoid conflict or friendship tensions.

The problem

A large city of nearly 2 million people is 80 km away from a popular coastal tourist resort city of 300 000 people. The two cities are presently connected by a four-lane freeway and a double rail line. The area between the two cities is the fastest growing region in Australia, and the government estimates that by the year 2050 an extra 1 million people will be living in the region. However, the present road and rail network will not be able to cope with this increased population.

On the eastern side of the present freeway and suburbs is a large area of natural forest containing the food trees for one of the largest koala colonies in Australia.

The government planners have designed two routes for a second four-lane freeway. See the map. Many of the residents do not want the freeway anywhere near the forest or parklands and say there are other alternatives.

Fig 9 Map of the area showing the koala habitat and the proposed freeways

Your task

Your task is to make a recommendation about the future of the area. Use the ideas and questions below as a guide.

1 Make a list of the main aspects of the problem.

2 What do you think are the present threats to the koalas in the area? Why is the freeway a threat to the koalas? How will the extra people in the area be a threat to the koalas?

3 Proposed route A is the cheaper route to construct. Planners say that some of the freeway will be elevated and will not restrict the movement of the koalas. Is route A a better alternative than route B? Why do you think most residents reject both routes A and B?

4 The present freeway is the only major road connecting the two cities. Should more lanes be added to it?

5 If the new freeway is not built and the old one is not upgraded, are there any other transportation alternatives?

6 Some groups say that the preservation of the koalas is the number one priority. Do you think this is a realistic idea?

7 Should residents and other people be able to influence the decision-making processes of a government?

Now make your recommendations about the future planning of this area to include housing, transportation and wildlife. You may be asked to present this to the class.

Check

1 Animal wastes are biodegradable but many pesticides are not. Explain the difference.

2 a Explain two ways in which human activities can cause water to become turbid (not clear).

b What effects would increased turbidity have on photosynthesis carried out by aquatic algae and plants?

3 How can the clearing of trees affect the level of the watertable many kilometres away?

Challenge

1 Use the graph on page 202 to answer these questions.

a What was the concentration of dissolved oxygen in the river before the wastes were added?

b Below what oxygen concentration do fish die?

c What distance downstream would you expect to find dead fish?

d About 8 km downstream, oxygen levels have returned to acceptable levels. How did this happen?

e When dissolved oxygen is low, BOD is high, and vice versa. Why is this?

f Use the graph to predict what will happen downstream from the 10 km mark.

2 Pesticides have been found in fish-eating birds that live in Antarctica. These pesticides were used to control pests on land thousands of kilometres away. Explain how the pesticides got from the areas where they were used into the birds.

3 Soon after a logging company started removing trees from slopes of a river valley, people noticed that there were fewer fish in the river. They inferred that removing the trees has caused changes in the environment that eventually affected the fish.

a Using what you have learnt in this section, explain how removing the trees could affect the fish.

b Suggest how it might be possible to allow loggers to remove trees without harming the fish.

8.3 The atmosphere

The Earth is a large self-sustaining ecosystem. Apart from the odd spacecraft and a small amount of hydrogen gas that escapes into space, all the matter on the Earth is recycled and re-used over and over.

Earth's atmosphere

If the Earth was a sphere 1 metre in diameter, 90% of the atmosphere would make a layer about 1 millimetre thick. So the atmosphere, which is essential to life and which protects us from meteors, UV light and deadly cosmic rays, is only a relatively very thin layer.

The force of gravity holds the atmosphere close to the Earth's surface. As you move away from the Earth, the atmosphere becomes less dense, and at a height of around 1000 km you reach the vacuum of space. Scientists describe the atmosphere as consisting of three main layers. Each layer fades into the next, so that it is difficult to say where one layer ends and the next begins.

Troposphere

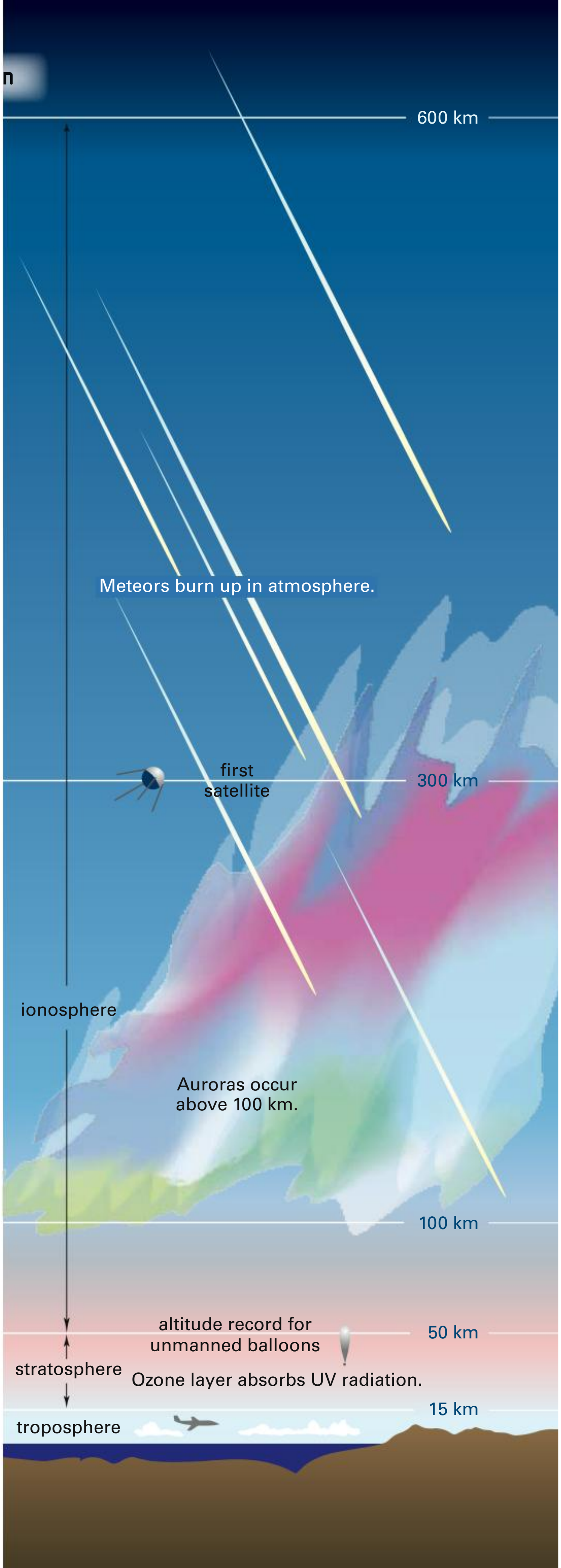
The layer closest to the Earth is called the **troposphere** (TROP-os-fear). It is about 15 km thick and contains about 75% of the air in the atmosphere. It also contains most of the water vapour, dust and clouds, and is the main influence on our weather. The temperature decreases with height in this layer.

Stratosphere

The **stratosphere** begins at a height of about 15 km. As you move upwards, the temperature increases due to the absorption of ultraviolet radiation from the sun by molecules of ozone gas.

Ionosphere

The **ionosphere** (eye-ON-os-fear) is the layer furthest from the Earth, and it gets very hot—about 1200°C at a height of 500 km. The sun constantly emits electrically charged particles. When these particles collide with the gases in the ionosphere, the gas molecules are changed into ions—hence the name ionosphere.



The greenhouse effect

Of all the planets in our solar system, only Earth has the correct temperature range to support life as we know it. On one side of us is the planet Venus, which is too hot for life, and on the other side is Mars, which is too cold. But it is not only our distance from the sun that is important. Our moon, which is the same distance from the sun as Earth, cannot support life. It is extremely hot during the day and extremely cold at night. It lacks a blanket of air to even out the temperature.

There are similarities in the way a greenhouse and the Earth's atmosphere work. Sunlight passes through a glass greenhouse. Inside the greenhouse, the soil and plants absorb this radiation and heat up. Heat is then radiated from everything in the greenhouse. However, this heat (infrared radiation) has a longer wavelength than light and cannot pass through glass, and is trapped inside. So the temperature inside a greenhouse can be quite high, even on a cold day.

The Earth constantly receives radiation from the sun, mostly as light. Some of this radiation is reflected back into space by the atmosphere (including clouds) before it reaches the surface. The rest of the solar radiation is absorbed, causing the land and oceans to warm up. The infrared radiation is then emitted from the Earth's surface out to space.

Unlike the glass, which traps the infrared radiation inside the greenhouse, water vapour, carbon dioxide and other gases in the atmosphere absorb some of this infrared radiation given off from the Earth's surface. These **greenhouse gases** re-emit this radiation in all directions, some back to the Earth. As a result, the Earth's surface loses less heat to space than it would if these gases were not there. The whole process is called the **greenhouse effect**.

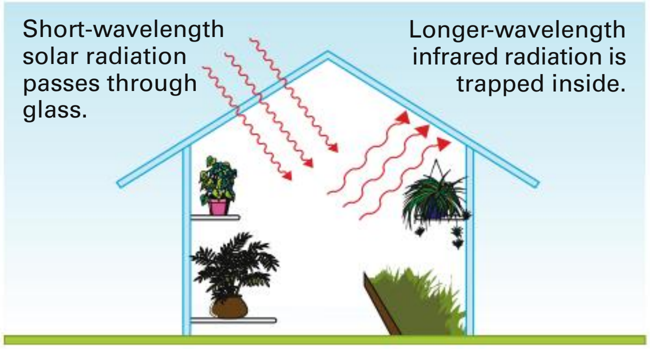
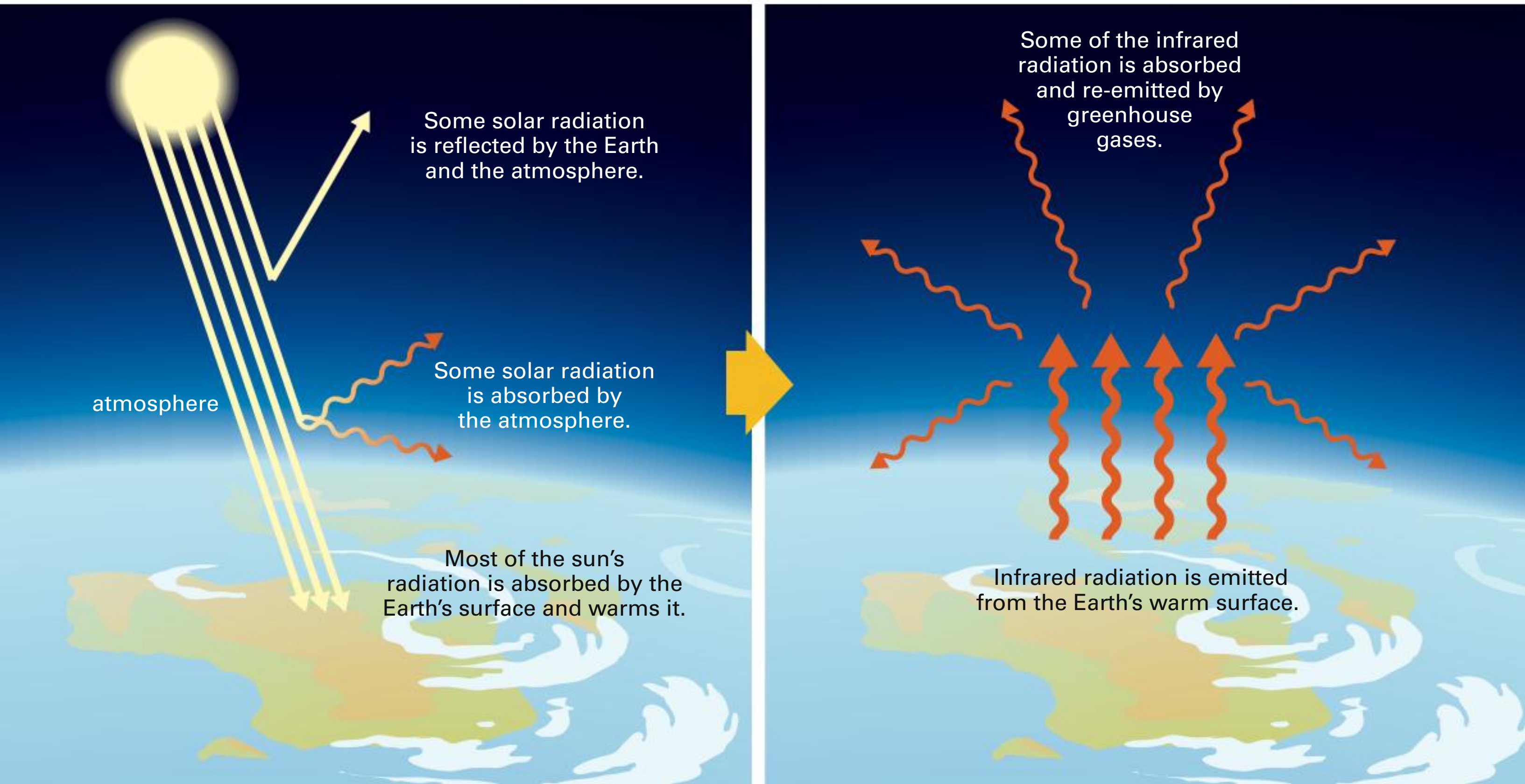


Fig 10 How a greenhouse works

Fig 11 Greenhouse gases in the atmosphere absorb infrared radiation and re-emit it back to Earth.



Investigation 15 A model greenhouse

Aim

To set up a model greenhouse.

Materials

- 2 microscope slides
- adhesive tape
- 2 small cardboard boxes or plastic containers, e.g. margarine or takeaway containers
- 2 thermometers

Planning and Safety Check

- Read through the Method carefully. You will need to leave your equipment for at least 20 minutes in the sun or, if it is overcast, you will need to set up lights.
- Prepare a data table for your results.

Working with technology: You could use a temperature probe and a datalogger instead of thermometers.

Method

1 Lay the two slides side by side and tape them together. Cut a hole in both boxes as shown.

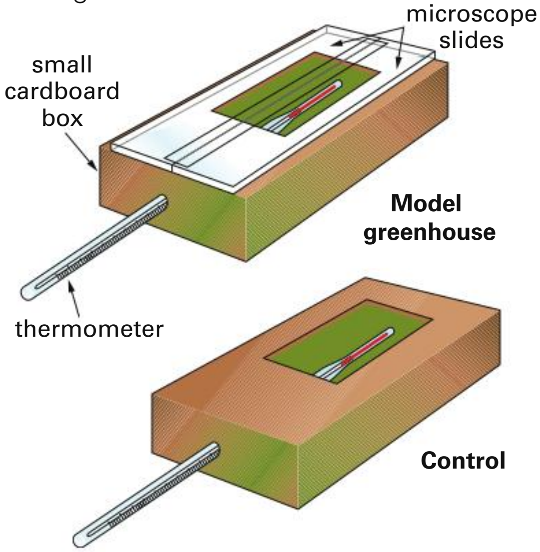
2 Lay the slides over the hole in one of the boxes. Punch a hole in one end of the box to insert a thermometer. This is your model greenhouse.

3 To see how effective your greenhouse is, set up a control box. It is the same as the other box, without the glass roof.

Record the temperatures in both boxes before you take them out into the sunlight.

4 Leave the greenhouse and the control in the sun for about 20 minutes.

Record the temperatures every 2 minutes during this time.



Discussion

1 Plot temperature against time for the greenhouse and the control on the one sheet of graph paper.

2 Interpret the graphs. That is, write a sentence or two saying what they tell you.

3 Use the model greenhouse to explain how the atmosphere affects the temperature of the Earth.

Working with technology: To see how the greenhouse effect works, open the **Greenhouse effect** animation at www.OneStopScience.com.au.

OneStopScience

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Enhanced greenhouse effect

This NOVA website has information on the greenhouse effect, global warming and what is being done about it.

Forests and the environment

Information is presented in cartoon and text form on how forests help to reduce greenhouse gases

OneStopScience

Human impact on the atmosphere

The amounts of gases in our atmosphere are just right to support life, and they remain fairly constant. For example, the amount of carbon dioxide in the air is kept in a state of balance or **equilibrium** (equal-LIB-ree-um) by the carbon cycle. (See the diagram on page 199.)

The world's population now is five times what it was in 1800. Since then, the number of factories and farms has increased, and scientists have become concerned about the increasing amounts of carbon dioxide in the atmosphere. Fossil fuels contain carbon, and when they are burnt carbon dioxide is released into the atmosphere. On average, about 4 tonnes of this gas is released each year for every person on the planet! About half of this carbon dioxide is absorbed by the oceans and by plants, but the rest stays in the atmosphere.

Carbon dioxide is one of the gases in the atmosphere called greenhouse gases. These are the gases that absorb the radiated heat from the Earth's surface and hence keep the Earth warm. Other natural greenhouse gases include methane and nitrous oxide. However, a number of manufactured gases also act as greenhouse gases, particularly a group called CFCs or chlorofluorocarbons. These CFCs were discovered in the 1920s and since then they have been widely used in refrigerators, airconditioners, aerosols, plastic foam and dry cleaning and for cleaning computer parts. Until 1990, Australians used more CFCs per person than any other country in the world. CFCs are now banned in most countries.

Global warming

Global warming refers to the rise in the Earth's temperature due to the **enhanced greenhouse effect**, caused by increased levels of carbon dioxide and other greenhouse gases in the atmosphere.

Greenhouse gas levels are shown in the table below. The global warming effect in the right-hand column shows how much warming one tonne of the gas causes in 100 years, compared with the warming produced by one tonne of carbon dioxide.

To investigate the relationship between CO_2 levels and temperature, scientists have drilled through Antarctic ice to a depth of over 2 km. When the snow fell thousands of years ago, tiny pockets of air were trapped in it. Hence, ice that is deep below the surface has older air trapped in it than ice at the surface. From these ice cores, CO_2 levels and changes in temperature for the last

Greenhouse gas and sources	Atmospheric concentration before 1750 (ppm)	Atmospheric concentration in 2011 (ppm)	Yearly increase (ppm)	Atmospheric lifetime (years)	Global warming effect
carbon dioxide (CO_2) burning fossil fuels and forests	280	391	2	100	1
methane (CH_4) cows & sheep, swamps, rice paddy fields, natural gas leakage, rubbish dumps	0.7	1.81	0.004	12	25
CFC II fridges, foams, aerosol sprays, solvents	zero	0.0002	0 CFC atmospheric concentrations are now declining	45	4750
nitrous oxide (N_2O) burning fossil fuels and forests	0.27	0.32	0.0006	114	298

Source: Carbon Dioxide Information Analysis Centre (CDIAC), updated February 2011. Website: http://cdiac.esd.ornl.gov/pns/current_ghg.html

160 000 years have been calculated. The graph on the right shows clearly that there is a link between the temperature and the concentration of CO_2 in the atmosphere. When the CO_2 concentration is high, so is the temperature.(See page 219.)

There has been an increase of 0.74°C in global surface air temperatures over the last 100 years, with 2005 and 2010 being the hottest years ever recorded. With this slight warming, the oceans have expanded and ice on land has melted, resulting in a rise in sea level of 18 centimetres.

In 2005 the Kyoto Protocol came into force. This agreement commits most countries to cutting emissions of CO_2 and other greenhouse gases by 5.2% from their 1990 levels by 2012.

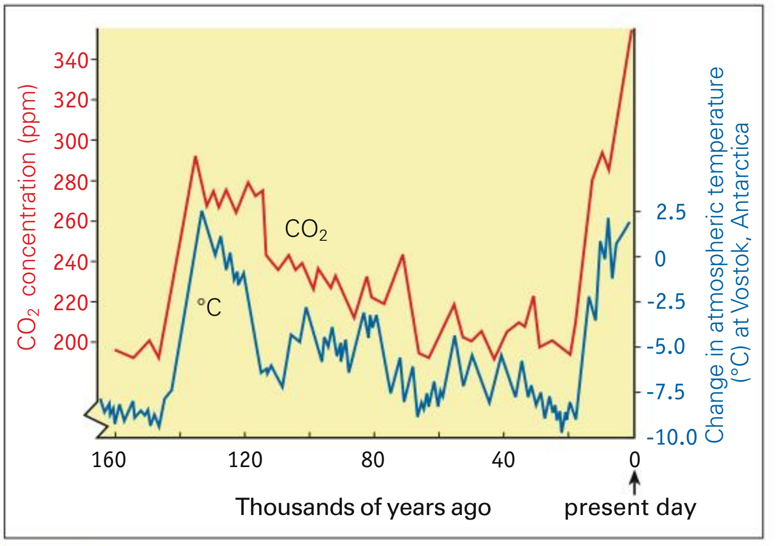


Fig 12 How the carbon dioxide content of the atmosphere and the global temperature have changed over the past 160 000 years (Intergovernmental Panel on Climate Change)

Activity

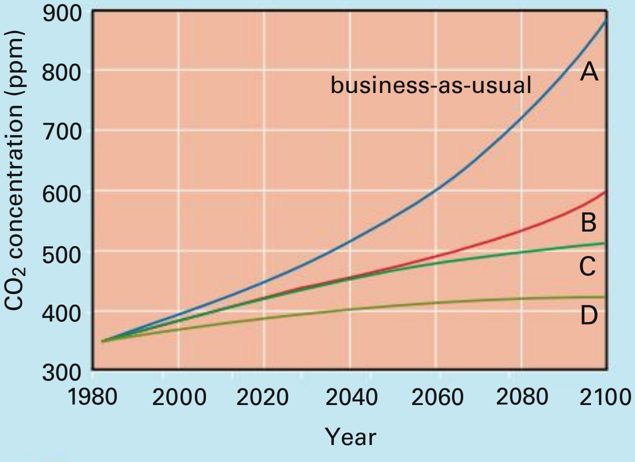
Predicting the future

Future greenhouse gas emissions will depend on future human activity, and this is not easy to predict.

One of the most useful ways of looking at what might happen is to construct scenarios of the future, using complex computer models. The graph shows four different scenarios for the concentration of carbon dioxide. Scenario A is called the business-as-usual scenario because it assumes that things will continue as they presently are. For example we will continue to burn coal to generate most of our electricity.

Scenarios B, C and D represent futures where there are more and more controls on the emission of greenhouse gases.

- Which scenario would have the strictest controls? Explain your answer.
- Suggest what the differences between the four scenarios A, B, C and D might be.



- What are the predicted CO_2 levels for the year 2100 for each of the four scenarios?
- If we do nothing to reduce emissions, in which year will the 2000 level double?
- Which do you think is the best scenario for planet Earth? Why? Do you think it is feasible? Justify your answer.

The ozone layer

What is the **ozone layer** and why has it got a hole in it? Ozone is found naturally with other gases in the atmosphere, and its concentration is greatest in the lower stratosphere. Even here, only about 1 molecule in every 100 000 is ozone. These ozone molecules are formed when UV radiation from the sun strikes an oxygen molecule. In a series of three reactions, ozone is formed and splits apart again, absorbing UV radiation in the process.

1. $O_2 \xrightarrow[\text{from the sun}]{\text{UV radiation}} O + O$
2. $O_2 + O \longrightarrow O_3$ (ozone)
3. $O_3 \xrightarrow[\text{from the sun}]{\text{UV radiation}} O_2 + O$

Fig 13 Ozone is formed when oxygen molecules in the stratosphere absorb UV radiation from the sun.

The natural balance or equilibrium between oxygen and ozone in the atmosphere was upset when CFCs began to be widely used.

CFCs contain chlorine and fluorine atoms bonded to carbon atoms. In the stratosphere, radiation from the sun causes the chlorine atoms from the CFCs to react with ozone molecules, breaking them apart. One molecule of CFC can destroy many thousands of ozone molecules.

In 1982, British scientists recorded a very low concentration of ozone in the stratosphere over Antarctica. Similar amounts were recorded during 1983 and 1984. The ozone layer had depleted by 30% since 1970. By 2004 this depletion had increased to 60%. Thus the term ‘hole in the ozone layer’.

The ‘ozone hole’ over the Antarctic is greater in the winter months. The warmer air during summer brings in more ozone and the ‘hole’ almost disappears.

CFCs stay in the atmosphere for many years. So even though CFCs are banned in most countries, the CFCs in the atmosphere are still affecting ozone concentration.

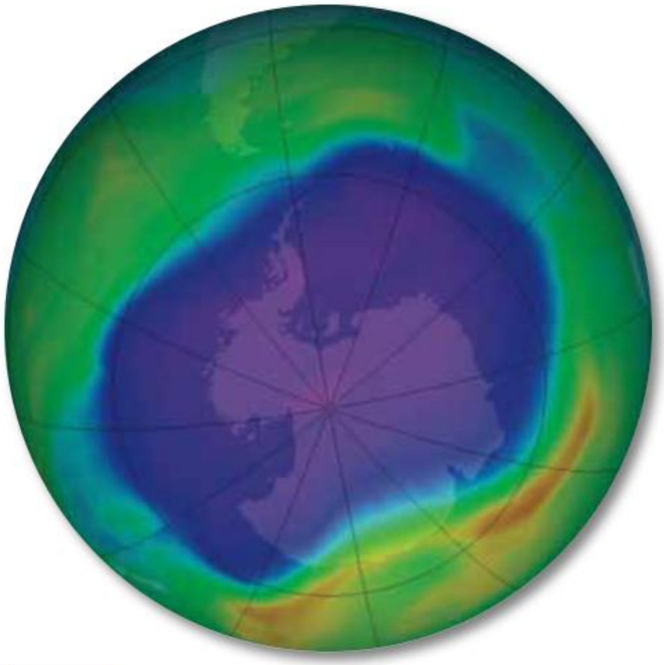


Fig 14 The largest hole in the ozone layer occurred in September 2006. The blue area is where the ozone has thinned most.

Effects of ozone depletion

Ultraviolet radiation from the sun is responsible for almost all skin cancers. For each 1% decrease in ozone, there is a corresponding 2% increase in harmful UV radiation reaching the Earth’s surface, and a 4% increase in skin cancer rates. Australians already have the highest rate of skin cancer in the world, so ozone depletion means that you will need to take extra precautions in the sun.

Exposure to UV radiation can also affect the human immune system so that you are more likely to contract diseases such as the herpes virus and hepatitis. Increased exposure to UV can also lead to eye problems, for example cataracts, where the lens of the eye becomes clouded.

Increased UV radiation can damage crops, leading to decreased yields. And photosynthetic plankton, which are the basis of most aquatic food webs, particularly in the ocean, are very sensitive to extra UV radiation. So ozone depletion is a serious threat to marine ecosystems.

Skillbuilder

Presenting a persuasive speech

The purpose of a persuasive speech is to convince your audience, through carefully reasoned and logical argument, that they should agree with your point of view. This Skillbuilder will show you some of the techniques used to make an effective persuasive speech.

Your task

Suppose you are to present a persuasive speech on the topic *Our future depends on household recycling*.

Research the topic

Before you can write your persuasive speech, it is essential you research the topic by following these steps.

1 Search the internet using the words *household recycling*, or just *recycling*. You can also use library books, magazines and brochures.
2 Scan the information and decide how useful it is.
3 If the information is relevant to the topic, read it carefully and make notes. Do this by summarising in your own words. Do not copy straight from the source.

Prepare the persuasive speech

1 In the **introduction** of your speech:
   - state your point of view firmly and clearly
   - summarise the case you are going to present.
2 In the **body** of the speech:
   - develop the argument in clear steps
   - support each main point with evidence
   - take one side of the argument only.
3 In the **conclusion** of your speech:
   - state your conclusion in strong, stirring language
   - do not introduce any new ideas.

Present your persuasive speech

As well as preparing a logical, factual and well-developed argument, there are some techniques

you might like to consider to enhance your presentation.

1 **Use emotive language**: Appeal to the personal and emotional side of your audience so that they feel involved. For example, *Every one of us has the responsiblity to ensure that the Earth's fragile ecosystems are not destroyed by...*
2 **Use rhetorical questions**: Involve the audience by asking questions and answering them. For example, *What can we do? First of all, each one of us...*
3 **Use repetition**: For example, *On this continent, over 100 species are lost by extinction each day. These 100 species...*
4 **Use alliteration**: Use words starting with the same letter. For example, *putrid, poisonous pollution.*
5 **Use short sentences**: The listener cannot return to what has been said, unlike the reader of an essay.

Have a go!

Work in a small group and practise preparing a short persuasive speech of no more than 2 minutes. Choose one of the topics in the Activity on the next page, research it and prepare a persuasive speech. Then take it in turns to present the speech to your group.

Activity

Choose one of the topics below and prepare a persuasive speech.

Your purpose is to present your speech to an audience (your class) and try to persuade them through logical arguments and presentation skills that your point of view is correct.

The websites on the right contain useful information for some of the topics. For more information, type the key words into the search engine of your internet browser.

Topics

1. Deforestation and land clearing means increased global warming.
2. Sun power—the only way to go!
3. Fossil fuels or renewable resources? The choice is simple!
4. Protecting our environment doesn't mean going without. It means using resources wisely.

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Tropical deforestation

This website has detailed information on the effects of deforestation.

Using energy wisely

Information on this website could be used as a guide to the preparation of a persuasive speech. There are links to fact sheets and activity sheets.

Global warming—frequently asked questions

This website has easy-to-read information on the greenhouse effect and global warming.

Global warming facts and our future

This website presents useful information and activities on the causes and effects of global warming.

Fossil fuels

This easy-to-read website has information on fossil fuels. It has links to alternative forms of energies.

OneStopScience

Check

1. The surface temperature of the Earth depends on the atmosphere. Explain what this statement means.
2. Explain the similarities and differences between how a greenhouse works and how the atmosphere moderates the Earth's temperature.
3. Use the table on page 211 to answer these questions about greenhouse gases.
   a. What are the sources of methane?
   b. Which gas increased in concentration the most rapidly in 2011?
   c. Suggest why the CO_2 concentration has increased greatly since 1750.
   d. Which gas has the most dramatic effect on the heating of the Earth's atmosphere? Explain your answer.
   e. Why is it that carbon dioxide is the major source of concern even though other gases have a greater global warming effect?
   f. The concentration of CO_2 in the atmosphere in 2011 was 391 ppm. What percentage of the atmosphere is this?
4. Explain in your own words the connection between fossil fuels and global warming.
5. Give two ways in which the logging of rainforests might contribute to an increase in global warming.
6. How is carbon dioxide removed naturally from the atmosphere?
7. Why does ozone depletion result in higher levels of UV radiation on the Earth?
8. In a group, discuss how each of the following could help to slow down global warming.
   a. recycling
   b. introducing a price on carbon
   c. replanting of cleared forest areas

- **d** driving smaller cars
- **e** using energy-efficient appliances
- **f** using public transport

9 The Bureau of Meteorology recorded the UV index on a typical cloud-free summer day. This is a measure of the amount of UV radiation reaching the ground. This data is shown in the table on the right.

- **a** Draw a graph of this data.
- **b** At what time of the day did the UV index reach a maximum?
- **c** The Skin Cancer Council says you need to protect your skin if the UV index goes above 3. When does this happen on this day?
- **d** Predict what the graph would be like on a cloudy day. Draw it.

Daylight saving time	UV index
7 am	0
8 am	1.0
9 am	2.5
10 am	5.5
11 am	7.5
12 noon	9.0
1 pm	9.0
2 pm	7.5
3 pm	5.0
4 pm	2.5
5 pm	0.5
6 pm	0

10 Form the same group as you did for the Getting started activity on page 196 and look at your discussion answers. As a result of what you have learnt in this chapter, what changes would you make to your answers?

Challenge

1 Suppose you are trying to explain to some adults who do not understand chemical equations how ozone protects us from UV radiation. Use the equations in Fig 13 on page 213 to write an explanation. (You may have to explain what UV radiation is, and the differences between O, O_2 and O_3.)

2 How is it possible to find out what the world's atmosphere was like thousands of years ago?

3 Maize plants were grown under two different conditions:

- normal atmosphere (391 ppm CO_2)
- double CO_2 levels (782 ppm CO_2).

Leaf area was measured every 5 days and recorded.

Days	Leaf area (cm^2)	
	391 ppm CO_2	782 ppm CO_2
5	27	28
10	110	117
15	358	460
20	690	879
25	660	882
30	491	761
35	386	588
40	280	412

- **a** Plot the data on graph paper.
- **b** Write a conclusion for the experiment.

4 Hamish made this comment: *I don't know what all the fuss is about global warming. In the last 100 years the temperature has increased less than 1°C.* How would you answer him?

5 Environmentalists often use the slogan *Think globally—act locally*. Explain what this means, using global warming or ozone depletion as an example.

6 The following equations show how CFCs destroy ozone.

1 $CCl_3F \xrightarrow[\text{from the sun}]{\text{UV radiation}} CCl_2F + Cl$ (chlorine atom)

2 $O_3 + Cl \longrightarrow ClO + O_2$

3 $ClO + O \longrightarrow O_2 + Cl$

Use the equations above to write an explanation of how CFCs destroy the ozone layer and allow more UV radiation to hit the Earth's surface.

You might like to make models of the various molecules using a molecular models kit.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 The Earth is made up of four spheres: the ______ (the solid part), the ______ (water), the biosphere (the ______ part) and the atmosphere.

2 The flow of carbon between the three spheres is called the ______. The ______ of nitrogen from the atmosphere is an essential part of the nitrogen cycle

3 Biodegradable wastes such as sewage in water can cause a decrease in dissolved ______, leading to ______.

4 ______ is the process in which non-biodegradable wastes such as ______ are concentrated as they move up a food chain.

5 The ______ is the warming of the ______ by carbon dioxide and other gases when they absorb energy radiated from the Earth's surface.

6 An increase in greenhouse gases may cause ______, which results in changes in the climate and a rise in sea levels.

7 The ______ protects the Earth from ______ from the sun. Chemicals such as ______ destroy ozone and have caused the layer to be thinned.

atmosphere
biomagnification
carbon cycle
CFCs
eutrophication
fixing
global warming
greenhouse effect
hydrosphere
insecticides
lithosphere
living
oxygen
ozone layer
UV radiation

Working with technology

Try doing the Chapter 8 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

1 Which of the following are true and which are false? Rewrite any that are false.

a Global warming is caused by the hole in the ozone layer.

b The ozone layer protects us from dangerous UV radiation from the sun.

c Global temperatures have increased by several degrees over the last 100 years.

d The greenhouse effect is good because it keeps the Earth warm, but the *enhanced* greenhouse effect is not so good because it makes the Earth *too* warm.

2 According to the graph on the right, which of the following statements correctly describes the relationship between the concentration of carbon dioxide dissolved in water and the temperature of the water?

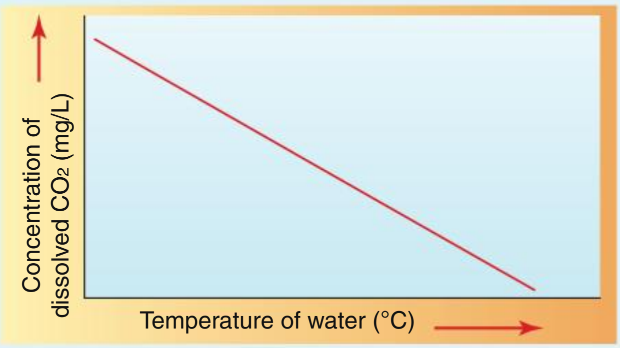
The graph indicates that the amount of dissolved carbon dioxide:

A increases as the temperature increases

B decreases as the temperature increases

C decreases as the temperature decreases

D does not change with temperature.



3 The table shows the five most abundant elements by mass in each of the Earth's spheres, in decreasing order of abundance.

Atmosphere	Hydrosphere	Lithosphere	Living matter
nitrogen	oxygen	oxygen	oxygen
oxygen	hydrogen	silicon	carbon
argon	chlorine	aluminium	hydrogen
hydrogen	sodium	iron	nitrogen
carbon	magnesium	calcium	calcium

a Which is the only element that is common to all four spheres?
b Which is the main carbon compound in the atmosphere?
c Why are the elements sodium and chlorine so common in the hydrosphere?
d Suggest why oxygen is the most abundant element in living matter.

4 Below is a list of organisms in a food chain. Copy and complete the table by writing the name of each organism next to the concentration of DDT you predict it would have in its body.

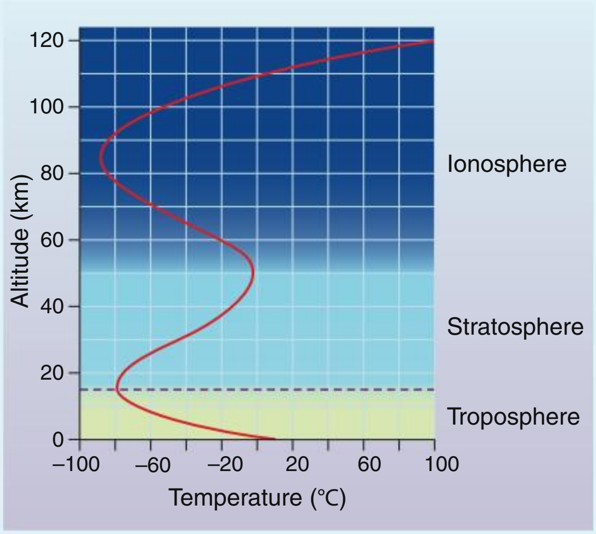
- algae and microscopic organisms
- fish
- fish-eating bird
- insect larvae

Concentration of DDT (ppm)	Organisms
0.3	
0.9	
2.4	
21.6	

5 Consider a small lake containing algae. Suppose that, further upstream, sewage is being pumped into the river that runs into the lake. Also, fertilisers from nearby farms are continually washed into the river by surface water. What will be the effect of these wastes and fertiliser on the following?

a the growth of the algae in the lake
b the number of bacteria in the lake
c the amount of dissolved oxygen in the lake
d the number of other living organisms in the lake
e the eventual fate of the lake

6 The graph below shows how the temperature changes with the distance from the Earth's surface (altitude).



a Where is the lowest temperature reached?
b In which layers does the temperature increase steadily with altitude?
c The region between the altitudes of 50 km and 80 km is often referred to as the mesosphere. Describe the temperature changes in this layer.
d O_2 molecules in the atmosphere absorb UV radiation from the sun and form ozone O_3. In the process, heat energy is released. In which layer does this occur? Justify your answer.

7 How have humans upset the balance of carbon dioxide between the Earth's spheres?

Check your answers on page 308.

Working with technology

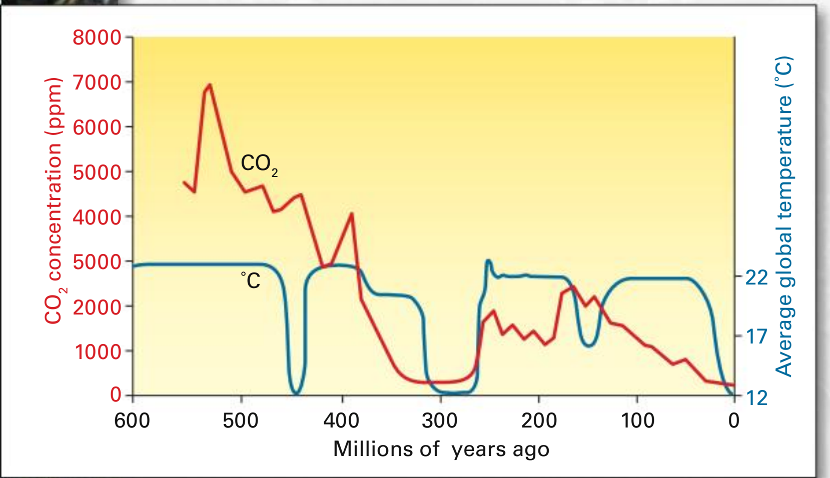
Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science as a Human Endeavour

When scientists disagree

The debate about climate change has highlighted the fact that scientists often disagree over the interpretation of data and predictions about the future. Look at Fig 12 at the top of page 212. Some scientists say we should instead look at the graph below.



1 According to this graph, what has happened to the concentration of CO_2 over the last 600 million years? How is this different from what Fig 12 tells you?

2 What has happened to the average global temperature over the past 600 million years? When did the Earth experience ice ages? Is today's temperature above or below the Earth's average temperature?

Fig 12 clearly shows a **correlation** between CO_2 concentration and global temperature. If one variable increases or decreases, so does the other. However, this does not necessarily mean that global warming is caused by an increase in CO_2.

3 Some scientists have noted that the global temperature changes *before* the CO_2 concentration does. What could this mean?

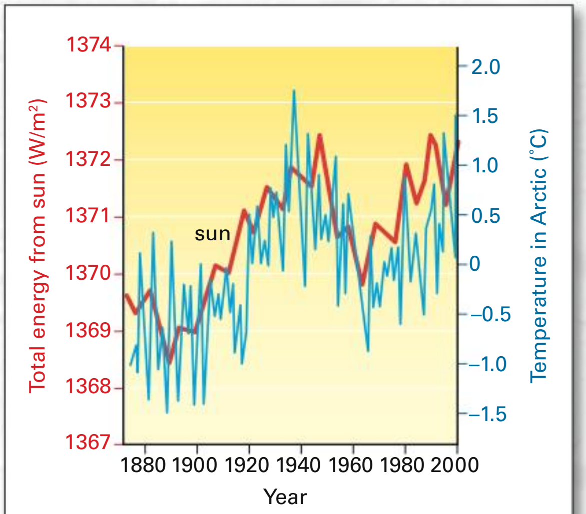
There are many variables that can affect the climate of the Earth, and CO_2 concentration is only one of these. For example, the graph to the right (top) shows how the temperature in the Arctic varies with the total energy received from the sun, which is greater when sunspots on its surface are more active.

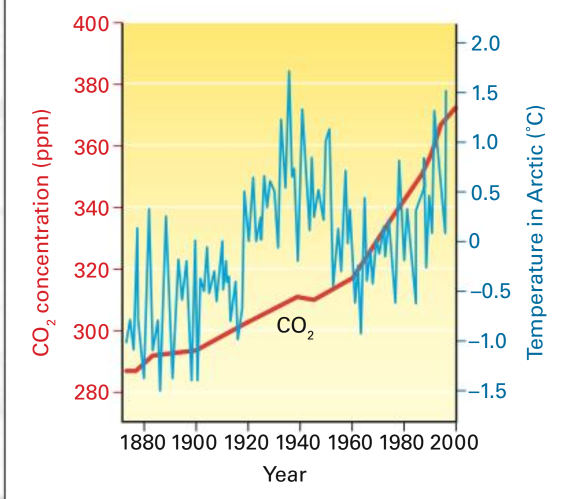
4 Is the Arctic temperature more closely correlated with the total energy from the sun or the CO_2 concentration? Explain your answer.

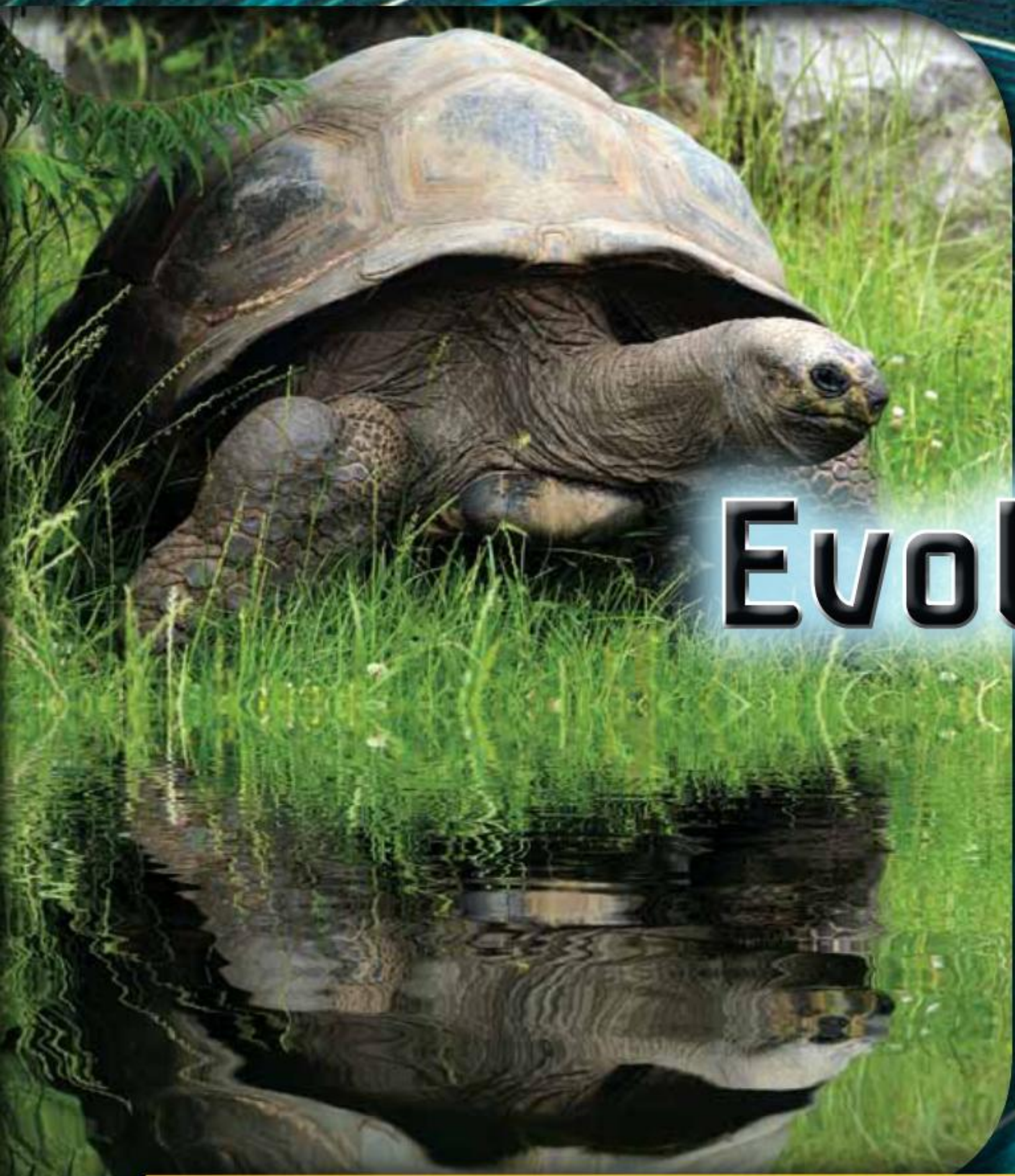
5 Does this mean that solar activity is responsible for climate change? Explain.

6 Could climate change be caused by solar activity *and* increasing CO_2? Could it be that *neither* is the cause? Explain.

7 Some scientists say that by trying to reduce levels of CO_2, we may be trying to solve a problem that may not exist. What do you think? You may want to refer back to *ScienceWorld 8*, page 51.







9 Evolution

In this chapter you will ...

Science Understanding

- gain an understanding of how sexual reproduction results in variations in organisms
- model and discuss the processes involved in natural selection and the formation of new species
- evaluate and interpret evidence for evolution—the fossil record, biogeography, embryo similarities and comparative DNA studies

Science as a Human Endeavour

- use evolution to illustrate that scientific theories are contestable and are refined over time
- research, discuss and debate the way in which GM foods, cloning and human gene therapy are affecting people's lives

Science Inquiry Skills

- use a model to show how gene technology can be used to cut and recombine genes

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Form into a small group and discuss the following questions.

1 Two orange trees were grown from cuttings so are genetically identical. The trees were planted in different areas many kilometres apart. One tree produced many kilograms of sweet oranges, the other tree produced a small number of small-sized fruit.
If the trees have the same genes, why are they so different?

2 Charles Darwin was a naturalist (biologist) on board the ship HMS *Beagle*. Between 1831 and 1836 the ship sailed along the coastline of South America and then across the Pacific. It docked in Sydney on 12 January 1836. Why is Darwin famous?

3 The photo shows a Leadbeater's possum. It is a highly endangered species and the small population of possums is protected by law. It is found only in the Victorian central highlands, where it lives in hollow parts of trees in old growth forests.
What does *endanged species* mean? Why do you think the population of the possum is now very small?

9.1 Variations in organisms

You found out in Chapter 3 that genes control many of the characteristics in humans. Earlobe attachment, the ability to roll your tongue into a tube, and the colour of your hair, eyes and skin are some of these characteristics.

Earlobe attachment is controlled by one pair of genes. Therefore, this characteristic has two phenotypes—you have attached earlobes or unattached earlobes.

Most other human characteristics such as height, weight, hair colour and skin colour are controlled by more than one pair of genes. This produces a range of phenotypes. For example, the colour of your eyes is controlled by at least three pairs of genes on different pairs of chromosomes. Some other genes may turn these genes off and on. So it is the way all of these genes combine that determines the exact colour of your eyes. And it is this combination that creates the wide range of variation in human eye colour.

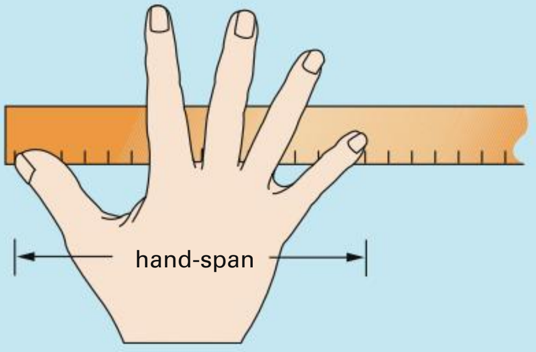
Variation in hair colour and skin colour, and such characteristics as head and face shape, are also due to the interaction of many genes.

Fig 1 Hair colour is controlled by many genes.

Activity

In this activity you will need data from all the members of your class.

1. Find out how many people in the class can roll their tongue, and how many cannot.
   Record your results and display them as a graph.
2. Measure the hand span of your right hand to the nearest 1 cm. To do this stretch your fingers out as wide as you can. Then place the tip of your thumb on the zero mark of a ruler and measure to the tip of your little finger.
   Record your results.



3. Draw up a table to record the hand span data for the class.
   Draw a bar graph of the class data for hand spans. What does this graph tell you?
   Suggest why the tongue-rolling and hand-span graphs are different.

The source of variations

The horticulturist in the photo below is taking cuttings from a geranium that produces good flowers. She knows that the cuttings from this plant will result in plants that produce exactly the same quality of flowers as the parent plant. This is an example of asexual reproduction. It does not produce variation in the offspring.

Fig 2 A horticulturist takes cuttings from the parent plant. These cuttings will grow into plants identical to the parent plant.

As you have seen in Chapter 3, organisms that reproduce sexually produce variations in the offspring. There are three main ways that this occurs:

- *independent assortment* of chromosomes during cell division in the reproductive organs
- *recombination* of genes in chromosome pairs during sex cell division
- *mutations* in the DNA in the cells in the testes and ovaries.

Independent assortment

You found out earlier that a cell with three pairs of chromosomes could produce sex cells with eight different combinations of chromosomes.

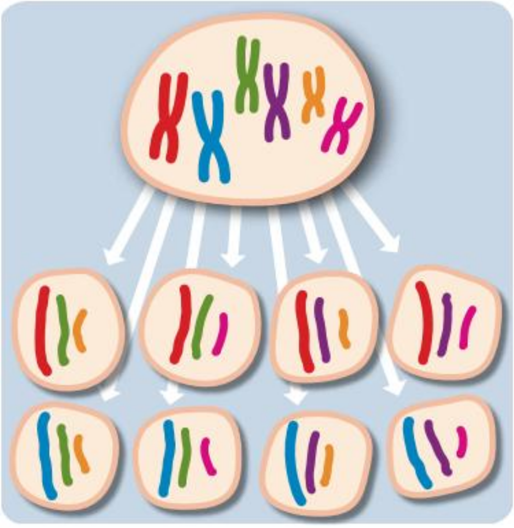


Fig 3 An organism with three pairs of chromosomes can produce eight different types of sex cells.

In humans with 23 pairs of chromosomes, there are about 8 million different possible combinations of chromosomes in the sex cells. This is why siblings look similar but not identical to each other and to their parents! The production of different arrangements of chromosomes in sex cells is called *independent assortment*.

Extra for experts

The numbers game

A cell with two pairs of chromosomes can produce sex cells with four different arrangements of chromosomes. A cell with three pairs of chromosomes can produce sex cells with eight different arrangements of chromosomes. How many different types of sex cells can a fruit fly whose cells contain four pairs of chromosomes produce?

Use the data to work out a formula to calculate this. Then calculate the different types of sex cells that an organism with seven pairs of chromosomes can produce.

Recombination

During the production of sex cells in the testes or ovaries, the pairs of chromosomes sometimes swap bits of each other, resulting in a different arrangement of genes on the chromosomes.

In the diagram below, the top section of the DNA on a pair of chromosomes exchanges. This process is called *crossing-over*, and it results in a **recombination** of genes in a pair of chromosomes.

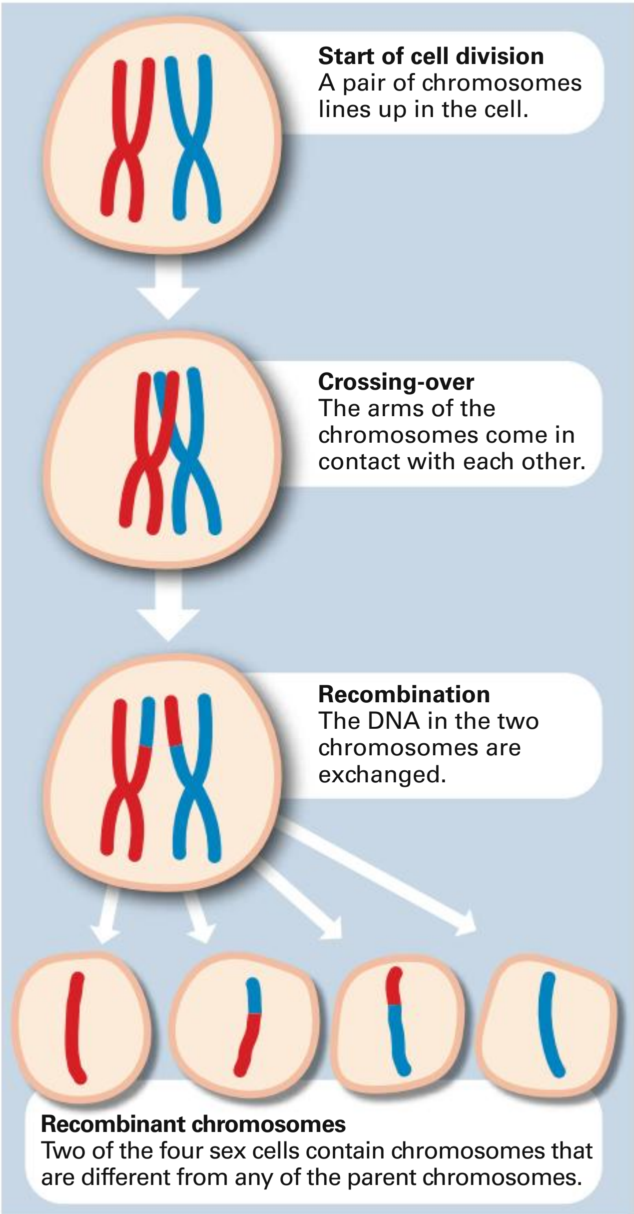


Fig 4 Crossing-over produces a different combination of genes in the chromosomes in the sex cells.

Activity

Recombining DNA

You will need two different colours of playdough for this activity. This is a simple hands-on activity to show you how chromosomes cross-over and result in a recombination of genes.

1. Using one colour of playdough, make two chromosomes the size of a pencil.
2. Lie them side by side and squeeze them together about halfway along their length so that they make an X shape.
3. Repeat Steps 1 and 2 using the other colour of playdough.
4. Use Fig 4 as a guide to show how the two chromosomes can cross over and recombine.

Challenge: Use your model to show that if two genes are a long way apart on a chromosome, they have a greater chance of recombining by crossing over.

Working with technology

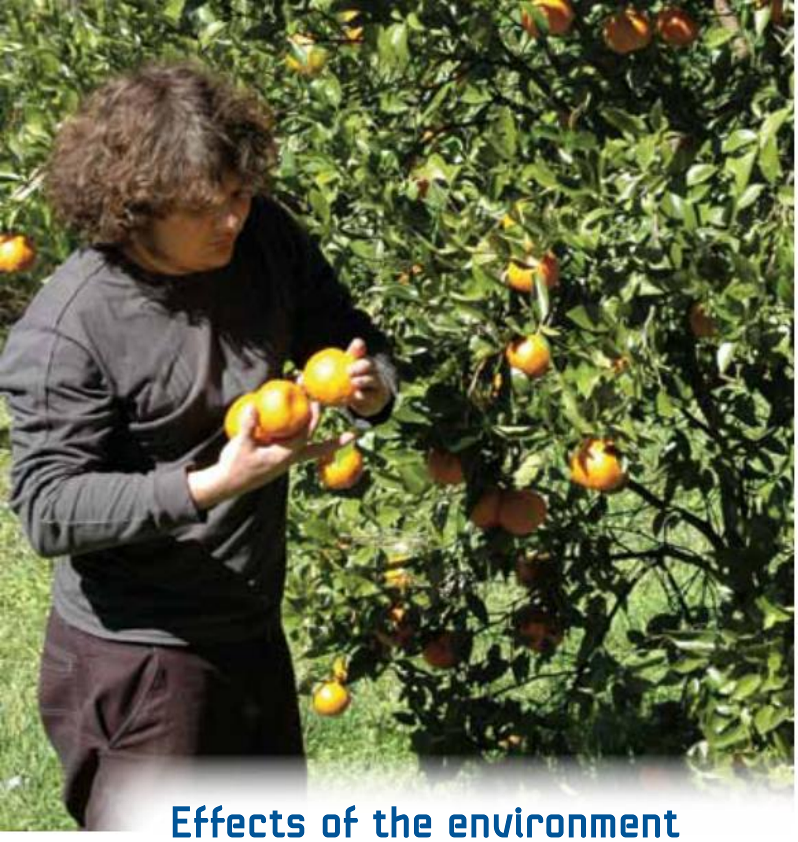
To see how crossing over creates a new assortment of genes on chromosomes, open the Recombining chromosomes animation at www.OneStopScience.com.au.

OneStopScience

Mutations

When the base sequence in a gene is changed, it is highly likely that the proteins that are produced by this gene will be different from the original. The random changes to the DNA are called mutations.

Mutations in body cells cause little or no change to the organism, although cancerous tumours can develop from these mutations. However, if mutations occur in a sex cell, the changed DNA may be passed to the next generation when fertilisation occurs.



Effects of the environment

This mandarin tree is loaded with sweet, juicy mandarins. About 100 km away, mandarin trees bear very few, fairly dry fruit. Why is this, when all the mandarin trees came from the same stock? The juicy mandarins are grown in an area that has had good autumn rain; the other area has had very low rainfall. Cold weather occurred at the start of winter, which increased the sugar in the juicy mandarins. The other area has had unusually warm weather.

Even though the mandarin trees have the same genotype, the environmental conditions have produced different phenotypes. The trees have the same alleles, but they are expressed differently because of the different environments they are in.

The young boy in the photo below has grown up in a country ravaged by malnutrition and disease. His growth is stunted, his immunity to disease is poor and his mental development may be limited—all because of environmental conditions.

It is the combination of genetic and environmental factors that determines the characteristics of a population of organisms. The genes determine the potential phenotype of an organism, while a combination of the genes and the environment determines its actual phenotype.

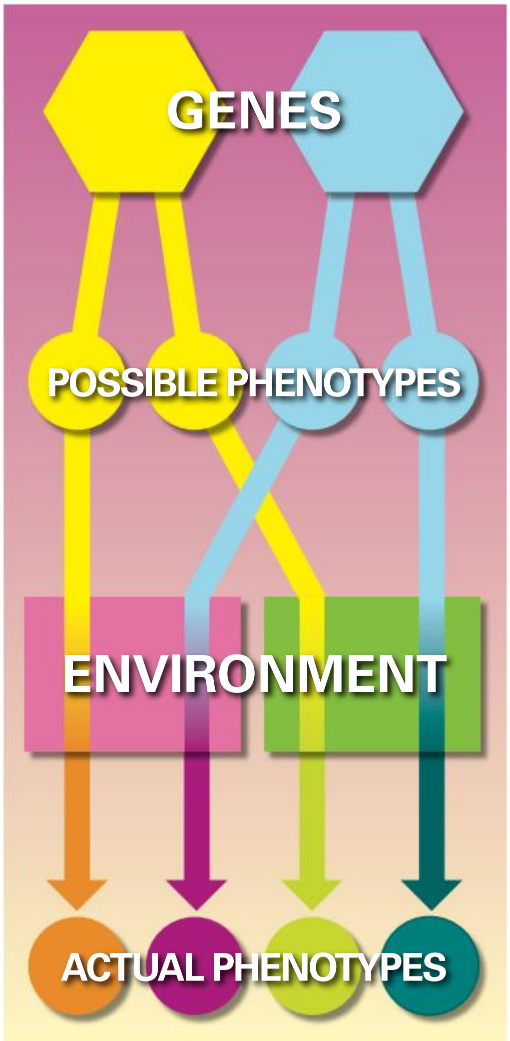


Fig 5 The characteristics of a population of organisms are determined by the environment as well as by the organism's genes.

Check

1 How do you account for the fact that some people have attached earlobes and others have unattached earlobes, while there is a wide range in the shapes and sizes of ears?

2 a Where does independent assortment occur in the body?

b What is the importance of the word *independent* in this process?

c Explain how this process produces variations in organisms.

3 What is crossing-over? Use a diagram to show how it is a source of variation in organisms.

4 Explain why a mutation in the cells in the skin does not affect the variation in future generations, whereas a mutation in the sex cells may.

5 Explain how variations in a population are caused by genetic factors as well as by environmental factors.

6 Explain, giving an example, how a particular environmental factor can affect the phenotype of an organism. (Do not use the examples in this book.)

Challenge

1 The particular type of Siamese cat in the photo has light-coloured fur on its body except on its face, ears, tail and legs. This cat carries a gene that makes a heat-sensitive version of the enzyme involved in making the dark colour (melanin) in the fur.

a Suggest why the extremities of the cat's body have darker fur.

b Do you think that the enzyme is turned off or turned on by high temperatures? Give a reason for your answer.

c When the cat was a kitten, a patch of fur from its back was removed and the skin kept warm until new fur grew. Would you expect this fur to be dark or light? Explain.

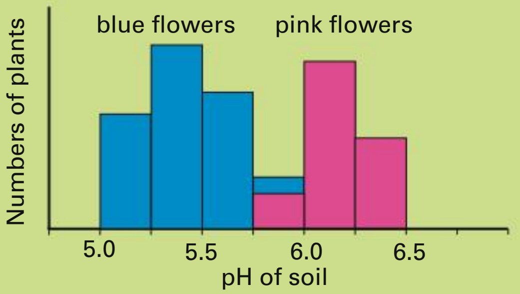
2 In biology books you often see the term *gene expression*.

a Suggest what this term means.

b Use biology books or the internet to find a definition of the term. In what ways is this definition different from yours?

c Use the example in Challenge 1 to explain how the environment can affect gene expression.

3 Hydrangea plants produce pink flowers and blue flowers depending on the acidity of the soil, as shown in the graph.



a Write a generalisation about the colour of flowers and the pH of the soil.

b What is the best soil pH for growing blue flowers? For growing pink flowers?

4 The colour of skin is controlled by three genes, each found on different chromosomes. The alleles for dark skin are M_1, M_2 and M_3, and they are dominant over the alleles for pale skin—m_1, m_2 and m_3. For example, a person with the darkest skin would have the alleles M_1M_1, M_2M_2 and M_3M_3.

a What genes would a person with the palest skin carry?

b How many combinations of skin colour are possible with these genes?

c Predict the shade of skin colour a person with the alleles M_1m_1, M_2m_2 and M_3m_3 might have.

d Is your prediction in **c** accurate? What other factors might affect the phenotype of this person?

9.2 Natural selection

Most organisms produce many more offspring than their habitat can support. If these offspring are produced by sexual reproduction, they will show variations of characteristics. Some of these characteristics will give the offspring a better chance of survival than others. Individuals with these particular characteristics are said to be better *adapted* to the environment. Individuals with unfavourable characteristics will usually die before they are able to reproduce.

Biologists say that the environment has selected certain characteristics for survival. This process is called **natural selection**, and is sometimes referred to as *survival of the fittest*. This means that the best adapted individuals will survive in a particular environment. It does not always mean that the largest, most muscular and physically fit individuals survive. In some cases, smaller or slower organisms may be better suited to a particular environment. For example, shrubs that grow close to the ground and have small leaves will be better suited to a windy environment than tall, large-leaved trees.

Selection agents in the environment

The factors in an organism's environment which affect its survival are called *selection agents*. These agents can be divided into two groups:

- biotic agents, including predators, disease, competition between members of the same species, and availability of food

- abiotic agents, including heat, cold and wind, availability of oxygen and water, pH of soil and water, and availability of living space.

The 'fittest' organisms are those that can reduce the effects of these selection agents.

In the investigation on the next page, you can use a model to help you understand how natural selection works.

Fig 6 The flowers on this plant will produce more seeds than can survive. The seeds have slightly different genotypes and only the ones best adapted to this environment will survive.

Fig 7 The plants that grow successfully on sand dunes can survive on very little water and withstand the damaging effects of salt spray, strong sunlight and strong winds.

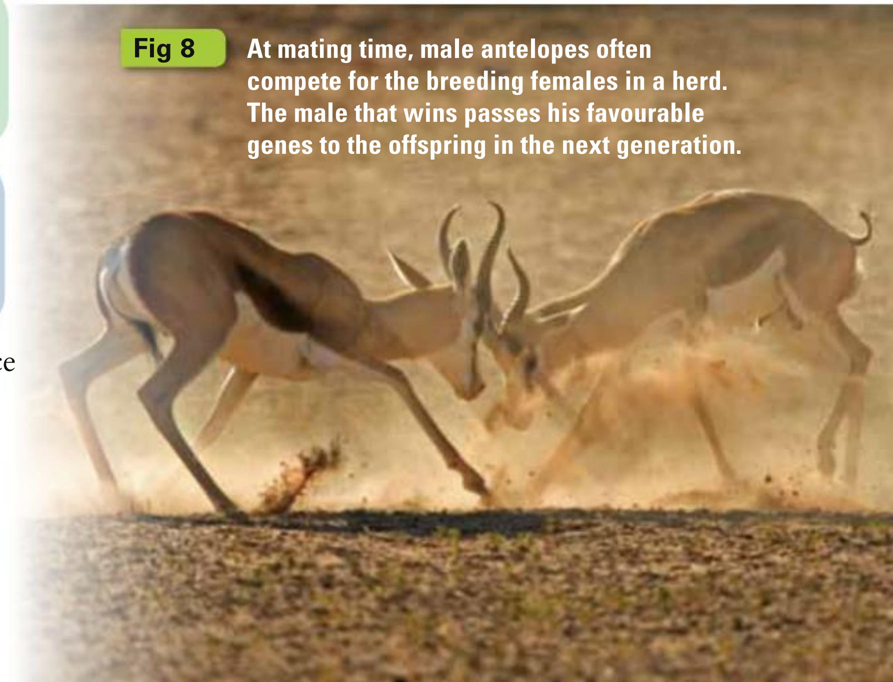


Fig 8 At mating time, male antelopes often compete for the breeding females in a herd. The male that wins passes his favourable genes to the offspring in the next generation.

Investigation 16 Frog selection

Aim

To use a model to show how natural selection affects two populations of frogs.

Materials

- three different colours of frog cards—20 red, 20 green and 20 yellow (for preparation see the Teacher note)
- a die

Teacher note: You will need A4 sheets of red, green and yellow card (about 120 gsm), which are available in newsagents. To prepare the frog cards, photocopy the frogs below so that you have 24 frogs on a sheet of white paper. Photocopy enough frogs on red card for the whole class—these are the red frogs. Do the same for the green and yellow frogs. There are also frog templates at **www.OneStopScience.com.au**.

Planning and Safety Check

- It is important you know exactly what to do before you proceed. Carefully read through the investigation. Then test your knowledge by telling your partner what you have to do and what you have to record.
- Prepare data tables for your results for the POND and the FOREST before you start.

Background

You will be investigating the process of natural selection in two different and separate environments—a pond and a rainforest. The pond is surrounded by reeds and rushes that are yellowish in colour, while the forest has much leafy green vegetation.

You will look at only two organisms in these environments—a frog that occurs in three colours, red, green and yellow, and a snake that is a predator of the frog.

In this model, for simplicity, assume that each pair of frogs produces one offspring each year, and that snakes eat 15 frogs each year.

PART A The frog population

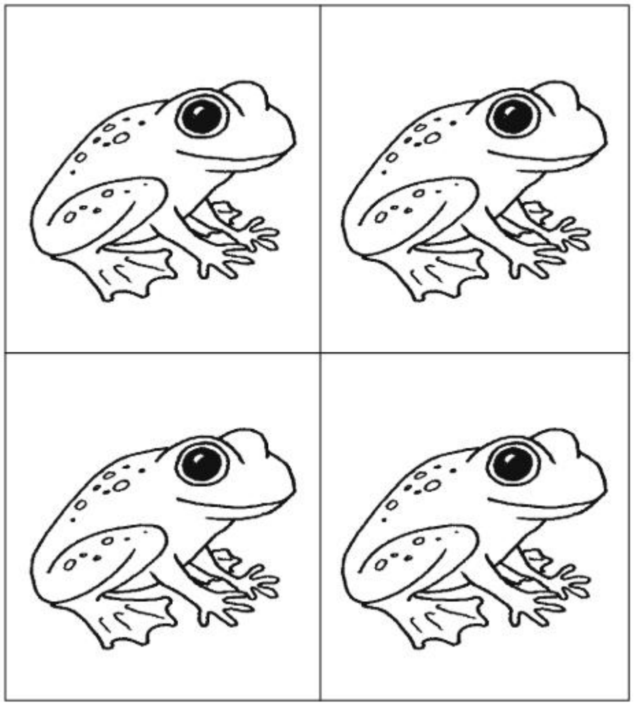
Method

1 Write POND on a sticky label and FOREST on another. Then stick them apart on a table. These labels represent the location of the two environments.

2 Count out 10 red frogs, 10 green frogs and 10 yellow frogs and place them in one of the two environments. Shuffle the cards thoroughly and place them at *random* into 15 pairs.

3 Repeat Step 2 for the other environment.

4 Each pair of frogs produces *one* offspring a year. To work out the colour of the offspring use Table 1 and Table 2 on the next page. Then add the correct coloured frog to each pair.



Notes

1 The three different colours of frogs are the same species and can interbreed and produce different coloured offspring.

2 If the parents in Table 1 produce more than one colour of offspring, throw a die and use Table 2 to work out the colour.

Table 1

Colour of parents		Colour of offspring
red x red	=	red
yellow x yellow	=	yellow
red x yellow	=	green
red x green	=	some red, some green—see Table 2
green x green	=	some red, some green, some yellow—see Table 2
green x yellow	=	some green, some yellow—see Table 2

Table 2

Number on die	Colour of offspring		
	red x green parents	green x green parents	green x yellow parents
1	red	red	green
2	red	red	green
3	red	green	green
4	green	green	yellow
5	green	yellow	yellow
6	green	yellow	yellow

Table 3

Number on die	Pond	Forest
1	red	yellow
2	red	yellow
3	red	yellow
4	green	red
5	green	red
6	yellow	green

PART B Predation by snakes

Method

1 Around the pond, the red frogs are the most likely to be eaten and the yellow frogs the least. In the forest, the yellow frogs are most likely to be eaten and the green frogs the least.

2 Mix all the frog cards for the POND, throw a die and use Table 3 to decide which 15 frogs are eaten. Remove an appropriately coloured frog each throw. (Note: If there are no frogs of a particular colour left, roll the die again.) Do the same for the FOREST.

3 After the 15th frog has been removed from each environment, tally the numbers. Record the numbers in the Year 2 row in the data tables you have prepared. (The POND data table is shown as an example.)

4 Repeat Parts A and B for 10 years or until all the frogs are the same colour.

Results: Pond

Year	Red frogs	Green frogs	Yellow frogs
1	10	10	10
2			
3			
4			
5			

Discussion

1 Suggest why the red frogs around the pond are most likely to be eaten by snakes. Why are the yellow frogs most likely to be eaten in the forest?

2 Draw a fully labelled line graph of the changes in the numbers of the different coloured frogs around the pond over 10 years. Do the same for the forest.

3 Compare your results with those from other groups. Why are the results similar? Why are there some differences?

4 Write a conclusion for this experiment. Use the words *model* and *natural selection*.

Sickle cell anaemia

Sickle cell anaemia is a blood condition caused by a mutated gene. The allele produces an abnormal type of haemoglobin (the red pigment found in red blood cells) which turns the normally concave disk-shaped red blood cells into sickle-shaped cells.

The abnormal haemoglobin allele is recessive to the allele that codes for normal haemoglobin.

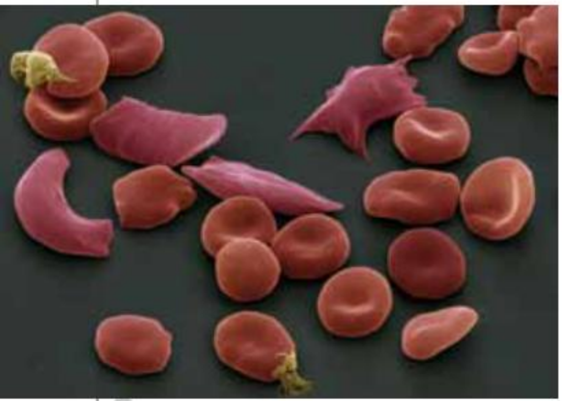


Fig 9

Normal red blood cells are rounded, in contrast with the distorted sickle-shaped cells (pink).

The sickle red blood cells are much less efficient at carrying oxygen than the normal cells. They also have a 'sticky' surface and the cells tend to stick together, causing blockages in blood vessels. This causes painful and sometimes fatal conditions such as heart attacks.

Most people who carry both abnormal haemoglobin alleles die in childhood. However, because the alleles are *co-dominant* (like human blood types on page 78) some of the blood cells of heterozygous people contain abnormal haemoglobin.

If sickle cell anaemia is fatal, why does the allele still exist in the human population?

Sickle cell anaemia and malaria

Sickle cell anaemia is much more common in Africa, India and parts of the Middle East than elsewhere in the world. Fig 10 shows the percentage of people in the population with the allele for abnormal haemoglobin.

Fig 11 shows the areas affected by malaria. The parasite that causes malaria lives in red blood cells and eventually destroys them, causing the death of the infected person. For some reason the parasite cannot live in cells that contain abnormal haemoglobin.

Questions

1 What does co-dominance mean?
2 What alleles would a person carry if they were homozygous for normal haemoglobin?
3 If sickle cell anaemia is fatal how does the allele stay in the population?
4 Why is it an advantage for people who are heterozygous for sickle cell anaemia to live in areas where malaria is common?
5 Suggest how *survival of the fittest* might apply to people with sickle cell anaemia.
6 Suggest how sickle cell anaemia might have originated in the human population.

Fig 10 The percentage of people carrying the sickle cell allele

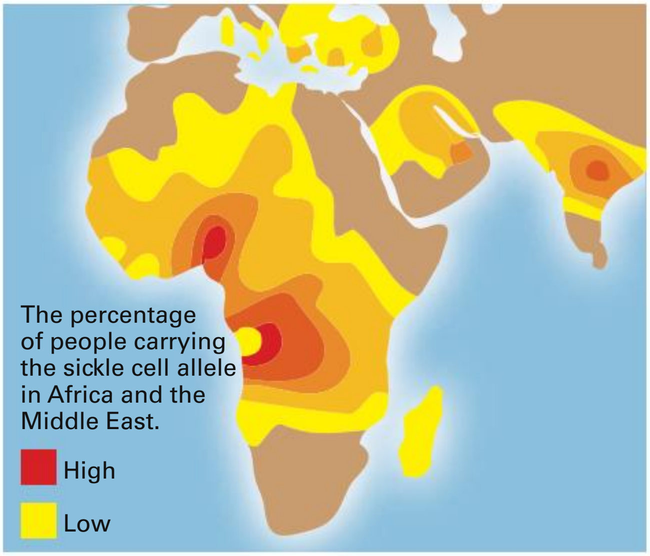


Fig 11 Areas in Africa, India and the Middle East where malaria is prevalent

Check

1 In your own words describe what is meant by the term *natural selection*.

2 A spider has spun a large web between two trees. Describe the selection agents that might affect the spider's survival.

3 What does *survival of the fittest* mean? Give two examples of where this could apply.

4 How does *survival of the fittest* apply to the people in the malaria regions of West Africa? Describe the selection agents in this case.

5 The albino kookaburra in the photo is in a wildlife sanctuary. Why do you think that an animal with this phenotype would have little chance of survival in the wild?

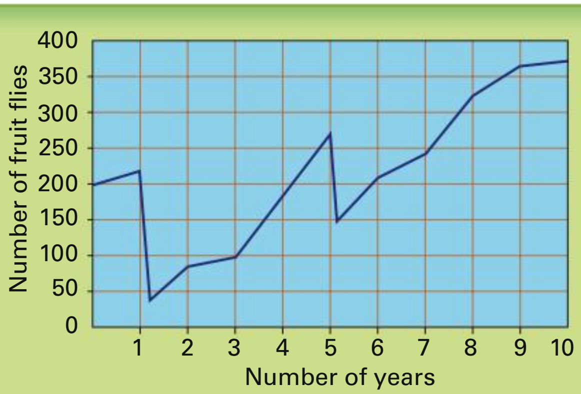
Challenge

1 Explain why natural selection works only if:
  a there is variation of characteristics within the species
  b characteristics are inherited.

2 About 65 million years ago, the Earth was inhabited by many species of dinosaurs. Some of them were herbivores but others were very efficient predators. Why did these enormously strong animals become extinct if they were such powerful and efficient predators?

3 The dodo was a flightless bird found on the island of Mauritius in the Indian Ocean off the coast of Africa. It laid one large egg in a nest on the ground. The dodo has been extinct since about 1680. Europeans who came to the island 100 years before this brought cats that ate the young chicks and pigs that ate the eggs.
  a Suggest why the dodo survived for so long prior to European settlement, and then became extinct so quickly.
  b Describe the selection agents in this case.

4 The graph above right is for a population of fruit flies that was sprayed with an insecticide.
  a How many times were the fruit flies sprayed with insecticide?
  b Why didn't all the fruit flies die after the first spraying?
  c How many fruit flies died after each spraying? Suggest reasons for the difference in the numbers.



  d What is the selection agent in this study?
  e Predict what might happen if the fruit flies were sprayed with a different insecticide after 10 years.

5 The butterfly in the photo has eye spots on its wings. When the butterfly rests on plants, it folds its wings so that the eye spots are not visible. However, when disturbed by a predator the butterfly opens its wings and displays the large eye spots.

  a How do the eye spots help the survival of this type of butterfly?
  b Can you think of any situations where this characteristic might be a problem for the butterfly?

9.3 Evolution

The best adapted organisms are those that survive environmental changes and pass on favourable characteristics to their offspring. But changes to the environment also affect the types of organisms that live there.

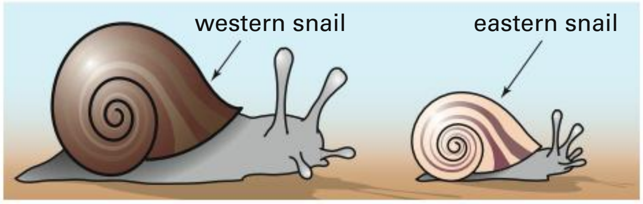
- Changed weather patterns cause short-term effects such as droughts, floods and cyclones, or long-term effects such as atmospheric warming and a rise in sea levels.
- Forces inside the Earth cause earthquakes and volcanoes, and the movement of Earth plates causes changes over millions of years.

Formation of new species

A population of land snails lives in moist areas on the forest floor throughout a wide valley many kilometres wide and in the hills on either side of the valley. The snails show a wide variation of colour and banding on their shells.

Over thousands of years, the climate changes. The creeks and wet areas in the valley dry up and the snails are no longer able to travel from one side of the valley to the other. The forest on the eastern side of the valley becomes drier than the forest on the western side. The eastern forest also contains lizards that eat snails. These predators are not found on the western side.

The two populations of snails become isolated and as a result they cannot mix and interbreed. Because of the different conditions in the two habitats, the phenotypes of the two snail populations eventually become distinctly different. The eastern snail is generally smaller and has a thicker shell with many bands. These features help the snail to avoid water loss, and protect and camouflage it against predators. The western snail, on the other hand, is generally larger and has few bands on its relatively thin shell.



A **species** is defined as a population of organisms that normally interbreed. The eastern and western snails are said to be different species because they have different mating seasons and behaviours, and do not interbreed.

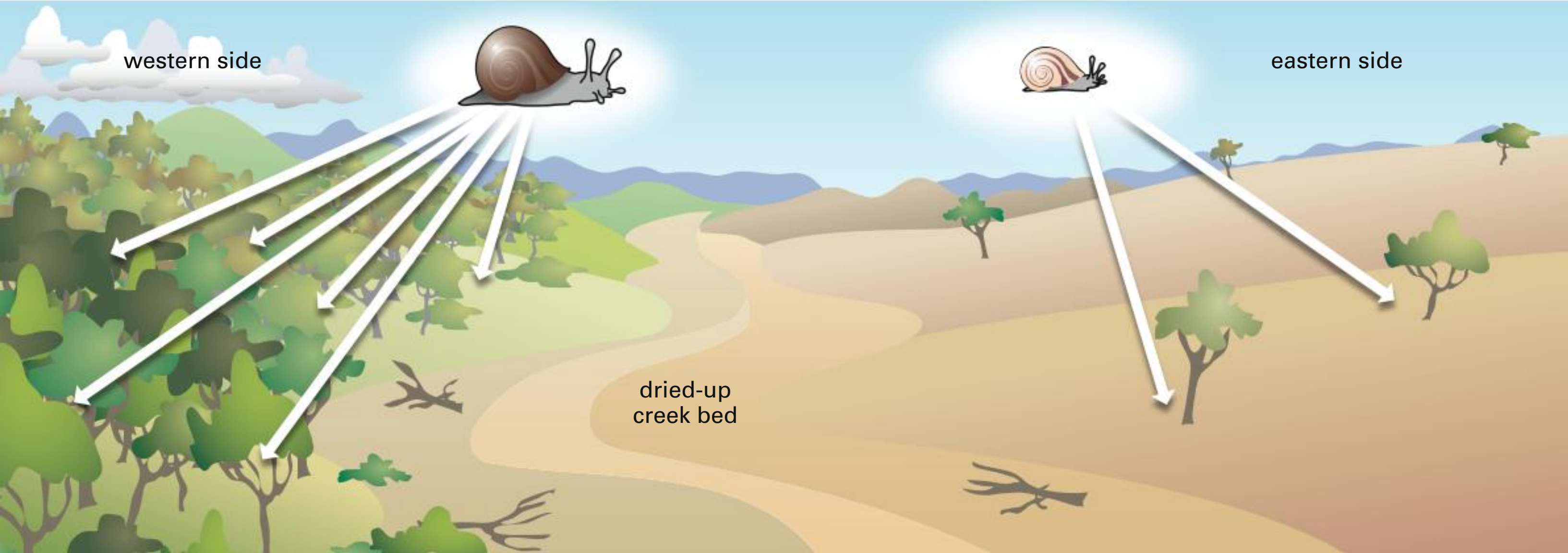


Fig 12 After many years of dry weather the creek and vegetation in the valley disappear.

Gene pools

A population of any organism contains all the genes that produce the variations of characteristics in its individuals. The sum of all these genes is called the **gene pool**. For example, the gene pool of the original snail population contained all the genes that produced the range of shell patterns and colours.

The gene pool of a population can change by mutations and by natural selection. Mutations add new genes to the gene pool, and selection removes genes. For example, the eastern snail population has a thick shell, which is an advantage against predators and water loss. The gene for this characteristic may have been added to the gene pool from a mutation in the snails' chromosomes. The gene for thin shells may have been removed from the gene pool because all snails with thin shells were eaten or dried out and died.

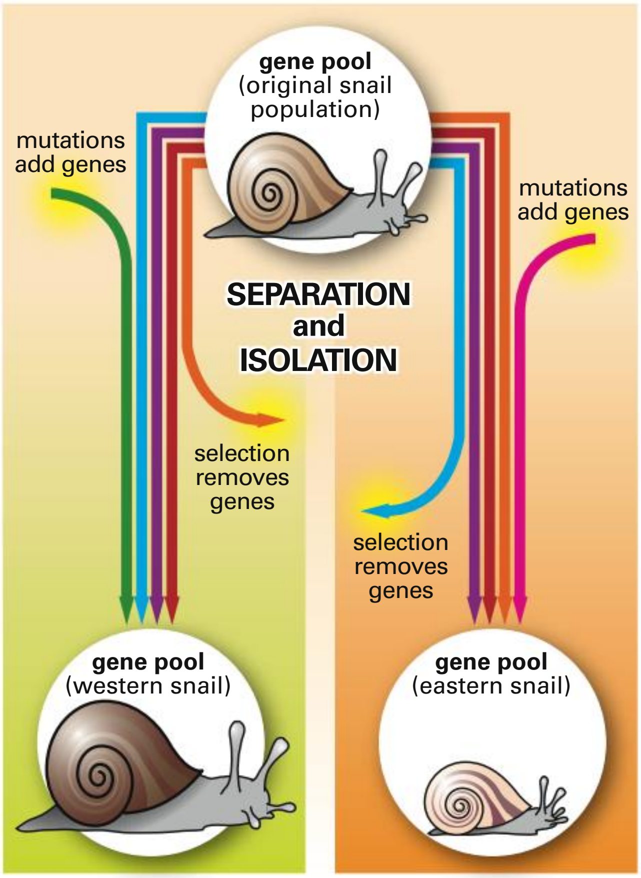


Fig 13 New species can be formed by separation and isolation of the gene pool.

Evolution—inferences and theories

In his famous book called *On the Origin of Species*, published in 1859, Charles Darwin suggested that natural selection was the process in which species change over time and develop into new species. This process is now called **evolution**. His ideas created a lot of controversy because they conflicted with the accepted Christian belief that all organisms were created at the same time.

Although Darwin was not the first person to suggest that currently living organisms evolved from earlier types of organisms, he was the first to argue that the change was brought about by the process of natural selection or 'survival of the fittest'. Darwin and his contemporaries had no knowledge of genetics and could not explain the cause of the variations and the way they are inherited.

To construct a theory explaining how species form, biologists made inferences from data obtained from the relationships between currently living species and those species that were previously living (fossils). These inferences were used to construct the *theory of evolution*. Biologists believe that this theory is useful for explaining how different species can form from a common ancestor. The changes to organisms usually occur over a very long period of time, very much longer than one human lifetime. Consequently, it is usually impossible for biologists to directly observe species formation and to test their inferences.

The evidence that is used to make inferences about evolution is gathered by many different people using many different techniques. As new discoveries and inferences are made, the theory of evolution is modified accordingly. Only the future will show whether the current ideas about evolution are correct.

Evidence for evolution

Fossil evidence

Fossils are the remains of once-living organisms, and are important pieces of evidence for the theory that life has evolved on Earth. The fact that many of these fossils are not like present-day organisms suggests that major changes have taken place on the Earth.

You learnt in your previous studies that most fossils form in sedimentary rock, and that usually only the hard parts of organisms become fossilised. Scientists can use various radioactive dating techniques to find the age of the surrounding rocks and then make inferences about the age of the fossils. It appears that not all fossils lived on Earth at the same time. Because of this it is likely that the various species evolved from earlier ones, and that many living organisms have common ancestors.

Even though the fossil record shows only a very small fraction of the organisms that have lived on the Earth, biologists have been able to suggest possible evolutionary changes that have taken place.

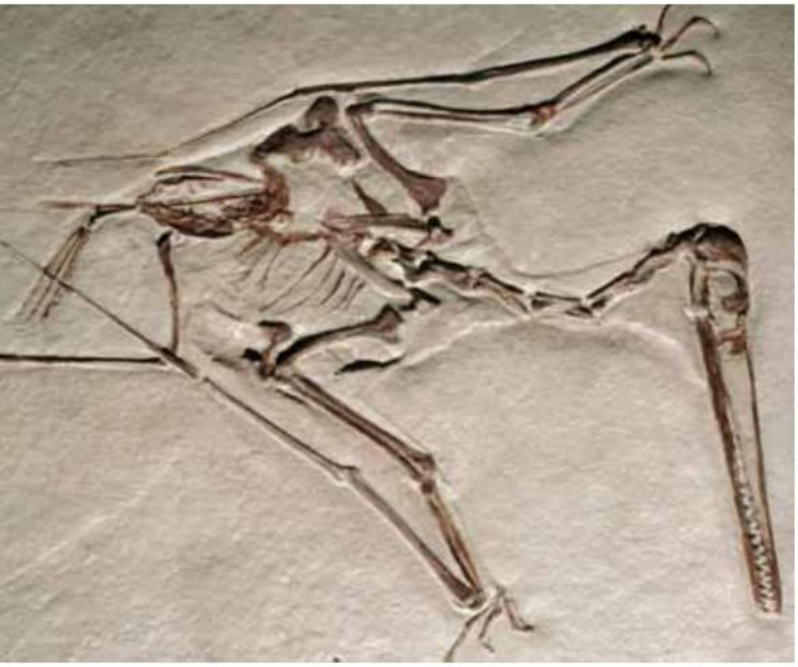


Fig 14 Dinosaur fossils are evidence that the types of organisms on Earth have changed over a long period of time.

Activity

The fossil record below shows the types of organisms that were alive at various times over the last 600 million years. Use this to answer the following questions.

- How long ago did the first fish appear?
- When did coal deposits form? What does this suggest about the environmental conditions at that time?
- How long have mammals been on Earth?
- What age are the oldest winged insects?
- Suggest inferences about how different organisms have appeared and disappeared on Earth at different times.

Age of rocks (Millions of years)	Fossils found in rocks	
2	first true humans	
15	first apes	
45		
70	first primates	
	mass extinction of many species, including dinosaurs	first flowering plants
150	first birds	first conifers
200	first mammals	
	first dinosaurs	
250	first winged insects	
	first reptiles	coal deposits formed
360	first amphibians	first ferns
	first fish	
410	first land arthropods	first land plants
	first marine vertebrates	
500		marine algae
	marine molluscs and arthropods	
570		
	bacteria and protists	

Biogeography

Biogeography is the study of the distribution of organisms. For example, marsupials are mainly found in Australia and include kangaroos, wallabies, koalas, wombats, possums and bandicoots. These mammals have pouches and give birth to immature young. Only two other types of marsupials live outside Australia—the possums and pouched shrews from South America. Fossil marsupials have been found in North America, South America and Australia, but none has ever been found in Africa or Europe. The present distribution of these animals gives clues to their evolution.

Scientists have inferred that millions of years ago Australia, Antarctica, South America and Africa formed the supercontinent Gondwana. Africa separated from this land mass about 100 million years ago and left the other continents joined. Marsupials were distributed widely over this remaining land mass. Then the plates that contain these continents started to separate. The South American plate separated first, and then about 55 million years ago, Australia separated from Antarctica, and drifted northwards towards the equator.

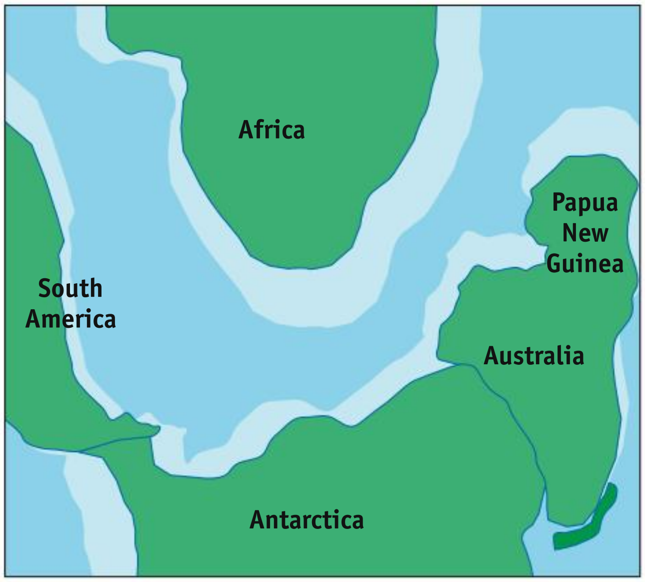


Fig 15 Part of the supercontinent Gondwana about 85 million years ago, which allowed organisms to spread over the now separated continents.

During the slow drift northwards the climate of Australia became progressively drier. Fossil records show that during this time marsupials became even more numerous and many different types evolved. In South America, however, the marsupials decreased in number and diversity, probably due to the competition from placental mammals such as the ancestors of jaguars. The very long period of isolation of Australia from other land masses has meant that many different marsupial species evolved.

By studying the distribution of the different types of living organisms and fossils, inferences have been made to show how the various types of organisms may have evolved.

Comparing embryos

When the embryos of different animals are studied, similarities can be seen. This is particularly evident when studying the embryos of vertebrates. The similarities, particularly in the very early stages, suggest that the genes that control the early growth of vertebrates may have come from common ancestors. The differences that embryos show as they develop further are due to other genes that are unique to each type of vertebrate.

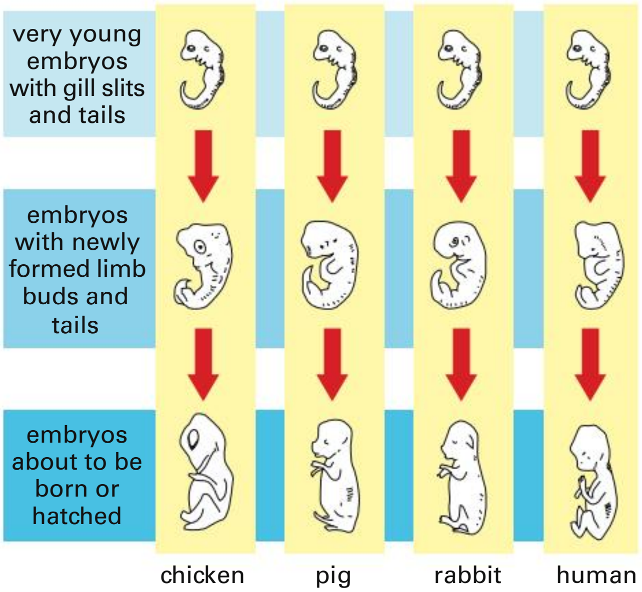
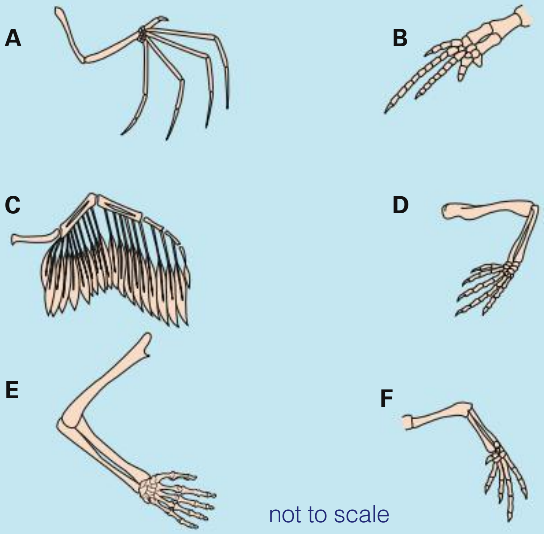


Fig 16 These vertebrate embryos are very similar at an early stage, suggesting that they might share a common ancestor.

Activity

The forelimbs shown below are from six different vertebrates. They show a number of similarities. This suggests that they share a common ancestor. However, they are each modified to suit a particular type of environment.



1 Match the name of the vertebrate in the list to its forelimb in the diagram.

bat	whale	bird
frog	human	lizard

Discuss how you arrived at your answers.

2 Make a list of the similarities of the forelimbs.

3 Suggest the specific function of each forelimb.

4 The study of the shapes and sizes of the bodies of different organisms is called comparative anatomy. Apart from forelimbs, which other parts of vertebrates could be useful for comparison?

Comparative DNA studies

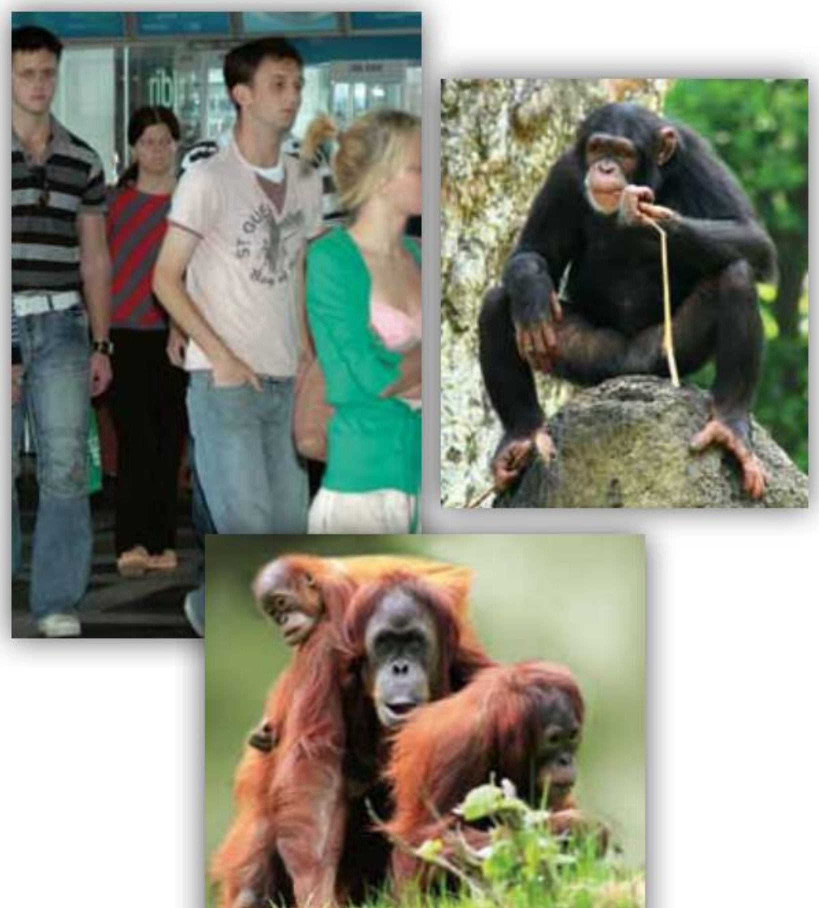
Until the last 30 years, most of the studies that show evolutionary links between organisms relied on *comparative anatomy* (used in the activity above), and evidence from fossils and biogeographical distribution. Now, however, the DNA in living species and that found in fossils can be analysed and compared.

A particular species is different from another species in the number and types of genes it contains. In comparative DNA tests, single strands of DNA from two different species are mixed together. If the two pieces of DNA are similar, the bases on each strand will bind strongly. The greater the difference between the DNA, the less tightly the strands will bind.

DNA studies have shown that the percentage similarity of DNA strands from humans and chimpanzees is 98.5%, while the similarity between humans and orang-utans is 96.5%. This shows that there is a close evolutionary link between these animals.

Using DNA tests, we can establish evolutionary links between various organisms and construct an evolutionary tree to show these links.

Fig 17 Strands of DNA from humans, apes and chimpanzees show a great degree of similarity, suggesting that these animals may have a common ancestor.



Science as a Human Endeavour

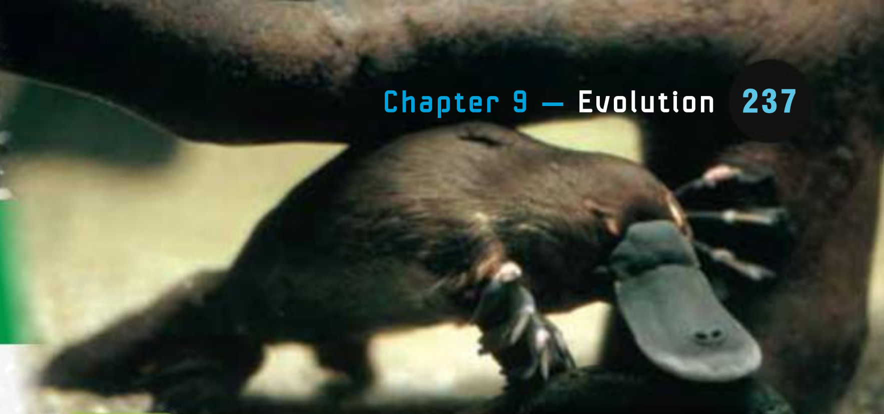


Fig 18 **The platypus was once thought to have lived in Australia only. Recent fossil evidence suggests that it may have lived in other continents as well.**

How theories change

If Charles Darwin was alive today and studied modern evolutionary theory, he would see many differences from the theory he proposed in 1859.

Scientific models and theories are constantly modified as new discoveries are made. For example, the platypus is an egg-laying mammal called a monotreme. Together with its relative the echidna, these mammals are the only living monotremes. No ancestral forms have been found, which led biologists to believe that these families of monotremes evolved separately from a common ancestor in Australia. However, in 1991 fossilised teeth found in sediments in South America were identified as very similar to fossil platypus teeth found in Australia. As a result of this discovery, biologists may have to modify their ideas about the ancestor of the platypus and its distribution.

Theories develop as inferences are suggested and evidence is collected to support or dispute them. This is why theories have to be treated as tentative—likely to change. In the future, new fossil discoveries and advanced technology will undoubtedly change some of the ideas that form the current theory of evolution.

Check

1 a What is a gene pool?
  b How do gene pools change over time?

2 Parrot A lives in forests and feeds on nectar and pollen. It has a repeating, high-pitched call, and breeds between May and August each year. Parrot B lives in the same habitat as parrot A and also feeds on nectar and pollen. It has a similar call to parrot A but breeds between September and November. Would you consider parrot A and parrot B to be the same species? Explain.

3 a What do you understand by the term *evolution*?
  b Use the snail story on page 232 and explain how it is an example of the process of evolution.
  c List the selection agents that acted on the snail populations over the period of time in the story.

4 What is the fossil record? How is it used as evidence for the evolution of organisms?

5 A particular type of tree called the Antarctic beech grows in small areas of Papua New Guinea, Australia's east coast, New Zealand and the far south of South America. Fossil beech trees have been found in these countries as well as in Antarctica. How do you account for the distribution of the Antarctic beech?

6 Apart from fossils and the distribution of organisms, what other evidence is used by biologists to support the theory that organisms have evolved on Earth?

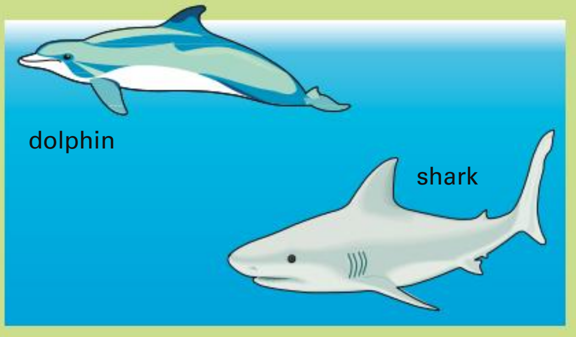
7 Suggest why evolutionary changes to organisms that reproduce many times a year are more rapid than those in organisms that reproduce only once a year.

8 The theory of evolution has changed since the time of Charles Darwin. Give reasons why this might have occurred.

9 Suggest why comparison of DNA is a more powerful tool in establishing evolutionary links than comparison of embryos.

Challenge

1 The shark is a fish and the dolphin is a mammal, but these two animals have the same basic body shape and structure. Suggest how natural selection might have caused this similarity.



2 The Tasmanian tiger (thylacine) was last seen in the wild in 1932. However, fossils show that it lived throughout Tasmania and mainland Australia. Biologists now think that this marsupial is extinct.

- **a** What does extinct mean? Use the term *gene pool* in your answer.
- **b** Some people think that endangered species should be protected and breeding programs established. Others think that it is simply natural selection at work and that the fittest species will survive. Outline your views on this and then discuss your views with others.

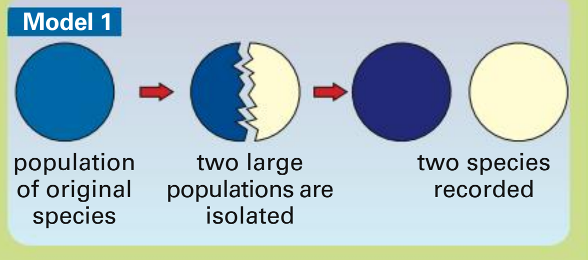
3 The map shows the distribution of Fletcher's frog. It is found in rainforests and breeds in small pools and creeks.

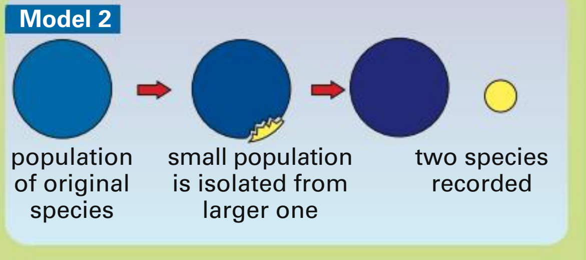
- **a** Suggest why this species of frog is found in two locations that are widely separated.

- **b** Suggest what could happen to the frog populations in the two different locations over a period of time.
- **c** Biologists say that distribution maps like this are only tentative and may change in years to come. Suggest factors which you think may cause this map to change.

4 Do you think that organisms stop evolving in environments that change very little over long periods of time? Explain your answer.

5 The models below show two ways in which the gene pools of an original species can be separated and isolated over a long period of time.
In model 2, only a very small number of organisms is isolated from the larger population. Biologists suggest that this model accounts for those species that change very quickly from the original one. Give reasons why biologists suggest this.





WEBwatch

Use the internet to find out how the work and theories of Jean Baptiste Lamarck and Alfred Wallace contributed to the modern theory of evolution. Compare and contrast the theories of both of these biologists to that put forward by Darwin.

Suggest why Darwin is more well known than Lamarck or Wallace.

9.4 Selecting genes

The fantail goldfish in the photo cannot swim very well, has vision problems and probably will not live as long as those in the wild. However, to a collector of fish it is worth hundreds of times the value of a wild form of goldfish.

Fig 19 A selectively bred fantail goldfish

Artificial selection

Artificial selection or *selective breeding* is the process in which *humans* select those phenotypes in organisms that have a value or serve a purpose. For example, the particular features of the goldfish are valued by certain people, so fish breeders select fish with unusual phenotypes and try to produce offspring with the same features.

Dogs are the oldest domestic animals and may have been selectively bred by humans for more than 10 000 years. At the time Europeans landed in North America, the indigenous American people had selectively bred more than 20 breeds of dogs.

The grey wolf is thought to be the ancestor of the dog, and many of the characteristics of the wolf are present in some dog breeds. For example, wolves tend to guard the den that houses their young. This feature has been selected in certain breeds of dogs, namely German shepherds and Doberman pinschers, which are used as guard or watch dogs. The hunting characteristic in the wolf has been selected in such breeds as the hounds and spaniels (for trailing after prey), retrievers (for finding and retrieving prey) and terriers (for attacking prey).

However, the selective breeding of dogs has also brought with it some genetic problems. For example, German shepherds have hip problems and suffer endocrine gland problems. Pugs and bulldogs suffer from breathing and teeth problems due to the odd shape of their jaws.

Fig 20 The pug, like the bulldog, was bred for its sporting and fighting ability but has inherited breathing and teeth problems due to the shape of its jaws.

Fig 21 Cocker spaniels have been bred for their ability to find prey. However, they often suffer ear infections because of their large floppy ears.

Biotechnology

Biotechnology is a field of science that uses organisms to produce materials for people to use, for example food, clothing and medicines. Most of the work in modern biotechnology is at the molecular level and involves the manipulation of genes in organisms. This is commonly called **genetic engineering** or *recombinant DNA technology* and is the technique of inserting desired genes from one species into the chromosomes of another species.

The photo above shows the caterpillar of the moth (cotton bollworm) that causes severe damage to cotton crops. Traditionally, farmers have used pesticides to control the caterpillars and to stop damage to crops. However, over the years the insect has become resistant to the pesticides. Consequently, farmers have to use more concentrated pesticide solutions to have any effect on the caterpillars.

A particular species of bacterium called *Bacillus thuringiensis*, or Bt, naturally produces a protein that kills caterpillars. In plant nurseries you can buy packets of Bt, which you mix with water and spray onto vegetable crops. The bacteria infect the caterpillars on the plants and cause them to die.

Scientists have found that a gene in the Bt chromosome is responsible for making the protein that kills caterpillars. They have inserted this gene into the chromosomes of cotton cells, so that as the cotton plant grows it makes the special protein. When the caterpillar eats the plant, it takes in the protein and dies. Using this technology the farmers enjoy a double benefit—they are able to reduce quite dramatically the amount of pesticide used and also increase their yields of cotton from the crop.

Transferring a gene between two unrelated species, like the bacterium and the cotton plant, produces a transgenic organism.

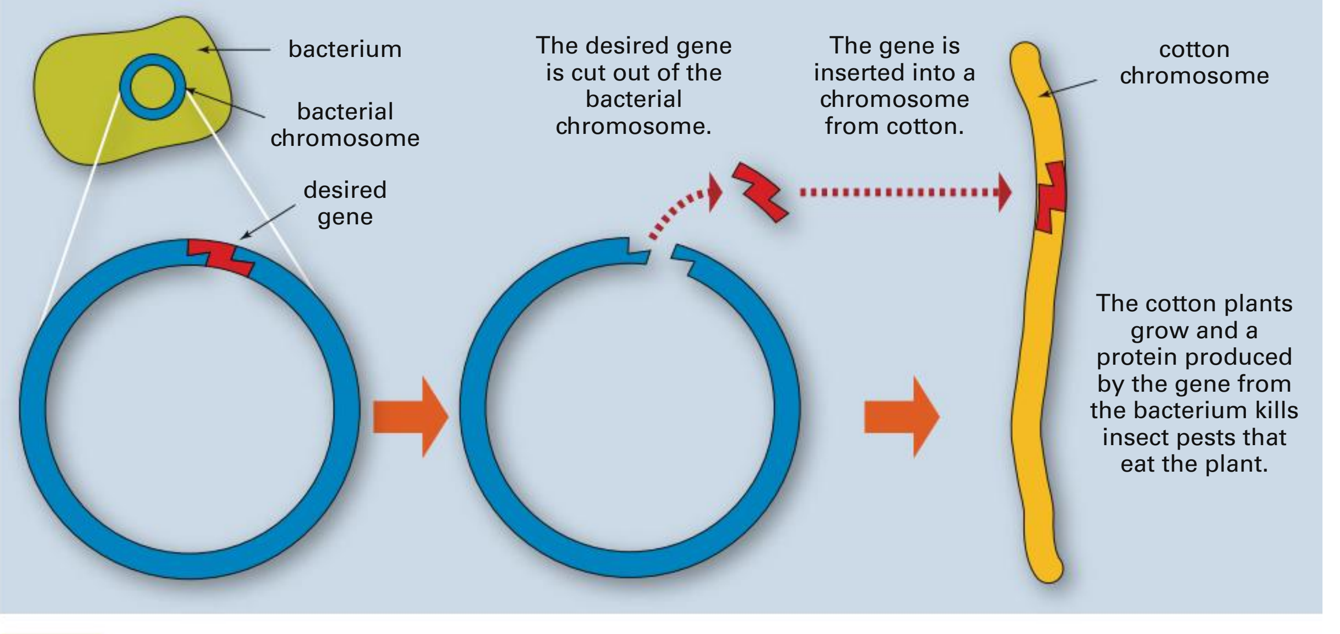


Fig 22 Transferring a gene from a bacterium to a chromosome in a cotton plant

Cutting and recombining genes

DNA normally consists of two strands and is called double-stranded DNA. Each base on one strand is paired to a *complementary base* on the other strand. You can see in the diagram below that A bonds only to T, and G only to C. So A is the complementary base to T.

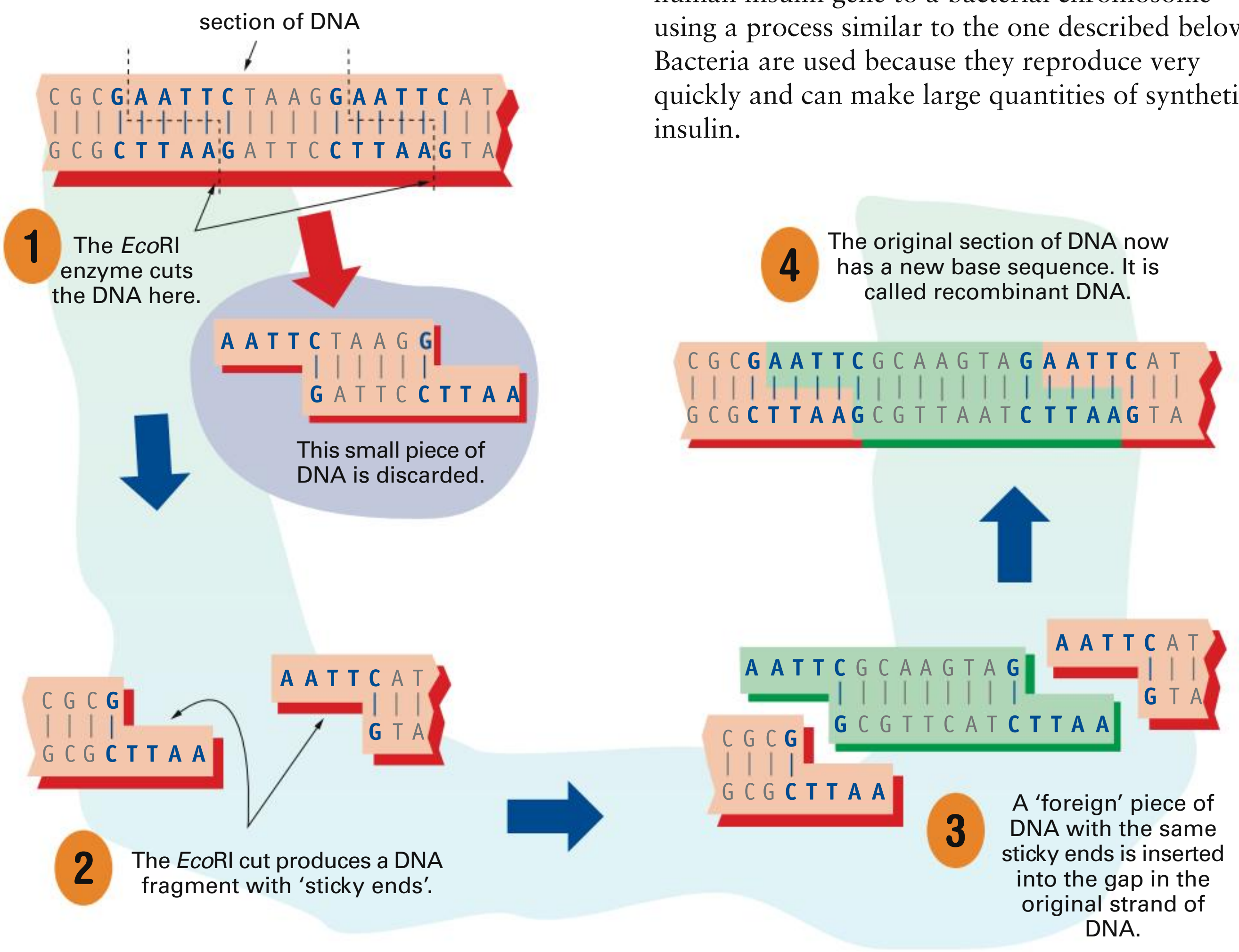
To cut DNA, biologists use special enzymes called restriction enzymes. These cut the DNA at particular places along the sequence of bases. There are several hundred restriction enzymes, each able to cut the DNA at a particular place. For example, the restriction enzyme *Eco*RI recognises the base sequence GAATTC and cuts the DNA after the G in this sequence, leaving a tail or 'sticky end'. In the diagram below, the *Eco*RI enzyme has found and cut two GAATTC sequences out of the piece of DNA.

To join the fragments of DNA, other enzymes called *ligases* (LYE-gay-zes) are used. These enzymes occur in the cells of most organisms and are used to repair pieces of DNA that have been broken or damaged. In the laboratory, ligases are used to recombine the fragments of DNA that have been cut.

Using gene technology to make insulin

People suffering from type 1 diabetes do not produce the hormone insulin. These people can lead normal lives by having daily injections of insulin. The insulin was traditionally obtained from pigs and cattle. However, it differed slightly from human insulin, and contained impurities that caused an allergic reaction in some people.

To overcome this problem, biologists added the human insulin gene to a bacterial chromosome using a process similar to the one described below. Bacteria are used because they reproduce very quickly and can make large quantities of synthetic insulin.



Investigation 17 Gene technology model

Aim

To use a model to show how genes are cut from chromosomes and recombined into other chromosomes.

Materials

- about 100 coloured paper clips (4 colours—red, green, yellow and blue)
- strip of cardboard 7 cm x 50 cm
- scissors

Planning and Safety Check

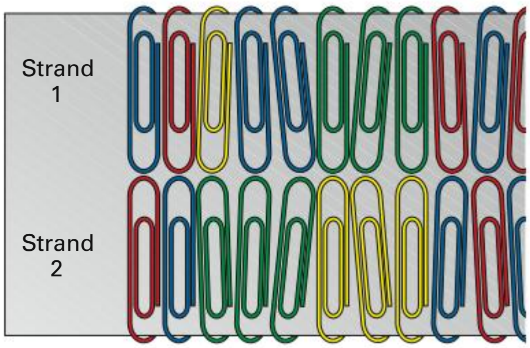
- In the activity on page 66 you made a model of DNA using coloured paper clips. The same model is used in this investigation. The four colours of the paper clips represent the four types of bases in DNA. Blue = A, red = T, yellow = G and green = C.
- Read through the Method carefully. You will need to refer to the table on page 67 to work out your amino acid sequence.

Method

1 On one side of the strip of cardboard strip, place about 50 paper clips in random order side by side. Make sure the total number can be divided by three. Label this strand 1.

2 Make sure you have two sets of the base sequence GAATTC somewhere along the chain of paper clips.

3 On the other side of the cardboard strip, place paper clips that represent the complementary bases to those on strand 1.



Remember, A bonds only to T, and G only to C. So if the first five bases on strand 1 are ATGAA, the complementary bases in strand 2 will be TACTT. This is your model of double-stranded DNA.

Use the code for amino acids in the table on page 67 to work out the sequence of amino acids that is coded by strand 1.

4 Look for the first base sequence GAATTC in strand 1 and cut through both strands as shown in the diagram on the previous page.

5 Locate the second GAATTC sequence and cut through both strands. You should now have three fragments of double-stranded DNA.

6 Keep the two end fragments of the double-stranded DNA and swap the middle fragment with another group.

7 Join the new middle fragment between the end fragments. Does it fit? Why?

Work out the amino acid sequence on your recombinant piece of DNA. Compare this one to the original sequence in Step 3.

Discussion

1 Write a conclusion for this experiment. Use the term *recombinant DNA technology*.

2 What is the complementary base sequence to the sequence CTTAAG? Read the complementary sequence back-to-front. What do you notice? What is the importance of this in the DNA molecule?

Science as a Human Endeavour

Genetically modified foods

Transgenic organisms are being bred to produce foods or ingredients for foods. These foods are called *genetically modified foods* or *GM foods*.

GM foods are usually defined as those foods that contain genetically modified ingredients. Sometimes the whole of the food is genetically modified, for example soybeans and corn. Other foods that are considered GM foods contain varying amounts of GM ingredients. For example, 10% of the mass of a doughnut may be GM soybean meal. Other foods might contain smaller amounts of GM ingredients such as food preservatives or additives.

What are the advantages of GM foods?

The GM foods currently available in Australia contain mostly soybeans, canola, corn, potato or sugar beet. In the United States, more than 70% of the foods in supermarkets contain some GM foods.

Some of the GM crops have been modified to protect them against either insect or virus attack. This means that farmers can reduce the amount of pesticides they spray on their crops. Other GM crops such as soybeans can withstand the effect of herbicides, which means that they can be sprayed with herbicides that kill weeds but not the crop.

Currently, scientists are experimenting to produce GM foods with greater amounts of vitamins and proteins, and ones that are free from the proteins that cause allergic reactions in some people.

Animals are also used to produce GM foods. Transgenic technology is being used to produce faster-growing and leaner pigs that use food more efficiently and are resistant to common diseases. This technique is also used to breed fish, sheep and poultry.

Concerns about GM foods

In 1992, scientists working for a multinational seed company produced a transgenic soybean containing a gene from a Brazil nut. The gene produces a protein rich in a particular amino acid that is found in small amounts in normal soybeans. Before being released, the soybean was given to a test group of people. Some of the people allergic to Brazil nuts became allergic to the soybeans. Because of this the GM soybeans were withdrawn and never released.

Some scientists are concerned about the use of GM crop plants. It has been estimated that 20% of crop plants escape from farms and establish wild populations. It is likely that the wild crops could crossbreed with weeds to produce plants that are herbicide and pesticide resistant, or drought, cold or salt tolerant. Also GM plants that are poisonous to insects kill both the 'pest' as well as beneficial insects. Then the insects may become resistant to the GM plants and farmers will again have to spray the crops with poisons.

Discussion and debate

The questions below deal with a number of GM food issues. To help in your discussion, search the internet under *genetically modified foods*, *transgenic animals* or *biotechnology*.

1. The Australian Food Standard 1.5.2, which came into effect in December 2001, requires labelling of GM foods. Go to **www.OneStopScience.com.au** and follow the links to **GM foods** to find out more about this requirement.
2. Do a supermarket survey to find out how many products contain GM foods.
3. Prepare a questionnaire to find out how much people in your neighbourhood know about the benefits and risks of GM foods.
4. The genes of some animals, for example pigs, have been added to plants that are grown for food. Should genes be allowed to be swapped between animals and plants? What are some of the consequences for people of certain religions or for vegetarians if this occurs?
5. What are the benefits of using GM crops that are resistant to pests and certain climatic conditions? What are the possible problems?
6. Prepare cases for and against GM foods and transgenics. Your teacher might organise you into groups for a class debate.

Cloning

In 1997, the world's first cloned mammal was born. 'Dolly' the lamb was developed from the single body cell of a ewe (female sheep). In this process the cell developed without being fertilised by a sperm.

Since Dolly, many improvements have been made to this cloning technique, which is often called *nuclear transfer*. The diagram shows the technique used to produce Australia's first cloned pigs in 2001.

The nuclear transfer technique allows the production of a large number of identical animals, called **clones**, all from the one cell grown in a culture. This could mean that herds of identical farm animals could be produced. For example, the best milk-producing cows could be cloned, and then smaller herds could produce large quantities of milk for less food and lower production costs.

Cloning is also important for future human organ transplants. For example, cloned pigs could be used as a source of transplant organs, namely the heart, lungs, liver and kidneys.

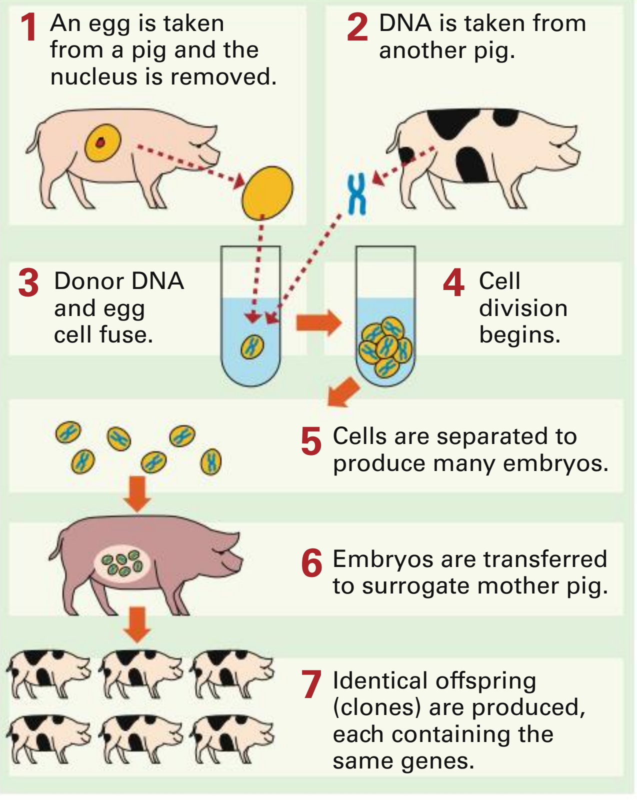


Fig 23 This baby gaur, a wild ox from India, was born in 2001 and was the first endangered animal to be cloned. The baby gaur, called Noah, died from an infection (unrelated to the procedure) two days after its birth.

Goodbye Dolly

Dolly the sheep died in February 2003, six years after her birth was headlined in newspapers around the world.

Dolly died from a lung infection, which is fairly common in sheep. She also had arthritis in her back legs. However, scientists are uncertain if her premature death was a result of the cloning procedure or just a natural occurrence.

Before developing arthritis, Dolly had given birth to six healthy lambs as a result of natural mating.

WEBwatch

For more information on cloning go to **www.OneStopScience.com.au** and follow the links to the websites below.

Cloning fact sheet

How cloning works

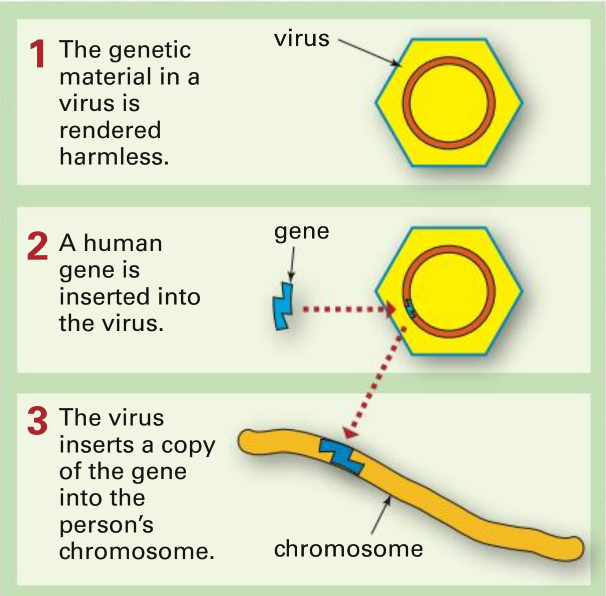
Science as a Human Endeavour

Human gene therapy

Human gene therapy is an experimental area of biotechnology that treats people with genetic diseases. It involves introducing a piece of DNA that carries a 'normal' dominant gene into a person who has a genetic disease. The 'normal' gene replaces the disease-causing gene in the body cells of the sick person. Currently only diseases that are caused by a single recessive gene are treatable. These include cystic fibrosis and thalassaemia.

How does the new gene get into body cells?

At present the most successful way to insert a gene into a person's chromosomes is to use another organism—a virus. When viruses infect people, they insert their genetic material into the person's chromosomes. Scientists render the virus's own genes harmless, and insert the human gene into the chromosome. The viruses are then injected or inhaled and invade the body cells, inserting the dominant gene into the affected person's chromosomes. This gene masks the recessive gene that is causing the disease.



Germ-line gene therapy—creating designer people?

Instead of inserting the gene into a person's body cells, it is possible to insert it into the cells of an embryo and allow the normal cell division and growth to occur. This is called *germ-line therapy* and is currently prohibited in Australia and in most other countries.

The main concern with this technology is that it could be used to create designer babies. For example, a woman could have an egg fertilised by sperm and cultured in the laboratory. Before it is placed into her uterus, the embryo's genes could be scanned for potential diseases and replaced if necessary. However, other 'selected' genes could also be inserted in the embryo at this stage.

Questions

1 Draw a simple flow chart to show how a virus can be used to insert a gene into chromosomes in a lung cell of a person suffering from cystic fibrosis.
2 Why do you think germ-line therapy is prohibited by most governments?
3 Use the internet to search for *human gene therapy* and *germ-line therapy*. Use the information to prepare a discussion for and against.

Check

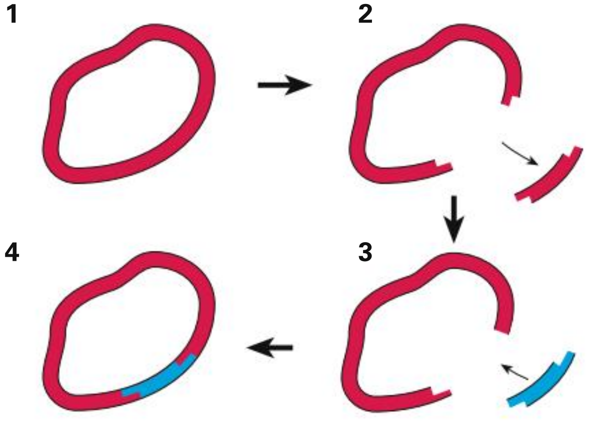
1 How does artificial selection differ from natural selection?
2 Genetic engineering is called recombinant DNA technology. Explain in simple language why these terms are interchangeable. (Hint: Refer to page 240.)

3 The greatest advantage of gene technology is that it can be used to make large amounts of substances needed by humans (e.g. hormones) by placing human genes into bacteria.
   a Why are bacteria used in this process?
   b At present many of these substances are extracted from other mammals. Suggest why there are problems with this.

4 Restriction enzymes have sometimes been called gene shears. What does the word *shears* mean? If you are unsure find the meaning in a dictionary. Why do you think this term describes the role of restriction enzymes?

5 a Describe what a clone is.
   b Why is cloning called nuclear transfer?
   c Suppose a farmer had a herd of 30 cloned sheep. What would be the advantages and disadvantages of a cloned herd compared with a normal herd?

6 The diagram on the right shows foreign DNA being placed into a bacterial chromosome.
   a Copy the diagram in your notebook and add these labels: bacterial chromosome containing donor DNA, deleted section of bacterial DNA, donor DNA, bacterial chromosome.
   b In which steps are restriction enzymes and ligase enzymes used? Explain your answer.

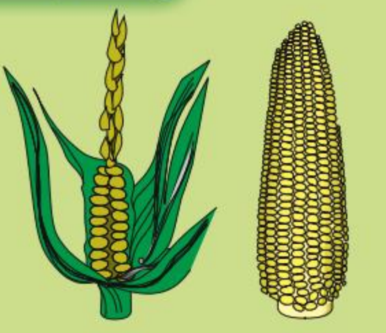


   c Why is the same type of restriction enzyme used for the bacterial DNA as for the donor DNA?

7 The cotton plant in the photo on page 240 is called a transgenic organism.
   a What does the word *transgenic* mean?
   b Why are some people worried about the effect of GM crops like this cotton on the environment?

Challenge

1 The diagram below shows an ear of modern corn and an ancestor of modern corn.



   a Unlike the ancestral corn, the seeds (or kernels) of modern corn cannot come away from the stem and therefore cannot self seed. Suggest why this characteristic would have been selectively bred in corn. Could modern corn survive in the wild?
   b Many biologists argue that the wild forms of plants like corn should not be allowed to become extinct. Suggest why.

2 Consider the following cloning scenario. Suppose a woman suffers from a severe genetic disorder. She and her husband want a child but are opposed to abortion and do not want an egg donated by another woman. Doctors say that the husband's DNA can be fused into one of his wife's eggs whose nucleus has been removed.
   a Use the diagram on page 244 as a guide to explain how this might be done.
   b What other technique in biotechnology could possibly be used in this case?

3 A CSIRO researcher found a gene that makes plants destroy their own seeds. Discuss the pros and cons of adding this gene to plants that supply our fruit and vegetables.

4 Selective breeding is just one technique used in what is now called traditional biotechnology. Find out about other techniques. Then make a list of the techniques in traditional and modern biotechnology. Beside each technique list its benefits and risks to our society.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 There are three ways in which variations in a genotype occur: ______ of chromosomes as well as recombination of DNA during sex cell division, and ______ in the chromosomes in sex cells.

2 The ______ of phenotypes in a population occur as a result of genetic factors and ______ factors such as nutrition and health.

3 ______ is the process in which individuals with favourable ______ have a better chance of surviving in a particular environment than other individuals.

4 The factors in an organism's environment that affect its survival are called ______. These include ______ and predation from other organisms, heat and cold, and the availability of soil and water.

5 A ______ is the sum of all the genes in a particular ______ of organisms.

6 ______ is the process in which species change over time and may develop into new species.

7 ______ or selective breeding by humans has changed the phenotypes of many types of organisms.

8 ______ describes the process in which ______ from one organism are inserted into the DNA of another organism.

artificial selection
competition
environmental
evolution
gene pool
genes
genetic engineering
independent assortment
mutations
natural selection
phenotypes
population
selection agents
variations

Working with technology

Try doing the Chapter 9 crossword at www.OneStopScience.com.au.

OneStopScience

REVIEW

1 Which is the best definition of a gene pool?
   A the type of gene in a population
   B the sum of all the genes in a population
   C the number of combinations of genes possible
   D the genes carried by the parents of a particular offspring

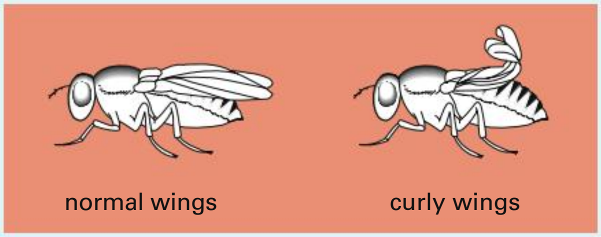
2 Which of the following factors would least influence natural selection?
   A natural death
   B competition from other species
   C mutation
   D interbreeding

3 Which statement about natural selection is *incorrect*?
   A It indicates how new species may form.
   B It relies upon the fact that characteristics are inherited.
   C It suggests that only the largest and most physically fit organisms survive.
   D It suggests that the biotic and abiotic factors may favour some individuals and not others.

4 The domestic dog has over 100 different breeds, yet wild dogs have very few variations (e.g. jackal, wolf, dingo). How can you explain this?

5 An organism's genotype is not the only factor that determines its characteristics (phenotype). The environment also plays an important part in how the organism's genes are expressed. Explain, giving an example, what this statement means.

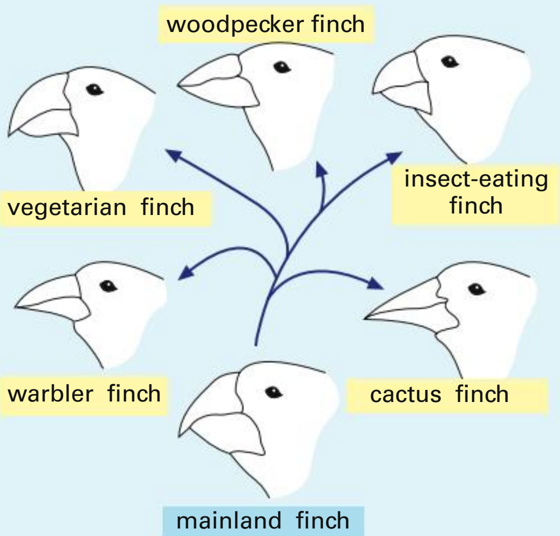
6 The diagram below shows a fruit fly with normal wings and one with curly wings. Flies with curly wings cannot fly. The gene for this characteristic occurs as a natural mutation. Suggest why very few adult fruit flies with this phenotype are found in nature.



7 In which of the following activities are humans least likely to influence the evolution of other organisms? Justify your answer.

A spraying gardens with pesticides
B breeding frost-resistant oranges
C recycling wastes from cities
D using antibiotics in the control of bacteria

8 The diagram below shows the five species of finches that Charles Darwin observed when he visited the Galapagos Islands. It also shows the finch that lived on the mainland of South America, which Darwin inferred was the ancestor of the Galapagos Islands finches. Suggest how modern DNA testing techniques could be used to support Darwin's inference.

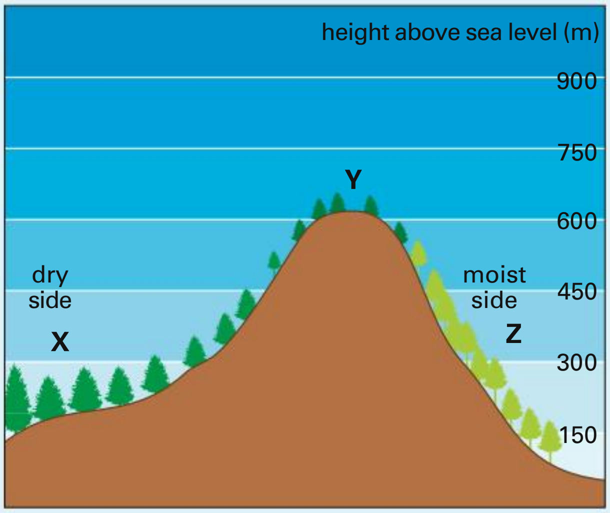


9 A human gene that is responsible for the manufacture of a growth hormone in humans can be produced in the laboratory by genetically modified bacteria. Use simple labelled diagrams to explain how this procedure works.

10 A particular species of moth exists in two forms, a light-coloured form and a dark-coloured form. These moths rest on the bark of trees in the daytime. When a bird catches a moth, it swallows the body and rejects the wings.

Suppose you had 100 of each type of moth. Design a test to show that birds are selection agents of this moth.

11 A species of forest tree has spread over a mountain from the dry side to the moist side. The three populations show different characteristics: the trees at X are drought-resistant, those at Y are frost-resistant, while those at Z need high humidity.



a List the selection agents in this situation.
b Explain why the populations of trees in each location are different.
c Suggest why the trees at X are more likely than the trees at Y to form a different species from the trees at Z.

Check your answers on page 308.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science as a Human Endeavour

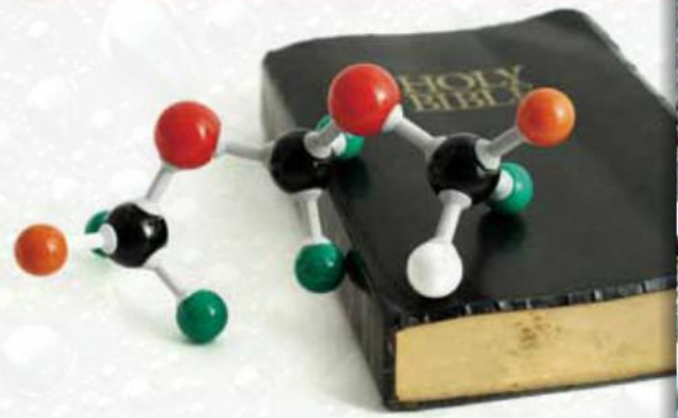
Evolution and creation

It is normal to wonder where humans and everything else in the universe came from. From the time that Charles Darwin first proposed the theory of evolution, it has been opposed by many creationists. Creationists believe that God created the Earth and all life on it as recorded in the Bible or the Koran. Other cultures such as Australian Aborigines also have their own stories of creation that differ from those of Christianity or Islam.

You have probably developed your own opinions about creation and evolution, based on what your parents, church, friends, teachers and others have said or taught you. We live in a diverse community with various belief systems and other students in the class may have opinions that are very different from yours. It is important that you respect their opinions, just as you would expect them to respect yours.

Your task is to analyse the arguments put forward by evolutionists and creationists to form your own opinion. Form groups and use the internet and other resources to research the questions below. Most websites are strongly biased towards either creation or evolution, so try to work out what their bias is. Different groups could answer different questions, although you should all answer the last question. To help you form your own opinion, your teacher may be able to invite experts to talk to the class about evolution and creation.

1 From your research, outline the main differences between evolution and creation.
2 Creationists believe that all living things on Earth were created at the same time. This means that humans and dinosaurs were on Earth together. How does this differ from what scientists tell us?
3 Scientists infer the universe is about 13.7 billion years old, and the Earth is 4.5 billion years old. However, creationists say the universe and everything in it was created between 6000 and 10 000 years ago. Why is there such a difference between the evolutionist view and the creationist view?



4 Scientists infer that fossils have been created by normal geological processes over the 3.5 billion years that life has been on Earth. What do creationists say about fossils?
5 Creationists claim that there are no transitional fossils that show a change from one species to another. Are they correct? Outline some evidence to support your answer.
6 Evolutionists say we didn't evolve directly from apes, but we share a common ancestor with the apes that exist today. Explain the difference.
7 What is the difference between microevolution and macroevolution? Where do creationists stand on this?
8 What does it mean to interpret the Bible literally? In what other way can it be interpreted?
9 From what you have learnt about theories in science, do you think creation is a scientific theory?
10 Does evolution prove that God doesn't exist? Explain your answer.
11 Someone once said 'Scientists tell us how the world was created. The Bible tells us who created it.' What does this mean, and do you agree?
12 Is it possible to accept the theory of evolution and yet believe that God created all life on Earth? Explain your answer.
13 *What conclusion have you personally reached about evolution and creation? (There is no right or wrong answer!)*

10 Exploring the universe

In this chapter you will …

Science Understanding

- explain how the sun produces energy, and compare its brightness and colour with other stars
- correctly use terms like nebula, supernova, neutron star and black hole to describe the birth and death of stars
- outline the Big Bang theory and the evidence supporting it

Science as a Human Endeavour

- research Australian Aboriginal people's knowledge of the night sky and how they used this knowledge

Science Inquiry Skills

- locate and record the positions of stars and constellations in the night sky
- use the internet to research the latest discoveries in space

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Do aliens exist? If so, where do they come from? To answer these questions you need to know something about the structure of the universe. Form a group of three or four people to discuss the questions below.

1 If aliens exist, is it likely that they come from our solar system or somewhere else? Give your reasons.
2 The nearest star is 4.2 light-years away. What does this mean?
3 How could you estimate the number of stars in the night sky? Is this the total number of stars in the universe? Explain.
  Could we get to any of these stars using our present methods of space travel? Suggest other ways of travelling to stars.
4 What is the Milky Way? Is it the whole universe?
5 How does the sun produce its energy? Will it shine forever?

10.1 The universe from Earth

On a clear night you can see about 3000 stars in the sky. To the ancient astronomers these stars, plus the moon and sun, made up the universe. And all the objects in the universe revolved around the Earth.

We now know that the Earth is not the centre of the universe, and that the sun is only one of millions and millions of stars. There are so many stars that if each of them was a grain of sand they would fill up the Sydney Opera House!

Star patterns

Many of the stars visible to the naked eye form recognisable patterns. These groups of stars are called **constellations**. A constellation keeps the same shape, although with the Earth's revolution around the sun, you see some constellations on summer nights and others in winter.

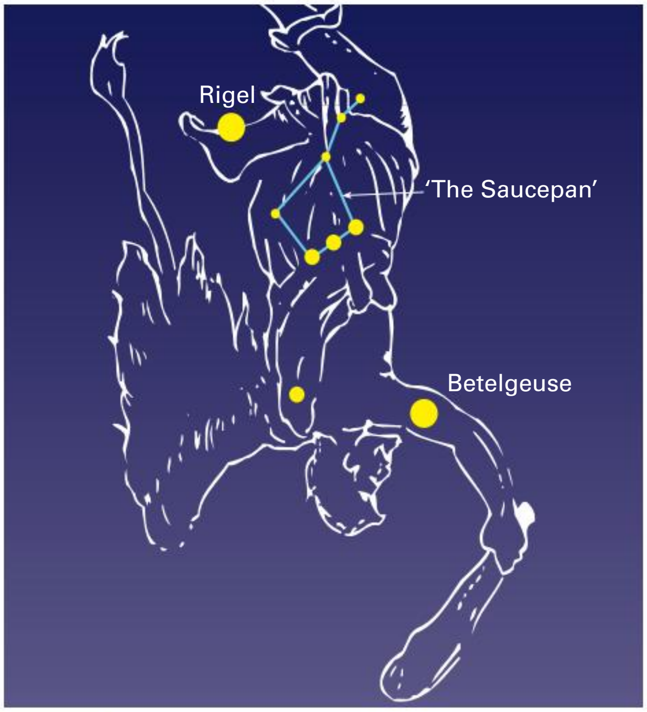


Fig 1 Ancient Greek astronomers named this constellation Orion after the mythological person who was a mighty hunter of great strength and beauty. The three bright stars that form Orion's belt are in a group of stars that we sometimes call The Saucepan.

People of all cultures have given names to the constellations. However, most astronomers accept the naming of constellations based on the ancient Greek classification. For example, most of the constellations have been named after animals or other objects such as the sails of a ship or a clock. Altogether there are 88 recognised constellations.

Astronomers use Latin names for the constellations. (Latin was the language of Ancient Rome.) The Southern Cross is called Crux (the Latin word for cross), and the lion is called Leo. More recently named constellations are also given Latin names. For example, the constellation shaped like a telescope is called Telescopium, even though there were no telescopes in Roman days.

Star distances

The closest star, our sun, is 150 000 000 km away. (It would take over 6 months to reach the sun if you travelled in the space shuttle.) The next closest star is 41 000 000 000 000 km away, or 270 000 times the distance of the sun. You can see from these figures that the distances to the stars are enormous, with vast spaces between them.

The distances to the stars are far too large to measure in kilometres. Instead an astronomical unit of distance called the **light-year** is used. This is the distance light travels in one year. Light travels at about 300 000 000 metres per second (3×10^8 m/s), so in one year, light travels about 9 500 000 000 000 km (9.5×10^{12} km).

The stars in a constellation are not all the same distance from Earth. For example, the four bright stars in the Southern Cross are very far apart. The closest star is 88 light-years away, while the furthest one is 360 light-years away. See Fig 2 on the next page.

When you look at stars, you are looking back in time. The light from the closest star in the Southern Cross left that star 88 years ago. In other words, you are seeing the star as it used to be in the 1920s!

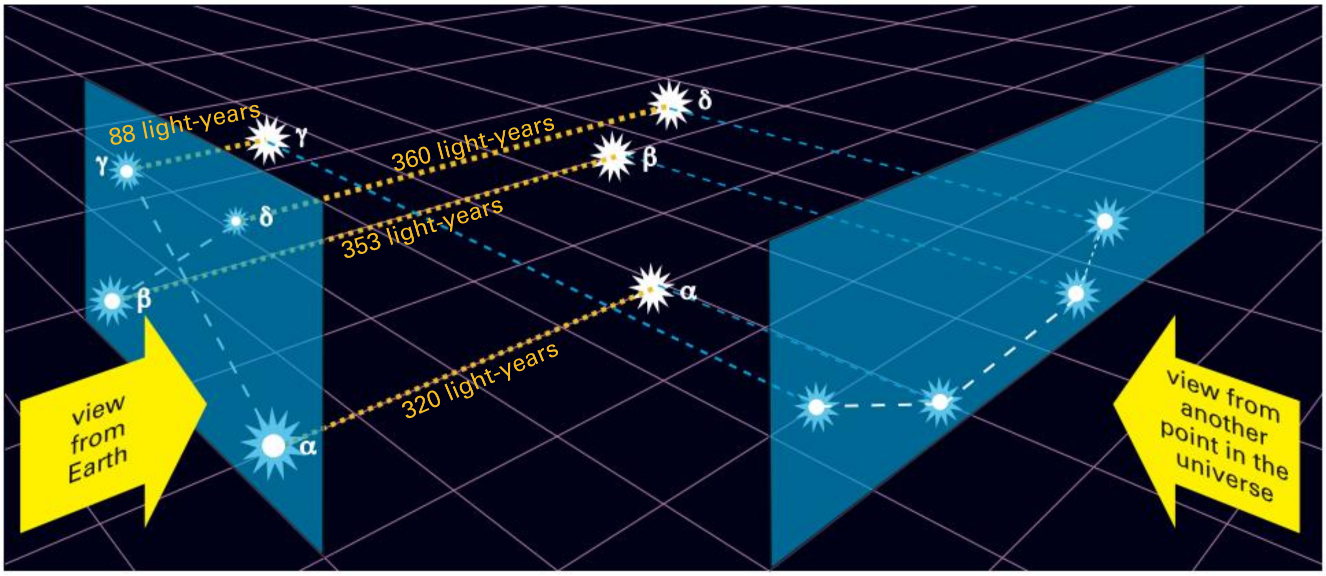


Fig 2 The four main stars in the Southern Cross appear to be in the same plane when viewed from Earth. However, you would not see the cross pattern if you looked at these stars from somewhere else in the universe.

Naming stars

Many of the bright stars in the sky have been given names. For example, the brightest star in the sky is called Sirius, and the two stars that make up the constellation Gemini are called Pollux and Castor. However, naming every individual star in the sky would be a huge task, even if you could remember their names.

In 1603 a German astronomer, Johann Bayer, thought up a system of naming stars in a constellation according to their brightness. The brightest star is called the alpha star (α-star), the second brightest the beta star (β-star), then gamma (γ), delta (δ), and so on.

If the sky is clear tonight, look for the Southern Cross. You will find the brightest star at the base of the cross. This is called α-Crucis (CREW-sis). Near the Southern Cross are the two bright stars in the constellation Centaurus (sen-TOR-us). These stars we usually call the Pointers. The brighter of the two stars in the Pointers is called α-Centauri and is the closest star to the Earth (apart from the sun).

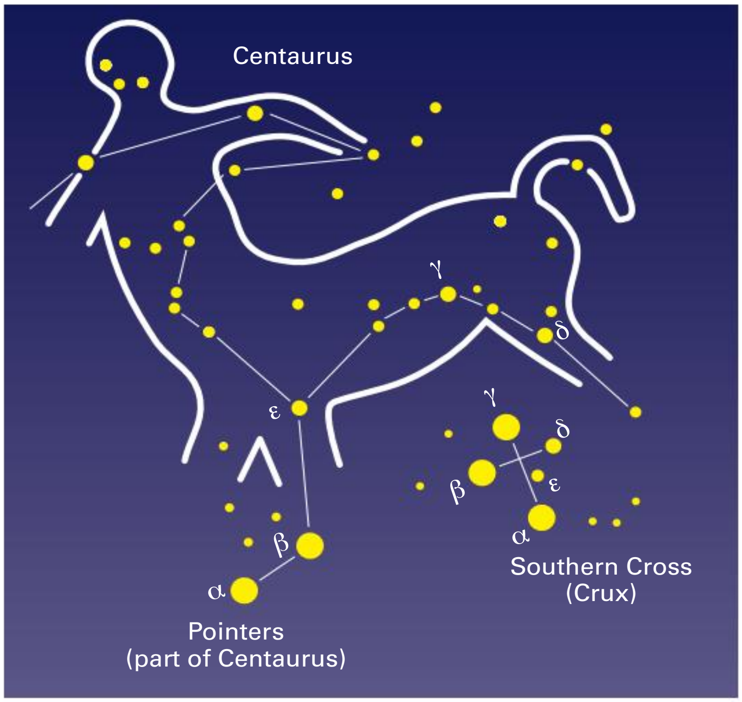


Fig 3 Stars in the constellations Crux and Centaurus

α-Centauri and β-Centauri form the front legs of the mythical half-human half-horse creature called the Centaur. This constellation was named by the Greek astronomer Ptolemy (TOL-em-ee) in about CE 150.

Activity

This is a night-time activity. Try to find a dark place without bright street lights. You will need a star chart like the one in the photo and a torch.

1. Read the instructions on the star chart. You will notice that one side of the star chart is used when looking in a southerly direction and the other side is used when looking north.
2. Rotate the star chart wheel until you come to the current month. Hold the south side of the star chart over your head and try to identify some of the constellations that are visible.
   - Look at the Crux. Identify the α, β, γ, δ and ε stars in this constellation.
   - Identify α-Centauri and β-Centauri.
3. Hold the north side of the star chart over your head and identify some of the constellations in the northern sky.

The movement of stars

The movement of the stars across the sky is caused by the west-to-east rotation of the Earth. If you point a camera in a southerly direction and leave the shutter open for a few hours, your photo will have dozens of concentric lines produced by the time-exposure of each of the stars as the Earth rotates. The centre of these concentric lines is an imaginary point in the sky called the *South Celestial Pole*.

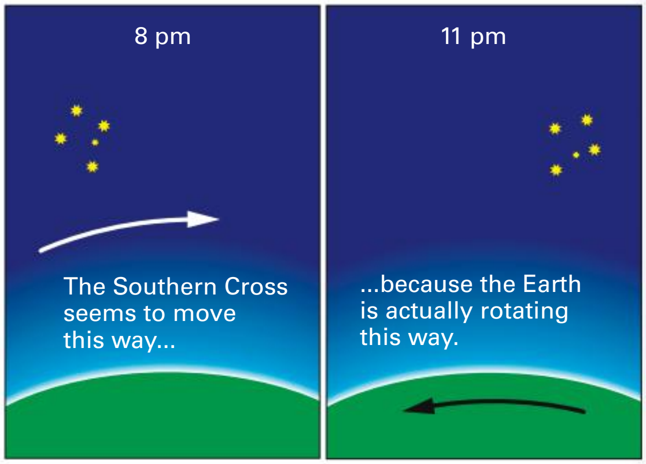


Fig 4 A time-exposure of the stars looking directly south. The bright arcs on the right were formed by the stars in the Southern Cross.

Investigation 18 Locating stars

Aim

To locate and record the positions of various stars in the sky.

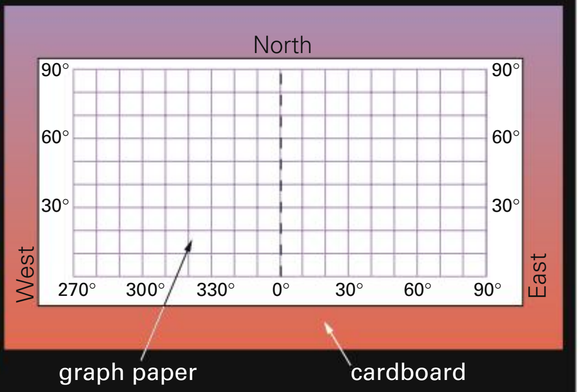
Materials

- sheet of graph paper
- piece of firm cardboard larger than the sheet of graph paper
- compass
- torch

Planning and Safety Check

This experiment has to be done at night. But before you begin your night-time observations, you have to prepare a sky grid.

Draw up your graph paper as shown in the diagram below, then paste it onto a piece of firm cardboard.



This is your sky grid for locating stars in the northern sky. If you hold the grid vertically at eye level, the bottom horizontal axis represents the horizon. The top horizontal line is directly overhead or 90° from the horizon and is called the *zenith*.

The vertical dotted line in the middle of the grid (0°) is the north–south line.

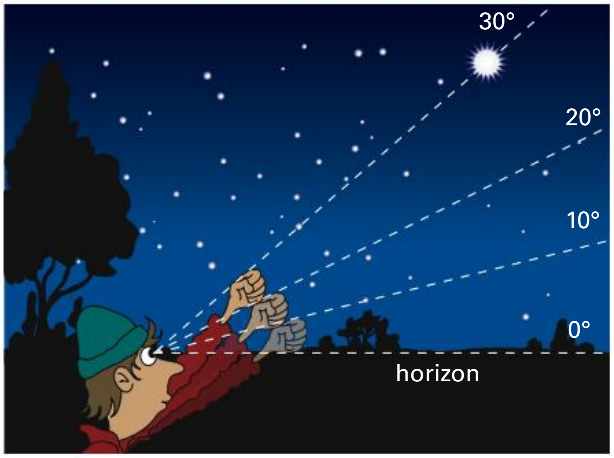
If you have time you can prepare a sky grid for locating the stars in the southern sky.

Method

1 Go outside on a clear night and use the compass to find north. Then lay your grid on the ground so that the compass needle and the north–south line (0°) line up.

2 Select a bright star in the sky. You now have to find its vertical angle or *elevation* from the horizon.

3 Use the 'fist method' to find the star's elevation. To do this clench your fist and hold it straight out from your body. Position the bottom of your fist on the horizon, ie the 0° mark. The top of your fist is about 10° above the horizon. So if the star is 3 'fists' above the horizon, its elevation is 30°.



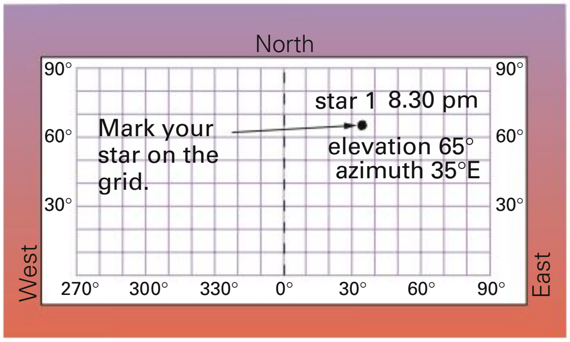
4 Measure how many 'fists' there are from the horizon (0°) to the star. Convert this to degrees. This is the star's elevation.

Record this angle.

5 The horizontal angle is called the *azimuth*. This is the angle measured from the 0° line, in an easterly direction through 360°. Now measure how many 'fists' from the 0° line the star is, and convert this to degrees. (If the star is to the west of the 0°, you subtract the angle from 360°.) This is the star's azimuth.

Record this angle.

6 Use the two angles to mark the position of the star on the grid. Also record the time next to the star.



7 Select another star and plot its position.

Discussion

1 Why did you record the time next to each of the stars on your grid?

2 What things might affect the accuracy of your star location measurements?

3 Suppose you found the location of a star and then repeated the measurement at the same time one week later. Would the star be in the same position? Explain your answer.

Inquiry

The 'fist' method of locating stars is only very approximate. Work in a group of two or three people and design a method to find the position of stars accurately. Write up your design and discuss it with your teacher.

The zodiac

You may have noticed that the sun and moon follow much the same path across the sky. The planets also follow this path, which is called the **ecliptic** (ek-CLIP-tick). For people in Australia, the ecliptic is in the northern part of the sky, and it is higher in the sky when viewed from Brisbane and lower when viewed from Hobart.

The ecliptic also passes through the twelve constellations that we call the **zodiac**. The symbol of each constellation is the shape each is supposed to make in the sky. Astrologers (not astronomers) use the zodiac and the positions of the sun, moon and planets to make predictions about your health and other life matters.

Making predictions from the positions of objects in the sky has been done for thousands of years. Many cultures have believed that everyday events such as the planting of crops and business dealings are influenced by the stars.

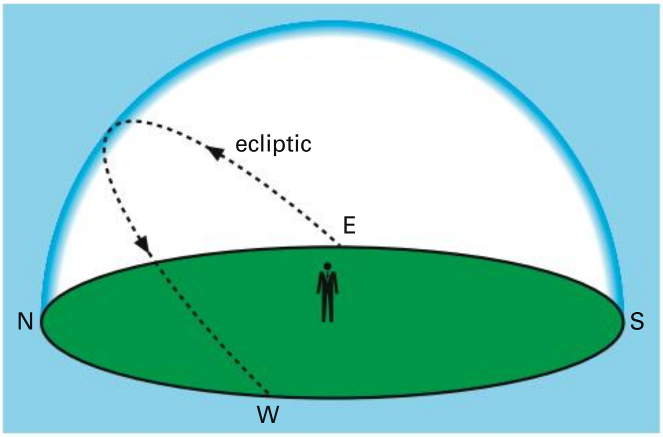


Fig 5 The ecliptic is the path followed by the sun, moon, planets and the twelve constellations in the zodiac.

Activity

1 Use newspapers or magazines to find out the names, symbols and birth dates for the twelve constellations in the zodiac.

2 Find out from horoscope books the personal characteristics of three or four star signs, including your own. Then group the members of your class into these star signs.

Would you say that the members of each group have similar characteristics? List these.

What other astronomical objects, other than the constellations, do astrologers believe influence these characteristics?

Cosmic catastrophes

Astronomers know that meteorites or comets have crashed into the Earth in the past. Two massive impacts 250 million years ago and 65 million years ago may have caused the extinction of many land and marine organisms. Nearly 70% of all known species of land animals and plants became extinct over a relatively short time.

Did an enormous meteorite cause the mass extinction of the dinosaurs and many other species about 65 million years ago? Many scientists believe the meteorite impact theory is the most likely cause of the massive loss of species around the world at that time.

Evidence for a meteorite impact

Iridium is a metal that is extremely rare on Earth but common in meteorites. In 1978 scientists found iridium in rocks about 65 million years old in Italy. Since then iridium has been found in rocks of the same age in many places throughout the world, for example Denmark, Spain and New Zealand.

Fig 6 The Barringer crater formed 30 000 years ago when a meteorite estimated to be 100 m in diameter and weighing 2 million tonnes slammed into the Arizona desert.

What could have happened 65 million years ago? The meteorite, perhaps about 13 km in diameter, is thought to have crashed into the ocean near Mexico. The impact would have thrown ash and dust into the atmosphere, causing global darkness over a long time. Fragments of the red-hot meteorite would have been thrown into the atmosphere, landing in forests across the world and causing widespread firestorms. The resulting smoke from the fires, as well as the ash and dust, would have reduced the amount of sunlight reaching the surface, causing a drop in global temperatures and almost stopping photosynthesis.

The impact would have caused enormous waves and tides—like when somebody jumps into a swimming pool. This movement of water would have killed many land organisms.

Questions and research

1. Suggest why a huge meteorite impact would result in loss of many plant and algae species.
2. Explain what you think the term *global firestorm* means.
3. Make a list of the changes a massive meteorite impact would cause if it occurred today.
4. Use the links below to find out why some scientists do not agree that a meteorite impact caused mass extinctions.

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below, or search under *meteorite impacts* or *meteorite mass extinctions*.

All about meteorites

Lots of information about the formation and history of meteorites as well as frequently asked questions

Crater links

Mass extinctions

Refutes the theory that meteorites caused mass extinction of life

Dinosaur extinction page

Theories about the extinction of the dinosaurs

OneStopScience

Check

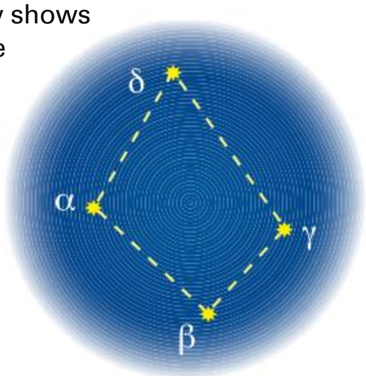
1 What is a light-year? Why do astronomers use this unit to measure distances?

2 How many constellations are recognised? Why are the constellations in the zodiac different from the others?

3 a What is the South Celestial Pole?
  b Why does the elevation of the South Celestial Pole decrease as you travel from Sydney to Brisbane?
  c Would you ever see the South Celestial Pole directly overhead? Explain.

4 What is the ecliptic? Where would it be in the northern hemisphere?

5 The drawing below shows the four stars in the constellation Libra. What do the letters next to each of the stars mean?



6 In Australia the constellation Leo can be seen during the months of December through to June. Why can't it be seen in the other months?

7 The bright star Canopus, which can be seen due south during March, is 98 light-years away.
  a How far away is Canopus in kilometres?
  b During which year did the light you see today from Canopus leave the star?

8 What is the difference between astronomy and astrology?

9 The group of stars we call the Saucepan is part of the constellation Orion. How would you explain to a group of younger children that these stars in the Saucepan may not be anywhere near each other in space?

10 The sun is 1.5×10^8 km from Earth. How long does light from the sun take to reach the Earth?

11 You have met a number of new words so far in this chapter—zodiac, ecliptic, zenith, azimuth and elevation. Without looking in your textbook, write your own definitions for these words. Then check them on pages 255 and 256 or in the glossary.

Challenge

1 Two of the stars in the constellation Centaurus are α-Centauri and β-Centauri. Can you tell from this information which star is:
  a closer to Earth?
  b the larger?
  c the brighter?
  Give reasons for your answers.

2 Pluto is a dwarf planet in our solar system—about 5.8×10^9 km from Earth. Why would it be inappropriate to use light-years to measure the distance to Pluto?

3 Lim told Yolanda that the bright blue-white star in the constellation Orion is called Rigel. It is 900 light-years away. Yolanda then wondered whether Rigel still exists. What answer could Lim give Yolanda?

4 Fig 4 on page 254 shows the movement of the stars when looking due south. What type of pattern would you get if you pointed the camera due east?

5 Look at Fig 2 on page 253.
  a How far away from the Earth are each of the four brightest stars in the Southern Cross?
  b Is there a relationship between the distance of the star from Earth and how bright it appears from Earth? Explain your answer.

6 Find out from the internet or library why astrologers associate a particular constellation with a particular time in the year.

10.2 Stars

What are stars made of?

Stars are gaseous objects in space that give off light and heat. They are made mainly of hydrogen and helium, with traces of heavier elements such as boron, carbon and nitrogen. For example, our sun contains about 80% hydrogen and 19% helium, while the remaining 1% is made up of the heavier elements. Compared with the size of the Earth, the sizes of stars are enormous. The sun is over one million times the size of the Earth, while one of the largest stars, Canopus, is 80 000 times the size of our sun.

The enormous size of a star creates huge gravitational forces that squeeze the atoms of the gases together and create immense pressure and heat. At this temperature electrons are stripped away from the atoms, leaving positively charged nuclei which are in constant rapid motion. The hot gases are in the state of matter called *plasma*, which has different properties from the other three states of matter. Plasma conducts electricity and also generates a magnetic field.

In the core of the sun, hydrogen nuclei join together (fuse) and release energy. This type of reaction is called *nuclear fusion*. Fusion reactions can occur only in extreme temperatures and pressures like those that exist in stars.

The reaction that occurs in stars involves the fusion of hydrogen nuclei to produce helium. Albert Einstein reasoned that under certain conditions, mass could be converted to energy. He proposed his famous equation $E = mc^2$ to explain this. (E stands for energy, m for mass and c for the speed of light.) In the fusion reactions that occur in the sun, about 655 million tonnes of hydrogen are converted to 650 million tonnes of helium every second. The 5 million tonnes of hydrogen used up release about 4.5×10^{26} joules of energy every second. This is about the same amount of energy that all the power stations in Australia could produce in 7 billion years!

If you would like to know more about Albert Einstein's famous equation, go to page 261.

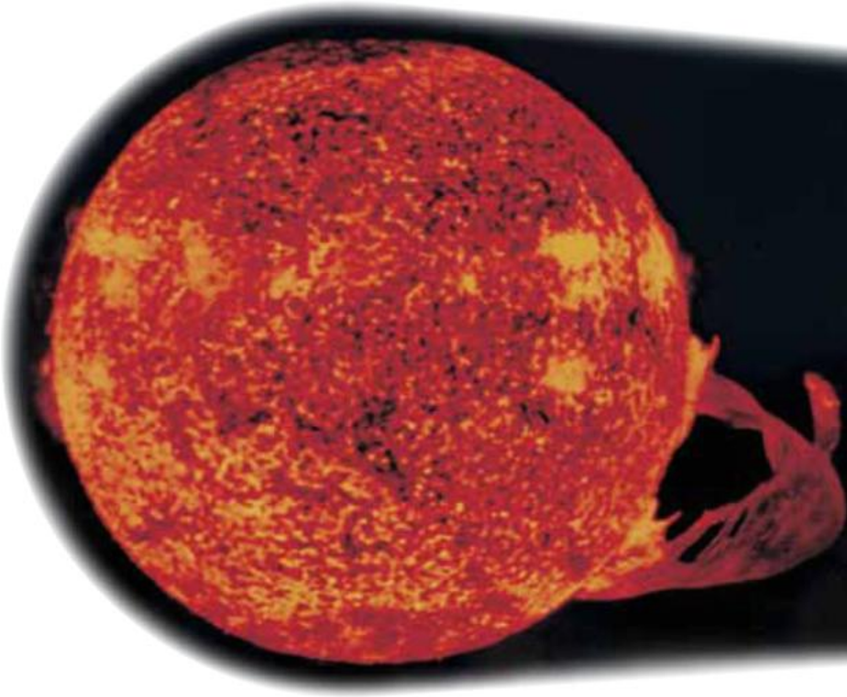
Structure of the sun

The energy produced in the core of the sun radiates outwards through thousands of kilometres of very dense gases. During this journey the radiation is absorbed and then re-radiated. This process takes a very long time, perhaps a million years for the radiation to get to the surface. This is why the sun's energy is released at a constant rate and not all at one time as in a nuclear bomb.

As the energy moves outwards from the core, the gases begin to transfer their energy by convection rather than by radiation. This process creates huge convection currents that boil up to the surface. (See Fig 8 on the next page.)

The **photosphere** is the visible part of the sun, the bright disk we actually see. It is the coolest part of the sun, with a temperature of about 6000°C. Over half the radiation released by the photosphere is visible light, with the remainder being infrared, ultraviolet, radio and X-rays. The photo of the sun below shows its surface speckled with what astronomers call *granules*. These are caused by columns of hot gases bubbling up in the convection currents beneath the sun's surface.

Fig 7 This photo of the sun was taken with special filters and shows the granules on the surface.



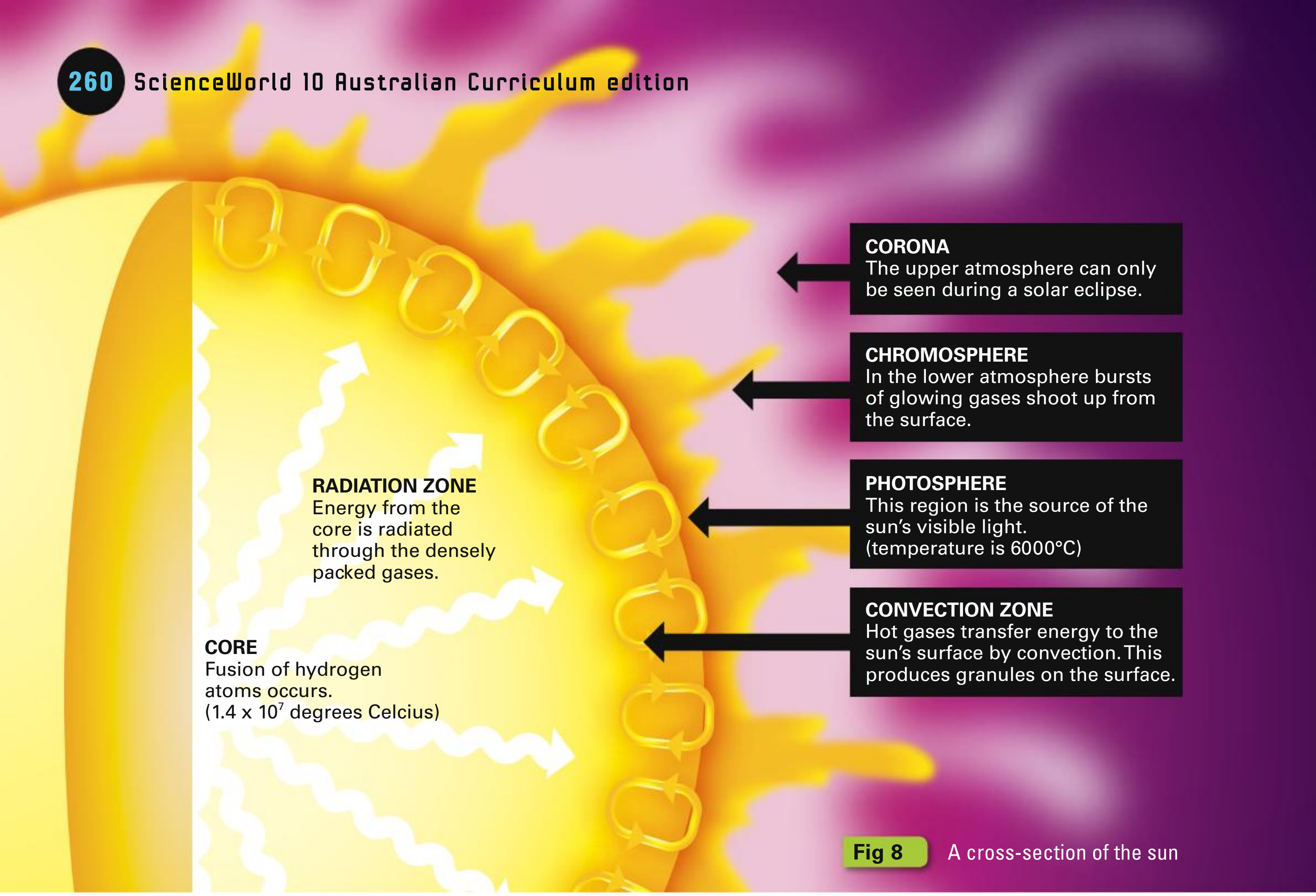


Fig 8 A cross-section of the sun

Small bursts of hot glowing gas constantly shoot out from the photosphere into the lower atmosphere or **chromosphere**. (Chromosphere means 'coloured ball' and it gets its name from the red colour of the glowing hydrogen atoms.) But sometimes massive bursts of hot erupting gases shoot out into space. (See Fig 7 on the previous page.) These are called *solar prominences*, and can extend out into space for up to half a million kilometres (about 50 Earth diameters).

The upper atmosphere of the sun is called the **corona**. Corona means crown, and it can be seen during solar eclipses as a halo of white light extending out into the blackness of space. The odd thing about the corona is that its temperature is about 1 000 000°C—hotter than the chromosphere and photosphere. Astronomers think that the heat comes from the ions and electrons that are being accelerated out into space from the corona.

Fig 9 The brightly glowing gases in the corona of the sun can be seen only during a total solar eclipse.

Science as a Human Endeavour

E = mc²

The sun's energy source

If the sun gives off about 4.5×10^{26} joules of energy each second, what is its source of energy? Will this energy source run out? When?

Fossil algae have been found on Earth that are more than 1000 million years old. These organisms could not have grown if the temperature of the Earth varied by more than 20°C from what it is now. Therefore the sun could not have changed its size or brightness over this time.

Geologists estimate using data from the radioactive decay of rocks, that the Earth is about 4.6 billion years old. Assuming that the sun is about 5 billion years old, then 7×10^{43} joules of energy must have been given off during this time.

Early theories

Many ancient cultures believed that the sun was a fiery mass whose fuel was wood. Scientists in the 1700s realised that chemical energy alone could not have supplied the sun's energy over many years. In fact it would have run out of fuel after about 300 000 years.

In the 1800s, a popular theory among astronomers was that the sun's energy source was gravitational potential energy. How does this work?

The sun has gravitational potential energy because of its large mass and volume. The laws of physics tell us that if the mass of the sun's gases contract inwards towards the centre, its volume will reduce and it will give off energy. Astronomers at the time believed that this was an acceptable theory. In the late 1800s, physicists calculated that if the sun used gravitational potential energy as its energy source, it would be 20 million years old. However, geologists objected to this theory because their evidence suggested that even the Earth was older than this.

Science was in a quandary. A new idea was needed.

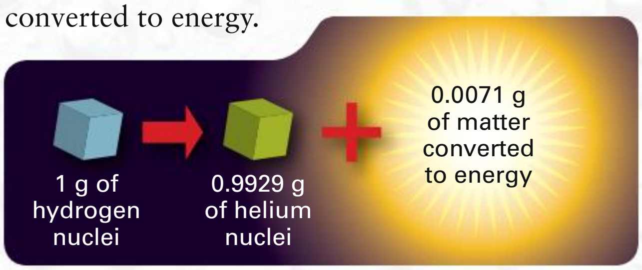
Special Theory of Relativity

Ever since the days of Newton, scientists thought that matter and energy were separate. They used the law of conservation of mass which said that the total mass of the reactants equals the total mass of the products.

In 1905, Albert Einstein published his Special Theory of Relativity. In this he reasoned that minuscule amounts of matter are actually lost in reactions, particularly the reactions in stars. This matter could be converted to energy according to his famous formula $E = mc^2$. This incredibly simple formula showed that large amounts of energy could be produced for very small amounts of matter. This is because the velocity of light, c, is such a large number (3×10^8 m/s).

Einstein showed that the sun could shine for billions of years if it used some of its mass to supply its energy. For example, if the mass of the sun is 2×10^{30} kg, then using $E = mc^2$, the sun could give off 2×10^{47} joules, or enough energy to shine for 15 000 billion years!

In the fusion reactions in the sun, hydrogen nuclei are converted to helium nuclei, and each gram of hydrogen loses 0.0071 g, which is converted to energy.



Questions

1 What were the problems with the early theories about the sun's source of energy?

2 In what main way is Einstein's theory different from the early theories?

3 How much energy would 1 kg of hydrogen give off in a fusion reaction?

Light from stars

You may have noticed when looking at the stars that some stars are much brighter than others and that they are not all the same colour. Some look red, while others look yellow, or white or even blue. The brightness and the colour of a star are very important factors in determining its size and its life expectancy.

Brightness

The brightness of a star when viewed from Earth is measured on a scale and is called *apparent magnitude*. The brightest star in the sky, excluding the sun, is Sirius with a magnitude of –1.4. The stars just visible with the naked eye have magnitudes of about 6. The apparent magnitude becomes more positive as the brightness of the star decreases.

The apparent magnitude is a useful scale for identifying stars from Earth, but it is not a measure of a star's *actual* brightness. This is because a star that is actually very bright may be a long way from Earth and appear quite dim. To measure the actual brightness of a star another scale, called absolute brightness or *absolute magnitude*, is used. The absolute magnitude scale compares the amount of light given off by a star if it was a set distance from Earth. Like the apparent magnitude scale, very bright stars have negative numbers. As the brightness decreases, the numbers become more positive.

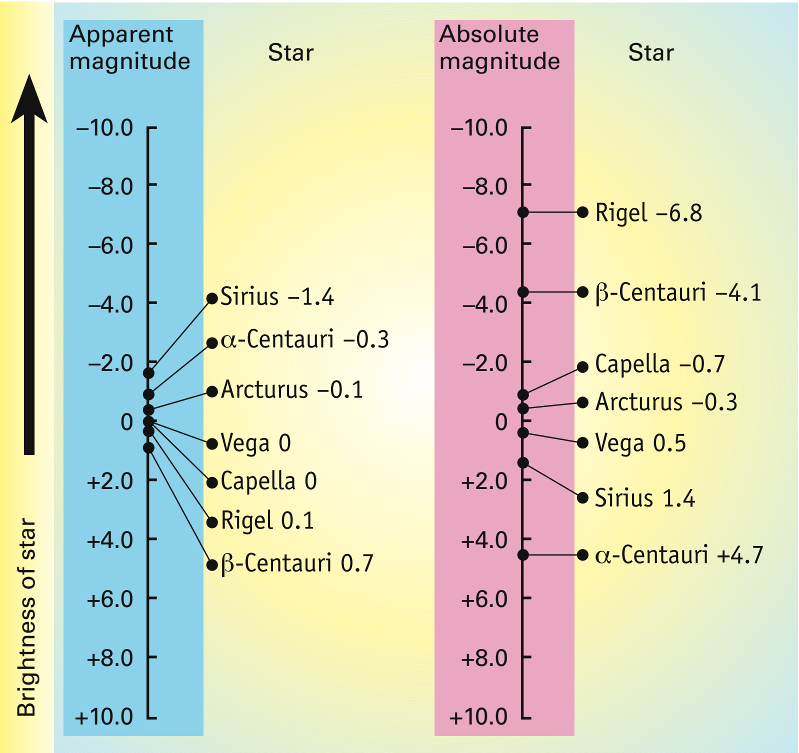
The amount of light a star gives off is determined usually by its size or the amount of matter in it. The rate of energy radiated by massive stars like Canopus (80 000 sun masses) is much greater than from smaller stars like our sun.

Colour

The colours of stars vary from blue to red. The hottest stars give off a white to blue light, while the coolest stars give off red light. Very hot stars like Rigel give off large amounts of ultraviolet light, but because our eyes cannot detect this light we see Rigel's colour as blue.

Astronomers are able to calculate the surface temperature of stars by measuring the wavelength of the light given off. A simple equation proposed by the German physicist Wilhelm Wien (pronounced VEEN) in 1907 and later called Wien's Law is used to do this.

How then are brightness and colour related? First, if two stars are the same colour they must have the same surface temperature. But if the absolute brightness of one of the stars is greater than the other, then it must be larger, since the size of the star determines its brightness. Second, if a red star and a blue star have the same size, they will have the same brightness, but the blue star will radiate more energy per second because it is hotter.



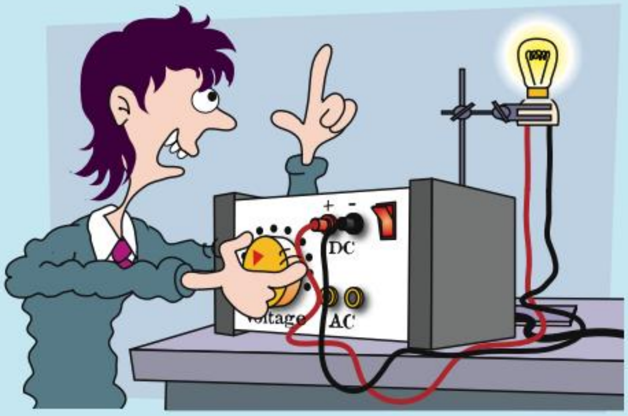
Activity

Part A: Colour of a filament

For this part of the activity you will need a 12 volt bulb and socket (e.g. from a ray box), a clamp and stand to hold it, and a power pack.

1 Connect the bulb and socket to the power pack.

2 Set the power pack on the lowest voltage, then increase the voltage until the filament of the bulb starts glowing.



3 Slowly increase the voltage up to 12 V.

Record the change in the colour of the light emitted from the filament as the voltage increases.

At what voltage does the filament give off most light energy? Explain.

Infer which would be the hotter filament—the yellow one at a low voltage or the white one at a higher voltage.

Give another example where the colour changes when an object's temperature changes.

Part B: Calculating the temperature of stars

All stars give off light. The wavelength of this light can be accurately recorded by electronic equipment, especially in satellites above the Earth's atmosphere.

Wien's Law shown below can then be used to calculate the temperature of the star:

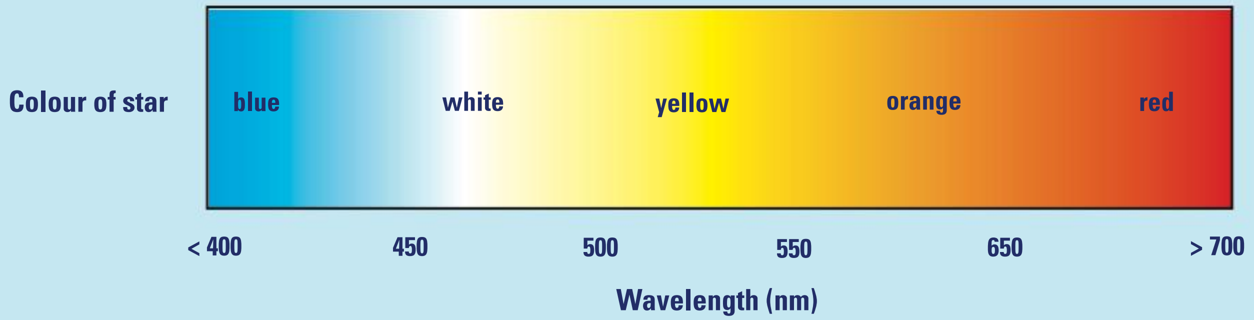
$$\text{temperature} = \frac{3 \times 10^6}{\text{wavelength}}$$

where the wavelength is measured in nanometres (nm) or 10^{-9} m, and the temperature is measured in kelvin. (The kelvin scale is the same as the Celsius scale except that zero degrees on the kelvin scale is –273°C. This means you add 273 to the Celsius reading to get the temperature in kelvin.)

1 Use the information in the table below and the formula above to calculate the temperature of each of the stars.

Star	Wavelength emitted (nm)
Arcturus	667
Betelgeuse	700
Canopus	440
Capella	545
Sun	510

2 Use the information below to prepare a data table listing each of the five stars, its temperature and its colour.



Binary stars

Many of the stars that you see as a single point of light are in fact double stars. Astronomers call these star couples **binary stars**. The two stars of a binary revolve around each other. You may be surprised to know that binary stars are not uncommon. Astronomers have observed nearly 700 000 binaries.

Usually the stars revolve around each other over a very long time—the revolution time is measured in centuries. For this reason the revolution time for only about 100 binaries has been accurately measured.

Sometimes one star in a binary will pass in front of the other during their revolution. This happens because we see the orbits of the binaries edge-on. The best example of this is a binary in the constellation Perseus near Orion. The beta star (Algol) is sometimes called the Demon Star because its brightness keeps changing. Astronomers now know that the two stars are very close together and revolve around each other in a very short time—2.8 days.

When the dimmer star (apparent magnitude 3.4) passes in front of the brighter star (apparent magnitude 2.0), the binary becomes three times fainter when viewed from Earth. Two other famous binaries in the southern hemisphere are α-Centauri and α-Crucis.

Some binary stars can be seen with binoculars. However, if you have access to a telescope you will see the binaries in the list below very clearly. Use your star chart to find and observe the following binary stars:

- α-Centauri—magnitudes 0 and 1.7 (the brighter star of the Pointers)
- α-Crucis—magnitudes 1.4 and 1.9 (the star at the foot of the Southern Cross).

Fig 10 Star 1 is the brighter star in this binary. In the position shown, the binary appears bright from Earth.

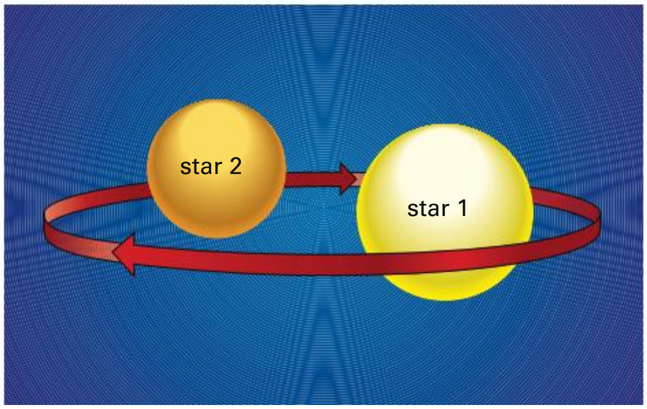
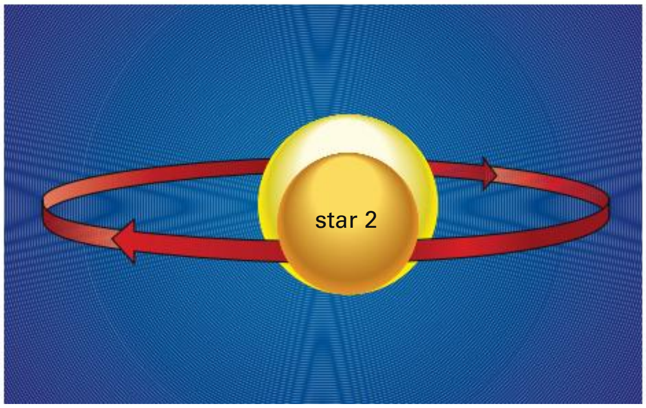


Fig 11 When star 2 passes in front of star 1, the brightness of the binary as seen from Earth decreases.



Check

1 Some of the following statements are incorrect. Choose the incorrect ones and rewrite them to make them correct.
  a The photosphere is the visible part of the sun.
  b The only energy the photosphere releases is visible light.
  c In the outer regions of the sun the energy is transferred by conduction rather than radiation.
  d The chromosphere of the sun can only be seen during a total solar eclipse.

2 a Explain how energy is produced in a star like our sun.
  b Why doesn't the fuel in the sun explode all at once in one gigantic nuclear explosion?

3 a What is the difference between a star's apparent brightness and its absolute brightness?
  b Design an activity using a 25 watt bulb and a 100 watt bulb that would demonstrate the difference.

4 a What do the E, m and c stand for in Einstein's formula $E = mc^2$?
  b How does this formula explain how energy is released in the nuclear reactions in the sun?

5 How do astronomers think the granules on the sun's surface are formed?

6 What is a binary star? Suppose our sun was a binary, describe what a 'day' would be like. How would it affect life on Earth?

7 What do the words *chromosphere* and *corona* mean? Suggest what the word *photosphere* means. Why was this part of the sun given this name?

Challenge

1 Star A gives off light of wavelength 430 nm while that of star B is 670 nm. What colours are the stars?

2 Suggest why plasma (like that found in the sun) conducts electricity. How is it different from the way a salt solution conducts electricity?

3 Use the information in the diagram on page 262 to answer the following questions.
  a Which star is the brightest from Earth?
  b Which star gives off the most light?
  c What does the diagram say about Vega and Capella?
  d What can you infer about the two stars in the Pointers?

4 a The ratio of hydrogen to helium in the sun is decreasing with time. Suggest why.
  b The ratio of hydrogen to helium is not constant throughout the sun. Suggest why the ratio is different in the core from what it is in the chromosphere.

5 Two stars of equal size have temperatures of 4500 K and 7600 K.
  a What does the K after the numbers mean?
  b Which star gives off more energy per second? Explain your answer.
  c Use Wien's Law and the information on page 263 to find the colour of each star.

6 Two stars called Uno and Duo form a binary star. They revolve around each other in 15 days. Uno has a magnitude of –1.1 and Duo has a magnitude of 1.3.
  a Would the magnitudes given be apparent magnitudes or absolute magnitudes? Justify your answer.
  b The light from most of the binary stars viewed from Earth does not change. Why is this?

7 Sunspots are dark areas that can be seen on the sun's surface.
  a Galileo calculated that the sun's period of rotation is about 25 days by observing sunspots. Suggest how he did this.
  b Astronomers have found that the sun's equator rotates in 25 days while a point at latitude 45° rotates in 31 days. How could this be possible?
  c How could the brightness of a star be affected by sunspots?

8 Write a narrative about life in a solar system that has a binary star as its sun.

10.3 Life cycles of stars

Fig 12 The Great Nebula of Orion is a huge expanding cloud of gas that resulted from a supernova.

If you look at the sword in the constellation Orion (the handle of the Saucepan) with powerful binoculars you will see a fuzzy bright object. This is a massive cloud of gas and dust called a **nebula** (NEB-you-la) and was caused by a **supernova**: a spectacular explosion which ended the life of a star. See the photo above.

Astronomers believe that stars are born in clouds of gas (mainly hydrogen) and dust that occur throughout the universe. Occasionally one of these clouds collapses on itself, becoming hotter and denser as the gravitational force increases. This is the embryonic stage in the life of a star and it is known as a *protostar*. Eventually the gas becomes hot enough to start nuclear fusion reactions and the star begins to glow.

Birth and death of stars

The life cycle of a star depends entirely on its mass. A protostar with a mass less than 0.1 of the mass of the sun will continue to shrink but will never get hot enough for nuclear reactions to begin. It will fade to form a small red star before turning cold and dead.

When a star about the size of our sun forms, it initially glows very brightly. After this initial period, the star settles down to a long stable middle-life period of about 10 billion years. Our sun is now at about midlife and has another 5 billion years to go before it runs out of fuel.

As the star ages and much of the hydrogen is used up, its surface temperature decreases. Finally, when little hydrogen remains, the star's core shrinks, the outer layers expand and cool, and the star forms a *red giant*. After this, the gases in the outer regions drift into space and the remaining gases collapse into a small, very dense object known as a *white dwarf*. These stars are very small and can be seen only with a powerful telescope. Eventually the white dwarf cools down and fades away. Betelgeuse, the red star in the constellation Orion, is a red giant and was probably once similar in size to the sun.

Stars two to six times the size of the sun have a much shorter but spectacular life. These stars live for only about 1 million years. The mass in large stars creates enormous gravitational forces in the core of the star. The nuclear reactions use fuel very rapidly, creating very hot bright stars that glow blue in the night sky. When the fuel runs out, there is a tremendous outburst of energy, which we see as a supernova. Much of the star's matter is blown into space, leaving a nebula. When such an explosion takes place, the brightness of the star increases a billion times.

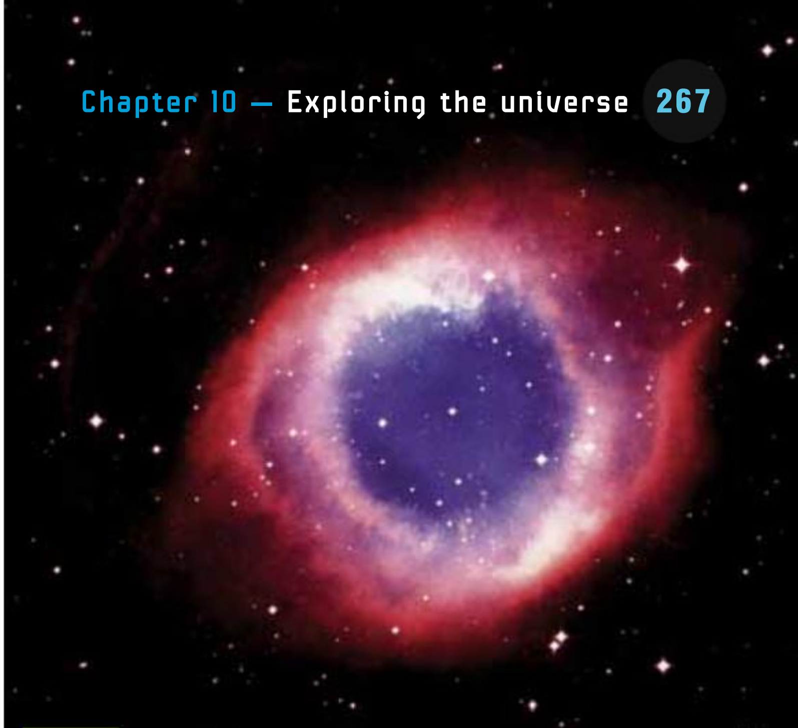
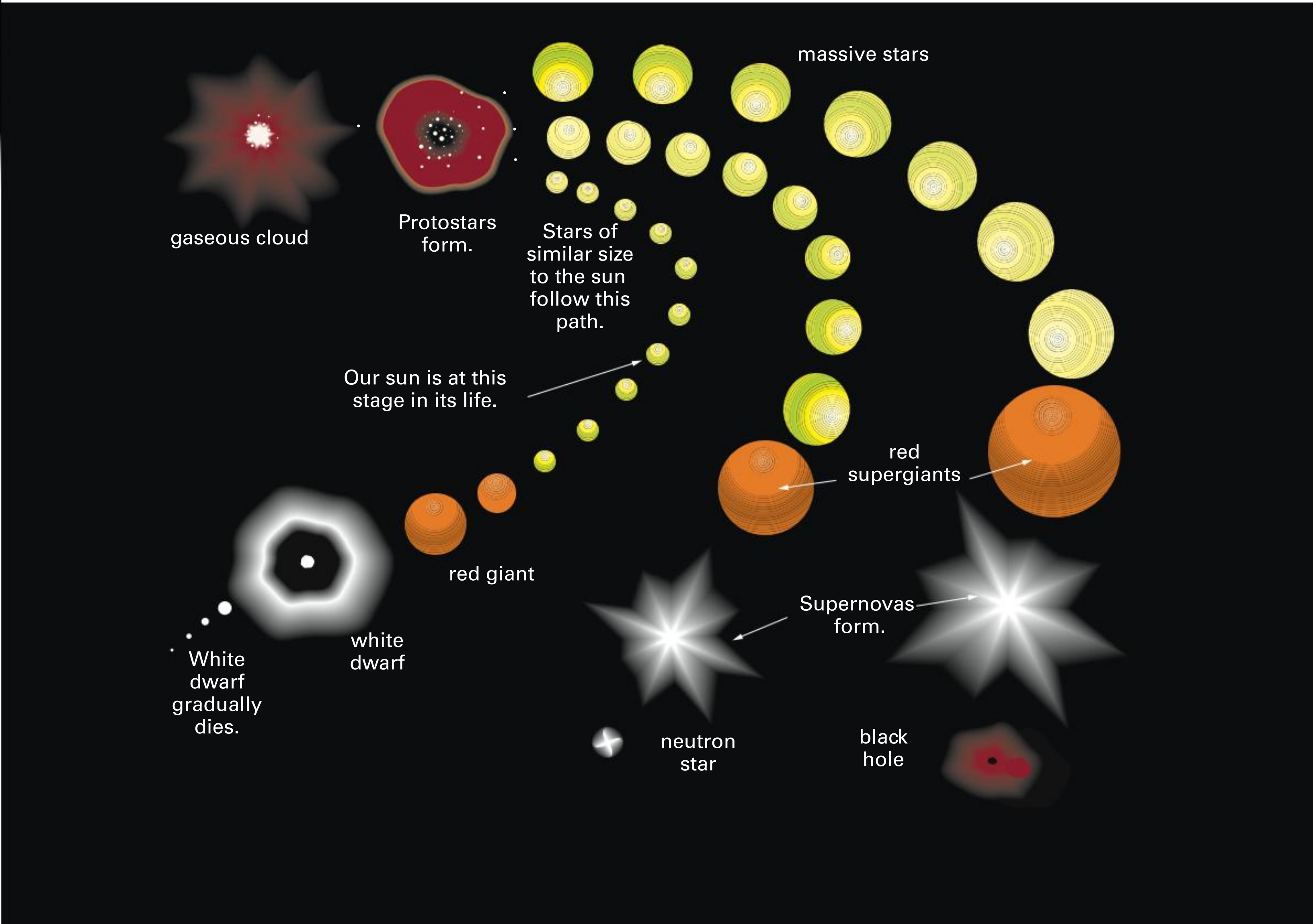


Fig 14 The Ring Nebula in Aquarius is expanding into space at 25 km/s. It has a central star that is probably forming into a white dwarf.

Fig 13 The evolution of stars. Our sun at present is in the middle of a stable period of its life.



Nebulas and neutron stars

When a massive star ends its life in a supernova explosion, much of its mass is blown out into space. Supernovas do not happen very often since most of the stars in the visible universe are of medium size. Astronomers estimate that a supernova occurs about once every 75 years in our galaxy.

Some nebulas emit their own light and glow like stars. They can glow pink, blue, yellow or green depending on the type of gases in the cloud. The rich pink colour of the Great Nebula of Orion indicates the presence of hydrogen gas. Other nebulas do not glow and block out the light from the stars behind them. The Horsehead Nebula (see the photo on page 273) is a dark nebula that can be seen against the glow of stars in the background.

During a supernova explosion, astronomers believe that the remainder of the star's core is pulled inwards by immense gravitational forces to form an incredibly dense star less than 20 km in diameter. The original protons and electrons in the core are squeezed so much that they fuse to form neutrons—atomic particles with zero charge. Thus this type of star is called a **neutron star** and its density is estimated to be a thousand billion billion times that of water. Because they are so small, neutron stars do not glow very brightly, but they do send out pulsating radio signals. For this reason they are often called *pulsars*. Astronomers do not understand pulsars very well but they think that the pulsating radiation they emit is due to the star spinning on its axis.

Black holes

It seems hard to imagine anything odder than a neutron star. But the greatest oddity of the universe is reserved for **black holes** which form when the massive stars, about ten times the size of our sun, explode.

After the supernova explosion, the core collapses on itself, and unlike a smaller star, these massive stars keep on collapsing. Nothing can halt this collapse, and the gravitational force that is created is so strong it will not even allow light to escape. What remains of the massive star is a dark 'hole' in space, which astronomers call a black hole. Astronomers have detected strong X-rays coming from invisible objects in space which they believe are black holes.

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below:

Is a black hole really a hole?

This is an informative website with great graphics.

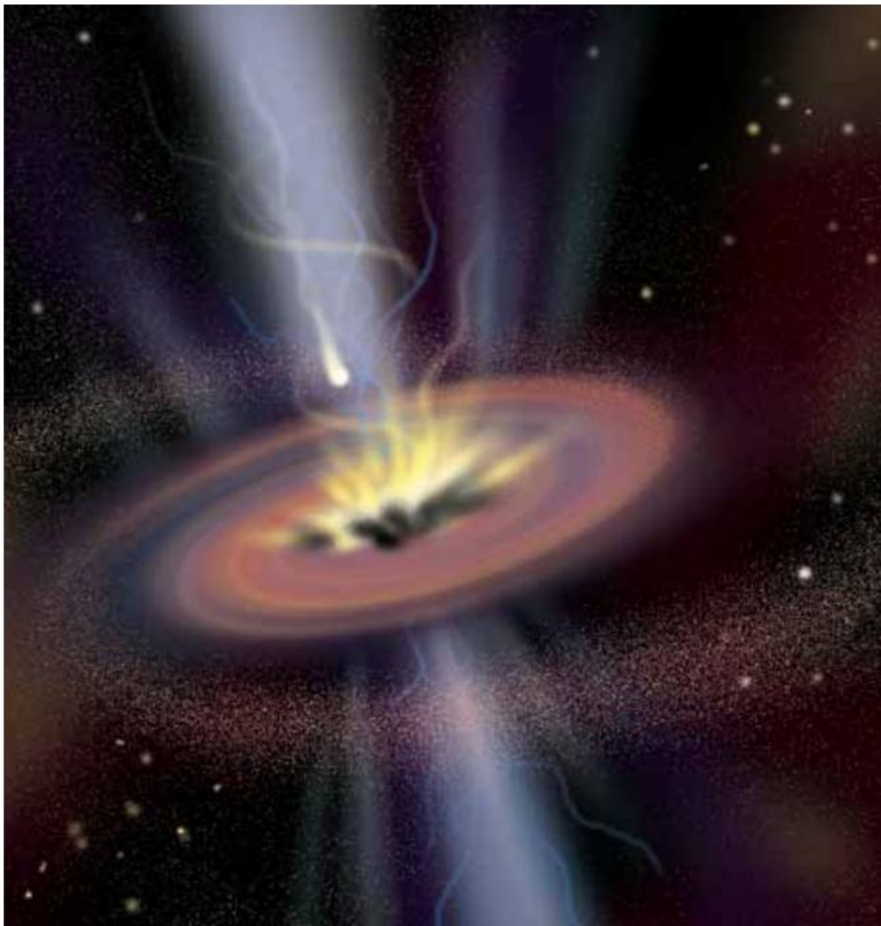
Black holes and beyond

Black holes

This website has an animation of a journey into a black hole.

OneStopScience

Fig 15 An artist's impression of a black hole. Gas and dust from a nearby star is being drawn towards the black hole where it circulates, heats up and gives out streams of X-rays.



Science as a Human Endeavour

Bryan Gaensler: astronomer

In 1999 Bryan Gaensler won the Young Australian of the Year award for outstanding achievement in the field of astrophysics. During his PhD studies at Sydney University, he discovered that a supernova acts as a 'cosmic compass' because it lines up with the magnetic field of the galaxy it is in. In the same year he won an international fellowship to study at the prestigious Center for Space Research at the Massachusetts Institute of Technology in the United States. He is only the second Australian to have won this award.

Bryan is Professor of Physics in the Institute for Astronomy at Sydney University. He used the data sent back to Earth from the Chandra X-ray Observatory, which was sent into an Earth orbit in 1999. One of the first images sent back to Earth was of the nebula called Cassiopeia A (see the photo below). Astronomers for years had been unable to detect any neutron star at its centre, even though they had predicted it had to be there. But in Chandra's images, Bryan found a bright central point which could be the missing neutron star.

Bryan is now planning to use the Square Kilometre Array—the world's biggest radio telescope, to be completed in 2024.

WEBwatch

If you would like to find out more about Bryan Gaensler's work, go to **www.OneStopScience.com.au** and follow the links to **Bryan Gaensler**. There you will find links to many interesting articles written for science magazines and newspapers.

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The death of a star

Cassiopeia A, or CAS A, was a giant star ten times larger than our sun and 12×10^{13} km away. The star had existed for more than 10 million years but ran out of hydrogen fuel.

Stars exist because the radiation forces generated by the fusion reactions pushing outwards are balanced by the inwards pull of gravity due to the star's enormous mass. Then, 10 320 years ago, with the nuclear fuel gone, the massive inward pull of gravity made the star collapse. What followed was a massive explosion and the total destruction of the star.

Cassiopeia's first pictures

In July 1999, after two attempts, the telescope Chandra was launched on board the space shuttle *Columbia*. Then on 19 August 1999 Chandra pointed its mirrors towards the supernova and took its first detailed picture of CAS A.

Questions

1. Use a diagram to show the forces acting in a star like our sun.
2. What date on Earth was it when CAS A exploded?
3. Use the internet or books to describe the conditions on Earth at the time of CAS A's birth and death.
4. In mythology, Cassiopeia was banished to the sky to hang head downwards for half the year. Find out about Cassiopeia and why she was punished.

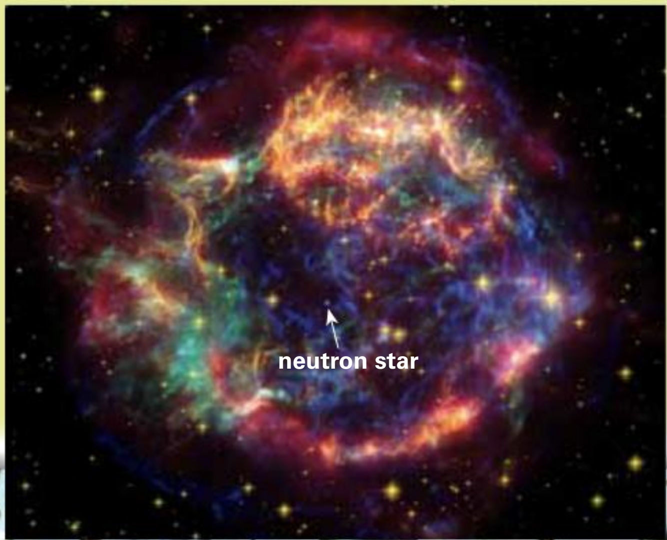


Fig 16 The nebula Cassiopeia A, showing a probable neutron star in the centre

Cosmic explosion lights up the galaxy

On 27 December 2004, a colleague of Bryan Gaensler sent him an email saying that he had detected a massive flash of light across the Milky Way galaxy. It was so bright that it bounced off the moon and lit up the Earth's atmosphere. The flash was the brightest explosion in the history of astronomy—brighter than any other explosion ever detected from outside our solar system.

What caused the flash?

Bryan Gaensler and his team of astronomers now know that the small neutron star called a *magnetar* exploded, releasing an enormous pulse of gamma radiation. The magnetar, named SGR 1806-20, was only about 20 km in diameter, but it gave off more energy in the 0.2 second flash than our sun gives off in 200 000 years.

Gamma radiation is very high energy radiation and can damage cells and tissues. It can also promote changes in chromosomes, leading to mutations.

Three other magnetar explosions have been recorded but this one was by far the biggest. Could a magnetar explosion closer to our solar system have been responsible for the mass extinction of organisms on Earth in the past?

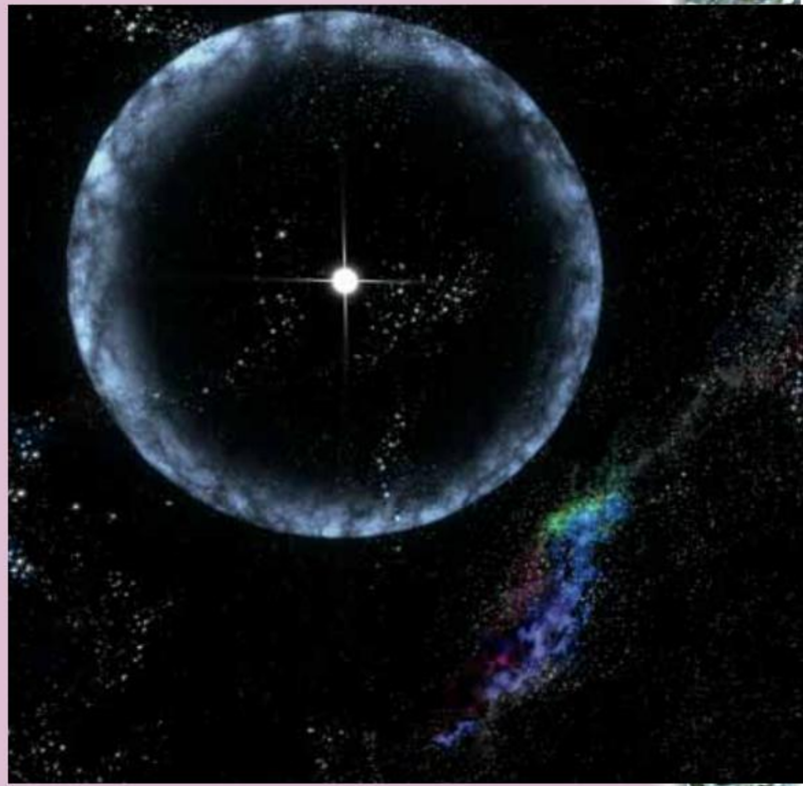


Fig 17 An artist's impression of the gamma-ray flare expanding outwards towards the Earth from the exploding magnetar SGR 1806-20

Activity

In your previous studies in science, you have learnt how to write a feature article. Here is a reminder.

1 Structure

There are three parts: introduction, body and conclusion. The introduction entices the reader to want to read more. The body needs to elaborate the issue raised in the introduction. The conclusion reminds the reader of the issue and finishes with a strong punchline.

2 Writing style

- The article must be a human interest story.
- Write in the active voice.
- Avoid lengthy, complex sentences. Use two to three sentences per paragraph.
- Make sure your information is accurate. Don't make it up!

Your task

Write a feature article about the life and death of stars, nebulas, black holes, space telescopes, or a day in the life of an astronomer like Bryan Gaensler.

Write about 700 to 1000 words. Your teacher may check your first draft of the feature article.

To read an example of a feature article, go to Bryan Gaensler's website and select the popular article 'A star is burst'.

Origin of the universe

Astronomers who study the universe are called *cosmologists*. **Cosmology** is the study of the origin and structure of the universe. Over the years a number of theories for the origin of the universe have been put forward by astronomers. Two of these theories are described on this page.

The Steady State theory

This theory proposes that the universe has always existed. That is, we see the universe now as it was in the past and will be in the future. This means that the universe would be infinitely old, it would have no birth date and would never end.

The theory suggests that new matter is created everywhere in the universe, and this matter forms galaxies that slowly move away from each other. This means that some galaxies in a particular region of space should be younger than others. However, evidence gathered over a number of years suggests that neighbouring galaxies are roughly the same age.

The Steady State theory has some attractive features. First, it says that the universe is endless in time and space. Second, it accounts for the fact that stars and galaxies die and re-form. And it avoids the difficult question of how the universe was created. However, today the Steady State theory has few supporters because recent astronomical evidence does not fit it at all.

The red shift

A spectrometer is an instrument that measures the wavelength of light. Astronomers have found that the wavelength of the light coming from most stars has shifted towards the red end of the spectrum. This is called the red shift.

Astronomers know that a red shift occurs when stars are moving rapidly away from Earth. This is considered evidence that the universe is expanding.

The Big Bang theory

The Milky Way galaxy is one of about 30 neighbouring galaxies in a cluster called the Local Group. Astronomers studying the galaxies in the Local Group noticed that many were moving away from us. And other galaxies deeper in space were moving away from us at even greater speed. It seemed that the universe was expanding in all directions.

Evidence that the universe is expanding has led astronomers to propose that all the matter in the universe must have come from a single source. At the beginning of time this source exploded, sending matter in all directions. This theory for the origin of the universe is called the **Big Bang theory**.

The Big Bang theory suggests that about 10 billion years ago all the matter in the universe was contained in a hot, dense ball of radiation and subatomic particles. The temperature of this ball of matter was incredibly high—billions and billions of degrees. The model makes no attempt to explain the origin of this dense ball of matter.

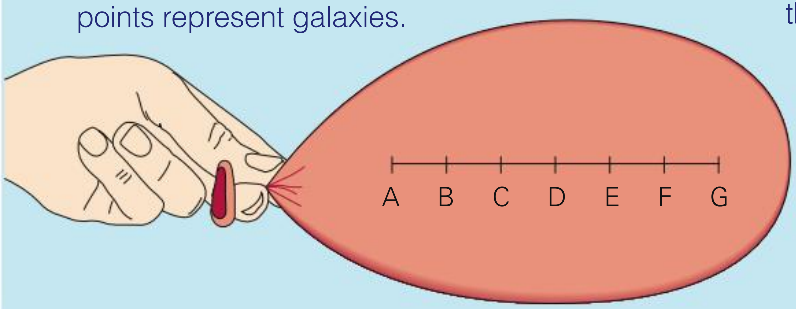
An explosion took place and the matter expanded. As it expanded it cooled and electrons, protons and neutrons formed. On further expansion and further cooling, small gaseous atoms like hydrogen and helium formed, then larger ones.

The matter thrown out by the Big Bang was denser in some places than others. In these denser places, gravitational forces squeezed particles of matter together and formed galaxies containing stars. However, astronomers predicted that small amounts of matter and also radiation would have been trapped in the spaces between galaxies as a result of the Big Bang explosion. Until recently these intergalactic spaces seemed totally empty. In 1989 the Cosmic Background Explorer satellite (COBE), and more recently the Hubble Space Telescope, have detected small amounts of matter and radiation in the intergalactic spaces.

Activity

You can make a balloon model of the expanding universe.

1. Inflate a round balloon until it is just tight and hold the end.
2. Use a marking pen to draw a line on the surface. Mark seven points (A to G) at 1 cm intervals along this line. These points represent galaxies.



3. Inflate the balloon further. Measure and record the distances between the points.
   - Did the points move apart by the same amount? How can you explain this?
   - Suppose you live in galaxy D. In which direction would the other galaxies move? Would they move at the same speed? Try to explain your answers.
   - How does this model demonstrate the expanding universe theory? What are the model's shortcomings?
   - Design a model that more accurately demonstrates the expanding universe.

The future of the universe

What will happen to the expanding universe in the future? There seem to be two answers to this question.

First, some astronomers believe that the universe will go on expanding forever. This theory is based on the inference that the universe does not have enough mass to create the gravitational forces needed to pull it back together. The universe will eventually die as the stars and galaxies are reduced to clouds of gas and dust.

The second, less popular view, is that the universe will expand to a certain point and then collapse back on itself in a reversal of the Big Bang called the 'Big Crunch'. This will once again form a hot, dense ball of matter. This will start a second Big Bang and a new universe will be born containing all the matter that was in the previous universe.

The websites on the right contain information about cosmology, the origins of the universe, and dark matter. You could find other websites by searching for *Big Bang*, *Big Crunch* or *cosmology*.

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below.

The Big Bang Time Machine

This website has an animated timeline of the events that occurred during the Big Bang. There are also links to information pages.

History of the Universe

This website has a more detailed animation of the events in the Big Bang.

The Big Bang

This website includes detailed information on the Big Bang.

Astronomy and the universe

This is a very easy-to-read website with comprehensive information on astronomy, with lots of photos.

The future of the universe

Will the universe expand forever or will it finish?

The Big Crunch

This is a theoretical animation of what might happen when energy flips and pulls the universe together.

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Check

1 Why do astronomers expect that our sun will end its life as a red giant?

2 A star has a mass 10 times greater than our sun. Describe the inferred life of this star.

3 Why do protostars, which have a very small mass, not form mature stars?

4 How does a neutron star form? Why is it given this name?

5 A star has a definite lifetime. What is the characteristic of a star that will determine the length of its life?

6 Suppose you were explaining the evolution of stars to some 9-year-old children. How would you describe a supernova and a black hole to them?

7 The photo below is the Horsehead Nebula in the constellation Orion. Suggest why the light of the stars behind it cannot be seen.

8 Why are neutron stars sometimes called pulsars?

9 How does a white dwarf differ from a neutron star?

10 The Hubble Space Telescope (see the photo below) is in an Earth orbit. Suggest why this telescope has detected objects in space that were previously unknown.
To find out more and to look at the photos and movies on Hubble, go to **www.OneStopScience.com.au**, and follow the links to **Hubble**.

11 Compare and contrast the Steady State and Big Bang theories on the origin of the universe.

Fig 18 The Hubble Space Telescope in orbit around the Earth, with the space shuttle nearby

Challenge

1 The Crab Nebula is 6300 light-years from Earth. If the supernova was seen in AD1064, work out when the actual supernova took place.

2 Astronomers have calculated that stars moving rapidly away from Earth cause a shift towards the red in the wavelength of light coming from them. Suggest what might happen if a star was moving rapidly towards the Earth.

3 A star has a surface temperature of 6200 K.
  a Use Wien's Law on page 263 to determine the wavelength of light actually coming from the star.
  b If the observed light coming from the star is yellow, is the star moving away from Earth or coming towards it? Explain your answer.

4 The fastest moving galaxies in the universe are the ones furthest away, whereas the slowest ones are located near the centre of the universe. How do these facts support the Big Bang theory of the formation of the universe?

5 Quasars are mysterious star-like objects that astronomers think may have the mass and energy of a galaxy concentrated into the size of our solar system. If you would like more information about quasars go to www.OneStopScience.com.au, and follow the links to Frequently Asked Questions about quasars.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 The stars that we can see in the sky form patterns called ______.

2 Because of the Earth's ______, an observer in the southern hemisphere sees the stars rotate from ______ around the South Celestial Pole.

3 Stars are made mainly of ______ and smaller amounts of helium. The energy in stars is released when hydrogen nuclei fuse to form helium nuclei. In the process ______ is converted to energy.

4 The sun's energy is generated in its ______. It then travels by radiation and ______ towards the surface (photosphere), where it is released in the form of ______.

5 The ______ or magnitude of a star depends on the amount of energy it radiates into space and is determined by its size.

6 Stars form in ______ of condensing gases. Some stars like the sun glow for a long time, whereas massive stars have a shorter life and end in a ______ explosion.

7 There are two main theories on the origin of the universe. The ______ model is most favoured and suggests that the universe is rapidly ______.

Big Bang
brightness
clouds
constellations
convection
core
east to west
expanding
hydrogen
mass
supernova
rotation
visible light

Working with technology

Try doing the Chapter 10 crossword at www.OneStopScience.com.au.

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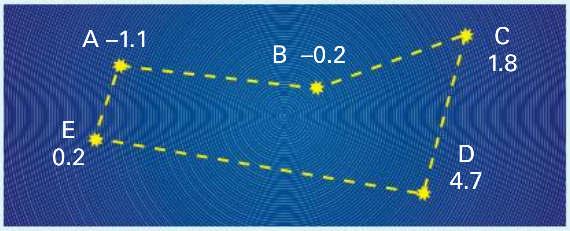
REVIEW

1 The visible part of the Sun is called the:
- **A** corona
- **B** photosphere
- **C** chromosphere
- **D** core.

2 A light-year is the distance:
- **A** light travels in one year
- **B** from the sun to the nearest star in our galaxy
- **C** the Earth travels in one year
- **D** from the Milky Way galaxy to the nearest galaxy.

3 The diagram below shows a constellation and the apparent magnitude of five of its stars.
- **a** List the stars in order from brightest to dimmest.
- **b** Which star is the alpha star?



4 A neutron star forms when a:

A white dwarf forms from a red giant
B star like our sun explodes
C massive star explodes
D protostar condenses.

5 Explain in simple language what Einstein's equation, $E = mc^2$, means.

6 Suppose you found the position of a bright star using your star grid. It had a 75° elevation and a 310° azimuth. In which part of the sky would you look to find the star?

A high in the sky in a north-east direction
B low in the sky in a south-east direction
C low in the sky in a north-west direction
D high in the sky in a north-west direction

7 Star A has an apparent magnitude of –1.3 while that of star B is +3.5. On the other hand, the absolute magnitude of star A is +4.5 while that of star B is –5.2. Explain what this means.

8 Explain why nuclear fusion reactions in the sun occur only in the core and not throughout the sun.

9 What do the words *ecliptic* and *zodiac* mean? Why is the ecliptic higher in the sky in Cairns than in Melbourne?

10 The two stars in a binary have magnitudes of 3.6 and 5.8. However, the magnitude of the binary varies from a maximum of 2.3 to a minimum of 4.6 over a period of 30 days.

a Which of the stars in the binary is the brighter?
b Suggest why the magnitude of the binary changes over time.

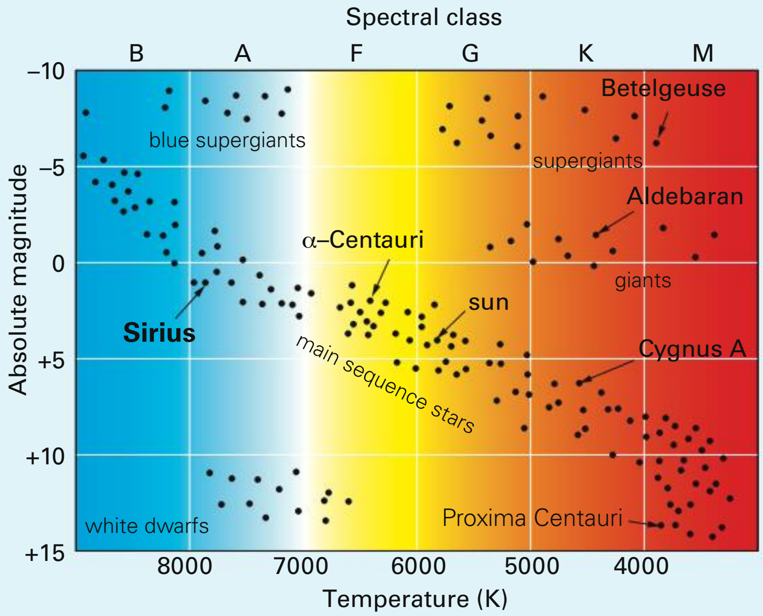
11 The absolute magnitude (brightness) of the known stars in the universe can be plotted against their temperatures on a graph. The spectral class indicates a star's colour.

Use the graph at the bottom of the page to answer the following questions.

a Which one of the statements is *incorrect*?

A Sirius is a main sequence star.
B Sirius has a greater surface temperature than the sun.
C Blue supergiants are hotter than giants.
D Spectral class G includes white stars.

b What is the approximate absolute magnitude of Sirius and Cygnus A? What does this indicate about the relative sizes of these two stars?
c Which of the stars α-Centauri, Sirius and our sun would probably be the oldest? Explain your answer.
d Compare and contrast the stars Proxima Centauri and Betelgeuse.
e Write a generalisation linking the absolute magnitude of the main sequence stars to their temperature and colour.



Check your answers on page 309.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

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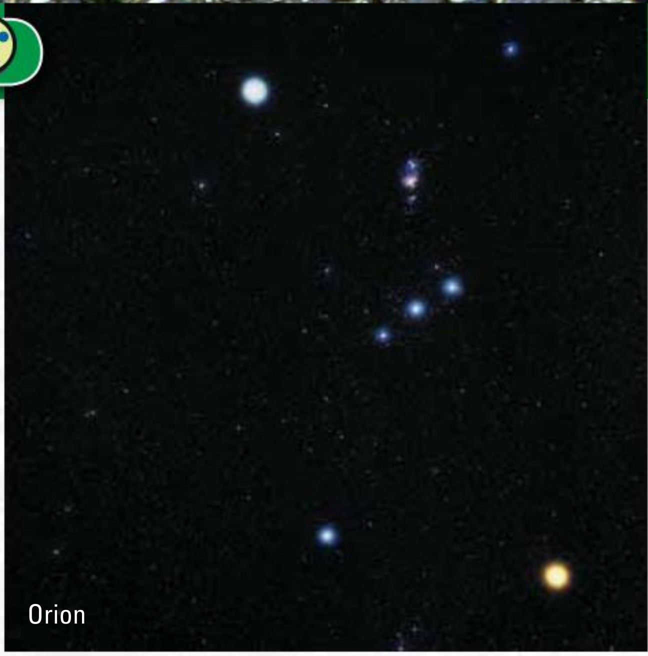
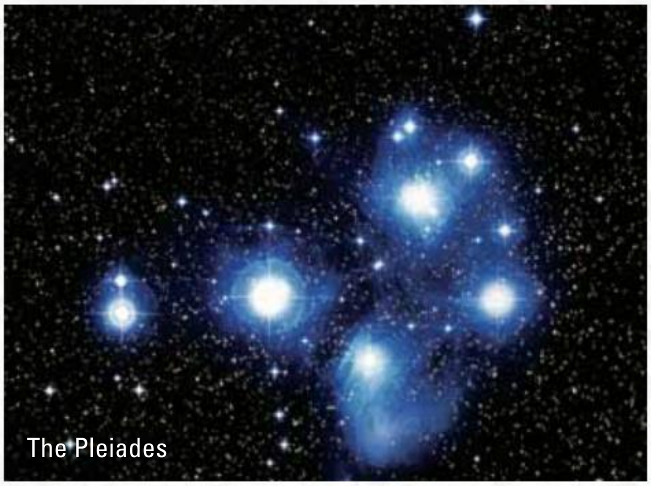
Science as a Human Endeavour

Aboriginal astronony

Use the internet and other resources to research the following questions about how the Australian Aboriginal people used their observations of the night sky in their everyday lives. You could search for 'Aboriginal astronomy' on Australian websites. Work in pairs and answer as many questions as you can. Record your answers in a way that you can present to other people; for example, in PowerPoint, with photos and diagrams. Record all the websites and other references you used in a bibliography.

1 a How did Aboriginal people explain day and night?
  b How did they explain eclipses?
2 What is a common Aboriginal story to explain the phases of the moon?
3 How can the Southern Cross be used to tell the time?
4 a Look at the photo of the Orion constellation. What is its common name in Australia?
  b What story did the ancient Greeks tell about Orion?
  c What stories did Australian Aboriginal people tell about it?
5 a What stories do Aboriginal people tell about the following star patterns?
  - the Southern Cross
  - the Pleiades (the Seven Sisters)
  - the Scorpion
  b Why are there different stories in different places?
6 a Aboriginal people talk about a giant emu in the sky. How is this star pattern different from normal constellations?
  b How can you find the giant emu in the sky?
  c Why could Aboriginal people see the giant emu so easily but we have so much trouble finding it?
7 It has been suggested that the Australian Aboriginal people were the first astronomers in the world. Could this be true? Explain.


Orion


The Pleiades

8 Why do you think it is so difficult to find information on Aboriginal astronomy?
9 Aboriginal people used constellations to tell them when to hunt or collect particular foods. How did they do this?
10 How were stories about the night sky used to teach Aboriginal law?
11 List at least four ways in which knowledge of the sky was important to Aboriginal people.
12 Research sky stories from different cultures around the world; for example, Maoris, Indigenous Americans, the Incas and Ancient Chinese.

Your teacher may be able to arrange for an Aboriginal person to tell you some of the local stories about the night sky.

11

Electrochemistry

In this chapter you will …

Science Understanding

- use a knowledge of chemical reactions to explain how different types of batteries produce electric current
- give examples of how chemistry can be used to produce a range of useful substances
- appreciate the significance of the chemical activity of metals in electrochemistry

Science as a Human Endeavour

- follow the historical development of batteries

Science Inquiry Skills

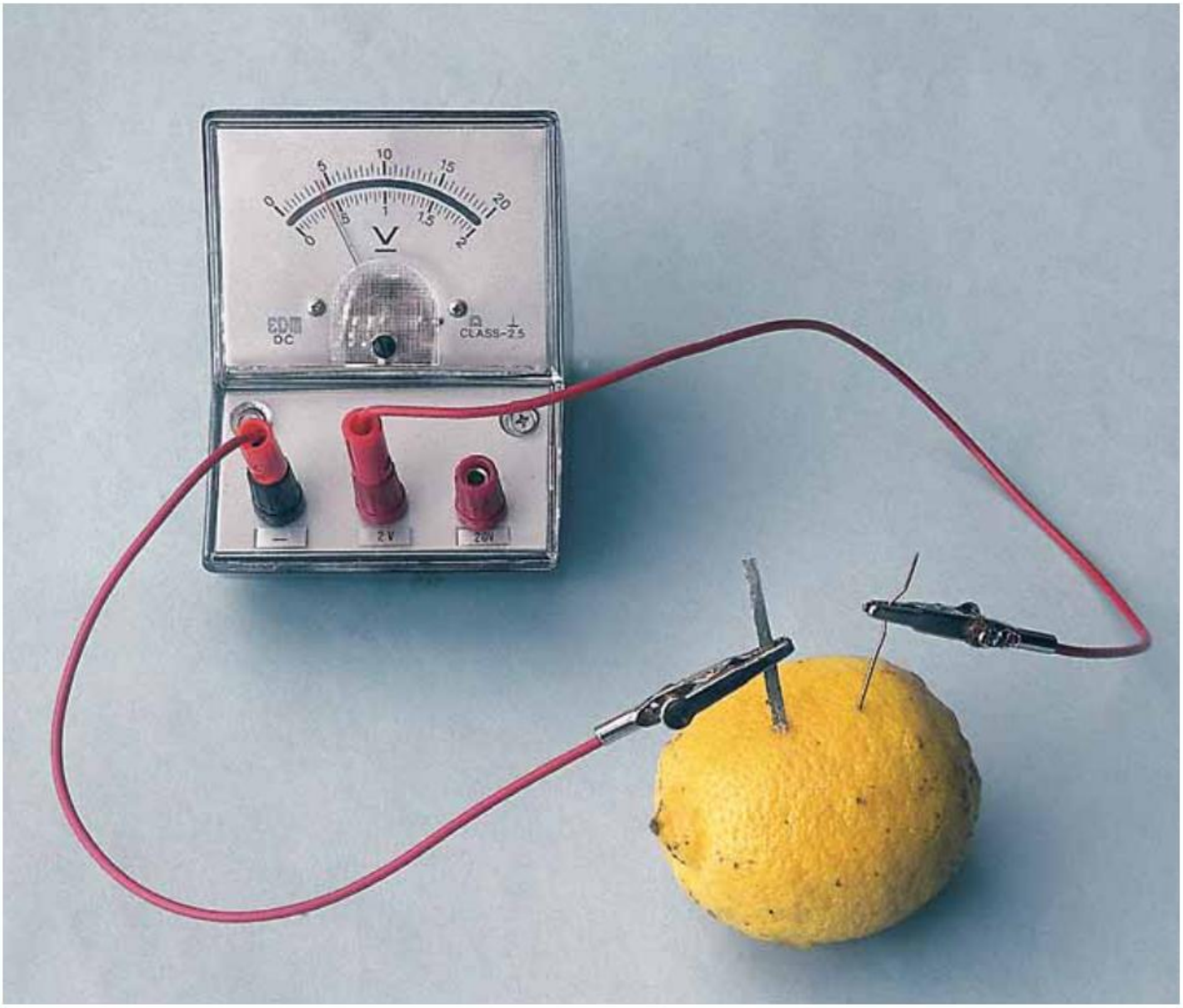
- describe and implement safety precautions when working with acids and electrical apparatus
- design a controlled experiment to investigate the corrosion of iron

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

You can make a simple electrical cell from a lemon, a thick piece of copper wire and a strip of magnesium.

1 Clean the copper wire and the magnesium strip with steel wool.
2 Push the wire and the strip into the lemon, about 2 cm apart, making sure they do not touch.
3 Connect the copper wire to the positive terminal of a sensitive voltmeter or multimeter as shown, and the magnesium to the negative terminal.
   What voltage is produced? Does the voltage stay the same? How many lemon cells would you need to make a 12 volt battery?
4 Does it make any difference how far apart the copper wire and the magnesium strip are, or how far you push them into the lemon?
5 What happens if you use different metals or different fruits?



11.1 Cells and batteries

What is an electric cell?

Do you have any grey amalgam fillings in your teeth? If so, have you ever bitten on a piece of metal foil and felt a tingle? This is caused by a small electric current in your mouth. All that is needed to produce this current is two different metals and a conducting solution.

When two different metals are placed in a conducting solution and connected together, an *electrochemical cell* is made. It is called an **electric cell** or voltaic cell. The conducting solution is called an **electrolyte** (ee-LEK-tro-lite). It conducts electricity because it contains ions. The metal strips are called **electrodes**.

In the Getting started activity, the lemon, the copper wire and the magnesium strip form an electric cell. At the magnesium electrode, a chemical reaction produces electrons, which flow through the wire and voltmeter to the copper electrode where another chemical reaction uses up these electrons. Ions carry the electric current through the electrolyte in the lemon to complete the circuit.

The voltage produced by an electric cell depends on a number of variables. In Investigation 19 you can investigate what happens when you use different metals as the electrodes.

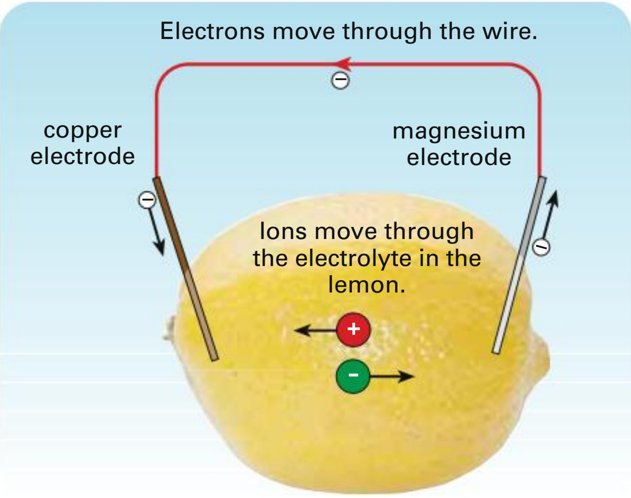


Fig 1 An electric cell is a device that uses chemical reactions to produce an electric current.

Science as a Human Endeavour

Luigi Galvani and Alessandro Volta

In the late 1700s, Luigi Galvani, an Italian biologist, made a great discovery. While dissecting a frog, he noticed that its leg twitched when he held the knife and probe in a certain way. He inferred that the twitch was due to 'animal electricity' generated in the tissues of the frog's leg. Many people accepted this inference, but Alessandro Volta, a young Italian physicist, did not. He said that the source of electricity was not the frog but the two different metals in Galvani's dissecting instruments.

Galvani still believed he was right and eventually managed to get the same effect with two pieces of the *same* metal. But Volta wasn't convinced, saying that the metals must somehow be different. So Galvani got rid of the metals altogether and produced the twitch by tying the nerve of the frog's leg to the other end of the muscle. To answer this, Volta produced an electric current using two different metals and an electrolyte, and no frog at all! He then went on to make the first battery, a pile of silver and zinc disks with pieces of cloth soaked in salty water between the disks. He took his 'pile' to France where Napoleon Bonaparte was so impressed with it he made Volta a count. Science later honoured Volta by naming the volt after him.

Galvani was shattered by Volta's discovery and died soon after. However, his animal electricity wasn't all wrong. We now know that electricity is generated by the nerve cells in our body. It regulates the beating of our heart and the operation of our brain and muscles.

Investigation 19 Voltages of electric cells

Aim

To investigate how the voltage of an electric cell varies, depending on the electrodes used.

Materials

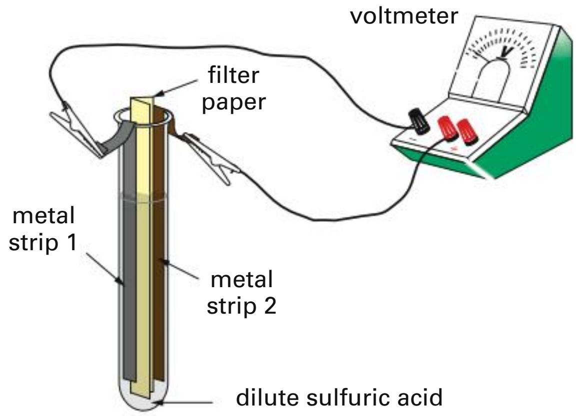
- large test tubes and test tube rack
- strips of metal, e.g. aluminium, zinc, copper, iron, lead, magnesium
- strips of filter paper (about as wide as and slightly longer than the test tubes)
- voltmeter (2–20 V) or multimeter
- connecting wires
- dilute **sulfuric acid** (0.1 M)
- steel wool or sandpaper

Planning and Safety Check

- Read the investigation carefully and design a suitable data table to record your results.
- What safety precautions will be necessary?

Method

1. Clean the metal strips by rubbing them with sandpaper or steel wool.
2. Select a pair of different metal strips and place them in a test tube. Bend the tops of the strips over the edge of the test tube, as shown.



3. Fold a strip of filter paper and push it down between the metal strips. This is to prevent the strips from touching.
4. Two-thirds fill the test tube with dilute sulfuric acid.
5. Attach the connecting wires from the metal strips to the voltmeter. If there is no reading, reverse the connections so that you have the positive electrode connected to the positive terminal of the voltmeter. This is how you tell which metal strip is positive and which is negative.

   Record the reading on the voltmeter, and which metal is positive and which is negative.

   Did the voltage remain constant or did it change?
6. Repeat, using other combinations of metal strips. Include at least one with both metals the same.

   For each pair of metals, record the voltage, which metal was positive and which was negative.

Discussion

1. Which pair of metals produced the largest voltage?
2. Did a particular metal always have the same charge? For example, was the zinc electrode always negative?
3. What happened when you used two strips of the same metal? Why is this?
4. If you wanted to light a small bulb or LED using one of your cells, which metals would you use, and why? (You could try this.)

Inquiry

1. Investigate whether it makes any difference what the electrolyte is. Instead of dilute sulfuric acid you could use dilute hydrochloric acid, sodium chloride solution, copper sulfate solution or sodium hydroxide.
2. What happens when you connect two or more cells together? Does it matter which way they are connected?

How an electric cell works

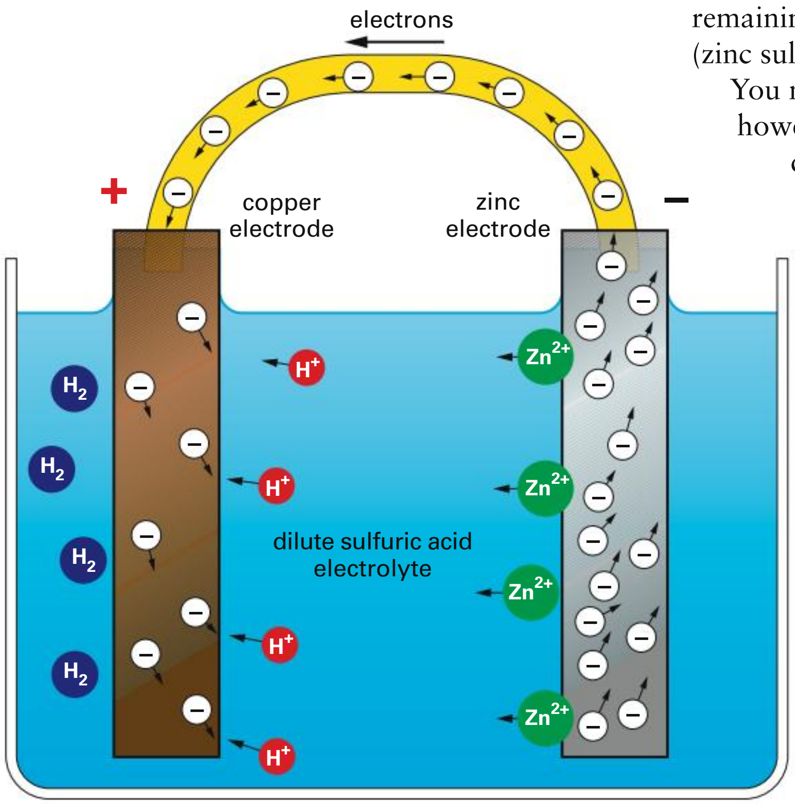
If you made an electric cell using zinc and copper strips in dilute sulfuric acid in Investigation 19, you should have made several observations.

- When the negative terminal of the voltmeter is connected to the zinc and the positive terminal to the copper, the cell produces about 1 volt (to start with).
- The copper is the positive electrode and bubbles of gas are produced there.
- The zinc is the negative electrode and slowly dissolves in the acid.

We can explain these observations as follows. The dilute sulfuric acid contains H^+ ions and SO_4^{2-} ions ($H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$). These ions allow the solution to conduct an electric current.

The zinc strip is more reactive than the copper strip. As a result, the zinc atoms lose electrons to become positive ions Zn^{2+}. This loss of electrons is called *oxidation*. The ionic equation for this reaction is:

$$Zn \rightarrow Zn^{2+} + 2e^-$$



The Zn^{2+} ions move into the electrolyte, leaving the electrons behind.

When the zinc strip is connected to the copper strip, the electrons from the zinc strip flow through the wire from the zinc to the copper. Positive H^+ ions from the electrolyte around the copper electrode use these electrons to form hydrogen atoms. The hydrogen atoms then combine with each other to form molecules of hydrogen gas. This gain of electrons by the hydrogen ions is called *reduction*.

$$2H^+ + 2e^- \rightarrow 2H \rightarrow H_2$$

Notice that oxidation occurs at one electrode and reduction at the other. The electrons produced at the negative electrode are used up at the positive electrode. There is now a continuous flow of electrons through the wire, and a continuous flow of positive and negative ions in the electrolyte.

Zinc ions are produced, and hydrogen ions are used up. In theory, the cell will continue to produce electricity until all the zinc or all the H^+ ions from the electrolyte are used up. The solution remaining will contain zinc ions and sulfate ions (zinc sulfate).

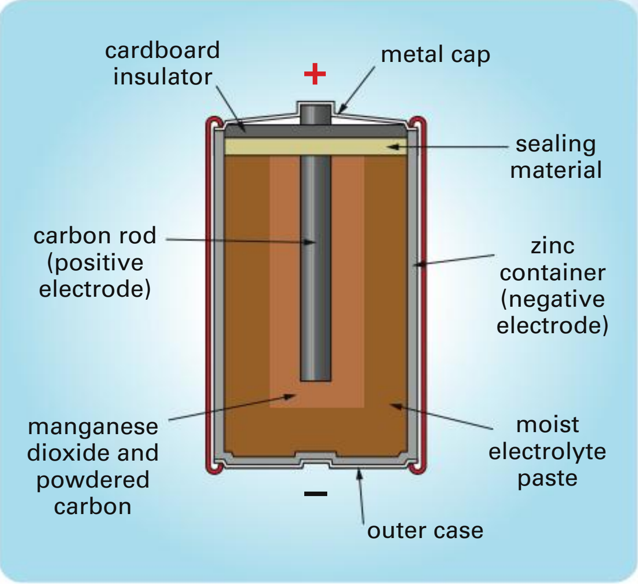
You may have noticed in Investigation 19, however, that the voltage produced by the cell drops fairly rapidly. This is because the positive electrode becomes covered with bubbles of hydrogen, which block the hydrogen ions in the solution from reacting with the electrons on the copper strip.

Working with technology
For an animation of this, open How an electric cell works at www.OneStopScience.com.au.
OneStopScience

Fig 2 How a simple electric cell works

Dry cells

The cells used in torches and portable radios are called **dry cells**. This is because the liquid electrolyte has been replaced by a moist electrolyte paste in a sealed container.



The outside case is made of zinc. This is the negative electrode, and it loses electrons (oxidation) to form zinc ions.

$$Zn \rightarrow Zn^{2+} + 2e^-$$

The positive electrode is a carbon rod surrounded by manganese(IV) oxide MnO_2. (Carbon is a good conductor of electricity.) The reduction reaction at this electrode is complicated, but it can be simplified as:

$$Mn^{4+} + e^- \rightarrow Mn^{3+}$$

The manganese dioxide also removes any hydrogen formed at the positive electrode by reacting with it. The electrolyte paste conducts the electricity.

A carbon–zinc dry cell produces 1.5 volts. Batteries are made by connecting several cells together. For example, a 9 V battery consists of six 1.5 V cells connected together as shown in Fig 3 (6 × 1.5 volts = 9 volts). In everyday language the word *battery* is also used for a single cell.

Fig 3 A 9 V battery cut open showing the six individual 1.5 V cells

Suppose you have a CD player that needs six 1.5 V dry cells. The cells have to be connected in series so that the top positive terminal of one touches the bottom negative terminal of the next. In the appliance illustrated below, there are two rows of three cells, one row on top of the other. The total voltage is 1.5 V × 6 = 9 V.

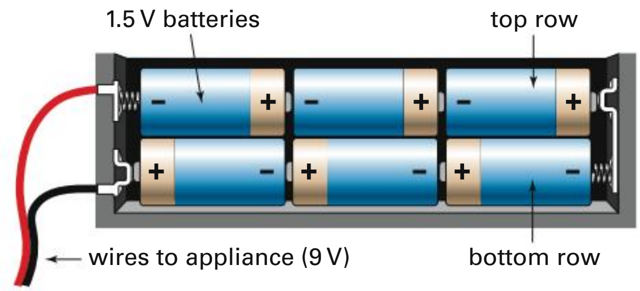
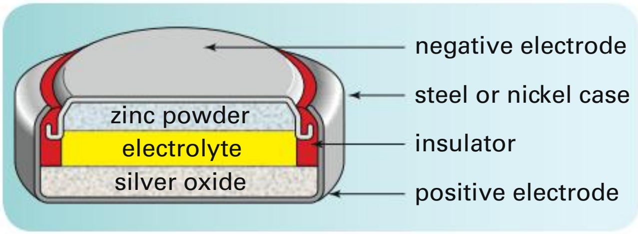


Fig 4 When putting batteries into an appliance, you must be careful to put them in the right way round.

Small button cells are used in watches, calculators, cameras, hearing aids and hand-held electronic games. One type consists of an outer container of nickel or steel, with zinc powder and silver oxide separated by an electrolyte. The zinc is oxidised and the silver ions in the silver oxide are reduced to silver atoms.



Rechargeable batteries

The cells discussed so far have a major disadvantage. Once the chemicals in them have reacted, the cells go 'flat' and have to be thrown away. However, with some cells it is possible to reverse these reactions by passing electricity through them in the opposite direction. Rechargeable cells are widely used in mobile phones, laptop computers, cordless drills and radio-controlled model cars and aeroplanes. Two common rechargeable cells are nickel–cadmium (NiCad) and lithium ion. Most space satellites also use rechargeable batteries, using electricity produced by solar cells to recharge them.

Fig 5 When this red nickel–cadmium battery is recharged, the chemical reactions that produced electricity in the electric drill are reversed.

The most common rechargeable battery is the car battery. It has electrodes of lead and lead oxide (PbO_2) in a sulfuric acid electrolyte. The battery produces an electric current to start the engine, but once the engine is running, an alternator (generator) is used to pass current back through the battery. In this way the chemical reactions that produced the battery current are reversed, and the battery is restored to full charge.

In theory, lead–acid batteries can be used and recharged forever. In practice, however, batteries last only 2–5 years. This is because small amounts of lead sulfate fall from the electrodes and collect on the bottom of the cells. Eventually there is not enough lead sulfate to produce lead on recharging.

During recharging, the battery becomes quite warm, causing some of the water in the electrolyte to evaporate. This is why you need to check most batteries occasionally and add distilled water to keep the acid at the correct concentration.

In Investigation 20 you can make a small lead–acid battery and charge and discharge it.

Fig 6 Topping up a car battery with distilled water

Extra for experts

A car battery consists of six cells connected together, as shown on the right. Each cell produces about 2 volts and contains two electrodes. The negative electrodes are lead and the positive electrodes are lead(IV) oxide PbO_2. These electrodes are immersed in fairly concentrated sulfuric acid, containing H^+ ions and SO_4^{2-} ions.

At the negative electrodes the lead atoms lose electrons (oxidation) to form lead ions.

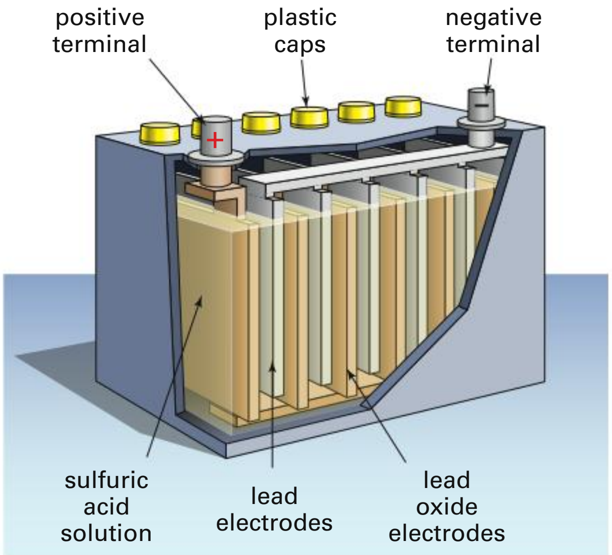
$$Pb \rightarrow Pb^{2+} + 2e^-$$

At the positive electrodes Pb^{4+} ions gain electrons (reduction) to form Pb^{2+} ions.

$$Pb^{4+} + 2e^- \rightarrow Pb^{2+} + 2H_2O$$

During discharge the Pb^{2+} ions react with the sulfuric acid to form lead sulfate (an insoluble white solid), which builds up on the electrodes. The reverse reaction occurs when the battery is recharged (whenever the engine of the car is running).

When you recharge a battery or jump start a car, the water in the battery is electrolysed to hydrogen and oxygen gases. For this reason it is important to leave the caps off and keep away from any sources of ignition such as a burning cigarette.



Batteries for hybrid cars

With the cost of petrol increasing and carbon dioxide from car exhausts contributing to global warming, more people are buying hybrid cars. These cars have an electric motor as well as a normal petrol engine. They also have a battery pack that fits under the floor in the back. When you accelerate, the battery powers the electric motor. When you reach cruising speed, the petrol engine starts up as well. Then, when you slow down, the electric motor acts in reverse. It acts as a generator and recharges the battery. This way you use much less petrol and produce less exhaust gas. Hybrid cars at present use nickel-metal hydride battery packs. For example, the Toyota Prius has a sealed 168-cell nickel-metal hydride battery which produces 201.6 volts. Scientists and technologists are constantly experimenting with new types of batteries.

Fig 7 The dashboard display in a Toyota Prius hybrid car

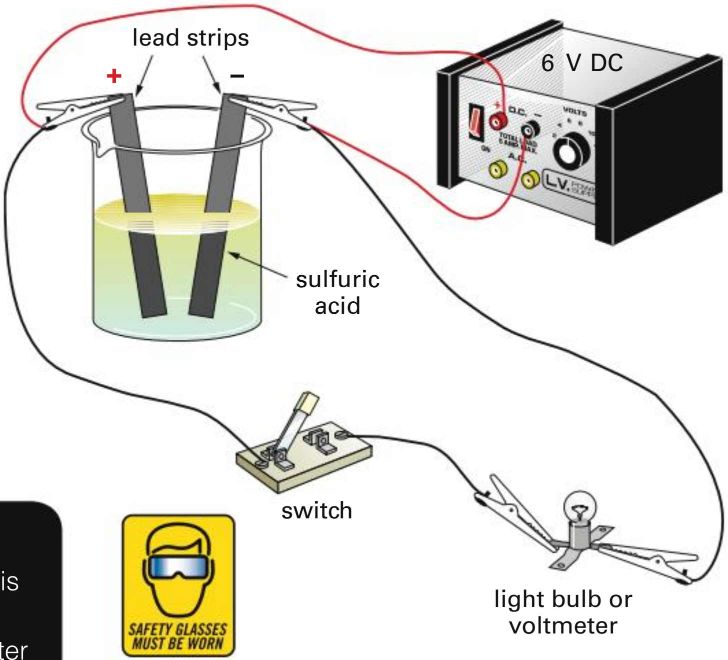
Investigation 20 A model car battery

Aim

To make a model lead–acid car battery and investigate how it works.

Materials

- 2 clean **lead** strips, e.g. 5 cm × 1 cm
- 100 mL beaker
- power pack
- 5 connecting wires
- 1.5 volt torch bulb in holder
- voltmeter or multimeter
- switch
- 1 M **sulfuric acid**



Planning and Safety Check

- 1 M sulfuric acid is very corrosive. If any is spilt, what should you do?
- Why should you wash your hands well after handling the lead strips?
- Why is it important to make sure that the lead strips do not touch during charging or discharging?

Method

1 Connect up the electric circuit as shown, and have your teacher check it. The lead electrode connected to the positive terminal of the power pack is the positive electrode.

2 Set the power pack to 6 V DC and turn it on to charge your 'battery'.

3 After 5 minutes, turn off the power pack and turn on the switch to connect the battery to the light bulb. The battery is now discharging.

How long does the bulb glow?

4 Recharge the battery by turning off the light bulb switch and turning the power pack on again for 5 minutes.

5 Remove the torch bulb and replace it with a voltmeter. Make sure the positive terminal of the voltmeter is connected to the positive electrode of the battery.

6 Switch on the voltmeter circuit.

Record the voltage of the battery.

What happens to the voltage as the battery continues to discharge?

Discussion

1 What evidence of chemical reactions did you observe during charging and discharging?

2 Explain in your own words the difference between charging and discharging.

3 Would you get as much energy out of the battery as you put into it? Explain your answer.

Inquiry

Use your battery to investigate the effect of one or more of these variables on its performance:

- the charging time and voltage used
- the distance between the lead strips
- the size of the strips.

Fuel cells

Fuel cells are electrochemical cells that produce electricity continuously and do not need to be recharged.

Hydrogen–oxygen fuel cells were used on the *Apollo* missions that put people on the moon, and they are currently used in the space shuttle. Each cell consists of two electrodes separated by an electrolyte (see Fig 8). Hydrogen (the fuel) is fed into one electrode and oxygen (air) into the other.

At the negative electrode the hydrogen gives up electrons (is oxidised):

$$2H_2 \rightarrow 4H^+ + 4e^-$$

At the positive electrode the oxygen accepts electrons (is reduced):

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Adding these two equations together, the overall reaction is:

$$2H_2 + O_2 \rightarrow 2H_2O$$

A big advantage of this fuel cell is that the only waste product is water. In fact, the fuel cells on the space shuttle were used to produce drinking water as well as electricity. At present fuel cells are too expensive for general use, but they were trialled in buses in Perth. It may not be long before they are widely used; for example, in hydrogen cars and mobile phones.

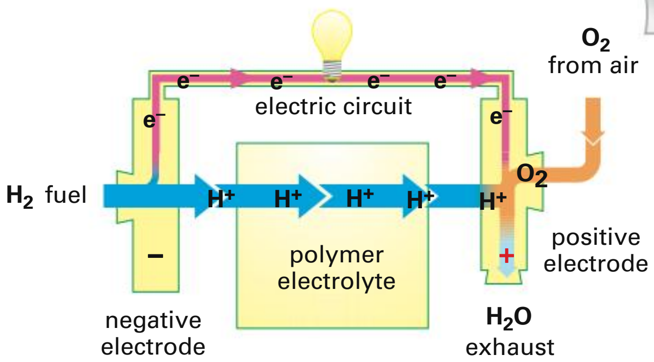


Fig 8 This type of fuel cell generates 0.7 volts. The electrodes contain a platinum catalyst and the electrolyte is made of a conducting plastic similar to Teflon. Many of these cells stacked together can be used to power a hydrogen car (below).

WEBwatch

Use the internet to research fuel cells and write a report which includes:

- types of fuel cells
- their advantages and disadvantages
- where they are used.

Go to **www.OneStopScience.com.au** and follow the links to these useful websites:

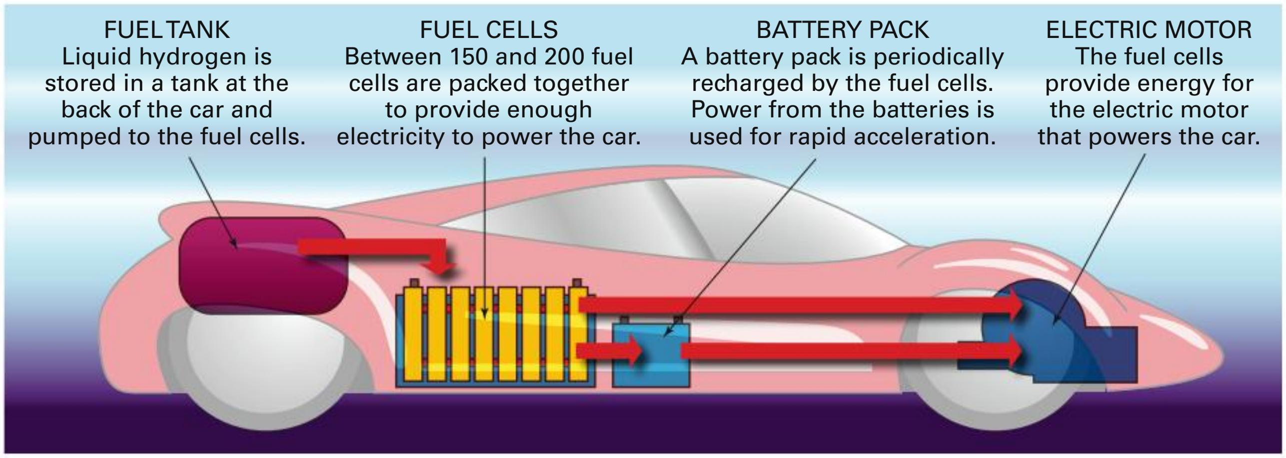
Fuelling the 21st century

Fuel cell technology

How fuel cells work

OneStopScience

Fig 9 How a hydrogen car works



Check

1 If you have amalgam fillings in your teeth and you bite on a piece of foil covering a chocolate bar, you feel a tingle of charge. Why is this so?

2 Draw a diagram of a simple electric cell and explain how it works.

3 Most people incorrectly refer to 1.5 V dry cells as batteries. Why is this incorrect?

4 How could you make a 4.5 V battery from 1.5 V dry cells?

5 What are the two electrodes in a dry cell made of?

6 What is the electrolyte in a car battery?

7 Why are lead–acid batteries often referred to as storage batteries?

8 What has happened when a battery is flat?

9 Explain how the flow of electric current in an electrolyte differs from that in the wire connecting the electrodes.

Challenge

1 I-Chung put a zinc strip and a copper strip in a test tube and added water. When he connected a voltmeter the reading was zero. How can you explain I-Chung's result?

2 Tanya decides to make a simple cell spillproof by sealing it with a rubber stopper. However, the rubber stopper keeps popping out. Suggest why this happens.

3 A copper–zinc cell gives a voltage of about 1 V while a copper–lead cell gives a voltage of less than 0.5 V. Write an inference to explain these observations.

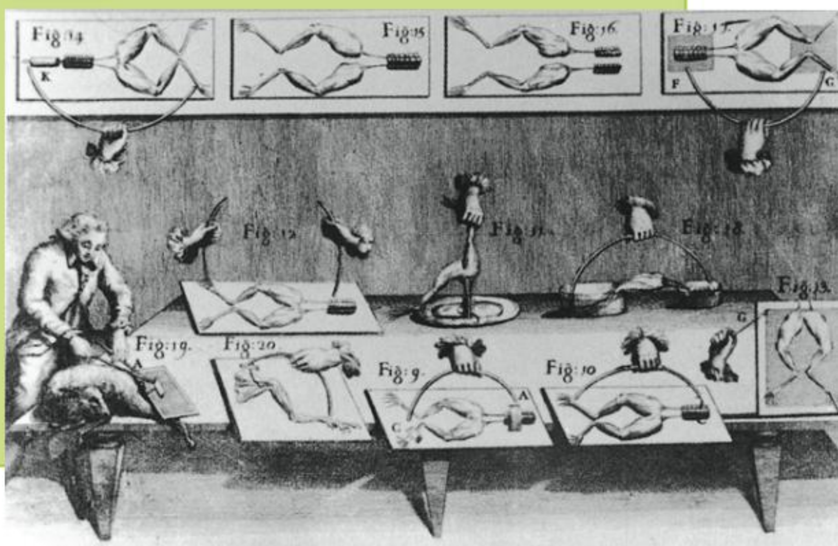
4 Alistair wants to recharge his car battery using a battery charger.
   a To which battery terminals should the positive and negative terminals of the battery charger be connected?
   b What would be the effect on the battery if the charger was connected incorrectly?
   c Why is it important to remove the plastic caps on each cell of the battery during recharging?
   d Explain why smoking during this procedure is hazardous.

5 In the Getting started activity you made an electric cell by putting a copper wire and a magnesium strip in a lemon (containing citric acid). Use what you have learnt in this section to answer these questions.
   a What is the electrolyte in this cell?
   b What reaction occurs at the magnesium electrode? Is this electrode positive or negative?
   c What reaction occurs at the copper electrode? Is this electrode positive or negative?

6 A torch bulb is connected to a copper–zinc cell. At first the bulb glows brightly, but it gradually becomes dimmer. Explain why this happens.

7 In 1780 Luigi Galvani investigated animal electricity. He connected different metals such as copper and iron to the hind legs of dead frogs, as shown in Fig 10. He found that the legs twitched.
   a Use what you have learnt in this chapter to explain Galvani's observation.
   b Look at Fig 9 (bottom middle) in the illustration below. It shows an iron bracelet (A) connected to a copper bracelet (C) by a curved wire. Redraw this, labelling the two electrodes and the direction of the current flow.

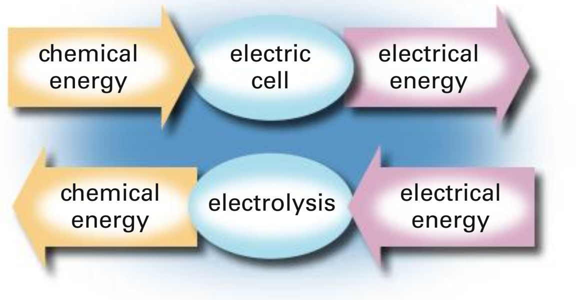
Fig 10 Galvani's experiments on animal electricity



11.2 Electrolysis

Electroplating

If you browse through a jeweller's shop, you will find many shiny 'silver' articles such as bracelets, necklaces, cutlery, trays and jugs. The silver on these objects is usually only a thin coating about 0.01–0.05 mm thick on top of an inexpensive metal such as copper, zinc or nickel. The coating has been put on by electrolysis, a process in which electricity is used to cause chemical reactions. It is the reverse of what happens in electric cells.



Putting a layer of metal on the surface of another metal is called *electroplating*. To put a coating of silver on a teapot you would use the apparatus in Fig 12. The teapot is connected to the negative terminal of a power supply and immersed in an electrolyte such as silver nitrate, which contains ions of the metal that is to form the coating. The positive electrode is a rod of silver. When the power is turned on, the positive silver ions in the electrolyte are attracted to the negative electrode (the teapot), where they accept electrons and are reduced to silver atoms.

$$Ag^+ + e^- \rightarrow Ag$$

At the positive silver electrode the silver atoms release electrons and are oxidised to silver ions.

$$Ag \rightarrow Ag^+ + e^-$$

The negative nitrate ions move towards the positive electrode but do not take part in any reaction. The overall result is that the silver rod slowly dissolves, and the teapot is coated with silver.

Fig 11 This motorcycle fuel tank has been electroplated with a thin layer of chromium (chrome) by placing it in a vat containing chrome solution and passing an electric current through it.

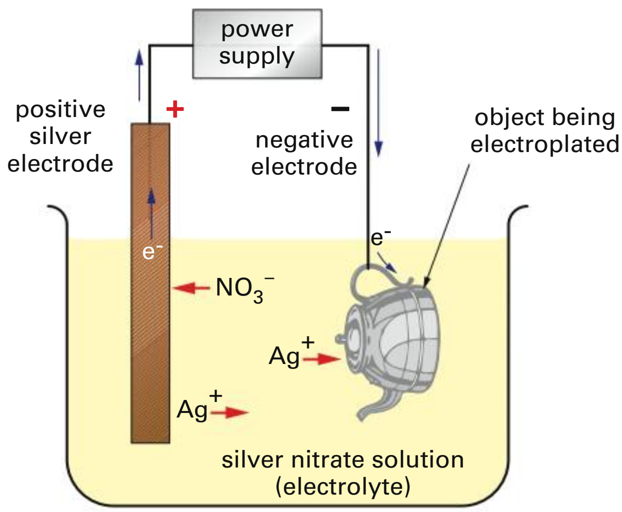


Fig 12 This teapot is being electroplated with a layer of silver.

Investigation 21 Copper plating

Aim

To investigate the electrolysis of copper sulfate solution.

Materials

- **acidified copper sulfate solution** (1 M)
- 250 mL beaker
- carbon rod
- copper strip
- power pack
- 2 connecting wires

Planning and Safety Check

- Read the investigation carefully and design a suitable data table to record your results.
- What safety precautions will be necessary?
- Discuss with your teacher how you will dispose of the copper sulfate solution.

Method

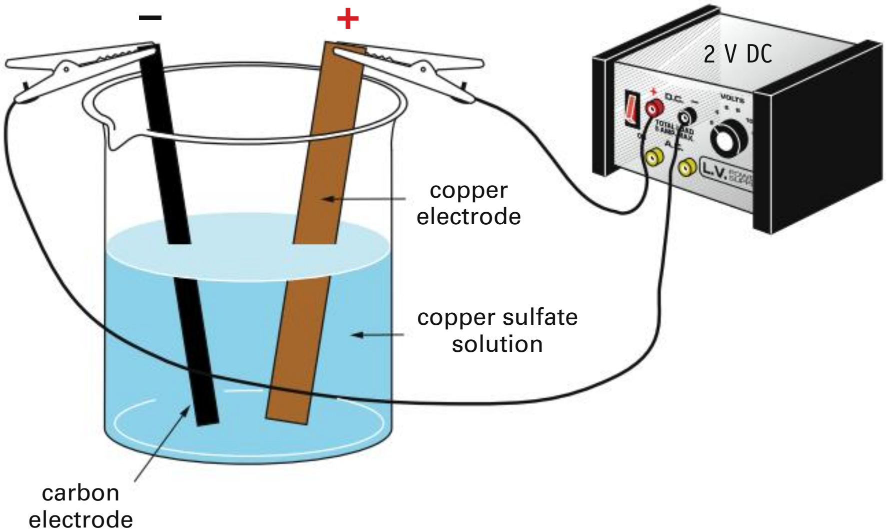
1 Set up the equipment as shown, with the carbon electrode connected to the negative terminal of the power supply.

2 Set the power supply to 2 V DC and turn it on for 3–4 minutes. *Don't let the electrodes touch.*
Observe the electrodes while the current is turned on.

3 Remove the electrodes, wash and inspect them.
What do you think the coating on the negative electrode is?

4 Reverse the connections to the electrodes so that the carbon electrode is connected to the positive terminal.

5 Allow the current to flow for 3 or 4 minutes.
Describe what happens this time.



Discussion

1 What ions are present in the copper sulfate solution?

2 Which electrode is negative in Step 2? Write an equation for the reaction that occurred there.

3 The copper sulfate tends to lose its blue colour after a while. Write an inference to explain this.

4 Did you observe bubbles of gas at the positive electrode? Infer what this gas is and where it came from.

5 How could you test your inference in Question 4?

6 Explain what happened in Step 5 when you reversed the connections.

7 The copper is always deposited at the same electrode. Which one is it—the positive or the negative?

Inquiry

Plan and carry out an experiment to electroplate various metal objects with copper. To get an even coating of copper, clean the metal to be plated with steel wool or dip it in nitric acid (caution) before you start. Use a low voltage (2 V DC) and leave for at least 20 minutes.

Electrolysis in industry

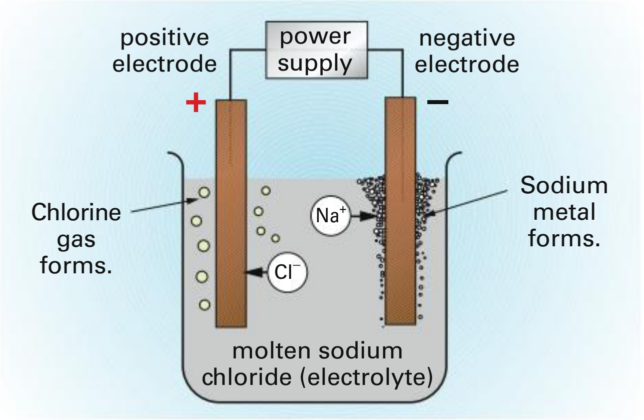
Electrolysis is widely used in industry to produce the materials we use in everyday life. For example, if you melt sodium chloride, it conducts an electric current and can be electrolysed as shown on the right. The electrodes are made of an unreactive material such as carbon.

The positive ions move to the negative electrode where they accept electrons to form sodium metal.

$$2Na^+ + 2e^- \rightarrow 2Na$$

The molten sodium is less dense than the molten sodium chloride and floats to the top of the cell, where it can be collected.

The negative chloride ions move to the positive electrode, where they give up their electrons to form chloride atoms, which immediately form molecules of chlorine gas.



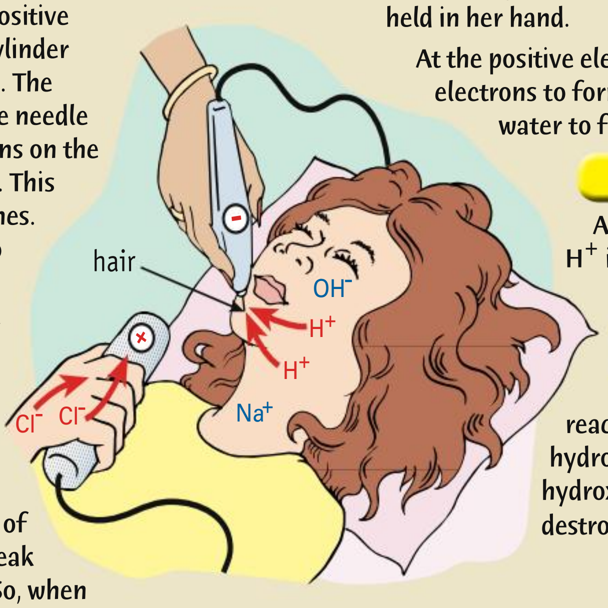
$$2Cl^- \rightarrow Cl_2 + 2e^-$$

Sodium is a very reactive metal. It is used in sodium vapour lamps. Chlorine is a toxic greenish-yellow gas used to sterilise drinking water and in the manufacture of polyvinyl chloride (PVC) and various pesticides.

Hair removal by electrolysis

Linda is always pulling hairs from her face, and has gone to a beauty salon to have the hairs removed permanently. The beautician uses a very fine, gold needle, which she connects to the negative terminal of a 9 V power supply. The positive electrode is a shiny metal cylinder that Linda holds in her hand. The beautician gently pushes the needle into the hair follicle and turns on the power for about 10 seconds. This is repeated three or four times. Finally, tweezers are used to remove the hair easily and painlessly. But how does the process work?

Your body tissues contain water, and dissolved in this water is sodium chloride, present as Na^+ ions and Cl^- ions. Some of the water molecules also break into H^+ ions and OH^- ions. So, when the electrolysis equipment is connected and turned on, Linda's body conducts an electric current. The positive ions move to the negative electrode in the hair follicle, and the negative ions move to the positive electrode held in her hand.



At the positive electrode the Cl^- ions give up their electrons to form chlorine gas, which dissolves in water to form hydrochloric acid.

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

At the negative electrode the H^+ ions accept electrons to form hydrogen gas.

$$2H^+ + 2e^- \rightarrow H_2$$

The Na^+ and OH^- ions do not react, but together form sodium hydroxide (NaOH). This sodium hydroxide is alkaline and gradually destroys the root of the hair.

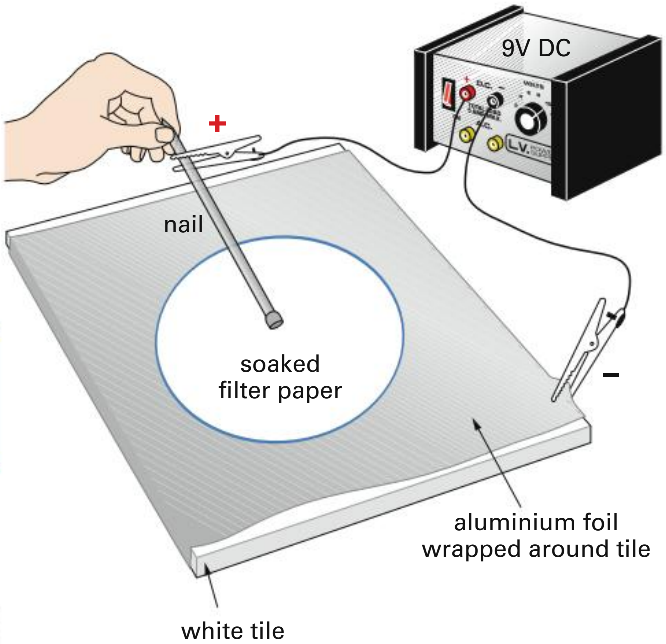
Investigation 22 Drawing by electrolysis

Aim

To electrolyse potassium iodide solution and explain what happens.

Materials

- power pack
- 2 connecting wires
- large evaporating basin
- large filter paper
- white tile or similar
- large shiny nail
- aluminium foil
- **potassium iodide** solution (0.5 M)
- sodium thiosulfate solution (0.5 M)
- starch suspension (1% freshly prepared)
- phenolphthalein indicator
- disposable gloves



Planning and Safety Check

Why is it important to wear disposable gloves for this experiment?

Method

1. Set up the equipment as shown.
2. Mix the following solutions in an evaporating basin:
   10 mL potassium iodide
   5 mL sodium thiosulfate
   5 drops starch
   5 drops phenolphthalein
3. Soak a large filter paper in the solution in the dish.
4. Wear gloves to remove the soaked filter paper from the dish, drain off any excess liquid, then place the filter paper on the aluminium foil wrapped around the tile. Press it down to make sure it has good contact with the foil.
5. Switch on the power pack and use the nail to draw a letter or shape on the damp filter paper. *Be careful not to tear it.*
6. Switch off, reverse the connections, and try again.

Discussion

To start with, the filter paper contains equal numbers of K^+ and I^- ions from the potassium iodide. It also contains equal numbers of H^+ and OH^- ions from the water.

1. When the nail is positive it produces a blue-black colour where it touches the filter paper. What can you infer from this blue-black colour? (Hint: The solution on the filter paper contains starch.)
2. Write an equation for what happens when iodide ions I^- give up electrons at the positive electrode. (Hint: It is similar to what happens with Cl^- ions—see page 290.)
3. When the nail is negative it produces a pink colour. What can you infer from this pink colour? (Hint: The solution on the filter paper contains phenolphthalein, an acid–base indicator.)
4. Write the equation for the reaction when H^+ ions accept electrons at the negative electrode. (Hint: See page 281.)
5. If H^+ ions are removed at the negative electrode, why would the phenolphthalein indicator change from colourless to pink?

Check

1 Explain the terms:
  a electrolysis
  b electrolyte.

2 a How is electrolysis different from what happens in an electric cell?
  b Is electrolysis an exothermic or an endothermic reaction? Explain.

3 a Which of the following materials could be used as an electrode for electrolysis: carbon, zinc, plastic, copper? Explain.
  b Which of the following liquids could be used as an electrolyte in electrolysis: dilute sulfuric acid, distilled water, lead sulfate solution, methylated spirits, sugar solution.

4 Why is it that one Cu^{2+} ion combines with two electrons?

5 In the electrolysis of aluminium, aluminium ions Al^{3+} accept electrons to become aluminium atoms. Write an equation for this reaction.

6 How could you coat a spoon with copper?

7 a Which ions exist in a copper sulfate solution?
  b When electricity is passed through copper sulfate solution, what happens at the negative electrode? Write an equation.

Challenge

1 A steel knife is to be electroplated with nickel using nickel sulfate solution.
  a Draw a diagram showing how this would be done.
  b What would the positive electrode be made of?
  c Write equations for the reactions occurring at both electrodes. (Nickel ions are Ni^{2+}.)

2 Why is a direct current and not an alternating current used in electroplating metals?

3 Use the explanation of hair removal by electrolysis on page 290 to answer these questions.
  a When the beautician is removing hairs from your face why do you need to hold the other electrode?
  b Why is a shiny metal cylinder used as the positive electrode?
  c Why does the area around the hair become quite warm during the treatment?
  d What happens to the hydrogen gas produced at the negative electrode?
  e Why is it that the root of the hair becomes alkaline during the treatment?
  f The electrical connections are sometimes reversed briefly at the end of the treatment. Suggest a reason for this.

4 The gold pendant below was made from a leaf. Suggest how this would have been done.

5 In the electrolysis of molten sodium chloride (page 290), explain the following.
  a Why is electricity conducted in the molten state but not in the solid state?
  b Why are the products formed only around the electrodes and not throughout the liquid?
  c What causes the electric current to flow in the liquid and in the connecting wires?
  d What are the similarities and differences between the electrolysis of molten sodium chloride and hair removal by electrolysis?

6 Predict what would happen if you electrolysed molten lead(II) bromide $PbBr_2$. Write equations.

Fig 13 When iron rusts it reacts slowly with air and water to form brown iron oxide. This ship was wrecked in 1893.

11.3 Corrosion of metals

Rusting

A big problem with metals is that they corrode; that is, they react chemically with moist air. Metallic corrosion and its prevention costs Australia hundreds of millions of dollars every year.

Corrosion is a reaction between a metal and moist air. For example, when iron rusts it reacts with oxygen to form iron oxide Fe_2O_3. This is the brown coating we call rust.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

For rusting to occur, both air and water are necessary. This is why objects made of iron and steel do not rust in the desert or in space.

The rusting of iron and steel is an electrochemical process. Consider a drop of water on a piece of iron. The water, which contains dissolved carbon dioxide and other gases from the air, acts as the electrolyte. Near the centre of the drop the iron atoms lose electrons to form Fe^{2+} ions, which move into the water. The metal in the centre of the drop becomes negatively charged.

$$Fe \rightarrow Fe^{2+} + 2e^-$$

Electrons flow across the surface of the iron to the edges of the drop, which have a positive charge. Here there is a high concentration of dissolved oxygen, and the oxygen molecules gain electrons to form hydroxide ions.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

These OH^- ions then react with the Fe^{2+} ions to form iron hydroxide then iron oxide Fe_2O_3. Salt water accelerates the corrosion because it is a very good conductor of electricity.

The presence of carbon in steel tends to accelerate corrosion. Other metals can either accelerate or slow down the corrosion. If conditions favour the loss of electrons, the rate of corrosion is increased, but if iron can be prevented from losing its electrons, corrosion can be slowed down or prevented.

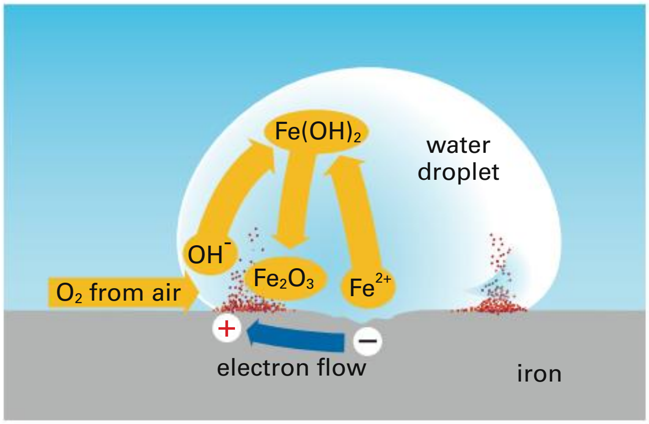


Fig 14 The corrosion of iron is similar to what happens in an electric cell.

Experiment 6 Corrosion of iron

Research questions

1 You suspect that iron rusts faster if you are near the coast where the air is salty. Is this true?

2 You have read that if iron is touching another metal, it rusts faster or slower, depending on the metal. Is this true?

Design your experiment

1 Work in a small group to design an experiment to answer the two questions above. Use the diagram and the hints below as a guide.

2 Write out the method for your experiment. Make sure your tests are fair. Which variable will you control? Which variable will you change?

3 Make a list of the materials you will need.

4 Discuss how you are going to record your observations. You could use a digital camera to record the corrosion of the nails.

5 Do a risk assessment for your experiment.

Hints

1 Use steel wool to clean the nails, copper and magnesium thoroughly before you start.

2 The copper and magnesium need to be in tight contact with the nail.

3 It is best to continue the experiment for several days, up to a week. You will need to put your experiment where it will not be disturbed.

Discussion

1 Use your results to answer research Question 1: does iron rust more rapidly in salt water? Are your results reliable? Should you do more tests?

2 What effect did the copper have on the rusting of the nail? What effect did the magnesium have?

3 Write inferences to explain why copper and magnesium affect the rusting of iron.

4 Use your results to list the three metals (iron, copper and magnesium) from most reactive to least reactive.

5 If you did the experiment again, could you improve your method? Explain.

6 Can you suggest ways of extending your experiment? Suggest other questions you could investigate.

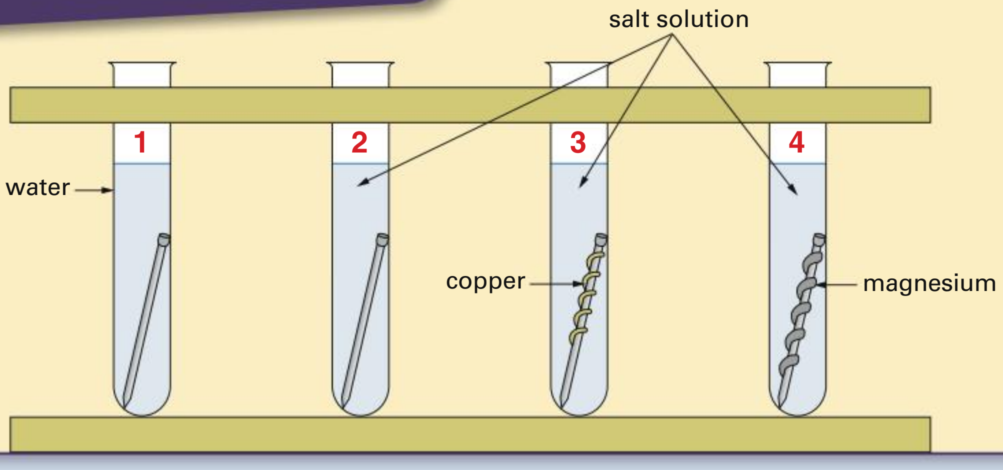
Write your report

Write a full report of your experiment, using the usual headings. In your conclusion, make sure you answer the two research questions.

Applying what you have learnt

1 Where would you expect iron to rust more rapidly—in a river or in the ocean? Explain.

2 Predict what would happen if you used copper screws in a steel boat in salt water. Explain your prediction.



Preventing corrosion

The results of your experiment on the previous page can be explained in terms of how chemically reactive the metals are.

Sodium and gold are both metals. Yet sodium reacts so quickly with air that it has to be stored in kerosene. On the other hand, gold and silver coins can lie on the ocean floor for hundreds of years without corroding. The metals can be arranged in a list with the most reactive at the top and the least reactive at the bottom. This is the **activity series**. It can be used to predict reactions of metals; for example which will react most rapidly with an acid.

Activity series

most reactive

(lose electrons most readily)

potassium	$K \rightarrow K^{+} + e^{-}$
calcium	$Ca \rightarrow Ca^{2+} + 2e^{-}$
sodium	$Na \rightarrow Na^{+} + e^{-}$
magnesium	$Mg \rightarrow Mg^{2+} + 2e^{-}$
aluminium	$Al \rightarrow Al^{3+} + 3e^{-}$
zinc	$Zn \rightarrow Zn^{2+} + 2e^{-}$
iron	$Fe \rightarrow Fe^{3+} + 3e^{-}$
tin	$Sn \rightarrow Sn^{2+} + 2e^{-}$
lead	$Pb \rightarrow Pb^{2+} + 2e^{-}$
copper	$Cu \rightarrow Cu^{2+} + 2e^{-}$
silver	$Ag \rightarrow Ag^{+} + e^{-}$

least reactive

You can see from the activity series that iron is more reactive than copper. So, when iron is in contact with copper in salt solution, the iron rapidly loses electrons to form Fe^{3+} and the electrons are transferred to the copper, as in an electric cell. So the iron corrodes more rapidly than normal, and the copper does not corrode.

When the iron is in contact with magnesium, it is the magnesium that loses electrons (because it is more reactive). The magnesium therefore corrodes rapidly and electrons are transferred to the iron, stopping it from corroding. This process is called *sacrificial protection* because the magnesium is sacrificed to protect the iron.

Another metal that slows down the corrosion of iron is zinc. Iron used on roofs is coated with zinc or a zinc–aluminium alloy to prevent the iron corroding. This zinc-coated iron is called galvanised iron, and a coloured version is available as Colorbond®. Because the zinc is more reactive than iron, it slowly corrodes in preference to the iron.

Lumps of zinc or magnesium are often attached to the steel hulls of ships to protect them from rusting. Because zinc is more reactive than the iron, it is corroded in preference to the iron. Once the zinc blocks have corroded, they have to be replaced.

Tin cans are made of iron (steel) coated with a thin layer of tin. Tin is a very unreactive metal, so it corrodes very slowly. The inside of the can is often coated with a thin layer of plastic to give extra protection from corrosion. However, if the can is damaged, the plastic and tin layers may be

Fig 15 The zinc blocks fitted to this ship corrode in preference to the steel in the hull.

broken, exposing the iron. Iron is higher on the activity series than tin, so it reacts rapidly with the contents of the can. Poisonous gases may be produced and these may get into the food. So beware of scratched and dented cans.

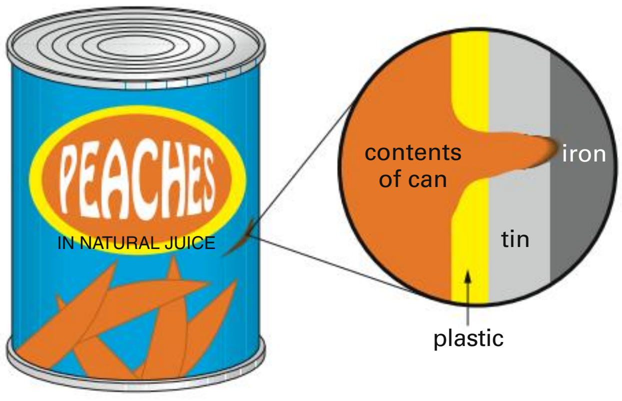


Fig 16 Magnified cross-section of the wall of a damaged tin can. When this happens the contents of the can may react with the iron.

Corrosion of aluminium

Aluminium is a very reactive metal yet it does not seem to need any special protection from corrosion. The secret is a very thin layer of aluminium oxide that forms on the surface of a freshly cut piece of aluminium when it is left in air. This layer of oxide sticks to the aluminium and prevents water and air attacking the uncorroded aluminium underneath. The aluminium has formed its own protective layer. See the diagram below.

To protect the aluminium even more, the oxide layer can be made thicker. This is done by an electrolysis process called **anodising**. The aluminium article is thoroughly cleaned and dipped in a dilute sulfuric acid electrolyte. It is then made the positive electrode (anode) by connecting it to the positive side of a power supply. Hydroxide ions from the water are attracted to the positive electrode where they give up electrons and form oxygen atoms.

$$2OH^- \rightarrow O + H_2O + 2e^-$$

These oxygen atoms then react with the aluminium anode to form aluminium oxide. This oxide coating can be dyed, so aluminium articles can be anodised different colours.

Fig 18 Anodised cups

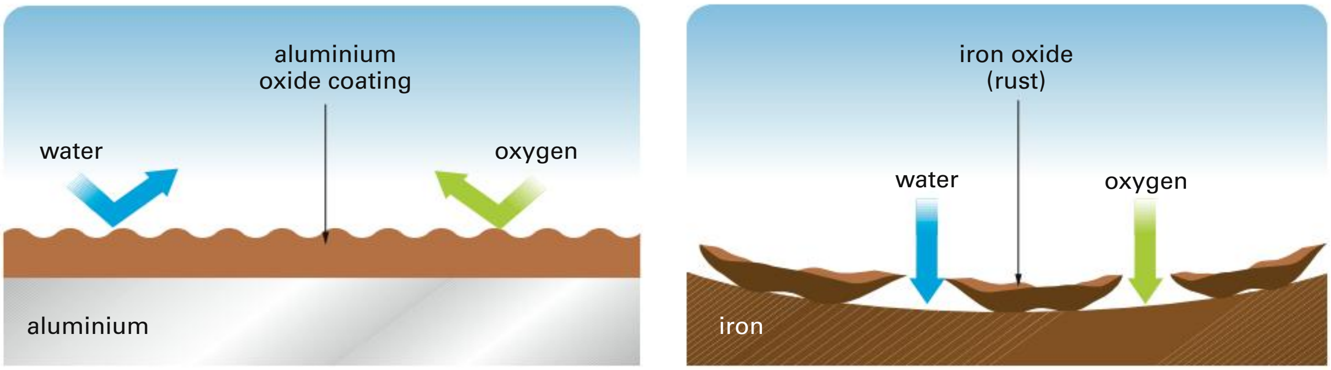


Fig 17 Aluminium oxide forms a protective coating on aluminium, compared with rust, which is flaky and does not keep the air and water from the iron underneath.

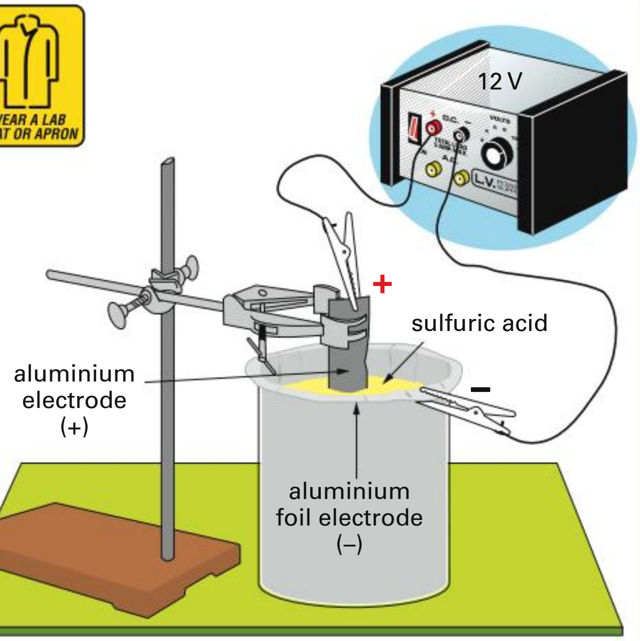
Investigation 23 Anodising aluminium

Aim

To anodise a piece of aluminium.

Materials

- piece of aluminium, e.g. 5 cm x 1 cm
- aluminium foil
- 2 beakers (100 mL)
- **2 M sulfuric acid**
- metal tongs
- safety glasses and disposable gloves
- hotplate (or burner, tripod and gauze)
- power pack and connecting wires
- fabric or food dye solution
- stand and clamp
- bench mat
- detergent
- tissues



Planning and Safety Check

- Read the investigation carefully before you start. There are many steps and you will need to be very safety conscious and well organised. You may want to do the investigation as part of a science project on anodising.
- Ask your teacher what you should do with the leftover sulfuric acid.

Method

1. Line a beaker with aluminium foil, then carefully three-quarters fill it with 2 M sulfuric acid.
2. Connect the aluminium foil to the negative terminal of the power supply (without allowing the alligator clip to dip into the acid).
3. Thoroughly clean the piece of aluminium to be anodised. Scrub it with warm water and detergent and dry it with a tissue. Once cleaned, the aluminium must be handled only with clean metal tongs.
4. Use the stand and clamp to suspend the piece of aluminium in the centre of the beaker *so that it does not touch the aluminium foil*. Connect the piece of aluminium to the positive terminal of the power pack.
5. Turn on the power supply and increase the voltage slowly to 12 volts. Leave for about 15 minutes, then use the tongs to remove the piece of aluminium and wash it in water.
   What did you observe during the electrolysis?
   How has the aluminium changed?
6. In a second beaker heat a prepared dye solution until it is almost boiling.
7. Immerse the anodised aluminium in the dye solution and leave it for 10 minutes, or until the aluminium has a permanent colour.
8. Rinse the aluminium and allow it to cool.
9. Seal the coloured oxide layer by immersing the aluminium in boiling water for 10 minutes.
10. Rinse the aluminium in water and dry it.

Discussion

1. Why do you think it was necessary to clean the aluminium in Step 3?
2. Why shouldn't you touch the aluminium with your fingers after Step 3?
3. Are you happy with your final product? Could you improve your method? How?

Check

1 An iron bar might last 20 years, a bar of aluminium 100 years and a gold bar thousands of years. Why is this so?

2 Use the activity series to place these metals in order from most reactive to least reactive:

copper gold magnesium sodium zinc

3 What is the chemical formula for rust?

4 a Which two substances are needed for rusting to occur?
b List two things that speed up the rusting of iron.

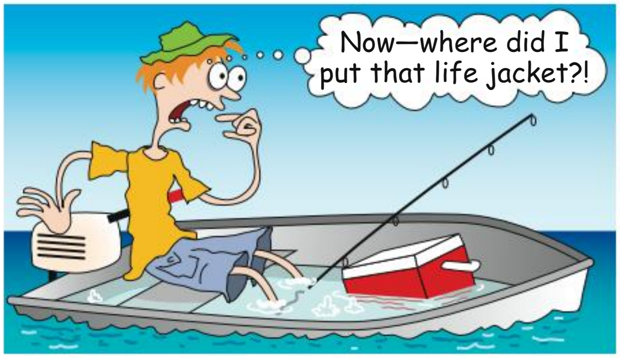
5 How does painting iron and steel prevent it from rusting?

6 What is the process of galvanising? How does it prevent iron from rusting?

7 The Water Board wants to protect its steel pipes from rusting. To do this they want to attach blocks of another metal to the pipes. They are considering three different metals—lead, magnesium and zinc. Which would be the best metal to use? Why?

8 Why does metal guttering on houses near the coast rust more quickly than guttering on houses in inland areas?

9 Alfredo left some lead sinkers in the bottom of his aluminium dingy the last time he went fishing.
a Write an inference to explain why his boat leaked the next time he used it.
b Design an experiment to test your inference.



Challenge

1 If you were going to put aluminium sheeting on a roof, would you use iron nails? Explain.

2 Why does iron rust more rapidly if the air is polluted?

3 Bethanie wonders why food cans are not covered with zinc, like galvanised iron roofs. Explain why zinc-coated cans wouldn't work.

4 Infer how rust bubbles form under paint.

5 Sue bought an expensive piece of art made from iron. To stop it rusting she attached a small block of zinc to it by wire.
a How does this prevent the iron art from rusting?
b Predict what would happen if she used a block of lead instead of zinc.
c Suggest other ways Sue could stop the art from rusting.

6 When iron rusts what change takes place in the iron atoms? Write an equation.

7 Write a balanced equation for the corrosion of aluminium when it reacts with oxygen. (Hint: the valency of aluminium is 3+.)

8 Look at your results from Investigation 19 on page 280 showing the voltages produced by different pairs of metals. How can you use the activity series to predict which pair of metals will produce the highest voltage?

9 Design a controlled experiment to compare the rate of corrosion of aluminium, copper and iron indoors and outdoors. If possible, carry out your experiment.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 An electric ______ consists of two different conductors (electrodes) immersed in a conducting solution (______).

2 Most dry cells cannot be ______, but the lead–acid batteries used in cars can be.

3 ______ is the process in which electricity is passed through an electrolyte to cause ______.

4 ______ is an electrolysis process in which a metal is coated with a thin layer of another metal.

5 In an electric cell and in electrolysis, ______ are lost at one electrode (oxidation) and ______ at the other electrode (reduction).

6 Iron and aluminium corrode by reacting with ______ in moist air to form ______.

7 To prevent iron rusting it is essential to stop oxygen and ______ from reaching the metal.

8 The ______ series lists the metals from the most reactive to the least reactive. When two different metals are in contact in moist air or in water, the more ______ metal corrodes.

activity
cell
chemical reactions
electrolysis
electrolyte
electrons
electroplating
gained
oxides
oxygen
reactive
recharged
water

Working with technology

Try doing the Chapter 11 crossword at www.OneStopScience.com.au.

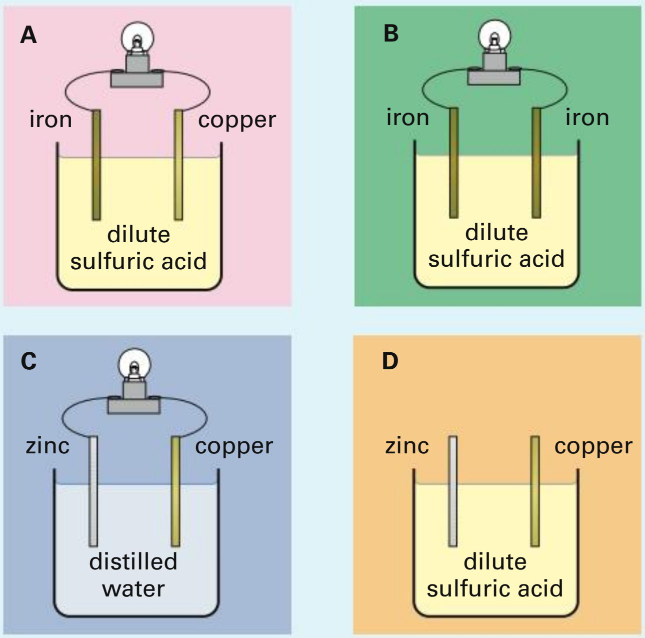
OneStopScience

REVIEW

1 Predict which of the following metals will react most rapidly with dilute sulfuric acid.
 A aluminium
 B magnesium
 C lead
 D silver

2 To coat a piece of zinc with copper, which liquid would you use in the electroplating bath?
 A copper sulfate solution
 B zinc sulfate solution
 C hydrochloric acid
 D distilled water

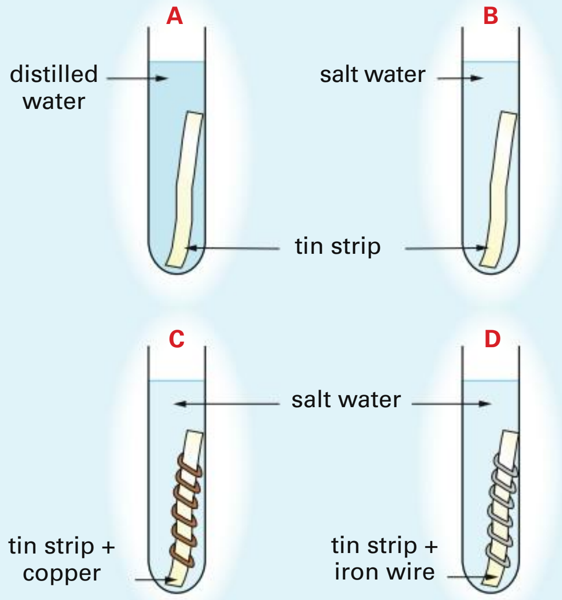
3 Predict which set-up on the right will act as an electric cell. Explain why each of the other set-ups will *not* work.



4 To investigate the corrosion of metals Allison set up four test tubes as shown below.

a Use the activity series on page 295 to work out which strip of tin would corrode the most.

b Which strip of tin would corrode the least? Why?



5 If an electric current is passed between two carbon electrodes placed in concentrated sodium chloride solution, chlorine gas is produced at the positive electrode. Which one of the following inferences best explains why this happens?

A Chlorine gas is dissolved in the solution, and when an electric current is passed through it, chlorine gas is forced out.

B Hydrogen ions from the water react with chloride ions to form hydrochloric acid, which in turn forms chlorine gas.

C When an electric current is passed through water, gases are given off and one of these is chlorine.

D Negative chloride ions from the solution move to the positive electrode and release electrons to form chlorine gas.

6 List at least three important differences between a car battery and a torch cell.

7 Consider this list of metals and alloys: aluminium, bronze (copper–tin), calcium, gold, iron, magnesium, steel, tin.

a Three of these are more resistant to corrosion than the others. Which are they?

b Suggest why each is resistant to corrosion.

c Which one of the other metals or alloys will corrode most quickly? Explain your answer.

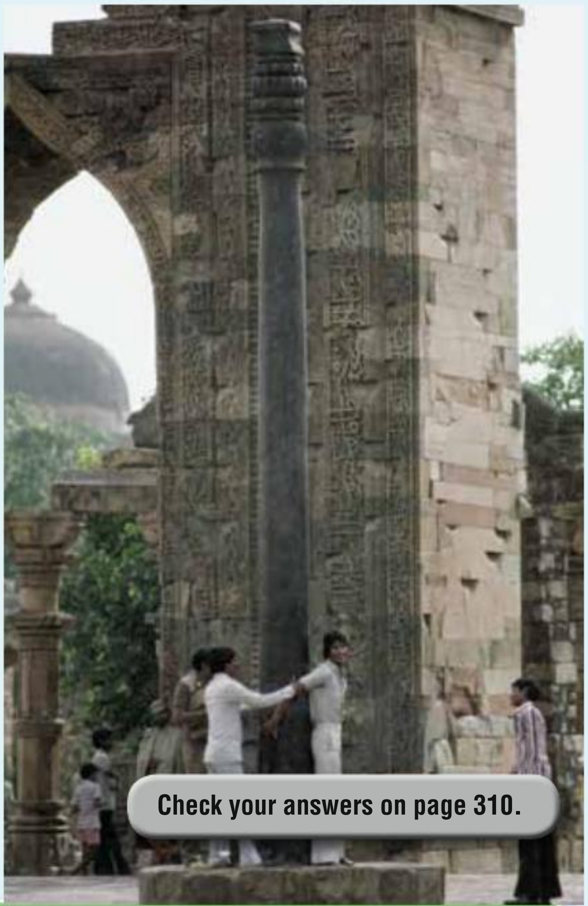
8 Magnesium chloride is melted and electricity passed through the liquid.

a Which ions will be in the liquid?

b At which electrode will magnesium metal be formed? Explain your answer.

c Which element will be formed at the other electrode? Write an ionic equation for the reaction that occurs.

9 The photo below shows an iron pillar in Delhi in central India. It shows little sign of rust, even though it is about 1500 years old. Write at least one inference to explain the absence of rust.



Check your answers on page 310.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

OneStopScience

Science as a Human Endeavour

The first battery

The Voltaic pile

The first battery was constructed by Italian scientist Alessandro Volta in 1800 (see page 279). He made a 'tower' of alternating silver coins and zinc plates. Between the plates he placed pieces of cloth soaked in salt solution. Volta discovered that if he used 40 silver coins and 40 pieces of zinc, he could give people a nasty electric shock. He apparently had great fun inviting people to put their hand on his tower, which soon became known as Volta's pile.

The trouble with Volta's pile was that it soon stopped working. He discovered this was because hydrogen gas was produced around the silver coins. This gas is an insulator and blocked the electric current. To make the pile work again Volta had to pull it apart, re-soak the cloth in salt water and then put it back together. Pulling the pile apart released the gas.

In 1836 British scientist John Frederic Daniell found a way to solve the hydrogen problem using copper and zinc electrodes in a copper sulfate electrolyte, similar to the electric cell shown on page 281. These cells were more convenient to use than Volta's pile and were widely used in telegraph and telephone networks until they were replaced in 1887 by dry cells (see page 282) that didn't spill.

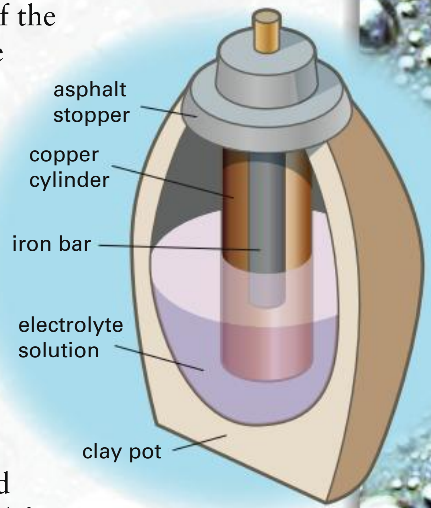
Questions

1 Was Volta's pile a cell or a battery?
2 Which two metals did Volta use in his pile? Which is the more reactive? Which would have been positive and which negative?

Fig 19 Volta demonstrating his Voltaic pile to Napoleon

The Baghdad battery

In 1936 German archaeologist Wilhelm Konig discovered some mysterious clay jars in a village near Baghdad in Iraq. Each jar had a stopper made of asphalt (bitumen) with an iron rod poking through the top of the stopper. Inside the jar, the rod was surrounded by a cylinder of copper. The jars showed signs of corrosion from an acid such as vinegar or wine. The jars are now thought to be over 2000 years old, originating from the time of the Parthian empire around 200 BCE. There is no written record of what the jars were used for, but Konig suggested they could have been the first batteries, 2000 years before Volta's pile.



When scientists made replicas of the Baghdad battery and filled them with an electrolyte such as grape juice, they generated voltages up to 2 volts. When they connected several of the jars together they were able to electroplate metal objects (see Investigation 21 on page 289). The *Mythbusters* team was also able to do this.

Whether such an ancient civilisation could have made the first batteries remains a mystery. It has been suggested they may have been used to produce mild electric shocks as a source of religious experience. Alternatively, the jars may simply have been used to store ancient scrolls that have since rotted away.

Questions

1 What is the negative electrode in the Baghdad battery? How do you know?
2 Why would you need to connect several jars together to coat a metal object with gold?
3 Why do you think there is so much uncertainty about how the Baghdad jars were used?

Answers to Reviews

If your answer does not agree with the answer given here, go back to the chapter and read the relevant section again. Your answers may be slightly different from the answers given here. If in doubt, check with your teacher.

Chapter 1 Investigating reactions

1 **C**—Some reactions occur very slowly, e.g. rusting.

2 **A** (**C** is unlikely since John repeated the experiment several times with the same result.)

3 **a**, **c** and **e** are exothermic—they release energy. **b** and **d** are endothermic—they need energy.

4 **A**, **C**, **D** and **E** can all indicate the rate of a reaction.

5 **a** slows it down, since the reactants are less concentrated
b speeds it up
c has no effect, since the *concentration* of the reactants is the same
d speeds it up
e slows it down
f speeds it up
g speeds it up, since the reactants have a larger surface area (see page 7).

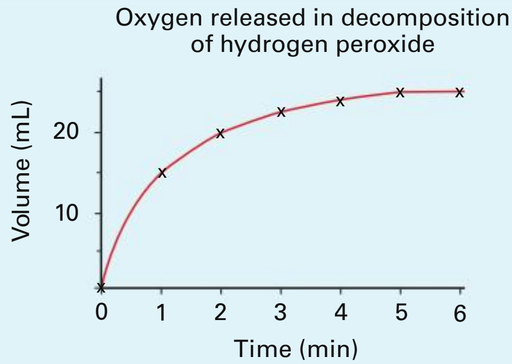
6 The reaction in test tube A will be faster than the reaction in tube B. This is because the acid in tube A is more concentrated (less water) than that in B.

7 **a** A and B. The height of the foam produced is greater than 2 cm, indicating the reaction rate has increased.
b Nothing was added to test tube 1, so that the reactions in the other tubes could be compared with it. This test tube is called a *control*.

8 For the flour to burn, it must react with the oxygen in the air. To do this, the flour must come into contact with the air.

Very little of the flour in the sack is in contact with the air, so the flour burns very slowly. However, there is a large area of contact between flour dust and the air. So the flour burns very rapidly. (See page 7.)

9 **a**



b 10 mL were produced in about ½ minute.
c about 18 mL
d about 5 minutes (graph no longer rising).
e The reaction was fast to start with (steep slope), then gradually slowed until it stopped after 5 minutes.
f Repeat the experiment using the same apparatus, the same volume of hydrogen peroxide, but powdered copper instead of manganese oxide. Work out when the reaction stops, as in **d**. If the reaction is complete in less than 5 minutes, then powdered copper is a better catalyst than manganese oxide.

Chapter 2 Road science

1 **D**

2
$$v_{av} = \frac{d}{t}$$
$$\text{so } t = \frac{d}{v_{av}}$$
$$= \frac{280\text{ km}}{80\text{ km/h}}$$
$$= 3.5\text{ h}$$

3 **a** C
b A or the first part of B
c D or the second part of B
d B

4 The furniture van would require more force to stop it because its mass is greater.

5 Before Scott braked, the golf clubs were moving with the car—at the same speed as it. When he braked, the seatbelt held him in his seat, but there was nothing to stop the clubs continuing to move forward, due to inertia.

6 Reaction distance depends on the driver and on the speed, so it would be the same for the motorbike, car and semitrailer. Braking distance, however, depends on the vehicle, especially its mass. So the braking distance would be shortest for the motorbike and longest for the semitrailer.

7 **a** When a stationary car is hit from behind by another car, the inertia of the people in the car causes them to move backwards into their seats. If they do not have head restraints, they may suffer whiplash injury.

b The car that hit the stationary car will stop suddenly, so inertia will cause the people in it to continue moving forwards. If they are not wearing seatbelts, they may be injured when they hit objects in front of them, e.g. the dashboard or the steering wheel.

8 **a** When a car's brakes 'lock', the wheels stop turning and slide (skid) across the road surface.

b The car may skid and you may lose control of it. It will also take longer to stop because the sliding friction is less than the static friction that exists when the wheels are rolling.

c Car designers have developed an antilock braking system (ABS), which senses when a wheel is about to lock up and pumps the brake off and on rapidly.

9 You need two different equations to solve this problem.

$$a_{av} = \frac{v - u}{t} = \frac{0 - 15 \text{ m/s}}{3 \text{ s}} = -5 \text{ m/s}^2$$

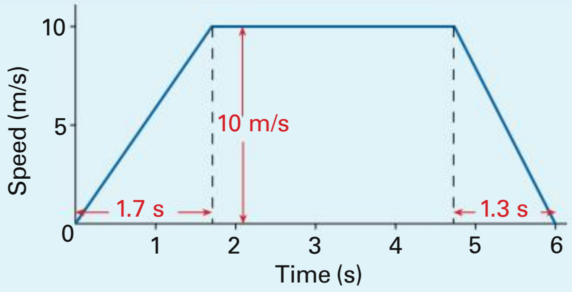
$$F = ma$$
$$= 80 \text{ kg} \times -5 \text{ m/s}^2$$
$$= -400 \text{ newtons}$$

(The force is negative because it is a braking force.)

10 **a** Initially the lift accelerates (upwards slope); it then continues to move at a constant speed (flat part of graph); finally the lift decelerates (downwards slope) and stops.

b To find the acceleration you calculate the slope of the graph.

$$a_{av} = \frac{10 - 0 \text{ m/s}}{1.7 \text{ s}}$$
$$= 5.9 \text{ m/s}^2$$



c Deceleration $= \frac{0 - 10 \text{ m/s}}{1.3 \text{ s}}$

$= -7.7 \text{ m/s}^2$

Chapter 3 Inheritance

1 **B**

2 **C**

3 **C**

4 **a** 32 pairs

b 32 single chromosomes

c An X chromosome and 31 others, or a Y chromosome and 31 others.

5 **a** TTCAG

b The two strands of DNA are held together by weak bonds between the base pairs on each strand.

6 **a** 7 amino acids

b leucine–arginine–leucine–lysine–glycine–serine–serine

c The mutation will change the lysine in the sequence to glutamic acid.

d The change in the amino acid sequence might stop the action of the gene and hence your blood would not clot when your skin was cut or damaged.

7 **a** The gene for blood type O is recessive, therefore Mrs Sloan with blood type O is definitely homozygous.

b The daughter's genotype is oo. One of these genes came from her father. Therefore, Mr Sloan's genotype must be Ao.

c Baby Sloan has a 50:50 chance of having A type blood (as shown on the next page).

mother \ father	A	o
o	Ao	oo
o	Ao	oo

8 a SS

b The plant would have smooth seeds because the gene S is dominant.

c ss

d The gene for wrinkled seeds (s) is recessive. Therefore for a plant to have wrinkled seeds its cells would have to contain two genes for wrinkled seeds (ss).

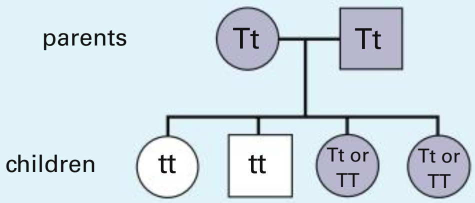
9 a The genotypes of the parent plants are TT and Tt. They are both tall.

	T	**T**
t	Tt	Tt
T	**TT**	TT

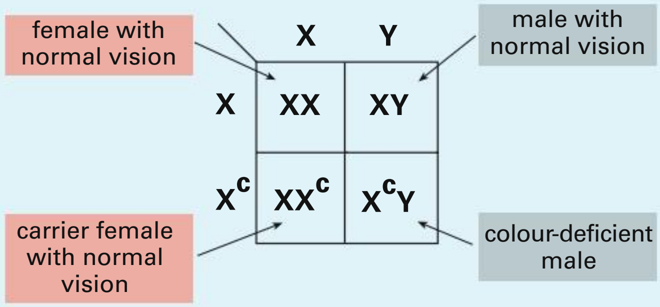
b All the plants are tall.

10 Suppose the gene for tongue-rolling is T and the gene for non-tongue-rolling is t. Then the phenotype for the daughter and son who cannot roll their tongues is tt. The father and mother must have genotypes Tt because they can both roll their tongues and have children who cannot.

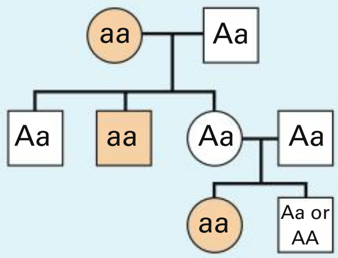
The purple circles and squares indicate those who can roll their tongues.



11 Suppose a woman with a gene for colour deficiency on one X chromosome (XX^c) has children with a man with normal colour vision (XY). The Punnett square at the top of the next column shows (in theory) that the female children will have normal vision but half of them will carry the colour-deficiency gene. In the male children, 50% of them will be colour deficient.



12 The characteristic is definitely recessive. If you represent the alleles as A and a, then the people with aa genes have the characteristic. You can see from the pedigree that this characteristic has 'skipped' a generation. The child in the bottom row has it, while her parents in the line above do not.



Chapter 4 Explaining reactions

1 a When an atom loses one electron its charge is 1+.

b When an atom gains two electrons its charge is 2–.

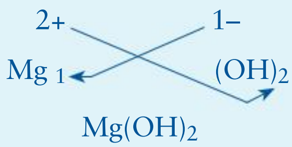
2 a C, D and E—since they contain only one type of atom

b A and B

c D and F

d A, B and E

3 B



4 a Three—Cu, S and O

b Cu^{2+} and SO_4^{2-} ions (see page 96)

c Ionic

5 **a** Ionic compounds are held together by the attraction between oppositely charged ions (see page 89).
b Covalent compounds are held together by the sharing of electrons (see page 92).

6 **a** $C + 2Br_2 \rightarrow CBr_4$
b $Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$
c $P_4 + 6H_2 \rightarrow 4PH_3$
d $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$
e $Al_2(SO_4)_3 + 3Pb(NO_3)_2 \rightarrow$
$3PbSO_4 + 2Al(NO_3)_3$

7 **a** $MgSO_4 \rightarrow Mg^{2+} + SO_4^{2-}$
$KOH \rightarrow K^+ + OH^-$
(See the table on page 96.)
b
magnesium sulfate + potassium hydroxide →
magnesium hydroxide + potassium sulfate
c $MgSO_4 + 2KOH \rightarrow Mg(OH)_2 + K_2SO_4$

8 When copper sulfate dissolves in water, Cu^{2+} and SO_4^{2-} ions are formed. These ions are free to move and conduct an electric current.
Distilled water contains uncharged H_2O molecules, which do not conduct an electric current.

9 X has a valency of 1–. (You can tell this from the formula HX, since H has a valency of 1+.)
Y has a valency of 2+ (because of YX_2).
Z has a valency of 2– (because of YZ).

10 **a** The nitric acid reacts with the copper to form copper ions which make the solution blue.
b Nitrogen dioxide (formula NO_2) contains nitrogen and oxygen atoms. These atoms must have come from the nitric acid (HNO_3).

11 **a** The blue colour is due to copper ions in solution. Since copper was produced in the reaction, you can infer that the copper ions changed to copper atoms. This is why the solution lost some of its blue colour.
b If copper is formed then you are left with iron sulfate.
copper sulfate + iron → copper + iron sulfate
$CuSO_4 + Fe \rightarrow Cu + FeSO_4$
(assuming a valency of 2+ for iron)
or $3CuSO_4 + 2Fe \rightarrow 3Cu + Fe_2(SO_4)_3$
(assuming a valency of 3+ for iron)

Chapter 5 Our energy future

1 **C**

2 **A**

3 **B**

power of sunlight = 500 watts/m^2

power of cell (10% efficient) = 50 watts/m^2

area of solar cells required $= \dfrac{1000 \text{ watts}}{50 \text{ watts/m}^2}$

$= 20 \text{ m}^2$

4 **a** solar cell—light energy
b coal-burning power station—chemical energy
c wind generator—kinetic energy
d hydro-electric power station—potential energy
e geothermal power station—heat energy

5 **a** about 10.8×10^9 tonnes oil equivalent per day
b 2003
c You would need to extrapolate the graph to the year 2015. This prediction would be unreliable, however, because you do not know how steeply the curve will rise. It could even fall.

6 The electricity we use at present comes from coal-burning power stations, which release huge amounts of carbon dioxide into the atmosphere. The petrol we burn in our cars also produces carbon dioxide. So by cutting down our use of electricity and petrol, we reduce our greenhouse gas emissions and consequently global warming.

7 **a** ‘Energy demand’ is how much energy is required. ‘Energy supply’ is the energy produced from local or imported resources.
b The energy gap on the left is only small and was probably filled by importing oil, coal or natural gas.
c The surplus is where supply is greater than demand. During this stage the production of energy in Bananaland reached a maximum.
d The surplus will end about 2009.
e About 150 million tonnes of oil equivalent
f Import fuel, decrease demand, find more fossil fuel reserves, use nuclear energy, use alternative fuels (e.g. ethanol), use alternative sources (e.g. solar, wind, tides).

8 There are a number of serious problems with the use of nuclear power, but it is a possible solution to our ever-decreasing reserves of fossil fuels and rising greenhouse gas emissions.

9 Wind, geothermal and tidal energy can be used only in certain areas—where there are strong winds, volcanic action or hot rocks, or large tides.

10 You could use a remote area power supply (RAPS) to generate electricity from solar cells and a wind generator (see page 135), if there was enough sunshine and wind. You could use a solar hot water system, and heating costs could be reduced by the house design described on page 133.

Chapter 6 Space science

1 **B**

2 **a** On Earth, falling objects are slowed down by the friction due to the air. Because the feather has a large surface area, there is more air resistance and the feather falls more slowly than the hammer. On the moon, where there is no air, the hammer and the feather fall together.

b The hammer (and the feather) would fall more slowly on the moon because the acceleration due to gravity is less.

3 **a** Jilly moves backwards if she throws the heavy weight forwards. This is due to action and reaction. (See page 147.)

b If the action force increases, the reaction force also increases. Therefore, Jilly would have moved backwards much more quickly.

4 **C**

5 Satellite A is closer to the Earth and will experience a greater gravitational pull than satellite B. Therefore, to stay in orbit satellite A will have to have a greater orbital speed than satellite B.

6 **a** There is no oxygen in space in which to burn the fuel. Therefore, oxygen has to be carried.

b The solid-fuel rocket engine is more powerful than a liquid-fuel engine of equivalent weight.

c The spacecraft uses a liquid-fuel engine because it can be adjusted or turned off and on to control the spacecraft's speed.

7 Microgravity causes the heart and pulse rates to decrease as well as blood pressure to decrease.

The bones tend to lose calcium and phosphorus during long periods in space. This causes a weakening of the bones.

Because of the lack of exercise of the weight-bearing bones, the body's muscle tissue tends to decrease. This is a similar effect to being bedridden for a long period of time.

8 **a** In microgravity, the blood and other liquids in your body flow to places like the neck and the head, causing puffiness and fullness in these parts.

b In the shuttle there was no 'down' because the spacecraft was in 'free fall'. Therefore, drinks did not flow 'downwards' and could be drunk in any position.

c When you sneeze in microgravity, the action of the air being forced out of your mouth in one direction pushes your body in the opposite direction.

d As the shuttle entered the Earth's atmosphere, the friction of the air created by the speed of the shuttle caused the tiles on exposed surfaces such as the nose to glow red hot.

9 **a** Mars (4.1 m/s^2)—since the acceleration due to gravity is about half that on Earth (9.8 m/s^2)

b Use the formula W = mg to find Ziro's mass.

$$W = mg,$$

$$\text{so} \quad m = \frac{W}{g} = \frac{88\ \text{N}}{1.6\ \text{m/s}^2} = 55\ \text{kg}$$

His mass is 55 kg on Mars (or anywhere else). On Uranus his weight is:

$$W = mg = 55\ \text{kg} \times 8.9\ \text{m/s}^2 = 489.5\ \text{N}$$

c Weight of rocket on Ganymede:

W = 75 000 kg × 3.9 m/s²

= 292 500 N

Net force accelerating rocket—

F = 75 000 kg × 5 m/s²

= 375 000 N

Net force = thrust − weight

so, thrust = net force + weight

= 375 000 N + 292 500 N

= 667 500 N

d On Uranus the rocket's weight is:

W = 75 000 N × 8.9 m/s²

= 667 500 N

The weight of the rocket is equal to the thrust, so there is zero net force and the rocket will not be able to leave the surface of Uranus.

10 a On Earth the weight of the astronaut is 110 kg × 9.8 m/s² = 1078 N

b $a = \frac{F}{m} = \frac{9\ N}{110\ kg}$

$= 0.08\ m/s^2$

c The total thrust developed by the 24 rockets is 24 × 9 = 216 N. This is much less than the astronaut's weight (1078 N), so the rockets would not lift her off the ground.

d On the moon the astronaut's weight is 110 × 1.6 = 176 N. This is less than the total thrust developed by the rockets, so she would lift off from the moon's surface.

Chapter 7 Periodic table

1 **D**

2 **A**

3 **B**—see pages 185 and 186

4 **B**—would seem to be the best alternative.
A—could have serious effects on the economy.
C—is expensive and only shifts the problem elsewhere.
D—only decreases the size of the problem.
E—not a long-term solution and the SO_2 is still being released into the atmosphere.
(Different people may have different opinions.)

5 a The copper goes into solution as copper ions Cu^{2+}, which move to the negative terminal, where they accept electrons to form copper metal. (See Fig 17 on page 187.)

b The silver is very unreactive and simply falls to the bottom of the container.

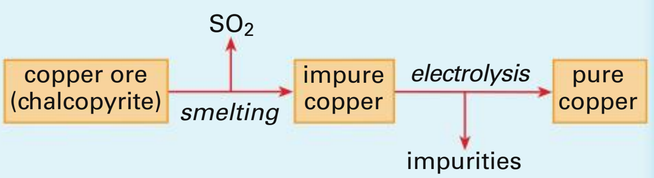
6 a B and E
b A, B and C; or D and E
c B and C
d A, D, F and H
e F and H
f C
g A
h G
i The reactive metals on the left of the periodic table (A and D) are likely to react with the non-metals on the right (B, E and G).

7 a zinc (most reactive), then copper and then platinum (least reactive)

b Platinum would make the best mirror because it does not corrode and hence its surface stays shiny.

8 If you go to the last element (112) in the periodic table and start numbering to the right, element 117 fits into Group 17. You would therefore expect it to be very reactive, like the other halogens in Group 17. Element 118 fits into Group 18 so you would expect it to be unreactive, like the other noble gases in Group 18.

9 Using the flow chart on page 191 as a guide:



10 In copper the electrons are not firmly bound to the atomic nuclei and can move freely in the spaces between the atoms (see page 176). Hence copper is a good conductor of electricity. In diamond all four of carbon's valence electrons are involved in strong covalent bonds with other carbon atoms (see page 181). Hence diamond does not conduct electricity.

11 a

Element	Symbol	Atomic number	No. of electrons		
			1st shell	2nd shell	3rd shell
hydrogen	H	1	1		
carbon	C	6	2	4	
neon	Ne	10	2	8	
sodium	Na	11	2	8	1
chlorine	Cl	17	2	8	7

b carbon
c neon
d 1
e hydrogen, sodium and chlorine

Chapter 8 Earth systems

1 a False—Global warming is almost certainly caused by *increased levels of greenhouse gases in the atmosphere*. The hole in the ozone layer results in more UV radiation reaching the Earth.
b True
c False—Global temperatures have increased by *0.74°C* over the last 100 years. See page 212.
d True—see pages 209 and 211.

2 B

3 a oxygen
b carbon dioxide CO_2
c The oceans contain dissolved salts, mainly sodium chloride, which contains the elements sodium and chlorine.
d About 70% of living matter is water H_2O, which contains the element oxygen. Also, the carbon compounds in living matter (e.g. proteins and fats) all contain oxygen.

4 See page 203.

Concentration of DDT (ppm)	Organisms
0.3	algae and microscopic organisms
0.9	insect larvae
2.4	fish
21.6	fish-eating bird

5 a The wastes and fertiliser are nutrients and will increase the growth of the algae.
b The number of bacteria in the lake will increase to decompose the algae as it dies.
c The amount of dissolved oxygen in the lake will decrease, since it will be used up by the bacteria.
d As the dissolved oxygen decreases, so will the number of other living things in the lake.
e Most living things will die, and the water will turn foul. This process is called eutrophication.

6 a The lowest temperature is in the ionosphere (about –90°C).
b The temperature increases steadily in the stratosphere and in the upper region of the ionosphere.
c The temperature in the mesosphere decreases with altitude.
d The formation of O_3 and the release of heat occurs at the top of the stratosphere. This is indicated by the increase in temperature from the lower stratosphere.

7 By burning fossil fuels, we release 5 gigatonnes of carbon (18.3 gigatonnes of CO_2) into the atmosphere each year. Also, deforestation effectively releases 2 gigatonnes of carbon (7.4 tonnes of CO_2) that would have been used up in photosynthesis and stored in the trees that were cut down. See the diagram on page 199.

Chapter 9 Evolution

1 B—see page 233

2 A

3 C

4 The ancestors of the domestic dog were selectively bred (artificially selected) by humans to produce breeds with the required characteristics. For example, the greyhound was bred for speed while the golden retriever was bred for hunting.

5 Two plants from the same stock have the same genotypes. However, if they are planted in different areas where the climate is different, then the environmental conditions will produce different characteristics (phenotypes).

6 Fruit flies born with curly wings cannot fly. Hence, they would die of starvation or would be easy prey for predators.

7 **C**—The other alternatives could change the gene pools and hence the characteristics of the organisms. For example in A most insects would die, but the naturally resistant ones would survive and hence the gene pool might change.

8 If the mainland finch was the ancestor of the Galapagos finches, then the DNA of each finch would be very similar. The higher the percentage similarity, the more Darwin's inference is supported.

9 See the diagram in Check 6 on page 246. Instead of the foreign DNA you would use the gene for human growth hormone.

10 Here is one suggestion for an experiment, although you may have a different design. If so, ask your teacher to check it.

In a very large cage (aviary), place a number of model tree trunks—all made from dark-coloured material (dark bark). Release 50 dark-coloured moths and 50 light-coloured ones. Also release a small number of birds. After a number of hours, remove the birds and record the number and colour of the wings of moths that have been eaten.

Repeat the experiment, this time using light-coloured model tree trunks, the same number of moths and the same number of birds.

By tabulating the number and colour of the moths' wings in each case, you should be able to see whether birds act as selection agents by eating light-coloured moths on the dark bark, or the dark-coloured moths on the light bark.

11 **a** The selection agents are temperature and availability of water.

b Over a long period of time, the trees have spread over both sides of the mountain, but only those trees best suited to the conditions in each of the locations have survived and reproduced.

c The trees at X are separated from the trees at Z by the cold conditions on the high parts of the mountain, and it is unlikely that trees at X and Z would interbreed. Therefore, if the gene pools of each group are isolated from each other for a long period of time, trees at X and Z could form two different species. On the other hand, trees at Y are not totally isolated from the trees at Z and might still interbreed.

Chapter 10 Exploring the universe

1 **B**

2 **A**

3 **a**

A	–1.1	brightest
B	–0.2	
E	0.2	
C	1.8	
D	4.7	dimmest

b Star A is the alpha star because it is the brightest.

4 **C**—see page 268

5 Einstein's equation, $E = mc^2$, means that matter, under conditions of extreme heat and pressure such as in a star's core, can be converted to energy.

6 **D**

7 If star A has an apparent magnitude of –1.3, it is much brighter when viewed from Earth than star B with an apparent magnitude of +3.5. However, star A must be very close to Earth because its absolute magnitude is only +4.5. The absolute magnitude of star B is –5.2, which means that it is a very bright star. However, it must be a very long way away because it looks dim when viewed from Earth.

8 Fusion reactions occur only in conditions of extreme temperature and pressure. These conditions occur only in the core of the sun where the gravity is the strongest.

9 The ecliptic is the path across the sky followed by the planets, sun and moon. The ecliptic is also the path followed by the 12 constellations that make up the zodiac.

Because of the curvature of the Earth, the ecliptic becomes lower in the sky as you move southwards in Australia.

10 **a** The star of magnitude 3.6 is brighter.

b The binary varies in magnitude when seen from Earth because the stars eclipse one another during their revolution. When the dimmer star passes in front of the other star, the brightness of the binary will decrease to a minimum. When they are side by side, the brightness increases to a maximum.

11 **a** **D**—Stars in spectral class G are mainly yellow-orange.

b Sirius is about 1 and Cygnus A about 6. Bright stars like Sirius have a greater mass than dimmer stars like Cygnus A.

c As main sequence stars age, their surface temperature decreases. Therefore, our sun is older than α-Centauri and Sirius.

d Proxima Centauri and Betelgeuse have the same surface temperature and hence the same colour. However, Betelgeuse is much brighter than Proxima Centauri and hence must be much larger.

e As the surface temperature of main sequence stars decreases, their colour changes from blue through to red and their absolute magnitude decreases.

Chapter 11 Electrochemistry

1 **B**—using the activity series on page 295

2 **A**—The electroplating solution must contain copper ions.

3 **A**—will work

B—will not work because the metal strips are the same.

C—will not work because distilled water is a poor conductor of electricity.

D—will not work because the metal strips are not connected.

4 **a** C—The tin and copper in contact in salt water act like an electrochemical cell. Because the tin is more reactive than copper, it corrodes rapidly.

b D—Because the iron is more reactive than tin, it corrodes in preference to the tin. Hence the tin corrodes only slowly.

5 **D**

6

Car battery	Torch cell
number of connected cells	single cell
usually 12 volts	usually 1.5 volts
can be recharged	cannot be recharged
contains acid	dry cell (no liquid)
bulky and heavy	compact

7 **a** aluminium, bronze and gold

b Aluminium forms a protective layer of aluminium oxide (see page 296).
Bronze is an alloy of copper and tin.
Gold is a very unreactive metal.

c Calcium is very reactive and will therefore corrode quickly.

8 The electrolysis of molten magnesium chloride is similar to the electrolysis of molten sodium chloride (see page 290).

a Magnesium ions Mg^{2+} and chloride ions Cl^-.

b Magnesium metal will be formed at the negative electrode since the Mg^{2+} ions are attracted to it.

c The Cl^- ions will be attracted to the positive electrode where they give up electrons to form chlorine gas: $2Cl^- \rightarrow Cl_2 + 2e^-$

9 Some possible inferences are:

- It is very dry in central India (very little water in the air to cause rusting).
- The iron is very pure (contains no carbon).
- The iron has a coating of oil from people's hands, which acts as a protective coating.

Glossary

The words in this list occur in dark type throughout the book. The number after each entry gives the page where you will find more information. For some words the pronunciation is given. The syllable in capitals should be stressed; for example, ionosphere (eye-ON-os-fear).

acceleration: the rate at which an object speeds up or slows down; average acceleration (in m/s^2) is calculated by dividing the change in speed by the time 31

activity series: a list of the metals arranged from the most reactive to the least reactive 295

alkali metals: very reactive elements in Group 1 of the periodic table, e.g. sodium and potassium 178

alkaline earth metals: reactive elements in Group 2 of the periodic table, e.g. magnesium and calcium 178

alleles (a-LEELs): different forms of the same gene; each allele produces variations in inherited characteristics, e.g. eye colour 73

allotropes: different forms of the same element, e.g. diamond, graphite and buckyballs are allotropes of carbon 181

anodising: an electrolysis process which thickens the protective film of oxide on the surface of aluminium 296

artificial selection: the selection and breeding of particular organisms to produce offspring with desired characteristics 239

atmosphere: the thin layer of gases surrounding the Earth (or any other planet) 197

atomic number: the number of protons in the nucleus of an atom; equal to the number of electrons 172

Big Bang theory: a model that suggests that the universe began as a massive explosion; it is based on evidence that the universe is expanding 271

binary stars: two stars that revolve around each other 264

biodegradable: able to be broken down or decayed by biological means (bacteria and fungi) 202

biological oxygen demand (BOD): a measure of the biodegradable material in a body of water; if the BOD is large, the water is considered to be polluted 202

biomagnification: the build-up in concentration of a chemical as it moves from organism to organism in a food chain 203

biomass: plant and animal material used as a source of renewable energy 126

biosphere: the thin layer where life exists on Earth 197

black holes: invisible objects in space that emit X-rays and are thought to form when the most massive stars explode 268

carbon cycle: the cycling of the element carbon between the atmosphere, biosphere, hydrosphere and lithosphere 199

catalysts (CAT-a-lists): substances that speed up chemical reactions, without being used up themselves 11

catalytic converters: devices fitted to cars to convert the exhaust gases to less harmful ones; they usually contain catalysts such as platinum 16

chemical bonds: attractive forces between atoms that hold them together 88

chromosomes: objects found in the nucleus of a cell that carry the genetic information 58

chromosphere: the lower atmosphere of the sun in which bursts of glowing gas shoot out from the surface 260

clones: organisms that have identical genes to their parents 244

co-dominance: where the genes for a particular characteristic combine to give features of both the individual genes 78

combustion (burning): a rapid chemical reaction that occurs when a substance reacts with oxygen in the air, producing heat and light energy 17

concentration: the amount of solute dissolved in a certain volume of solution 7

conservation of energy: this law says that energy cannot be created, destroyed or lost—it can only be changed from one form to another 50

conservation of mass: this law says that the total mass of the reactants in a chemical reaction is always equal to the total mass of the products 21

constellations: groups of stars that form unchanging patterns in the sky 252

corona: the upper atmosphere of the sun, which can be seen only during a solar eclipse 260

correlation: how closely two variables depend on each other 219

corrosion: the process in which water and air react with metals; rusting is the corrosion of iron 293

cosmology: the study of origin and structure of the universe 271

covalent bond: a chemical bond formed by the sharing of electrons between two or more atoms 92

decomposition: a chemical reaction where a substance breaks down to simpler substances 111

DNA (deoxyribonucleic acid): the complex chemical compound found in chromosomes that contains the genetic code 64

dominant gene: a gene for a particular characteristic that completely hides or masks the alternative (recessive) gene 73

dry cells: electric cells that contain a moist paste rather than a liquid electrolyte 282

ecliptic (ek-CLIP-tick): the path followed by the sun, moon, planets and a number of constellations in their apparent movement across the sky 256

efficiency: a measure of how well a machine uses the energy put into it; a perfect machine would have an efficiency of 100% 50

electric cell: an electrochemical cell that converts chemical energy into electrical energy using chemical reactions 279

electrodes: conductors that allow electric current to flow into or out of an electrolyte 279

electrolysis (ee-lek-TROL-e-sis): the process of passing an electric current through an electrolyte to produce chemical reactions at the electrodes 135

electrolyte (ee-LEK-tro-lite): a substance in solution or molten that conducts an electric current and is decomposed in the process 279

electron shells: the electrons surrounding the nucleus of an atom are arranged in electron shells or energy levels; electrons in the outer shells have more energy than those in inner shells 173

electroplating: depositing a thin layer of metal on another using electrolysis 17

endothermic reaction: a reaction during which energy is absorbed; energy must be supplied to keep the reaction going 17

enhanced greenhouse effect: an increase in the natural greenhouse effect, brought about by increased levels of greenhouse gases in the atmosphere 211

enzymes (EN-zimes): biological catalysts that speed up (or control) chemical reactions in organisms 13

equilibrium (equal-LIB-ree-um): the condition of a system in which competing influences are balanced, resulting in no net change, e.g. equal and opposite forces, or gases in the atmosphere 211

eutrophication (YOU-tro-fi-KAY-shun): a reduction in the oxygen concentration in water caused by decomposing organisms following excess plant growth 202

evolution: a process in which species change over time and develop into new species 233

exothermic reaction: a reaction that releases energy 17

friction: a force that opposes motion of one surface across another; before sliding occurs, you have **static friction**, and once sliding occurs, you have **sliding friction** 40

fuel cells: electric cells in which the reactants are supplied continuously; in a common fuel cell, hydrogen and oxygen react to produce water 136

gene pool: the sum of all genes in a population of a particular organism 233

genes: segments of DNA that carry genetic information from one generation to the next 64

genetic engineering: the common term for a technique in biotechnology of inserting desired genes from one species into the chromosomes of another species 240

genome: the total genetic material in an organism 69

genotype (GEN-o-type): the type of genes in an organism 75

geostationary orbits: satellite orbits at a particular altitude so that it remains over the same point on the Earth's surface 155

geothermal power stations: power stations that use hot water or steam from deep within the Earth to generate electricity 127

global warming: an increase in the global temperature of the Earth thought to be due to the build-up of greenhouse gases in the atmosphere 211

greenhouse effect: the trapping of heat energy by gases in the atmosphere, causing its temperature to rise; carbon dioxide is the main greenhouse gas 209

greenhouse gases: gases in the Earth's atmosphere that absorb solar energy and hence contribute to the warming of the Earth (e.g. carbon dioxide, methane) 209

groundwater: water that has soaked underground through soil and rocks 203

half-life: the time it takes a radioactive substance to lose half of its radioactivity 116

halogens: very reactive non-metals in Group 17 of the periodic table, e.g. chlorine and iodine 180

heterozygous (HET-er-o-ZYE-gus): where the genes for a particular characteristic are different, resulting in a hybrid 75

homozygous (HO-mo-ZYE-gus): where the genes for a particular characteristic are the same, resulting in a pure breeder 75

hydrosphere: all the water on Earth; this includes oceans, lakes, rivers, groundwater and water in the atmosphere 197

incomplete dominance: where the genes for a particular characteristic are neither dominant nor recessive but combine to give a mixture or blend of characteristics 78

inertia (in-ER-sha): the tendency of a body to stay at rest or continue its motion, unless acted on by a force; this is called Newton's first law of motion 44

ions (EYE-ons): atoms or groups of atoms that have a positive or negative charge, caused by the loss or gain of electrons 88

ionic bond: a chemical bond resulting from the attraction between oppositely charged ions 89

ionosphere (eye-ON-os-fear): the top layer of the atmosphere; it contains ions formed from collisions of cosmic rays with gas molecules 208

light-year: an astronomical unit that is used to measure the huge distances between stars; it is the distance light travels in one year 252

lithosphere: the rigid outer later of the Earth; it includes the crust and the upper part of the mantle 197

meiosis (my-OH-sis): the process of cell division that produces sex cells that have half the number of chromosomes of body cells 60

microgravity: a term that describes the apparent weightlessness of an object that is in orbit 158

minerals: metal compounds found in the Earth 184

mitosis (my-TOE-sis): a process where a single cell divides to produce two identical daughter cells 58

momentum: the mass of a moving body multiplied by its speed 44

mutations: permanent changes in genes; they may be caused by exposure to radiation or chemicals 66

natural selection: the process on which the best adapted individuals survive in a particular habitat (often called survival of the fittest) 227

nebula (NEB-you-la): a huge expanding cloud made up of dust and gases formed after a massive star explodes (supernova) 266

neutron star: a small star made of extremely dense matter and formed from the remaining matter after a massive star explodes 268

nitrogen cycle: the cycling of the element nitrogen between the atmosphere, biosphere, hydrosphere and lithosphere 200

noble gases (or inert gases): unreactive gases in Group 18 of the periodic table, e.g. helium and neon 180

non-renewable energy: energy resources that are not replaced as they are used, e.g. coal and oil 116

nuclear fission: the splitting of the nucleus of a large atom such as uranium into smaller atoms, with the subsequent release of a large amount of energy 116

nuclear fusion: the combining of nuclei of small atoms, such as hydrogen, into larger nuclei, with the release of large amounts of energy; the process occurs in stars 118

orbit: the path followed by an object in space as it moves around another object 152

ores: mineral-containing rocks that are suitable for mining and mineral extraction 184

ozone layer: a layer containing ozone gas found at the top of the stratosphere; it absorbs some of the dangerous UV radiation from the sun 216

pedigrees: family trees, showing the inheritance of particular characteristics from one generation to later generations 76

periodic table: a listing of the elements in order of their atomic numbers; elements are grouped according to their chemical properties 172

phenotype (FEE-no-type): the physical appearance or characteristics of an organism 75

photosphere: the visible part of the sun 259

phytoplankton (FIGHT-o-plank-ton): microscopic organisms, mainly algae, that float or drift near the surface of oceans and lakes; they are the basis of aquatic food chains 198

plasma: an extremely hot gas-like state of matter composed of positive ions and free electrons; found in the sun, fission reactors and plasma screens 118

reaction rate: the speed of a chemical reaction 3

reaction time: the time it takes you to respond to a stimulus, e.g. the time between seeing a red light and applying the brakes of a car 38

recessive gene: a gene for a particular characteristic that is completely hidden or masked by the alternative (dominant) gene 73

recombination: the process by which offspring have a combination of genes from each parent 224

reliable: results are reliable if they are the same when the experiment is repeated many times 8

renewable energy: energy resources that can be replaced as they are used, e.g. wood, wind and solar energy 116

replication: the process by which DNA makes identical copies of itself 65

satellite: a natural or man-made object that orbits a planet 152

sewage (SUE-idge): water and wastes that come from kitchen sinks, bathrooms, laundries, toilets and industries 202

smelting: the process of extracting metals from their ores through melting 185

solar cells (or photovoltaic cells): devices containing a semiconductor, which absorbs solar energy and converts it directly to electrical energy 121

species: a population of organisms that has similar features and can interbreed 232

speed (average): the total distance travelled, divided by the time it takes to go that distance; usually measured in m/s or km/h 29

stratosphere: the middle layer of the atmosphere; its upper region contains the ozone layer 208

supernova: occurs when a massive star explodes, scattering most of its matter into space 266

sustainable: an activity is sustainable if it can be continued for a very long time without damaging the environment or using up our natural resources 131

thrust: the force created by a rocket's engines to move it forward 149

transition metals: the elements found in the middle of the periodic table; they include common metals such as iron and copper 179

troposphere (TROP-os-fear): the layer of the atmosphere closest to the Earth 208

valency: the number of electrons an atom gains, shares or loses when combining with other atoms 95

valence electrons: the electrons in the outer shell of an atom; these electrons participate in chemical reactions 174

valid: the results of an experiment are valid if they are logical and relevant to what you are trying to find out; the variables must also be properly controlled 25

X-linked: genes that are found on the X chromosome but have no equivalent on the Y chromosome 80

zodiac: the twelve constellations that follow the same path as the sun, moon and planets across the sky 256

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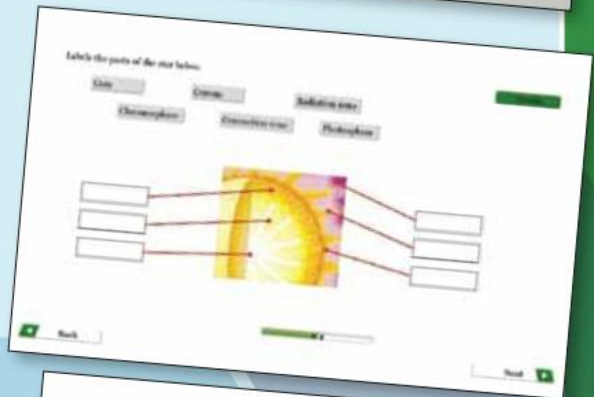

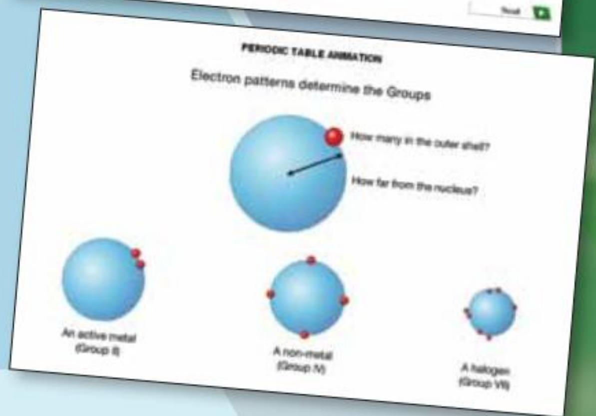

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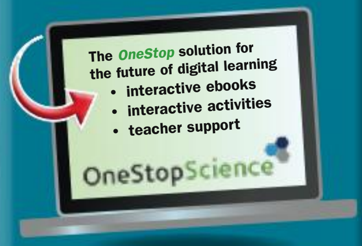

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