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Foreword by **Dr Karl**

SCIENCEWORLD

SW·10

> Explore
> Question
> Imagine

Peter Saffin Peter Stannard Ken Williamson

WESTERN AUSTRALIA

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Peter Saffin
BSc, BEd, GD Env. Sci

Peter Stannard
BSc, DipEd

Ken Williamson
BSc (Hons), DipEd

Contributing authors: Hannah Fay Joanne Parker Melanie Lee

WESTERN AUSTRALIA

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T: 1300 277 235
E: customersupport@matildaed.com.au
www.matildaeducation.com.au

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Warning: It is recommended that Aboriginal and Torres Strait Islander peoples exercise caution
when viewing this publication as it may contain images of deceased persons.

Contents

Using *ScienceWorld*

ScienceWorld takes a constructivist approach to learning, helping students explore what they already know, then building on that knowledge as they progress. This guide will show the key features of *ScienceWorld*, and help you understand how best to use it in the classroom.

Each chapter starts with a **Chapter opening page** containing an engaging photo for discussion. It shows the main content and skills to be covered in that chapter.

Students' prior knowledge is explored with a **Get started** activity, each with an **Explore**, **Question** or **Imagine** task that introduces the chapter topic.

Each chapter is broken into sections focusing on certain aspects of theory and skills covered. *ScienceWorld* uses engaging photos, illustrations, cartoons and contexts to make science accessible to all students.

Activities are dispersed throughout each section to reinforce concepts and provide hands-on learning opportunities for each lesson.

Explore online boxes provide opportunity for wider research.

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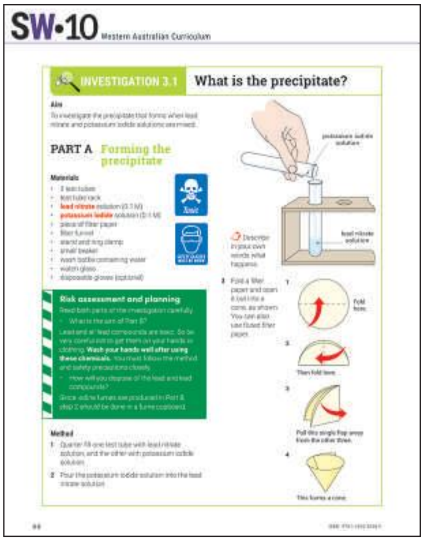
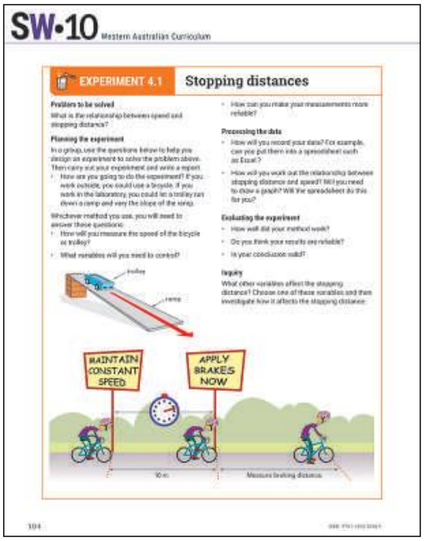
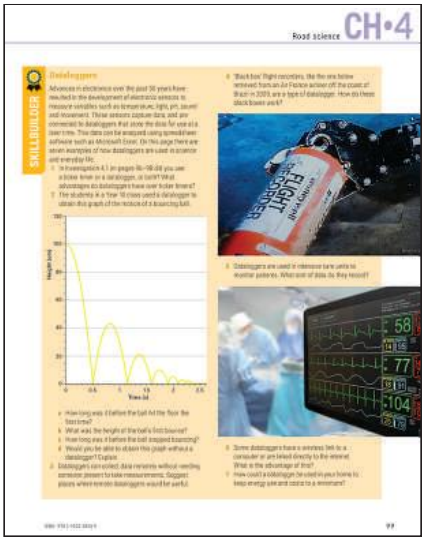


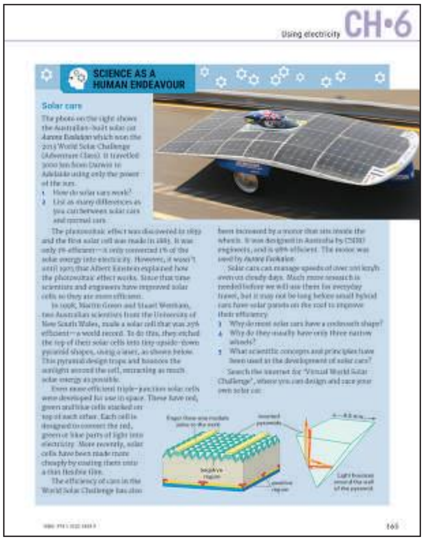
Investigations provide opportunities for students to apply Science Inquiry skills while exploring key concepts.



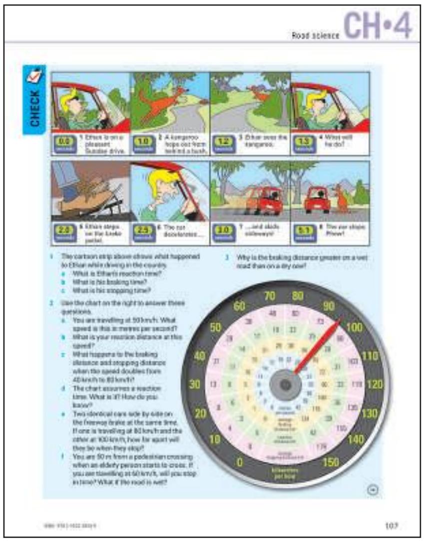
Experiments allow students to design their own experiments and inventions. Students explore and apply science skills and method while solving problems. This allows students to discover and engage with science concepts for themselves.



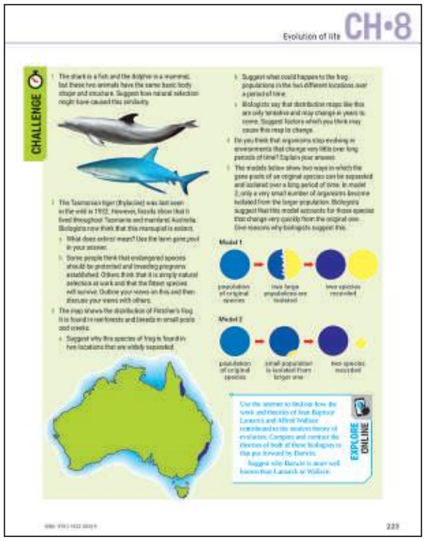
Skillbuilders teach key skills explicitly, supporting a clear progression of skill development throughout the book.



Science as a human endeavour features bring science to life, putting science in context historically, for today and for the future. These features include activities that allow students to understand the nature and context of science and to imagine the future.



Check questions review students' understanding of concepts for each section.



Challenge questions provide an opportunity for students to apply their knowledge and skills in context, and challenge students to think at a higher level.

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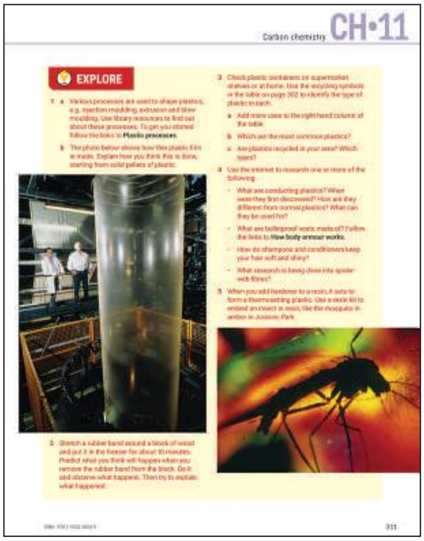
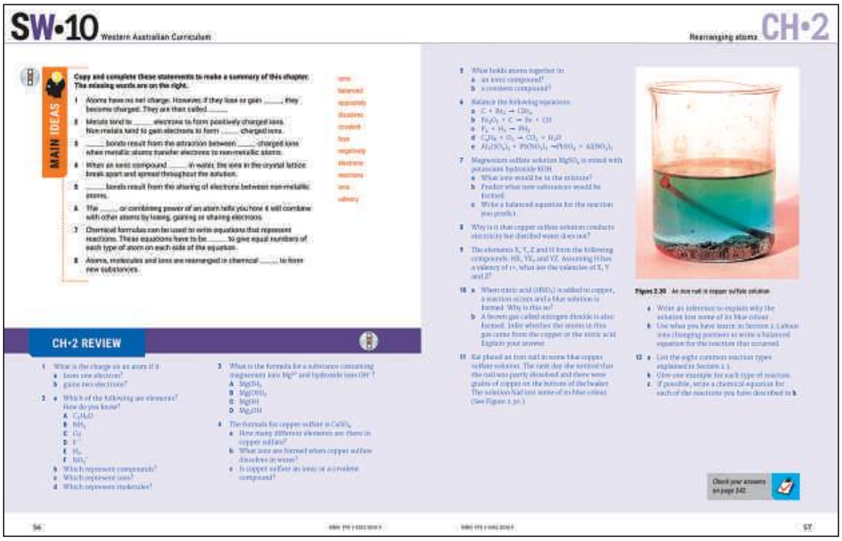


Explore sections allow students to create, invent and inquire into concepts learnt throughout the chapters.



Each chapter ends with a **Main ideas** cloze exercise to test students' understanding of the key chapter concepts through comprehension.

The **Chapter review** then provides an opportunity for students to revise key science knowledge and skills developed through each chapter.

Extra for experts features provide opportunities for students to engage at a higher level, to challenge their scientific thinking and understanding.

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Foreword

As you probably know, I'm mad about science. Every day I learn something new about the world around me—dark matter and dark energy, living creatures of all shapes and sizes, the amazing irrationalities and untapped abilities of our human brain, etc. My *Great Moments in Science* radio series/podcast is one way in which I explore these things and try to make them easier for people to understand. In this book you will explore all these things and learn how to think scientifically, asking questions about the world and imagining new solutions to these questions.

Doing science can lead to so many different and fascinating careers where you can design intelligent robots, use giant telescopes in space, produce food in a world where global warming is real, or go as an astronaut to planet Mars! It's fun to apply your knowledge of science to the real world and let your imagination run riot. After all, it's not the answer that gets you the Nobel Prize, it's the question. You could be the next Elizabeth Blackburn who won a Nobel Prize for her work on the telomere—a previously unexplored section of the human chromosome that gives us new and deep insights into ageing.

And remember the words of Richard Feynman, 'Science is a way of trying not to fool yourself' …

Dr Karl

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Links to the Western Australian Curriculum

This scope and sequence provides an overview of how *ScienceWorld 10* covers the Western Australian Curriculum. The focus is on the Science Understanding strand, although only some of the Science as a Human Endeavour content and elaborations are covered in this version of the scope and sequence. Included online in the teacher support are curriculum scope and sequence guides that detail how *ScienceWorld* covers the Western Australian Curriculum content descriptions across all four books, and these also include a full mapping of the Science as a Human Endeavour sub-strand, and the Science Inquiry Skills.

Abbreviations:
SHE: Science as a Human Endeavour
BS: Biological Sciences
CS: Chemical Sciences
ESS: Earth and Space Sciences
PS: Physical Sciences

ScienceWorld 10

Chapter and Unit titles	Science Understanding	Elaborations
Chemical sciences		
1 The periodic table		
1.1 The periodic table	CS: The atomic structure and properties of elements are used to organise them in the Periodic Table (ACSSU186)	• recognising that elements in the same group of the periodic table have similar properties • describing the structure of atoms in terms of electron shells • explaining how the electronic structure of an atom determines its position in the periodic table and its properties
1.2 Metals	CS: The atomic structure and properties of elements are used to organise them in the Periodic Table (ACSSU186) CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• investigating the chemical activity of metals • investigating how chemistry can be used to produce a range of useful substances such as fuels, metals and pharmaceuticals • using word or symbol equations to represent chemical reactions
1.3 Non-metals	CS: The atomic structure and properties of elements are used to organise them in the Periodic Table (ACSSU186)	• recognising that elements in the same group of the periodic table have similar properties
2 Rearranging atoms		
2.1 Chemical bonds	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	
2.2 Formulas and equations	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• using word or symbol equations to represent chemical reactions • modelling chemical reactions in terms of rearrangement of atoms
2.3 Classifying chemical reactions	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• using word or symbol equations to represent chemical reactions

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3 Investigating reactions		
3.1 Predicting a reaction	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• predicting the products of different types of simple chemical reactions • using word or symbol equations to represent chemical reactions
3.2 Reaction rates	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• investigating the effect of a range of factors, such as temperature and catalysts, on the rate of chemical reactions
3.3 Energy and mass in reactions	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• considering the role of energy in chemical reactions • recognising that the conservation of mass in a chemical reaction can be demonstrated by simple chemical equations • investigating a range of different reactions to classify them as exothermic or endothermic
Physical sciences		
4 Road science		
4.1 Speed and acceleration	PS: The motion of objects can be described and predicted using the laws of physics (ACSSU229)	• recognising that a stationary object, or a moving object with constant motion, has balanced forces acting on it • gathering data to analyse everyday motions produced by forces, such as measurements of distance and time, speed, force, mass and acceleration
4.2 Stopping	PS: The motion of objects can be described and predicted using the laws of physics (ACSSU229)	• gathering data to analyse everyday motions produced by forces, such as measurements of distance and time, speed, force, mass and acceleration
4.3 Collisions	PS: The motion of objects can be described and predicted using the laws of physics (ACSSU229) PS: Energy conservation in a system can be explained by describing energy transfers and transformations (ACSSU190)	• using Newton's Second Law to predict how a force affects the movement of an object • recognising that the Law of Conservation of Energy explains that total energy is maintained in energy transfers and transformations • recognising that in energy transfer and transformation, a variety of processes can occur, so that the usable energy is reduced and the system is not 100% efficient • comparing energy changes in interactions such as car crashes, the motion of pendulums, lifting and dropping
5 Space engineering		
5.1 Getting into space	PS: The motion of objects can be described and predicted using the laws of physics (ACSSU229)	• recognising and applying Newton's Third Law to describe the effects of interactions between two objects
5.2 Orbiting the Earth	PS: The motion of objects can be described and predicted using the laws of physics (ACSSU229)	• gathering data to analyse everyday motions produced by forces, such as measurements of distance and time, speed, force, mass and acceleration
5.3 Living in space	SHE: People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people's lives, including generating new career opportunities (ACSHE194) SHE: Values and needs of contemporary society can influence the focus of scientific research (ACSHE230)	• recognising that the study of the universe and the exploration of space involve teams of specialists from the different branches of science, engineering and technology • recognising that financial backing from governments or commercial organisations is required for scientific developments and that this can determine what research is carried out
6 Using electricity		
6.1 Electrical safety	PS: Energy conservation in a system can be explained by describing energy transfers and transformations (ACSSU190)	• investigating series and parallel circuits • identifying electrical safety devices in the home
6.2 Measuring electricity	PS: Energy conservation in a system can be explained by describing energy transfers and transformations (ACSSU190)	• measuring current and voltage in electric circuits
6.3 Where does electricity come from?	PS: Energy conservation in a system can be explained by describing energy transfers and transformations (ACSSU190)	• describing how electric generators and motors work

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Biological sciences		
7 Inheritance		
7.1 DNA	BS: Transmission of heritable characteristics from one generation to the next involves DNA and genes (ACSSU184)	• recognising the role of DNA as the blueprint for controlling the characteristics of organisms • using models and diagrams to represent the relationship between DNA, genes and chromosomes • describing mutations as changes in DNA or chromosomes and outlining the factors that contribute to causing mutations
7.2 Chromosomes	BS: Transmission of heritable characteristics from one generation to the next involves DNA and genes (ACSSU184)	• recognising that genetic information passed on to offspring is from both parents by meiosis and fertilisation
7.3 Dominant and recessive	BS: Transmission of heritable characteristics from one generation to the next involves DNA and genes (ACSSU184)	• representing patterns of inheritance of a simple dominant/recessive characteristic through generations of a family • predicting simple ratios of offspring genotypes and phenotypes in crosses involving dominant/recessive gene pairs or in genes that are sex-linked
8 Evolution of life		
8.1 Biodiversity and variation	BS: The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (ACSSU185)	• describing biodiversity as a function of evolution
8.2 Natural selection	BS: The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (ACSSU185)	• outlining processes involved in natural selection including variation, isolation and selection • investigating changes caused by natural selection in a particular population as a result of a specified selection pressure such as artificial selection in breeding for desired characteristics
8.3 Evolution	BS: The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (ACSSU185)	• evaluating and interpreting evidence for evolution, including the fossil record, chemical and anatomical similarities, and geographical distribution of species • relating genetic characteristics to survival and reproduction rates
8.4 Biotechnology	BS: The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence (ACSSU185) SHE: Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE192)	• investigating changes caused by natural selection in a particular population as a result of a specified selection pressure such as artificial selection in breeding for desired characteristics • recognising that the development of fast computers has made possible the analysis of DNA sequencing, radio astronomy signals and other data
Earth and space sciences		
9 Earth systems		
9.1 The Earth's cycles	ESS: Global systems, including the carbon cycle, rely on interactions involving the atmosphere, biosphere, hydrosphere and lithosphere (ACSSU189)	• modelling a cycle such as the water, carbon, nitrogen or phosphorus cycle within the biosphere
9.2 Effects of human activity	ESS: Global systems, including the carbon cycle, rely on interactions involving the atmosphere, biosphere, hydrosphere and lithosphere (ACSSU189)	• investigating how human activity affects global systems
9.3 The atmosphere	ESS: Global systems, including the carbon cycle, rely on interactions involving the atmosphere, biosphere, hydrosphere and lithosphere (ACSSU189)	• investigating how human activity affects global systems • explaining the causes and effect of the greenhouse effect • investigating the effect of climate change on sea levels and biodiversity

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10 Origin of the universe		
10.1 The night sky	ESS: 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)	• describing how the evolution of the universe, including the formation of galaxies and stars, has continued since the Big Bang
10.2 Stars and galaxies	ESS: 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)	• describing how the evolution of the universe, including the formation of galaxies and stars, has continued since the Big Bang
10.3 Life cycle of stars	ESS: 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)	• describing how the evolution of the universe, including the formation of galaxies and stars, has continued since the Big Bang • recognising that the age of the universe can be derived using knowledge of the Big Bang theory • identifying the evidence supporting the Big Bang theory, such as Edwin Hubble's observations and the detection of microwave radiation
Options		
11 Carbon chemistry		
11.1 Carbon compounds	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• using word or symbol equations to represent chemical reactions
11.2 Plastics and fibres	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• investigating how chemistry can be used to produce a range of useful substances such as fuels, metals and pharmaceuticals • using word or symbol equations to represent chemical reactions
11.3 Carbon in fuels	CS: Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)	• investigating how chemistry can be used to produce a range of useful substances such as fuels, metals and pharmaceuticals
12 Psychology		
12.1 What is psychology?		
12.2 Memory		
12.3 Behaviour		
12.4 Research methods in psychology	SIS: Formulate questions or hypotheses that can be investigated scientifically (ACSIS198)	• formulating questions that can be investigated within the scope of the classroom or field with available resources

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Online resources

Throughout this book you will find links to activities and video or audio files. The activities are for students to practise key skills, or to reinforce learning on key concepts. Activities vary in type and include crosswords, matching, drag and drop, labelling, multiple choice, true and false, and sequencing activities. Students can repeat these activities as revision and practise them at any time.

Each activity is scored and the teacher can review student progress in the digital mark book. In *ScienceWorld 10* there are approximately 80 activities.

When one or more activities are available, you will find an icon on the page of the book where it is most relevant to learning.

Digital activity **Audio or video material**

We hope you enjoy using these activities to improve learning outcomes.

Satellites

In 1957, the Soviet Union launched the world's first satellite, *Sputnik 1*. Since then, about 6600 satellites from more than 40 countries have been launched into space on rockets. Many of these no longer operate and have become 'space junk'.

Satellites take pictures of the planet to help meteorologists predict the weather and track cyclones. Other satellites are used mainly for communications, such as beaming TV signals and phone calls around the world. A group of 20 or more satellites make up the Global Positioning System (GPS), so you always know exactly where you are.

You can find out more about satellites in Chapter 5, 'Space engineering'.

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Transition science

ScienceWorld 10 is designed to help you make the transition from the junior secondary school to the senior secondary 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 inquiry skills in the four areas of science below. Check the contents list on page iii. Which are the Physical sciences chapters? Which are Biological sciences chapters? Which ones are Biological sciences? Which are Chemical sciences? And which are Earth and space sciences?

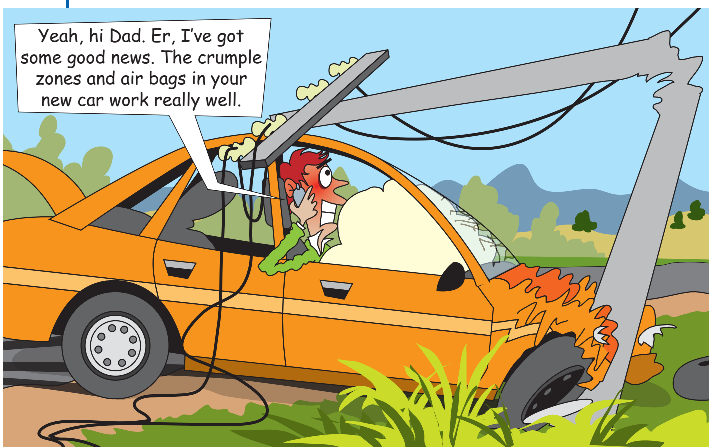
3 Which of the four areas do you like best? Why?

4 Which of the four areas would you need to study environmental science? Explain.

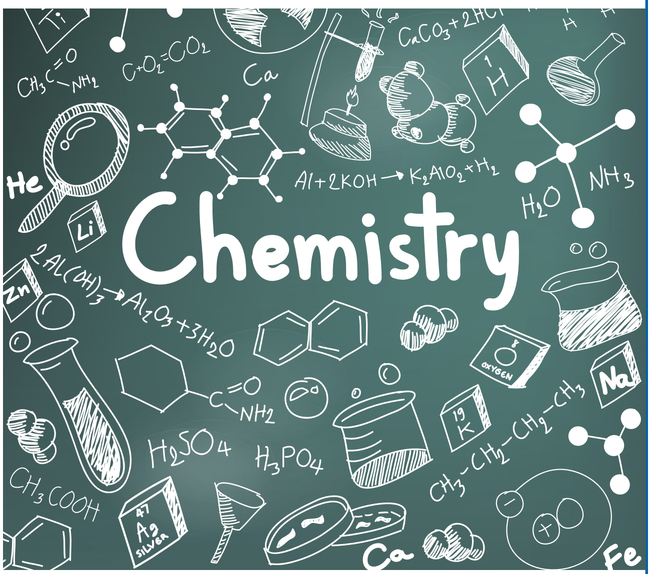
5 Whether or not you do science next year, this book explores **Science as a Human Endeavour**. It contains many ideas and issues that you will hear about in the news and discuss with others. For instance:

- solar cars (page 165)
- gene technology and cloning (Chapter 8)
- what to do about rising levels of CO_2 in the atmosphere (Chapter 9)
- cosmic catastrophes such as a meteorite crashing into the Earth (page 269).

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

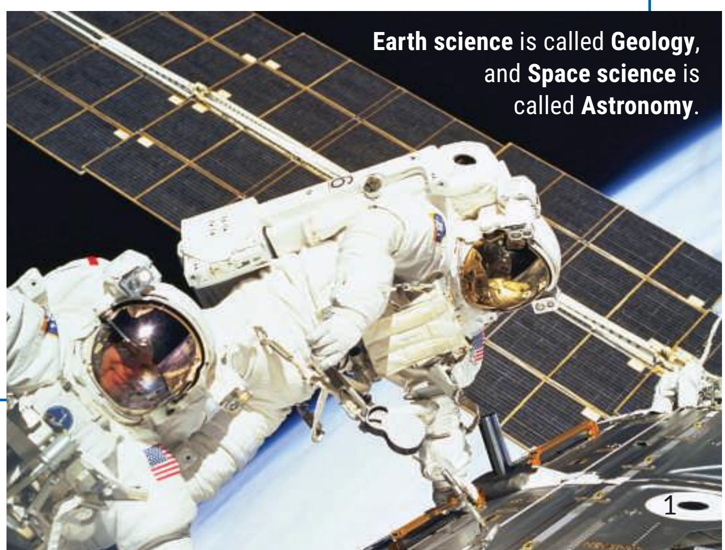


Physical sciences or **Physics** is the study of how objects, from the very tiny to the very big, behave.



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**.

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IN THIS CHAPTER

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
- 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

CH•1 The periodic table

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GET STARTED: *QUESTION*

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?

copper nugget

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	2	2.7	660	80
copper	Cu	0.007	6	8.9	1083	150
gold	Au	0.0000005	55 000	19.3	1063	120
iron	Fe	5.0	0.07	7.9	1535	300
lead	Pb	0.002	3	11.3	327	15
silver	Ag	0.0000004	805	10.5	961	150
tin	Sn	0.0004	26	7.3	232	30
titanium	Ti	0.6	5	4.5	1668	620
zinc	Zn	0.013	3	7.1	420	150

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Periodic table of the elements

Periodic table of the elements

Elements in the same vertical column have similar properties

Key

6 (atomic number)
C (symbol)
Carbon (name of element)
12.01 (relative atomic mass)

The colour of the name for each element indicates its state at room temperature:

black—solid

blue—liquid

pink—gas

Elements in red are synthetic.

Period	Group 1	2	3	4	5	6	7	8	9
1	1 H Hydrogen 1.008								
2	3 Li Lithium 6.941	4 Be Beryllium 9.012							
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31							
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.95	43 Tc Technetium (97)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9
6	55 Cs Caesium 132.9	56 Ba Barium 137.3		72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.8	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2
7	87 Fr Francium (223)	88 Ra Radium (226)		104 Rf Rutherfordium (267)	105 Db Dubnium (270)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (270)	109 Mt Meitnerium (278)

57 La Lanthanum 138.9	58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4
89 Ac Actinium (227)	90 Th Thorium 232.0	91 Pa Protactinium 231.0	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (244)

For a lighthearted look at the periodic table, follow the links to **The elements**.

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Atomic number and relative atomic mass

Each element in the periodic table has two numbers assigned to it. The atomic number tells you the number of protons, and the **relative atomic mass** (sometimes referred to as the *atomic weight*) tells you the relative mass of an atom of that element. The atomic mass is calculated by taking the average mass of the isotopes of the element. Carbon has a relative mass of 12.01, while hydrogen has a relative mass of 1.008. That means that an atom of hydrogen weighs about 1/12th of what an atom of carbon weighs.

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 4.003
			5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
			13 Al Aluminium 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 83.80
46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
110 Ds Darmstadtium (281)	111 Rg Roentgenium (281)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (288)	116 Lv Livermorium (293)	117 Ts Tennessine (293)	118 Og Oganesson (294)

63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

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1.1 The periodic table

Imagine searching through lists of unsorted albums looking for the latest album of your favourite artist. Such a task could take days. Fortunately music apps arrange their albums in separate sections. They then divide each of these groups into smaller groups according to the type of music; for example, rock, popular, jazz and classical. Artists within each group are then arranged alphabetically.

Scientists have a problem similar to that of the music app 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 elements 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 in Figure 1.1, April 4, 11, 18 and 25 are all Mondays. In Mendeleev's table, elements in the same family were in the same column.

Look at the left-hand blue column in the table on page 4. This column contains lithium, sodium and potassium, which all have similar properties. The number above each element is its

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

Figure 1.1 The periodic table is a bit like a calendar.

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.


ПЕРИОДИЧЕСКАЯ СИСТЕМА ЭЛЕМЕНТОВ

		ГРУППЫ ЭЛЕМЕНТОВ								
		I	II	III	IV	V	VI	VII	VIII	0
1	I	H 1 1,008								He 2 4,003
2	II	Li 3 6,940	Be 4 9,02	5 B 10,82	6 C 12,010	7 N 14,008	8 O 16,000	9 F 19,00		Ne 10 20,183
3	III	Na 11 22,997	Mg 12 24,32	13 Al 26,97	14 Si 28,06	15 P 30,98	16 S 32,06	17 Cl 35,457		Ar 18 39,944
4	IV	K 19 39,096	Ca 20 40,08	Sc 21 45,10	Ti 22 47,90	V 23 50,95	Cr 24 52,01	Mn 25 54,93	Fe 26 55,85; Co 27 58,94; Ni 28 58,69	
	V	29 Cu 63,57	30 Zn 65,38	31 Ga 69,72	32 Ge 72,60	33 As 74,91	34 Se 78,96	35 Br 79,916		Kr 36 83,7
5	VI	Rb 37 85,48	Sr 38 87,63	Y 39 88,92	Zr 40 91,22	Nb 41 92,91	Mo 42 95,95	Ma 43 —	Ru 44 101,7; Rh 45 102,91; Pd 46 106,7	
	VII	47 Ag 107,88	48 Cd 112,41	49 In 114,76	50 Sn 118,70	51 Sb 121,76	52 Te 127,61	53 J 126,92		Xe 54 131,3
6	VIII	Cs 55 132,91	Ba 56 137,36	La 57 * 138,92	Hf 72 178,6	Ta 73 180,88	W 74 183,92	Re 75 186,31	Os 76 190,2; Ir 77 193,1; Pt 78 195,23	
	IX	79 Au 197,2	80 Hg 200,61	81 Tl 204,39	82 Pb 207,21	83 Bi 209,00	84 Po 210	85 —		Rn 86 222
7	X	— 87	Ra 88 226,05	Ac 89 227	Th 90 232,12	Pa 91 231	U 92 238,07			

* ЛАНТАНИДЫ 58–71

Ce 58 140,13	Pr 59 140,92	Nd 60 144,27	61 —
Tb 65 159,2	Dy 66 162,46	Ho 67 164,94	Er 68 167,2
Sm 62 150,43	Eu 63 152,0	Gd 64 156,9	
Tu 69 169,4	Yb 70 173,04	Cp 71 174,99	

Figure 1.2 Mendeleev's periodic table

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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 57–71 and 89–103 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 zigzag 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 zigzag 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**.

EXPLORE ONLINE

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 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.

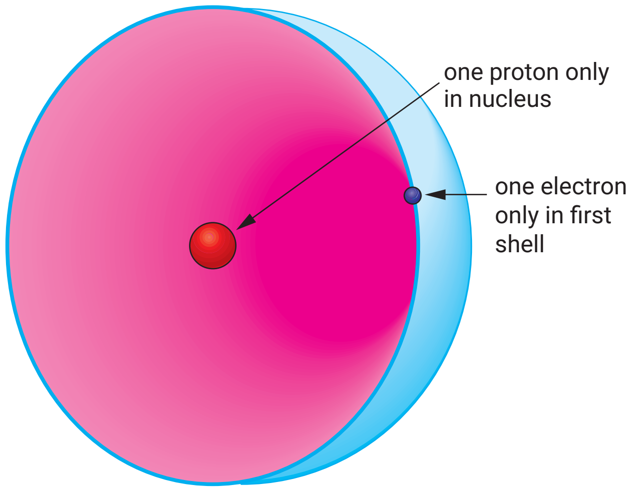

Figure 1.3 A cutaway view of a hydrogen atom (atomic number = 1), showing its nucleus and spherical electron shell

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 (above) has one electron and helium has two.

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.

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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.

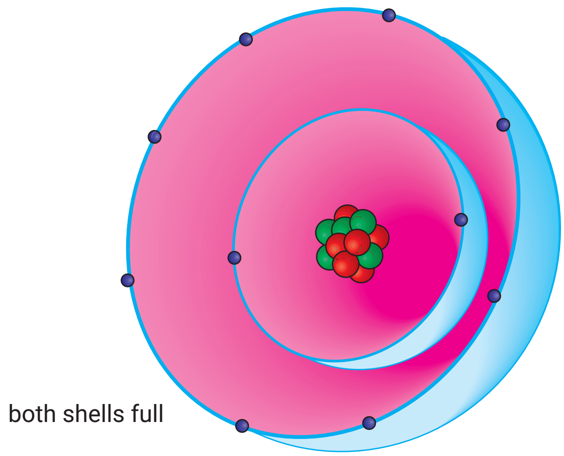

Figure 1.4 A neon atom (atomic number = 10)

Note that *the periodic table group number is related to 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 such as 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+.

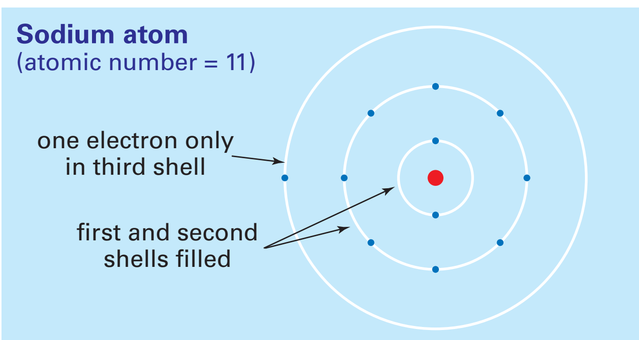

Figure 1.5 In chemical reactions a sodium atom tends to lose its outer electron to form a Na^+ ion. For simplicity the electron shells have been drawn in two dimensions.

Atoms such as chlorine, with seven electrons in their outer shell, are one electron short of a full shell. They 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.

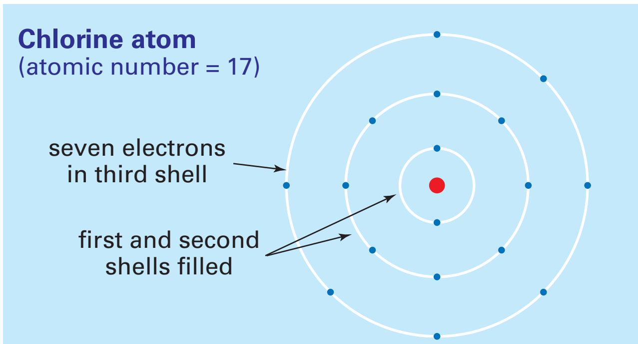

Figure 1.6 A chlorine atom tends to gain an electron to form a Cl^- ion with a full outer shell.

Carbon, in Group 14, has four electrons in its outer shell and therefore has a valency of 4. See Figure 1.7. Rather than losing or gaining electrons to form ions, it *shares* electrons to form covalent bonds. When carbon 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.

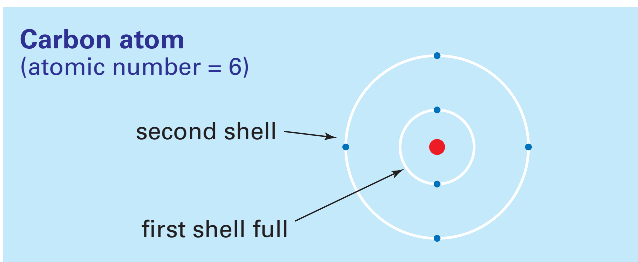

Figure 1.7 Carbon has 4 electrons in its outer shell and can therefore form 4 covalent bonds.

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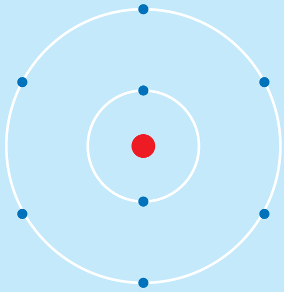
SKILLBUILDER

Electron configuration

The diagrams of electron shells have shown that electrons occupy different energy levels. As we see an increase in the atomic number of an element, we see an increase in the number of electrons, and so an increase in the number of electron shells. Rather than having to draw the structure to show the arrangement of electrons within an atom, we can use a shorthand notation called the **electron configuration**.

Oxygen has an atomic number of 8, meaning that in total it has eight protons and, when neutral, eight electrons. The first two electrons fill the first shell, with the remaining six occupying the second shell. We can therefore write the electron configuration for oxygen as 2, 6. This shows the number of electrons in each shell.

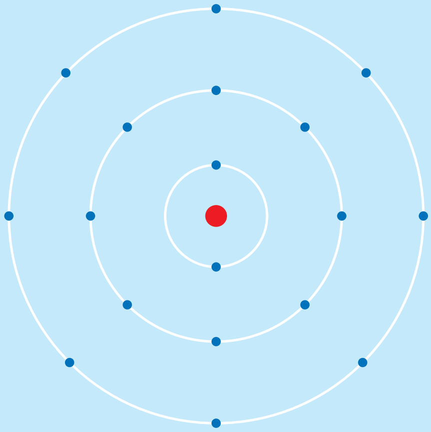
Oxygen atom
(atomic number = 8)



Electron configuration: 2, 6

Argon, being a noble gas, has a full outer electron shell, which is why it is unreactive. The diagram shows how many electrons are in each shell and the electron configuration is 2, 8, 8.

Argon atom
(atomic number = 18)



Electron configuration: 2, 8, 8

You can work out the electron configuration of elements by observing their location in the periodic table. Argon is located in period 3, and so has 3 energy levels. Because it is in group 18 it has eight valence electrons, or eight electrons in its outer shell. This is reflected in its electron configuration.

Questions

1 Complete the table below. The first one has been done for you.
2 Find elements in the same group as each of the five elements in the table.

Element name	Symbol	Period	Group	Electron configuration
Calcium	Ca	4	2	2, 8, 8, 2
Lithium				
Phosphorous				
Neon				
Nitrogen				

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CHECK

For most of these exercises you will need to refer to the periodic table on pages 4 and 5.

1 What does the atomic number of an element tell you?

2 What is the atomic number of these elements?
  a hydrogen
  c copper
  b carbon
  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 Scientists have been trying to make a new element with atomic number 119. Predict which elements it would be 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 a rhyme to help you remember facts; for example, **M**y **V**ery **E**ducated **M**other **J**ust **S**erved **U**s **N**achos refers to the eight planets in the solar system.)

5 Copy and complete the table on the top 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 the previous page.

Elements	Atomic number	Number of electrons in 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?

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1.2 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.

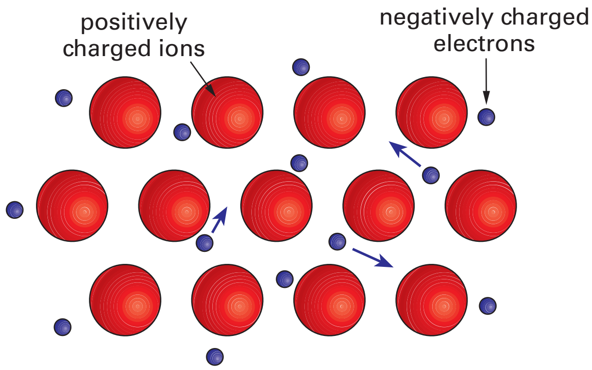

Figure 1.8 A metallic lattice

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.

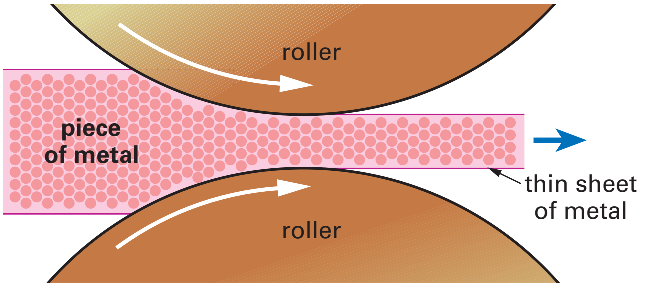

Figure 1.9 Metals can be shaped because they are malleable.

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.

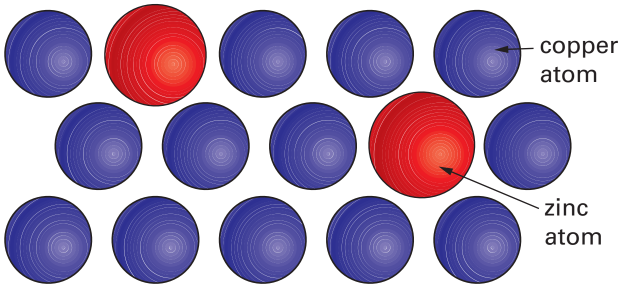

Figure 1.10 An alloy of copper and zinc

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.

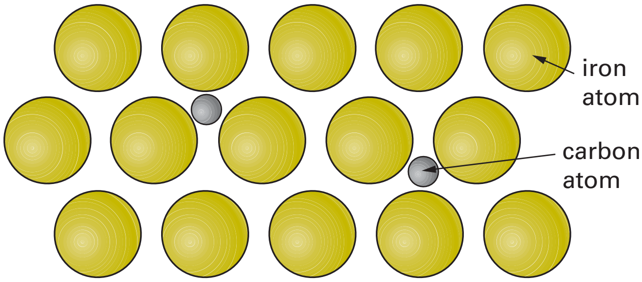

Figure 1.11 Steel is an alloy of iron with smaller carbon atoms.

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

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INVESTIGATION 1.1 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

Risk assessment and planning

- 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: *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.

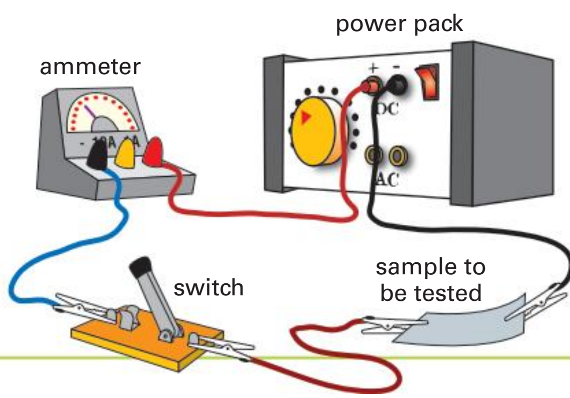
4 Suppose you wanted to make a metal tank to hold copper sulfate solution. Which would be the best metal to use? Why?

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?



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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. Group 1 elements 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.

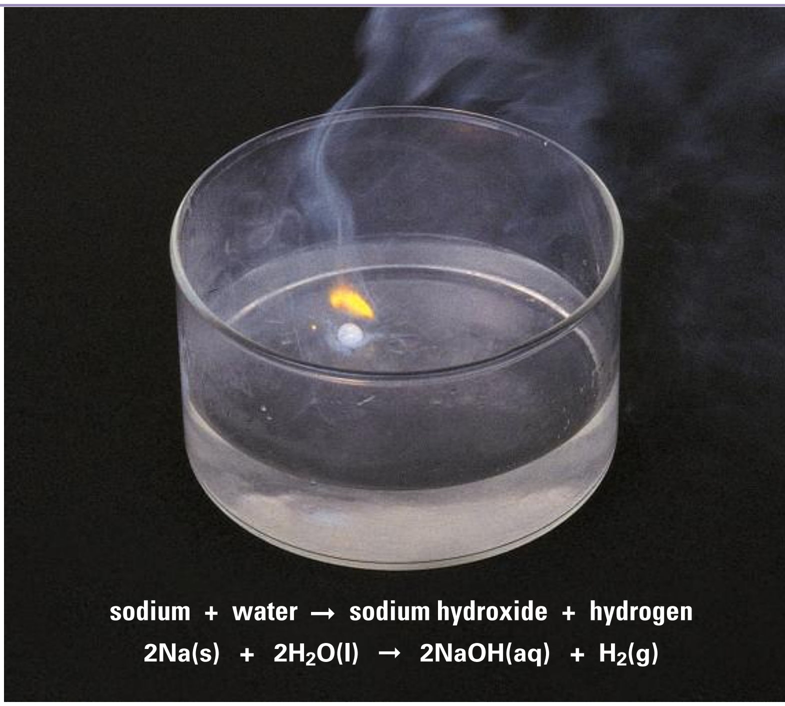

Figure 1.12 Sodium reacts violently with water. Your teacher may demonstrate this.

INVESTIGATION 1.2 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

Risk assessment and planning

- 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.

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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 (for example, aluminium and zinc) are generally more reactive than those towards the bottom of the table (for example, 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 1.3.

INVESTIGATION 1.3 Flame colours

Aim

To observe the characteristic flame colours produced by metal salts.

Materials

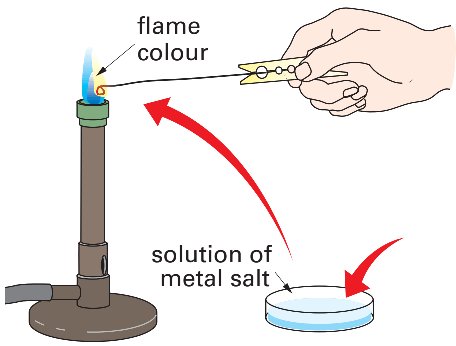
- Petri dish
- piece of nichrome wire, about 10 cm long
- wooden peg or test tube holder
- Bunsen burner
- saturated solutions of chlorides or carbonates of the following metals: barium, calcium, copper, potassium, sodium, strontium

Risk assessment and planning

- 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.

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EXPERIMENT 1.1 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.

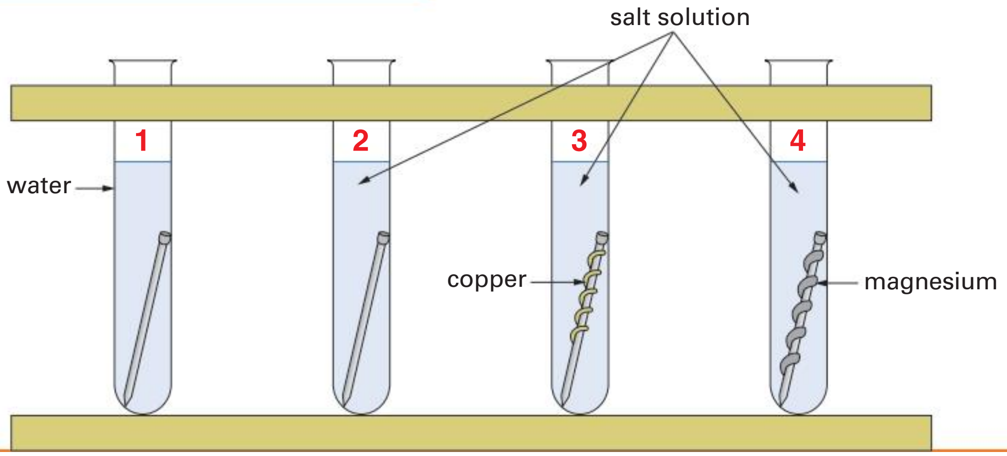
Write your report

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.



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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).

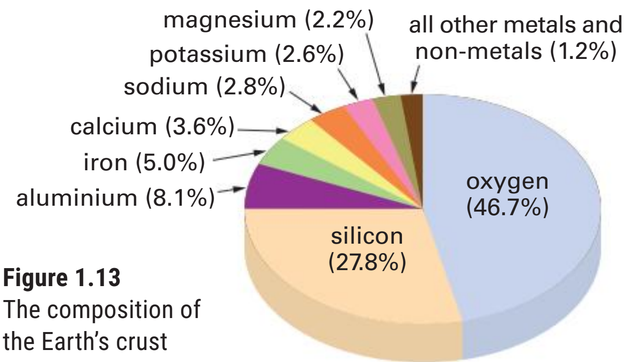

Figure 1.13 The composition of the Earth's crust

Metals are usually found as compounds with non-metals, although some unreactive metals such as gold can be found as elements. The table below lists some common metal compounds, called **minerals**, that have formed within rock formations. Iron, nickel, gold and copper are abundant in Western Australia, and mining is an industry that contributes to the WA economy. In order to extract the metal from the mineral, a number of processes are used, which are referred to as metal extraction. The most common types of metal extraction are described on the following pages, with chemical equations showing the reactions that occur.

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

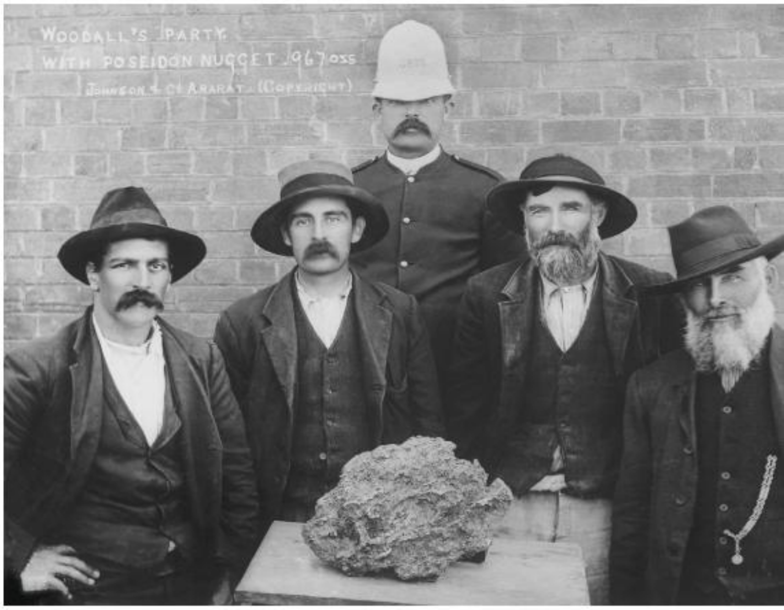

Figure 1.14 Gold is usually found in its uncombined state. This is the Poseidon nugget found in central Victoria in 1906. It weighed 27 kilograms.

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:

$$Pb^{2+}(s) + 2e^- \rightarrow Pb(s)$$

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The blast furnace

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 Figure 1.15 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.

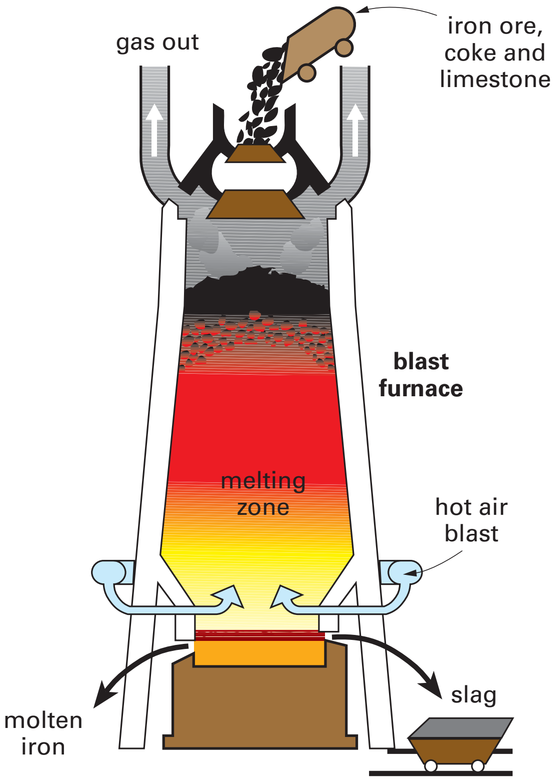

Figure 1.15 Smelting in a blast furnace

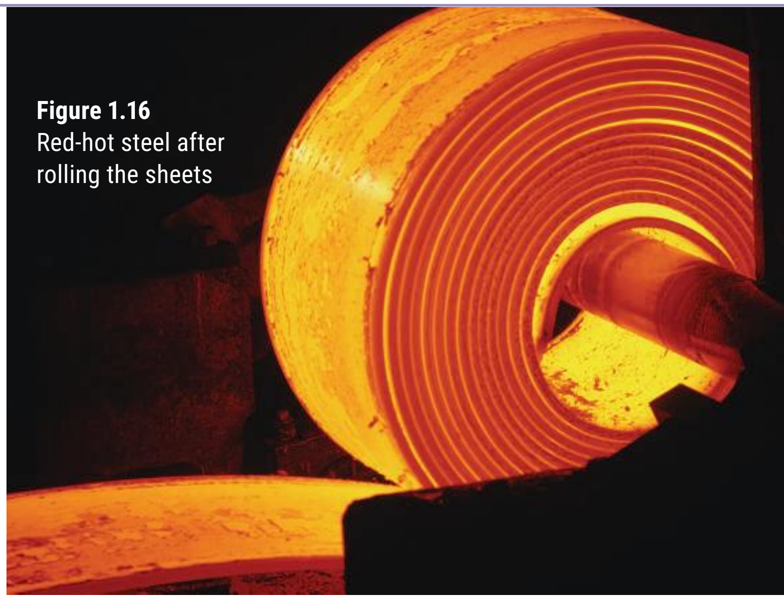

Figure 1.16
Red-hot steel after rolling the sheets

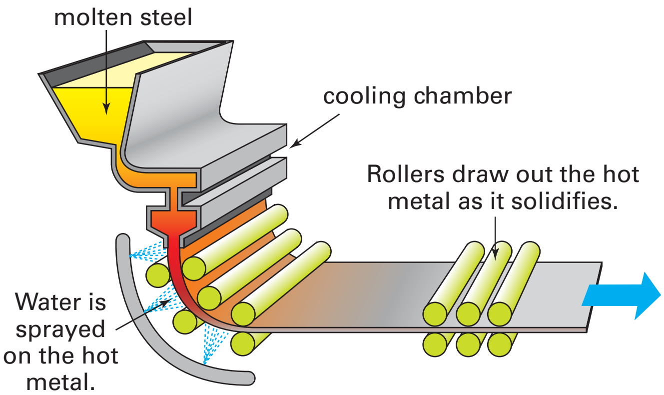

Figure 1.17 The red-hot steel is rolled into flat sheets and cut into sheets or rolled up as in Figure 1.16.

Roasting copper

Copper can be extracted from its ore by 'roasting'. 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.

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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), in which 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 a considerable amount of 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.

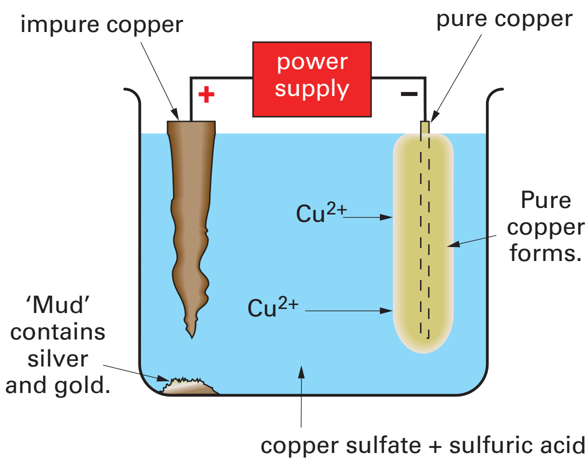

Figure 1.18 Purifying copper by electrolysis

Displacement

In Investigation 1.1 Part B (page 12), 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 the solution as magnesium chloride, and the titanium comes out of the solution as the metal.

ACTIVITY

You will need a test tube and test tube 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, and hook 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.

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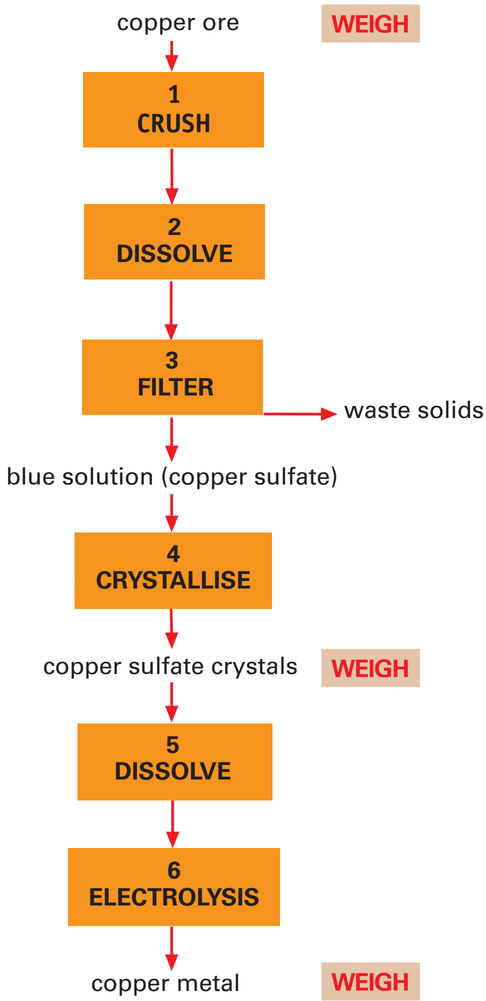
INVESTIGATION 1.4 Copper metal from copper ore

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 it 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



Risk assessment and planning

This is a complex investigation that will take several days. You will need to work carefully so that you don't lose any copper.

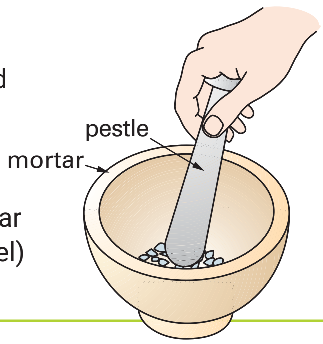
- In a group, describe what you will be doing in each of the six steps shown in the flow diagram on the right.
- When will you need to weigh things?
- What safety precautions will be necessary?

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 or flask. 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. (A fluted filter paper is faster.)

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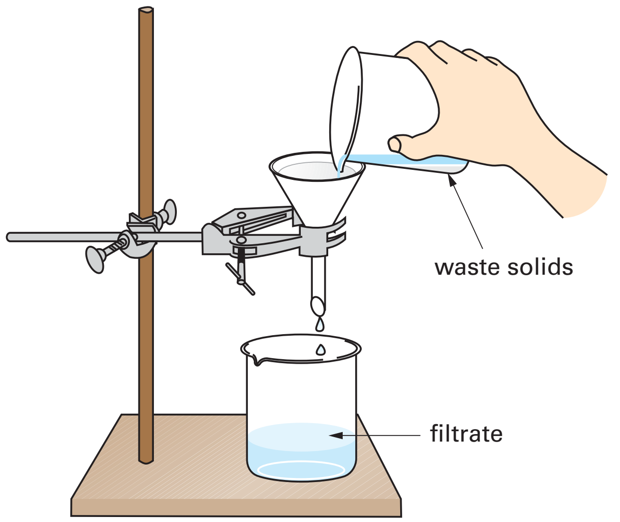


- **c** Rinse the solid left in the beaker with a further 10 mL of water, and filter this rinse water as well.

  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:

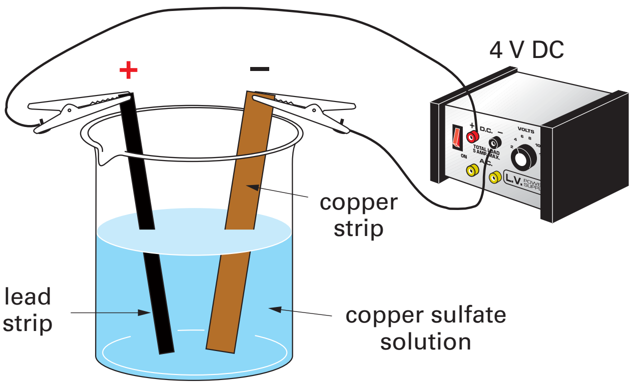
$$\% \text{ yield} = \frac{\text{mass of copper sulfate}}{\text{mass of ore}} \times 100$$

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 the positive terminal and the copper to the negative one.
- **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?

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CHECK

1 List four physical properties of metals.

2 Explain the difference between a metal and an alloy, using a diagram.

3 Define the following terms, and then use each term in a sentence:
  a malleable
  b transition metal
  c lustre

4 Identify from the periodic table the following elements, writing their name and atomic number.
  a the most reactive alkali metal
  b a very unreactive transition metal used to make water pipes
  c a transition metal that reacts very slowly with oxygen to form rust
  d a metalloid that is highly poisonous

5 Aluminium is the most abundant metal in the Earth's crust, but it is not the cheapest. Suggest why.

6 Write a chemical equation for the smelting of copper oxide using carbon. (See page 16.)

7 Would you expect miners to find nuggets (lumps) of magnesium metal? Explain your answer.

8 Why is it that one Cu^{2+} ion combines with two electrons?

9 Write down at least three uses for copper.

10 Identify the substances that make up steel and stainless steel. How do the physical properties of steel and stainless steel differ?

CHALLENGE

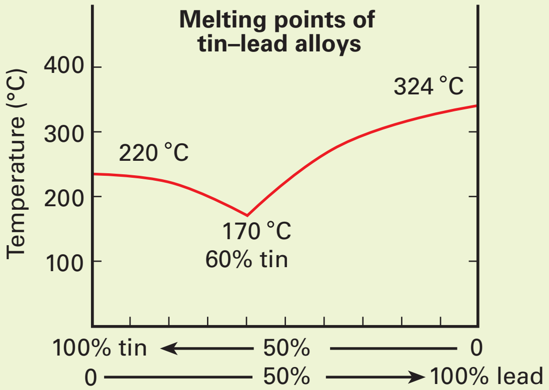
1 Alloying iron with carbon makes it harder. Explain this in terms of the structure of alloys.

2 Explain the following properties of metals in terms of their structure:
  a high melting point
  b high density
  c malleability (can be rolled into sheets)

3 Describe in your own words three trends you have learnt about in the periodic table. For example, what happens to the reactivity of metals as you move from left to right?

4 a The transition metal copper forms two different ions: Cu(I) and Cu(II). Write the chemical formula for copper(I) sulfate, and copper(II) sulfate.
  b The transition metal iron can exist as Fe(II) or Fe(III). Write the chemical formula for the two versions of iron oxide that could be formed.

5 The graph below 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?



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1.3 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)**	**→**	**2NaCl(s)**

Figure 1.19 The red tubes in this sign contain the noble gas neon. The green, yellow and blue tubes contain argon.

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.

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.

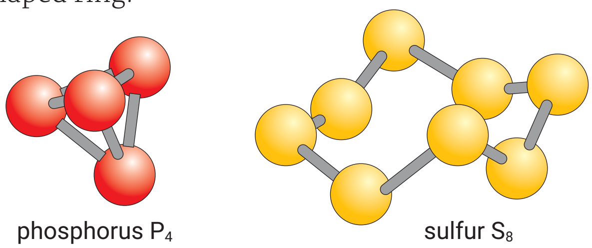
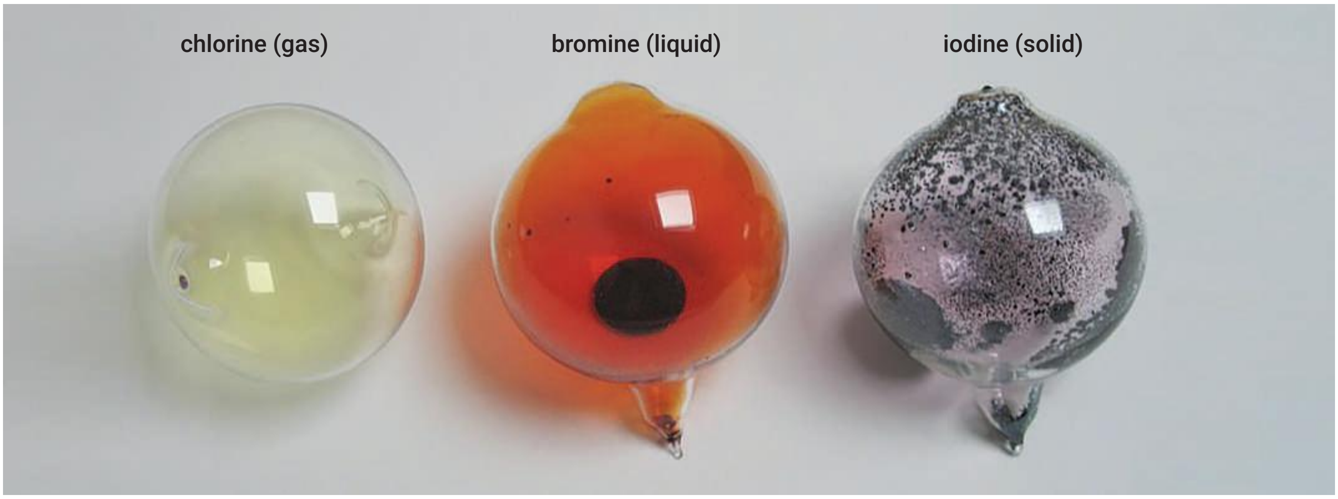


Figure 1.20 As you move to the left in the periodic table, the non-metals form a greater number of covalent bonds.



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Allotropes of carbon

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. In contrast, 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.

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.

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 *buckyball* in which the carbon atoms are linked to form single molecules rather than a giant network. The first buckyball to be found contains 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 Figure 1.23, about a millionth of a millimetre in size.

Figure 1.21
Diamond's unique properties are due to its structure of tetrahedrally bonded carbon atoms.

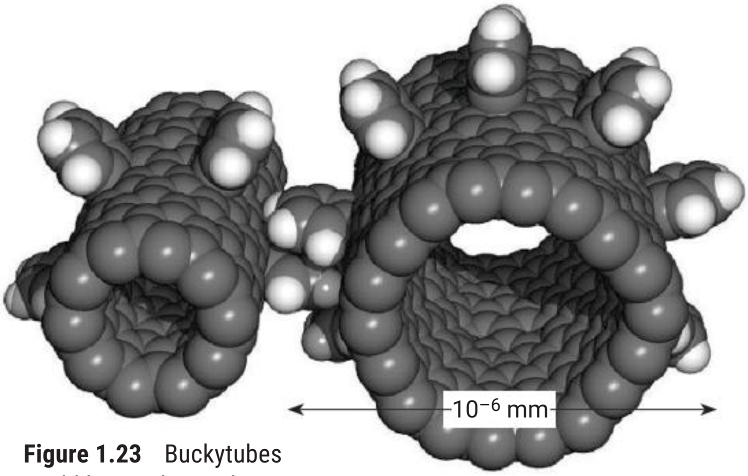

Figure 1.23 Buckytubes could be used to make gears in nanomachines.

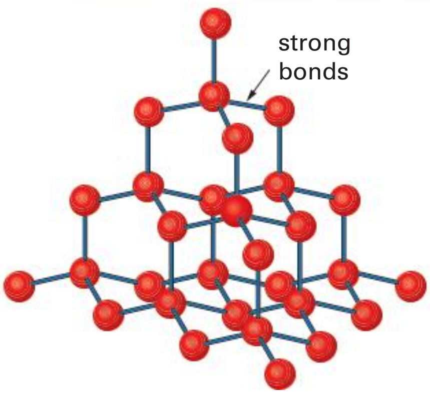

Figure 1.22
Diamond, a tetrahedral covalent lattice

Note: These diagrams show only part of the structure of diamond and graphite.

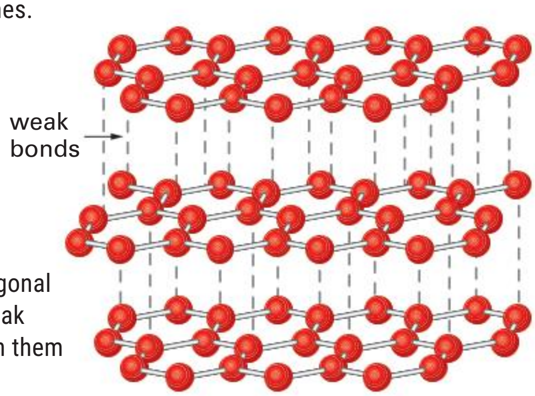

Figure 1.24
Graphite, hexagonal sheets with weak forces between them

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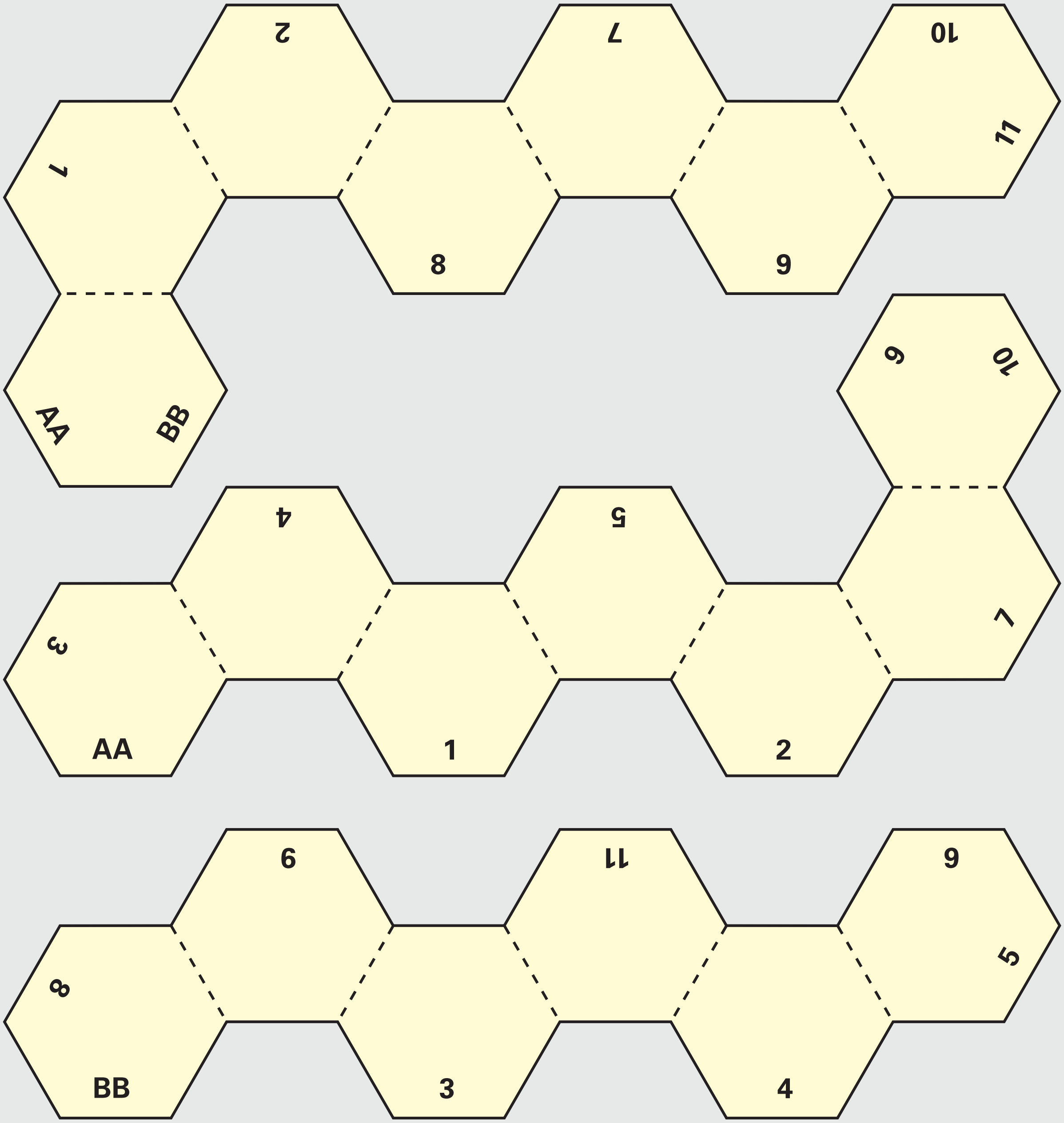
ACTIVITY

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?



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SCIENCE AS A HUMAN ENDEAVOUR

Nanotubes

Carbon nanotubes or buckytubes 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.

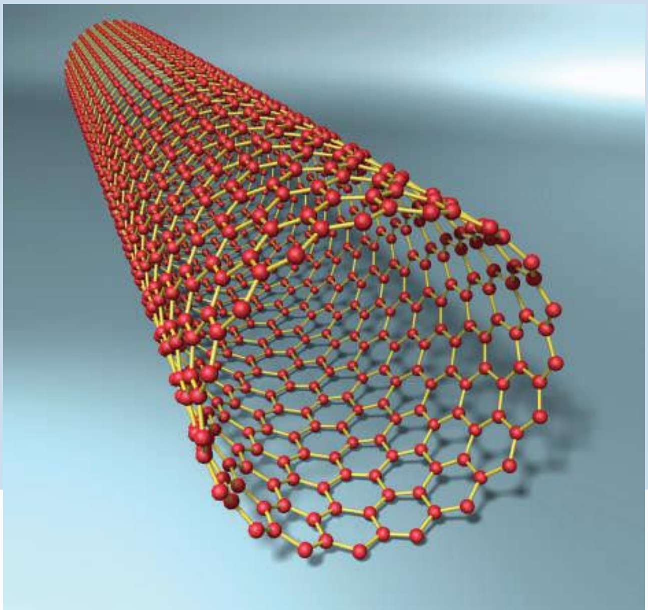
Nanotubes could be used to make super-light, super-strong nanocars powered by fuel cells using hydrogen. The flammable hydrogen could be safely stored in fuel tanks consisting of arrays of nanotubes that act like a sponge, absorbing hydrogen gas in large quantities. The hydrogen can then be released 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.



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Hydrocarbons

Aside from existing as a range of allotropes, carbon also has the ability to form a number of compounds with hydrogen, which falls under the branch of chemistry called **organic chemistry**. The simplest of these compounds is methane, a **hydrocarbon** whose molecules contain one carbon and four hydrogen atoms. Methane represents the start of a *homologous series*, where the series shows an increase in the number of carbon atoms for each compound in the series.

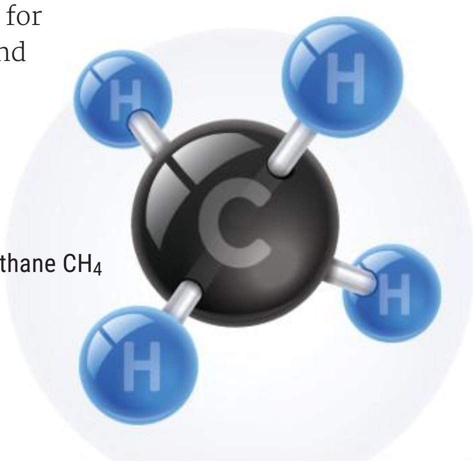


Figure 1.25 Methane CH_4

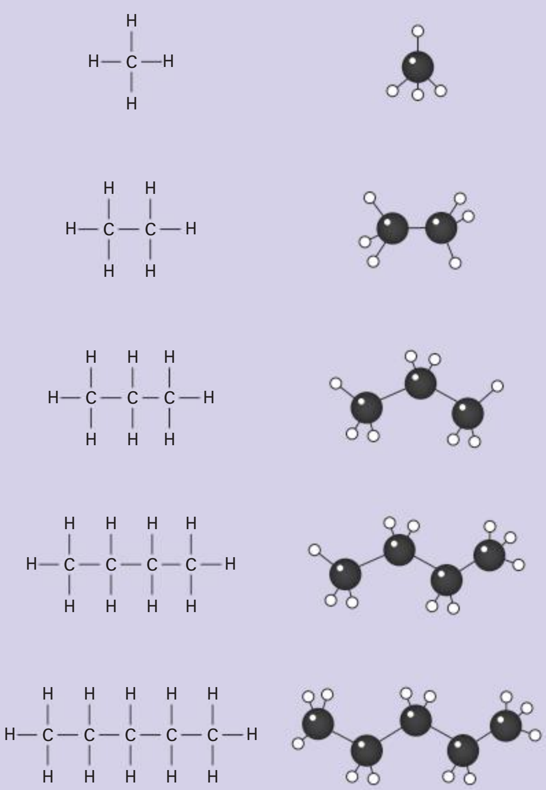
Methane CH_4

Ethane C_2H_6

Propane C_3H_8

Butane C_4H_{10}

Pentane C_5H_{12}



As hydrocarbons get bigger and heavier, their properties change. Methane, ethane, propane and butane are usually gases, but as the molecules increase in size, their melting and boiling points increase. This means that at room temperature the bigger hydrocarbons in the homologous series are liquids or even solids.

Hydrocarbons have a range of uses, and make up substances that we use every day. Have you heard of a substance called octane? It is a major component of petrol. Octane molecules contains eight carbon atoms and 18 hydrogen atoms. Butane is also a commonly used fuel, and you may have used it in camping stoves. Hydrocarbons readily undergo combustion reactions, where they burn in oxygen gas to release carbon dioxide and water.

You can learn more about carbon compounds and some of their reactions in optional Chapter 11.

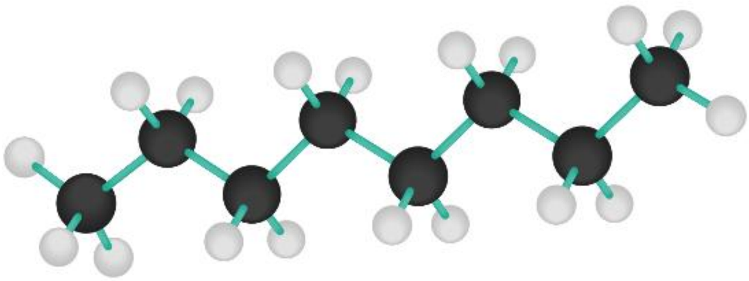


Figure 1.26 C_8H_{18} octane

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CHECK

1 What is the difference between a monatomic and a diatomic gas? Give examples of each.

2 What is an allotrope? What are the names of the four allotropes of carbon?

3 Explain in terms of its structure why graphite is flaky and feels greasy.

4 Define the following terms, and then use each term in a sentence.
- a tetrahedron
- b allotrope
- c noble gas

5 Name five non-metals and write the chemical formula of a molecule they form.

6 Identify from the periodic table the following elements, writing their name and atomic number.
- a a highly reactive green gas that belongs to the halogen group
- b a non-metal gas that is very unreactive
- c the most reactive element in group 16

7 a Research the formulas and boiling points of:
- methane
- propane
- hexane

b Use these points to predict the boiling points of:
- ethane
- pentane
- octane

c Plot these data points on a graph and comment on the trend.

CHALLENGE

1 Suggest how buckyballs might be useful as lubricants.

2 Research why noble gases such as argon are used in incandescent light globes.

3 How many bonds does nitrogen form with hydrogen in the compound ammonia?

4 Write equations for the following reactions of phosphorus P_4.
- a Phosphorus reacts with a plentiful supply of oxygen gas to form P_4O_{10}.
- b Phosphorus reacts with a limited supply of oxygen gas to form P_4O_6.

Figure 1.27 Incandescent light bulbs containing argon

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MAIN IDEAS

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

gain
atomic number
periodic table
electrons
halogens
non-metals
ores
valency
properties
electrolysis
reactive

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.

CH•1 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 4 and 5 to predict which one of the following elements has properties different from the other three.
A aluminium
B barium
C calcium
D radium

3 Which of the following contains the most non-metal atoms?
A P_2O_5
B CO_2
C BaO
D CH_3COOH

4 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.

5 Study your copy of the periodic table and name the element or elements that:
a have names like planets
b have names like countries
c are in neon lights
d are gases in air (two)
e is a poison used in detective stories
f are common metals (four)

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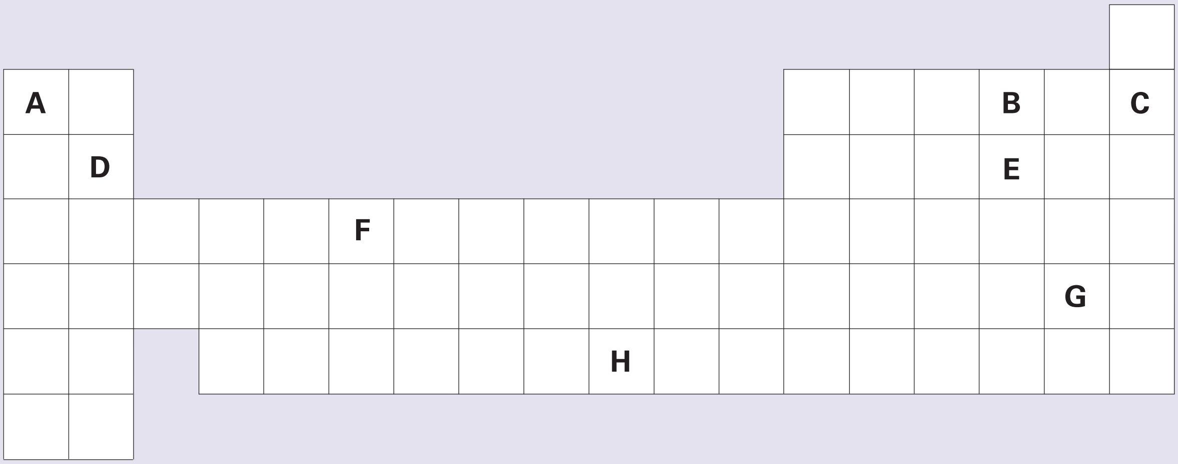

6 In the periodic table above, some elements have been replaced by letters. Use the letters to answer these questions. Find:
- **a** the two elements that are in the same group
- **b** two elements that are in the same period
- **c** the two elements that are gases at room temperature
- **d** the elements 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 119 and 120. Use the periodic table on pages 4 and 5 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 7 and 8.
- **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			Electron configuration
			1st shell	2nd shell	3rd shell	
hydrogen						
carbon						
neon						
sodium						
chlorine						

Check your answers on page 341.

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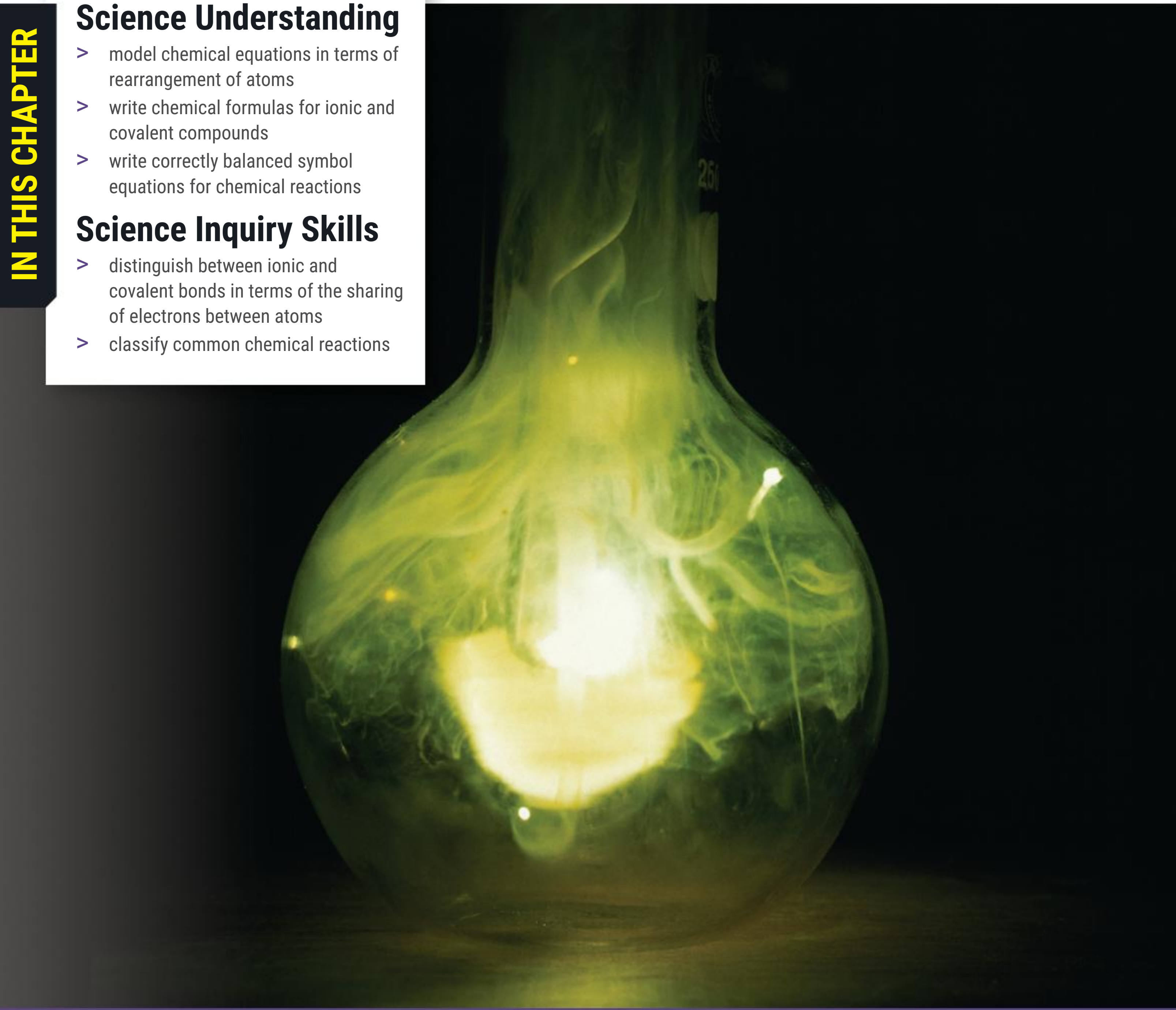
IN THIS CHAPTER

Science Understanding

- model chemical equations in terms of rearrangement of atoms
- write chemical formulas for ionic and covalent compounds
- write correctly balanced symbol equations for chemical reactions

Science Inquiry Skills

- distinguish between ionic and covalent bonds in terms of the sharing of electrons between atoms
- classify common chemical reactions



CH•2 Rearranging atoms

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GET STARTED: *QUESTION*

The image shows what happened when the teacher mixed two clear 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.

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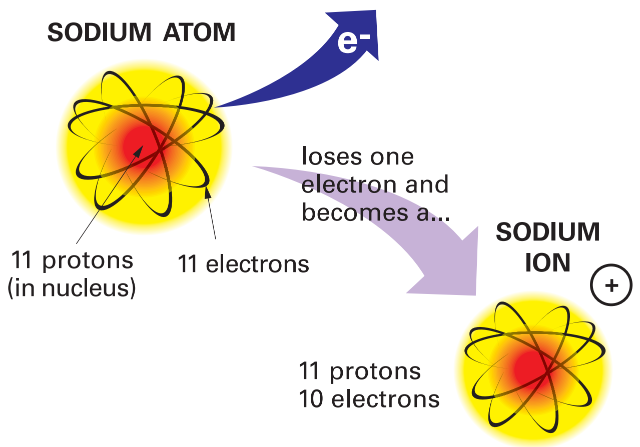
2.1 Chemical bonds

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. In contrast, 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.

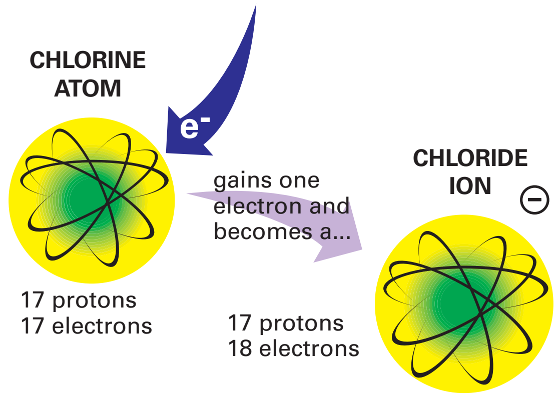
Atoms of metals tend to lose electrons. You will find out the reason for this in Chapter 3. For example, a sodium atom can lose one electron to form an ion with a single positive charge Na^+, as shown below. Copper atoms lose two electrons to form Cu^{2+} ions with two positive charges, and aluminium loses three electrons to form Al^{3+}.



Na → Na^+ + 1 electron

Figure 2.1 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^-.



Cl + 1 electron → Cl^-

Figure 2.2 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 → Na^+ + 1 electron)

copper (Cu → Cu^{2+} + 2 electrons)

aluminium (Al → 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 → Cl^-)

bromine (Br + 1 electron → Br^-)

iodine (I + 1 electron → 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

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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.

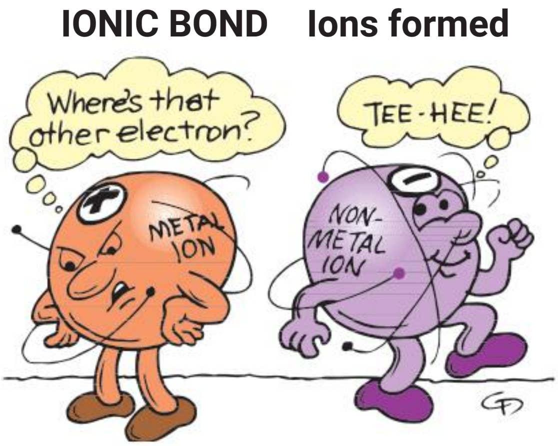


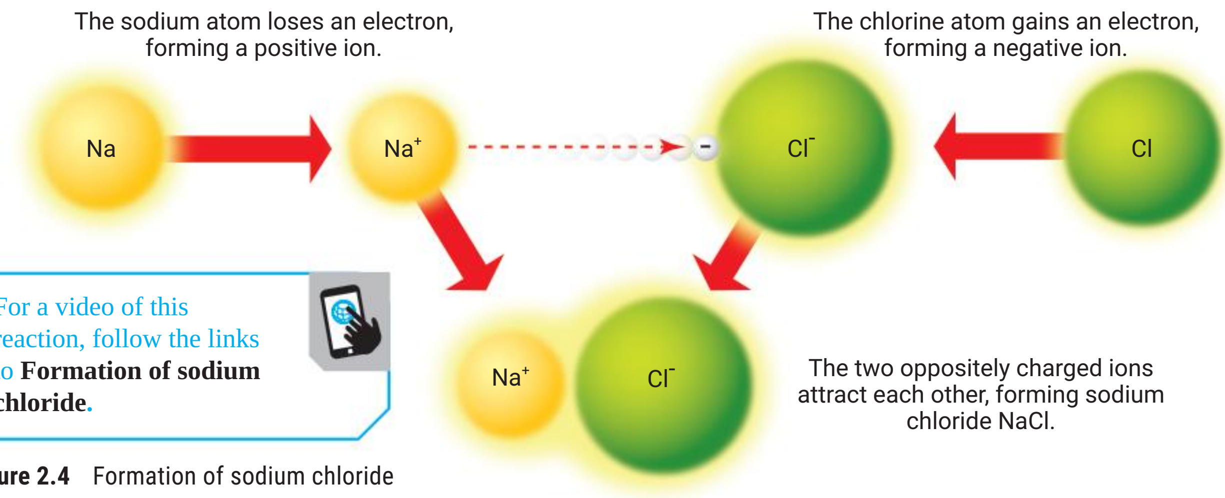
Figure 2.3 In an ionic compound, electrons are transferred from a metal to a non-metal.

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.

Ionic lattice

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 Figure 2.5 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, sodium chloride 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 Figure 2.6 on the next page.



For a video of this reaction, follow the links to **Formation of sodium chloride**.

Figure 2.4 Formation of sodium chloride

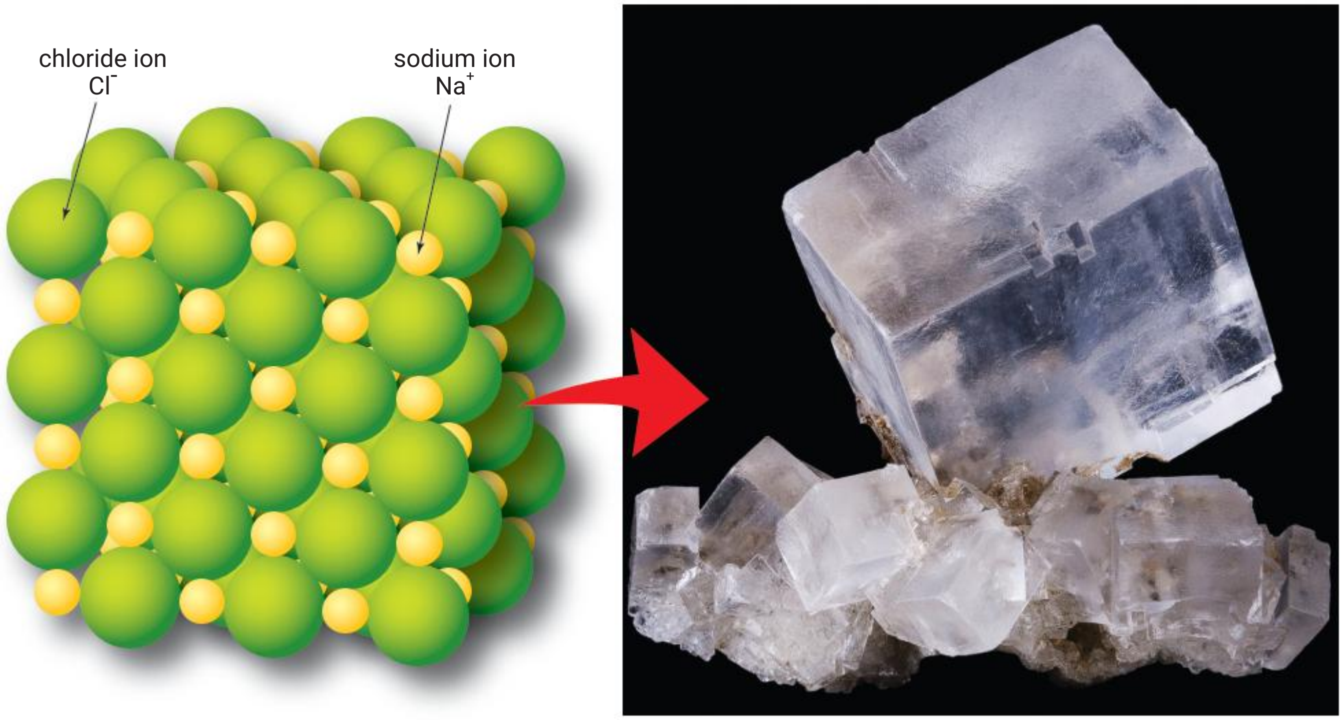


Figure 2.5 Sodium chloride crystals and their lattice of sodium chloride and ions. The positive and negative charges balance each other, so there is no overall charge.

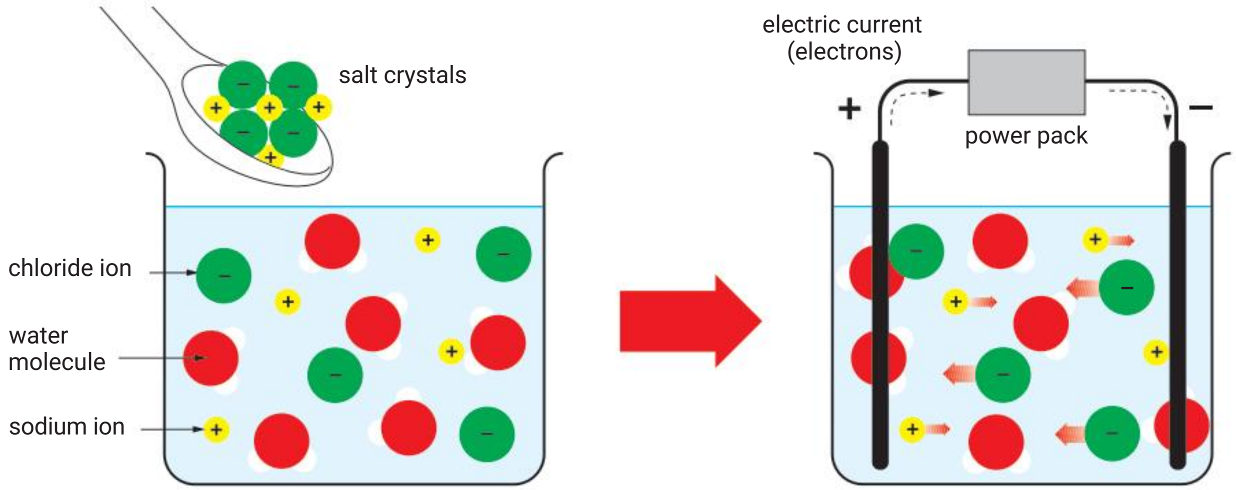


Figure 2.6 Sodium ions and chloride ions break apart in the solution. The ions carry the electric current through the solution, and electrons carry it through the wires to and from the power pack.

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 2.1 on the next page.

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INVESTIGATION 2.1 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

Risk assessment and planning

- 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?

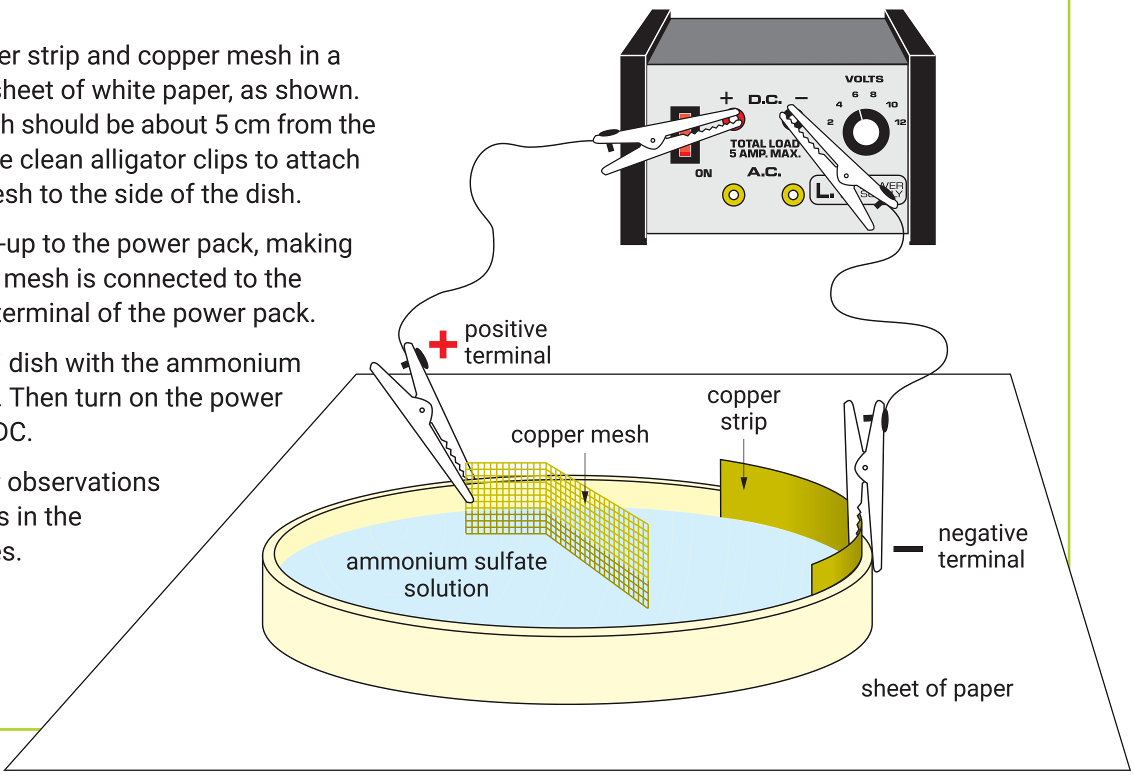
3 Infer where the copper ions came from.

4 In forming ions, did the copper atoms lose electrons or gain electrons? Write an equation for this (see page 32).

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.)



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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

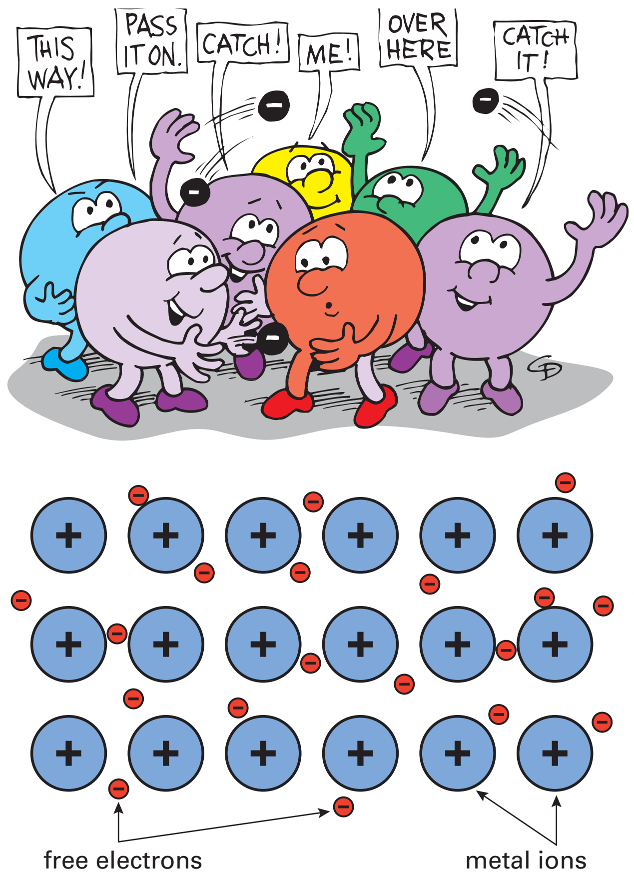

Figure 2.7 The properties of metals can be explained in terms of their atomic structure.

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, the electron from each atom is shared by the other atom. 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

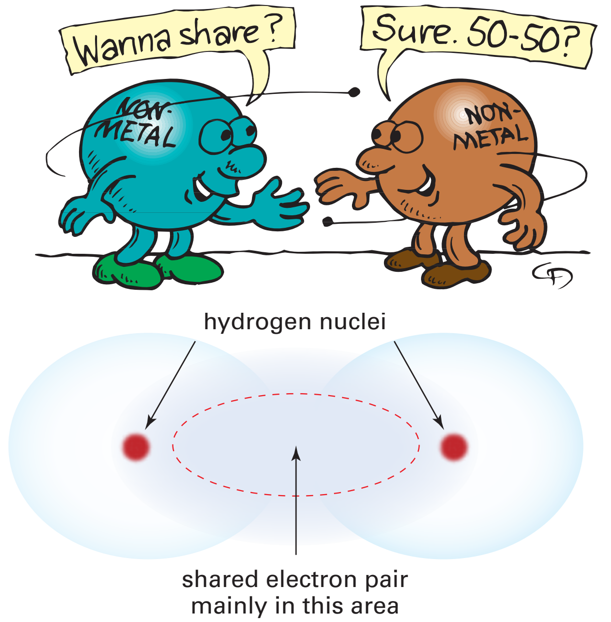

Figure 2.8 In a hydrogen molecule the hydrogen atoms share electrons equally.

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 Figure 2.10 on the next page). Compounds containing covalent bonds are called *covalent compounds*.

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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.

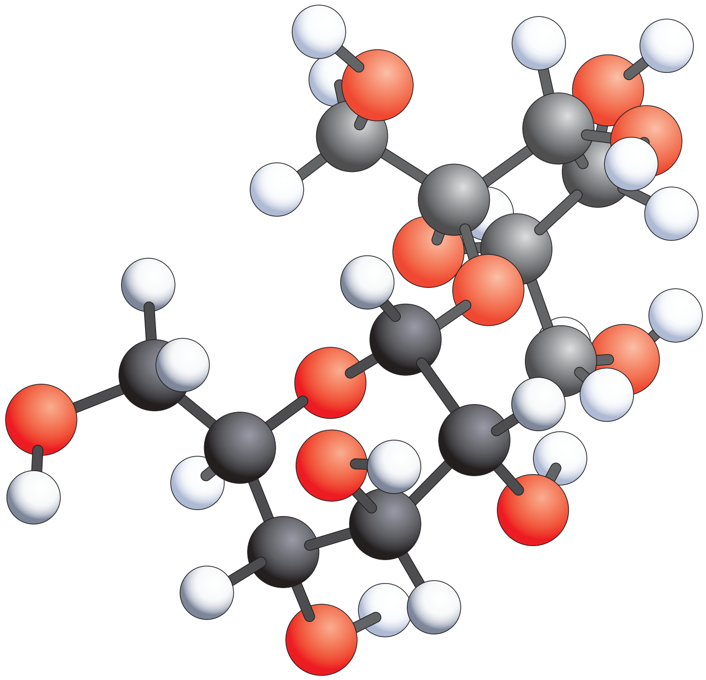


Figure 2.10 Sucrose (cane sugar) is a covalent compound with the formula $C_{12}H_{22}O_{11}$. In this model carbon atoms are black, hydrogen white and oxygen red.

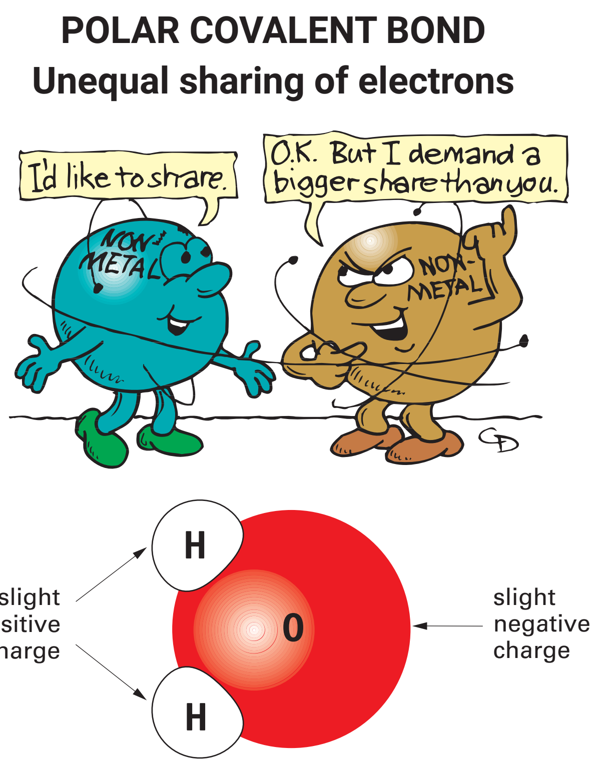
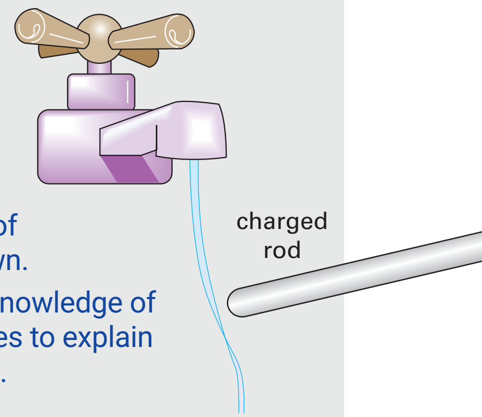


Figure 2.9 Water molecules are polar because the bonding electrons are pulled slightly towards the oxygen atom. The positive and negative charges balance each other, so the molecule has no overall charge.

Bonds between different non-metals are always polar, since no two non-metals are equally greedy for electrons. In contrast, 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.

For a summary of the different types of bonds, follow the links to **Bonding**.

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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?

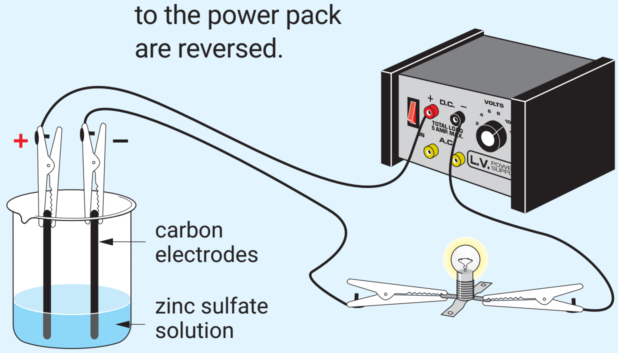
5 Bromine is a non-metal similar to chlorine. Predict whether bromine atoms tend to lose electrons or gain them. Explain your answer.

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 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?

8 Use your diagram from Question 7 to explain why metals are such good conductors of electricity.

9 Electricity is passed through a zinc sulfate solution containing zinc ions and sulfate ions.
   a Draw a 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?

8 How would the metallic bonding in an alloy differ from the metallic bonding in a pure metal?

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2.2 Formulas and equations

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

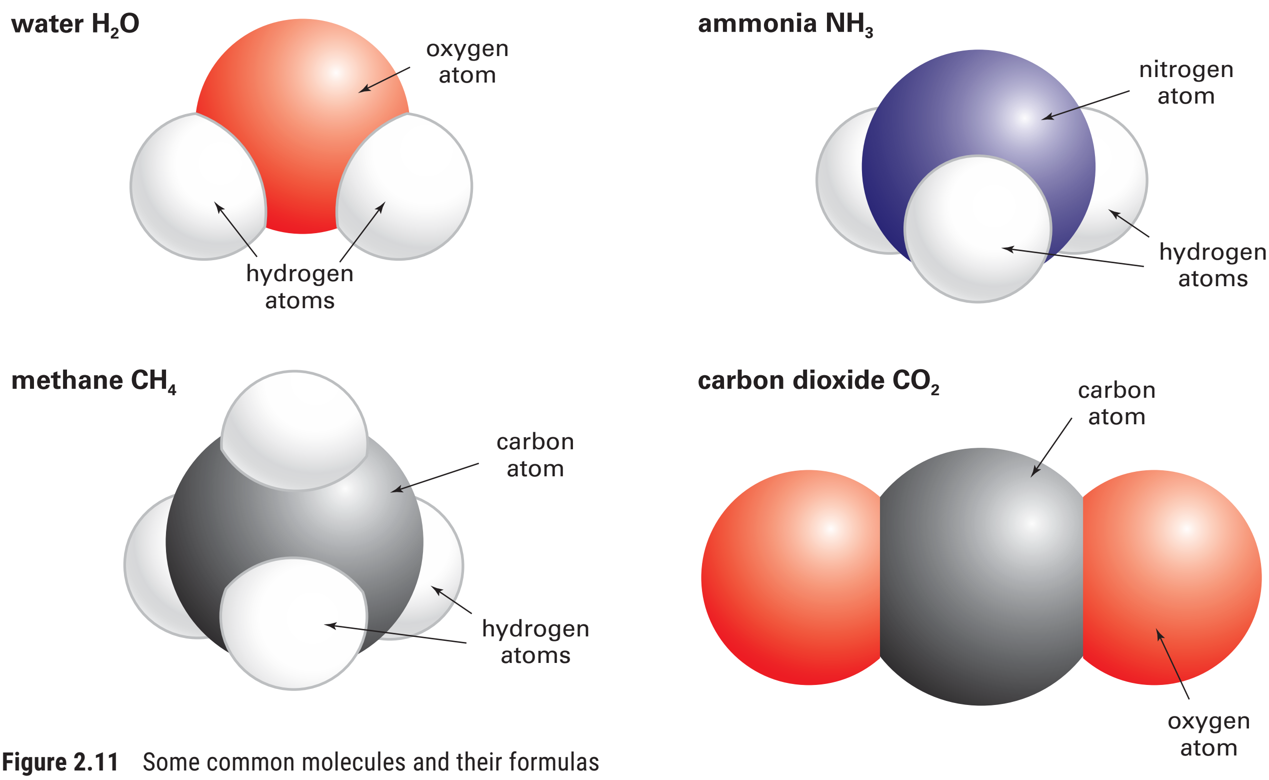

Figure 2.11 Some common molecules and their formulas

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Sometimes the ions consist of groups of atoms called *polyatomic ions* (*poly* means 'many'). 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.

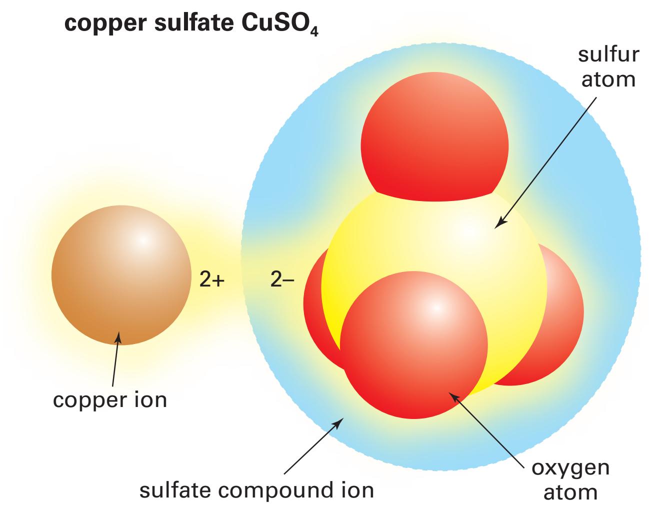


Figure 2.12 A model of copper sulfate $CuSO_4$. Note that these ions would be arranged in a crystal lattice similar to that for sodium chloride (Figure 2.5 on page 34).

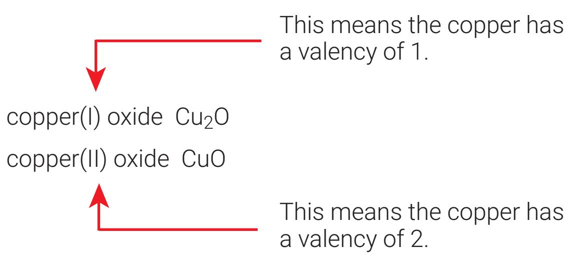
The sulfate compound ion has two negative charges, which balance the two positive charges on the copper ion. Similarly each unit of copper nitrate $Cu(NO_3)_2$ contains one Cu^{2+} ion and two nitrate NO_3^- compound ions, and each sodium carbonate Na_2CO_3 contains two Na^+ ions and one carbonate CO_3^{2-} 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 3.

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–

Some common monatomic and polyatomic ions



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Writing ionic formulas

To write the formula for an ionic compound, follow these rules.

Example 1

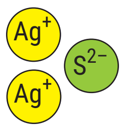
1. Write down the symbols of the ions. Note that the positive ion (usually a metal) goes first. Write the valencies above the symbols.

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

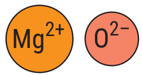


3. Write the correct formula with subscripts, leaving out the 1. Note that the charges are balanced. You need two Ag^+ ions to balance one S^{2-} ion.

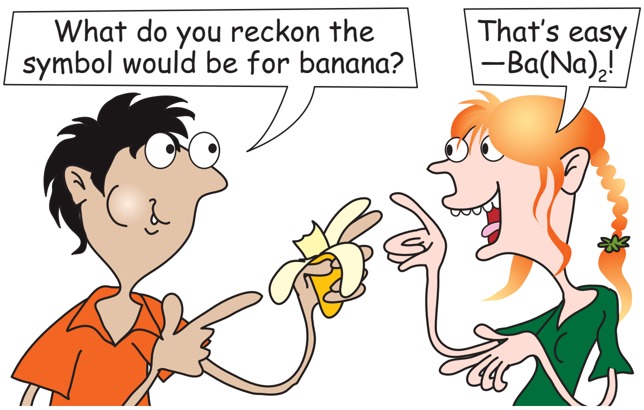
Example 2

magnesium	oxide
2+	2−
Mg_2	O_2

MgO



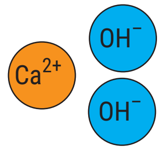
In this example, you simplify Mg_2O_2 to MgO since the magnesium and oxygen are in the ratio 1:1.



Example 3

calcium	hydroxide
2+	1−
Ca_1	$(OH)_2$

$Ca(OH)_2$

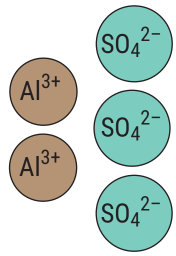


In this example, you put the compound ion in brackets to indicate that it acts as a single unit. The subscript 2 refers to everything inside the brackets. In other words, there are two oxygen atoms and two hydrogen atoms. Where there is only one unit of the compound ion, you can omit the brackets, e.g. NaOH rather than Na(OH).

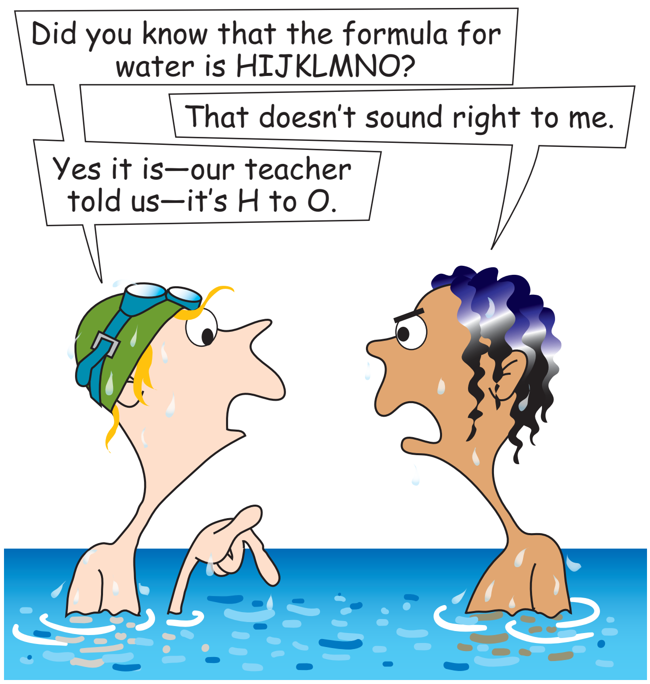
Example 4

aluminium	sulfate
+3	−2
Al_2	$(SO_4)_3$

$Al_2(SO_4)_3$



Two 3+ charges balance three 2− charges.



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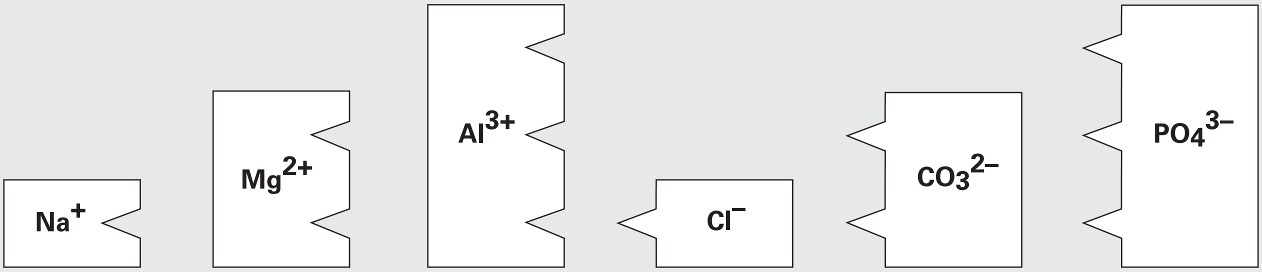

You can use paper or cardboard cut-outs to make models of various compounds. Look at the models above for various ions. Notches represent electrons lost to form positive ions. One notch indicates one positive charge or a valency of 1, two notches indicate a valency of 2, and three notches indicate a 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.

Figure 2.13 The mineral magnesite is composed of magnesium carbonate.

Figure 2.14 Sodium chloride is more commonly known as table salt.

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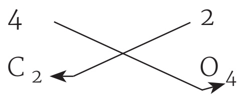
Covalent compounds

You can also use valencies to write the formulas for covalent compounds. For example:

carbon oxide



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; for example, hydrogen H_2, oxygen O_2, nitrogen N_2, chlorine Cl_2 and iodine I_2. It is best to remember these formulas.

Figure 2.15 Nitrogen gas (N_2) is a diatomic molecule. Nitrogen gas turns to liquid at −196 °C and is used to freeze biological samples, such as in this large insulated tank.

Most non-metals exist as molecules, where they have a stable number of electrons. By sharing electrons between atoms, each atom gains a full valence shell. So when carbon and oxygen bond, each atom shares some or all of its valence electrons so that in return it gets electrons shared with it. The number of electrons that an atom shares is determined by the number of valence electrons it has.

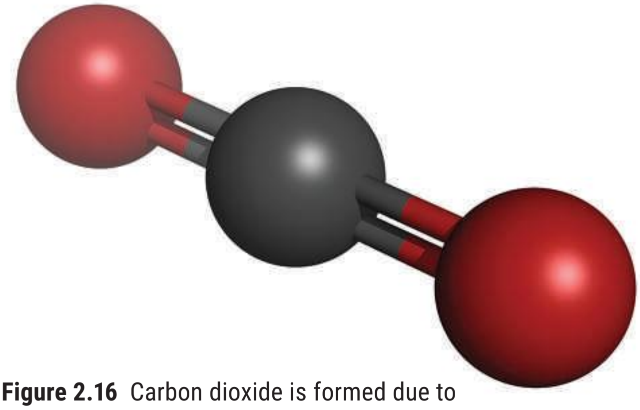


Figure 2.16 Carbon dioxide is formed due to electrons being shared between carbon and oxygen.

Nitrogen and oxygen together can form a number of different compounds, whose names indicate different ratios of nitrogen and oxygen. Nitrogen dioxide, NO_2, has one nitrogen atom and two oxygen atoms, whereas dinitrogen monoxide, N_2O, has two nitrogen and only one oxygen. Even though these compounds are made from the same elements, they are very different.

Figure 2.17 Nitrogen dioxide, NO_2, is a toxic brown gas.

Figure 2.18 Dinitrogen monoxide, N_2O, is an anaesthetic commonly called 'laughing gas'.

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Common compounds

Here is a list of common chemicals including their common name, chemical name and formula. You may have heard of many of these. You will find the list contains a mixture of substances with different types of bonding.

sulfur

marble

quartz

Common name	Chemical name	Formula
ammonia	nitrogen trihydride	NH_3
baking soda	sodium hydrogen carbonate or sodium bicarbonate	$NaHCO_3$
bleach (liquid)	sodium hypochlorite	$NaClO$
bleach (liquid)	hydrogen peroxide	H_2O_2
bleach (solid)	sodium perborate	$NaBO_3$
borax	sodium tetraborate	$Na_2B_4O_7$
brimstone	sulfur	S_8
-	carbon dioxide	CO_2
caustic soda	sodium hydroxide	$NaOH$
cream of tartar	potassium hydrogen tartrate	$KHC_4H_4O_6$
Epsom salts	magnesium sulfate	$MgSO_4$
freon	dichlorodifluoromethane	CCl_2F_2
galena	lead (II) sulfide	PbS
alcohol	ethanol	C_2H_5OH
-	gold	Au
graphite	carbon	C
gypsum	calcium sulfate	$CaSO_4$
hypo	sodium thiosulfate	$Na_2S_2O_3$
iron pyrites (fool's gold)	iron disulfide	FeS_2
laughing gas	dinitrogen oxide	N_2O
lime	calcium oxide	CaO
limestone	calcium carbonate	$CaCO_3$
marble	calcium carbonate	$CaCO_3$
marsh gas	methane	CH_4
milk of magnesia	magnesium hydroxide	$Mg(OH)_2$
-	nitrogen gas	N_2
-	hydrochloric acid	HCl
oil of vitriol	sulfuric acid	H_2SO_4
-	oxygen gas	O_2
plaster of Paris	calcium sulfate	$CaSO_4$
potash	potassium carbonate	K_2CO_3
quartz/sand	silicon dioxide	SiO_2
quicksilver	mercury	Hg
rubbing alcohol	isopropyl alcohol	C_3H_7OH
sal ammoniac	ammonium chloride	NH_4Cl
salt	sodium chloride	$NaCl$
-	potassium chloride	KCl
saltpetre	potassium nitrate	KNO_3
slaked lime	calcium hydroxide	$Ca(OH)_2$
sugar	sucrose	$C_{12}H_{22}O_{11}$
-	trisodium phosphate	Na_3PO_4
washing soda	sodium carbonate	Na_2CO_3
water	oxygen dihydride	H_2O
-	methyl alcohol	CH_3OH

ACTIVITY

Look at the table and answer the following questions.

1 Draw a table like the one on the right and list the formula of each compound above to classify them by the type of bonding they contain. The first two are completed for you.

Ionic	Metallic	Covalent
$NaHCO_3$		NH_3

2 Select five chemicals in the list that you have not heard of before. Find out what they are used for.

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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 40. 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:

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Figure 2.19 $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

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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 $4Fe + 3O_2 \rightarrow 2Fe_2O_3$.

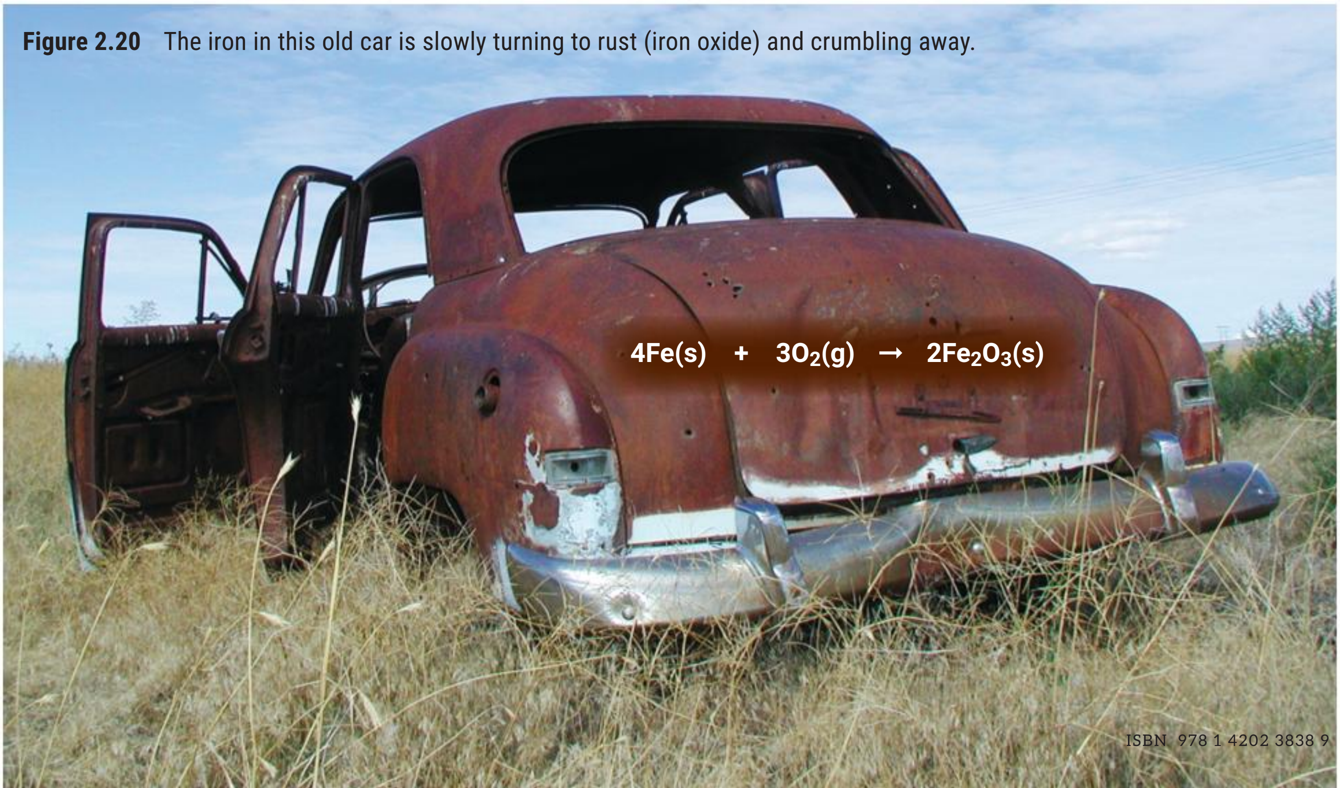

Figure 2.20 The iron in this old car is slowly turning to rust (iron oxide) and crumbling away.

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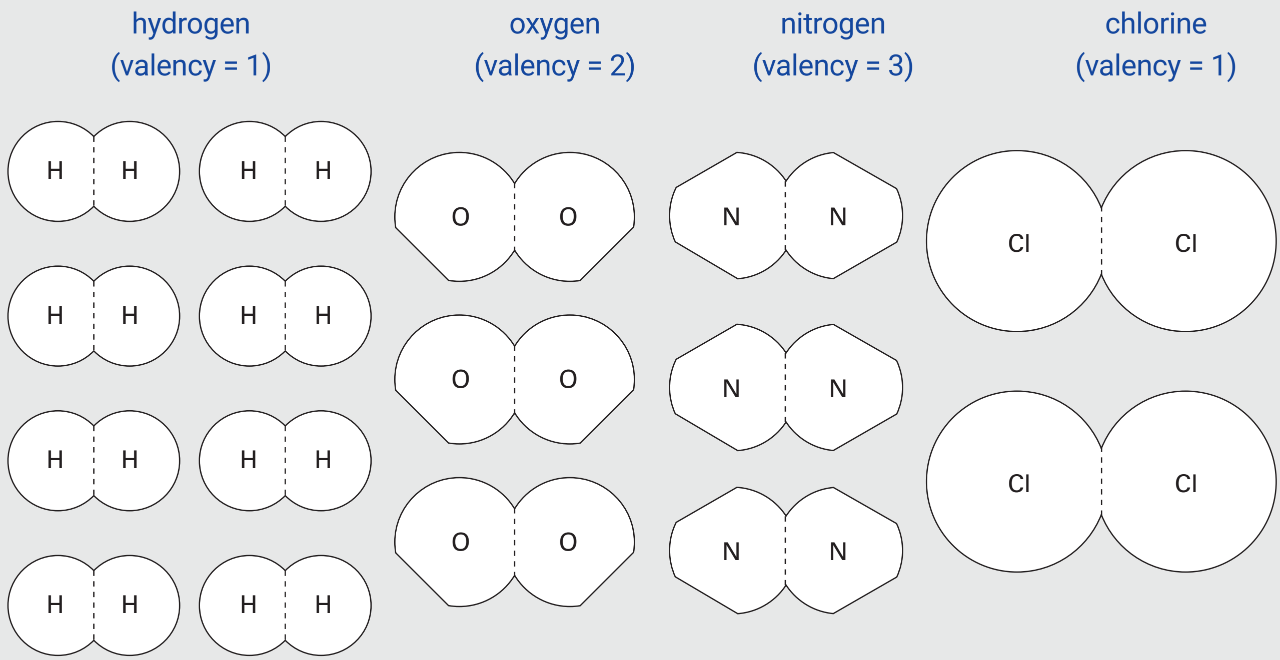


As you did on page 42, you can use paper or cardboard cut-outs to make models of chemical reactions. The cut-outs above represent some diatomic molecules.

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:

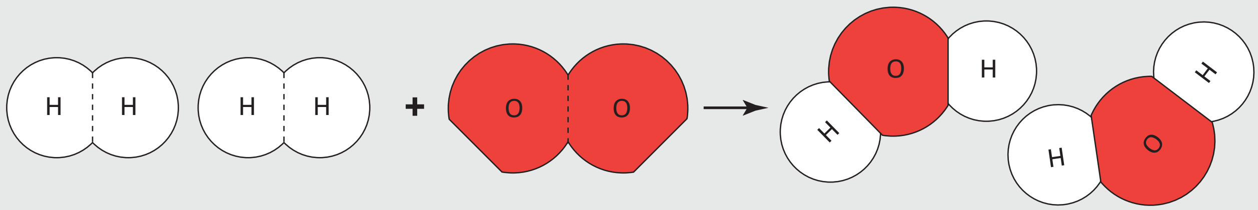
   hydrogen + chlorine → hydrogen chloride

   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**



$$2H_2 + O_2 \rightarrow 2H_2O$$

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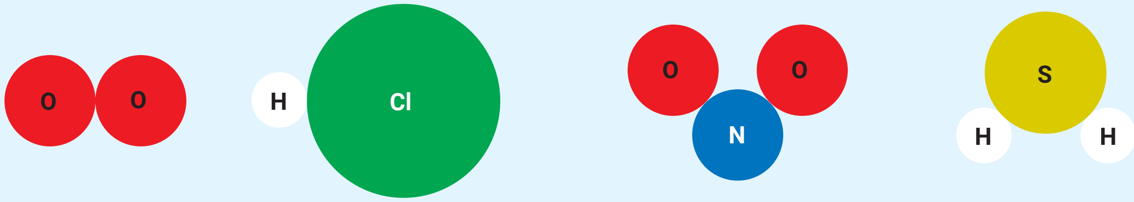
CHECK



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 40 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 Write balanced equations for each of the following reactions.
- a Carbon burns in a limited supply of oxygen to form carbon monoxide (CO).
- b Calcium carbonate when heated forms carbon dioxide gas and solid calcium oxide.
- c Dilute sulfuric acid reacts with sodium hydroxide solution to form sodium sulfate solution and water.

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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 $Cu + HNO_3 \rightarrow Cu(NO_3)_2 + H_2O + NO$

EXPLORE

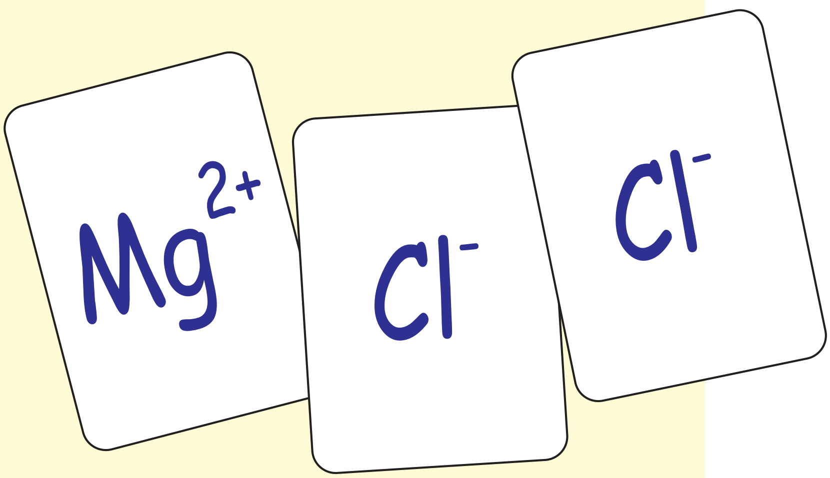
For this activity you will need playing cards with the names and valencies of positive and negative ions. Use all the ions listed on page 40 and make four identical cards for each one. You will need a total of 96 cards. (Use the 2+ valency for Cu, Fe and Pb.)

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.



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2.3 Classifying chemical reactions

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.

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$$

Another common combination reaction that we can observe around us is rusting, which is when iron and oxygen react together.

Figure 2.21 Iron oxide, Fe_2O_3, is formed as iron reacts with oxygen.

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.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Figure 2.22 Combustion occurs in a car engine.

Combustion reactions are used in internal combustion engines in cars. Petrol contains hydrocarbons, and when they burn the heat and gases produced cause the engine to produce kinetic energy, which allows the car to move.

3 Decomposition

Decomposition reactions are the opposite of combination 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.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Figure 2.23 An airbag is inflated by a decomposition reaction.

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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

In order for a precipitate to form, the attraction between the positive metal ions and the negative non-metal ions has to be high enough or they will stay in solution. When solutions of cobalt chloride and sodium hydroxide are mixed together, the precipitate cobalt hydroxide is formed. The remaining ions stay in solution as the soluble salt sodium chloride.

$$CoCl_2 + 2NaOH \rightarrow Co(OH)_2 + 2NaCl$$

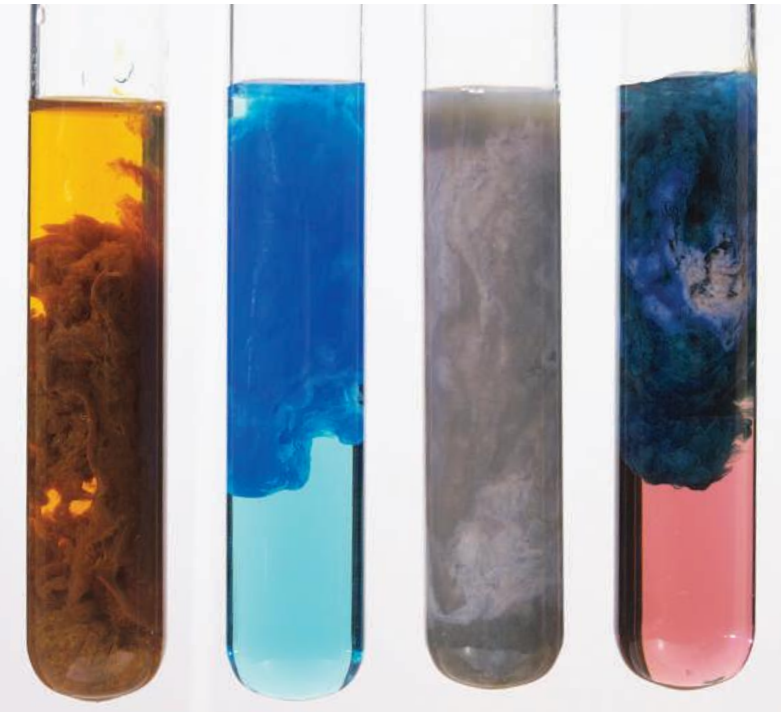

Figure 2.24 A range of coloured precipitates forming from clear solutions; cobalt chloride on the right

5 *Acid-metal reactions*

When acids are mixed with most reactive metals, the metal will dissolve and bubbles will form.

metal + dilute acid → salt + hydrogen

As the acid reacts with the metal, it causes it to dissolve into ions. Meanwhile, the hydrogen atoms from the acid join together to form hydrogen gas, which is why we observe bubbling.

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

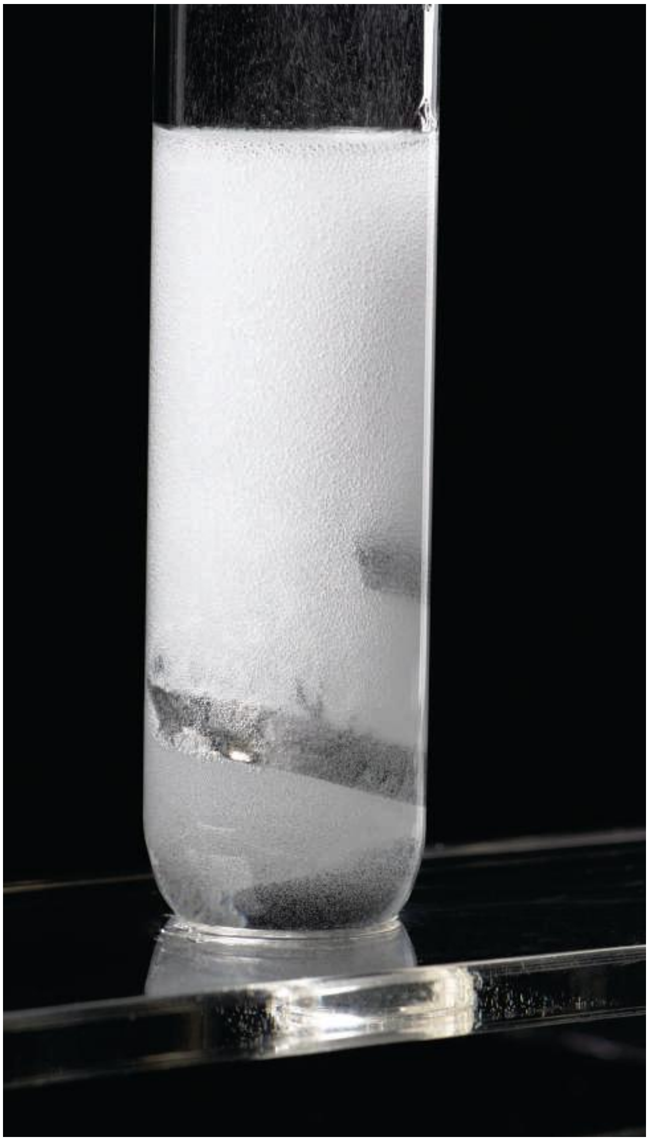

Figure 2.25 When a reactive metal is placed in acid it dissolves and the colourless gas hydrogen is produced.

We can test for the presence of hydrogen gas using a reaction called the pop test. Hydrogen is a very flammable gas and so reacts vigorously with oxygen in the air when an ignition source is present.

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6 *Acid-carbonate reactions*

As you have previously learnt, acids can also react with metal carbonates.

acid + metal carbonate → salt + water + carbon dioxide

The production of carbon dioxide means that this reaction bubbles, but rather than burning (like hydrogen gas does), CO_2 is a flame retardant and is often used in fire extinguishers because it prevents combustion from occurring.

When calcium carbonate, or chalk, is added to nitric acid, we see the solid dissolve as a gas is formed.

$$CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$$

A common science project is to make a model volcano, which erupts when vinegar (acetic acid) is added to baking soda (sodium hydrogen carbonate). This is an acid–carbonate reaction.

7 *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. This acid is mainly hydrochloric acid. After a big meal or during times of stress, some people experience heartburn, where excess stomach acid is causing them pain. An antacid neutralises that acid by reacting with it to produce harmless products.

$$2HCl + Mg(OH)_2 \rightarrow MgCl_2 + 2H_2O$$

Figure 2.27 Antacids contain metal hydroxides that help to neutralise stomach acid.

Figure 2.26 A model volcano erupting, with carbon dioxide being released

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8 Metal displacement

Metal displacement reactions involve the swapping of metals, one from a solid into ions in solution, the other from ions into a solid. When a reactive metal is placed in a solution of a less reactive metal ion, the metals swap places. For example, when a strip of nickel is placed in copper sulfate solution (Figure 2.28), copper metal is displaced and the solution turns from blue to colourless.

$$Ni + CuSO_4 \rightarrow Cu + NiSO_4$$

Figure 2.28 Nickel displacing copper from copper sulfate solution

The metals can be arranged in a list with the most reactive at the top and the least reactive at the bottom. This is called the **activity series**. Sodium, near the top of the list, 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 activity series can be used to predict reactions of metals; for example, which ones will react most rapidly with an acid. You can also use the activity series to predict which metal will displace another metal from its solution. For example, nickel is more reactive than copper, so it displaces copper from copper sulfate solution. But it cannot displace a more reactive metal like magnesium that is above it in the activity series. The metals at the top of the activity series are also harder to extract from their ores than the ones at the bottom. For example, aluminium is much harder to extract than lead.

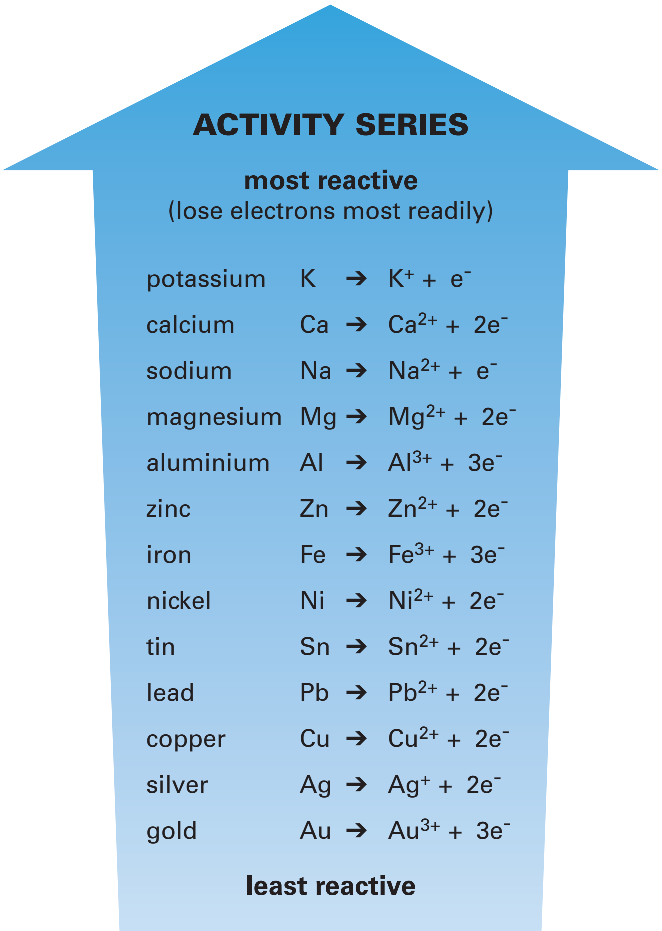

Figure 2.29 In the activity series the metals are listed from the most reactive to the least reactive.

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INVESTIGATION 2.2 Common reaction types

Aim

To investigate some common reaction types.

Risk assessment and planning

Read the investigation carefully. Make a list of any risks and discuss them with your teacher before starting.

PART A Reaction 1 and 2

Materials

- 2 test tubes
- test tube rack
- hydrochloric acid solution (0.1 M)
- magnesium strip, approx. 2 cm
- splint and matches
- disposable gloves (optional)

Method

1. Quarter fill a test tube with hydrochloric acid.
2. Add a 2 cm strip of magnesium metal.
3. Place a second test tube over the top of the reaction test tube to collect the gas.
4. Use a lighted splint to test the gas collected.
   Record your observations for both reactions.

Discussion

1. There are two reactions you just performed. What common reaction type does each belong to?
2. What was the gas produced in the reaction, and how do you know?
3. Identify and name the reactants and products in each reaction, and write the chemical formula for each.
4. Write a balanced chemical equation for each reaction.

PART B Reaction 3

Materials

- 1 test tube
- test tube rack
- pH paper
- hydrochloric acid solution (0.1 M)
- sodium hydroxide solution (0.1 M)
- 10 mL measuring cylinder
- disposable gloves (optional)

Method

1. Ensure the measuring cylinder is clean and measure 2 mL of hydrochloric acid.
2. Pour the acid into a test tube and test the pH of the acid with the pH paper.
   Record the pH.
3. Ensure the measuring cylinder is clean and has no acid in it. Measure 2 mL of sodium hydroxide solution and test its pH with indicator paper.
   Record the pH.
4. Pour the sodium hydroxide into the test tube containing the hydrochloric acid. Gently shake to mix.
5. Test the mixture with pH paper.
   Record the pH of the mixture.

Discussion

1. What common reaction type does this reaction belong to? What evidence have you used to make this decision?
2. Identify and name the reactants and products in the reaction, and write the chemical formula for each.
3. Write a balanced chemical equation for the reaction.

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CHECK

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.
   f Propane (C_3H_8) burns in air to produce carbon dioxide and water vapour.
   g A few marble chips ($CaCO_3$) are placed into a beaker of hydrochloric acid.

2 Write balanced equations for each of the reactions listed in Question 1.

3 Lead nitrate and potassium iodide are both colourless solutions. The photo shows what happens when they are mixed. Explain what has happened.

CHALLENGE

A salt is an ionic compound made up of positive and negative ions. To tell whether a salt is soluble or not, you can use a solubility table. Determine whether the following salts are soluble or insoluble:

a calcium phosphate
b lithium nitrate
c barium hydroxide
d iron carbonate
e nickel iodide
f copper sulfate
g manganese chloride
h cobalt nitrate

Soluble in water	Examples of the rule	Exceptions to the rule
Salts of chloride, bromide (Cl^-, Br^-)	NaCl, KBr, etc.	AgCl, AgBr
Salts of iodide (I^-)	MgI_2	AgI, PbI_2
Salts of nitrate (NO_3^-)	$AgNO_3$	None
Salts of sulphate (SO_4^{2-})	Li_2SO_4	$BaSO_4$, $PbSO_4$

Insoluble in water	Examples of the rule	Exceptions to the rule
Salts of hydroxide (OH^-)	$Ca(OH)_2$	NaOH, KOH
Salts of carbonate (CO_3^{2-})	$MgCO_3$	Na_2CO_3, K_2CO_3
Salts of phosphate (PO_4^{3-})	$FePO_4$	Na_3PO_4, K_3PO_4

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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.

ionic
balanced
oppositely
dissolves
covalent
lose
negatively
electrons
reactions
ions
valency

CH•2 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?

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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?

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, a 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 Figure 2.30.)

Figure 2.30 An iron nail in copper sulfate solution

- **a** Write an inference to explain why the solution lost some of its blue colour.
- **b** Use what you have learnt in Section 2.3 about ions changing partners to write a balanced equation for the reaction that occurred.

12
- **a** List the eight common reaction types explained in Section 2.3.
- **b** Give one example for each type of reaction.
- **c** If possible, write a chemical equation for each of the reactions you have described in **b**.

Check your answers on page 342.

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EXTRA FOR EXPERTS

Mole calculations

What is a mole?

Chemical reactions always involve huge numbers of atoms, which are incredibly small. It is impossible for us to count how many atoms are involved, so we use **Avogadro's number** to make the calculations more manageable. You are probably familiar with buying a dozen eggs or half a dozen bread rolls. In the same way that a dozen always means 12, or half a dozen is six, a **mole** is always 6.022×10^{23} atoms or molecules. That's 602 200 000 000 000 000 000 000 atoms or molecules!

One mole of a range of substances. While they have different masses, they all contain the same number of particles.

Avogadro's number may look daunting, but the idea behind it is simple. It allows us to weigh out 1 mole of a substance, because 6.022×10^{23} atoms of an element have the same mass in grams as its relative atomic mass from the periodic table. This means that 1 mole of any substance has the same number of particles. By using the concept of a mole, we can easily weigh out samples and calculate how many particles are in that substance.

So what do we use moles for? If we know the number of moles of a substance, we can use it to figure out how many moles of other substances it reacts with, and the quantity of products that is formed. For example, look at the following balanced equation:

$$2Mg + O_2 \rightarrow 2MgO$$

This equation tells us that two atoms of magnesium react with one molecule of oxygen gas. The *law of multiple proportions* says that when elements combine to form compounds, they do so in the ratio of whole numbers. Combining this with the mole concept we can conclude that two moles of magnesium will react with one mole of oxygen. Can you figure out how many moles of magnesium oxide will form?

Magnesium ribbon burning

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Atoms, molecules and moles

Now that we know that one mole always contains 6.022×10^{23} atoms or molecules, we can figure out how many moles we have, given different numbers of particles.

$$\text{number of moles} = \frac{\text{number of particles}}{\text{Avogadro's number}}$$

or

$$\text{number of particles} = \text{number of moles} \times \text{Avogadro's number}$$

Example 1: Hydrogen atoms

How many atoms of hydrogen (H) are there in 0.5 mole of hydrogen?

To calculate this, we use a formula that allows us to convert between the number of moles and the number of particles.

So, number of atoms $= 0.5 \times 6.022 \times 10^{23}$
$= 3.011 \times 10^{23}$ atoms of H

Example 2: Hydrogen molecules

What if we had 0.5 moles of hydrogen gas (H_2)? Would we have the same number of particles? And would we have the same number of atoms? Let's take a look.

number of molecules $= 0.5 \times 6.022 \times 10^{23}$
$= 3.011 \times 10^{23}$

If we want to know how many *atoms* of hydrogen we have, we need to know that each molecule of H_2 contains two atoms of hydrogen. So to calculate the number of atoms of hydrogen, we multiply the number of molecules by 2.

number of atoms $= 2 \times$ number of molecules
$= 2 \times 3.011 \times 10^{23}$
$= 6.022 \times 10^{23}$

Questions

1 Calculate the number of atoms, given the following number of moles:
   - a 0.8 mole of silver
   - b 0.1 mole of neon
   - c 3.5 moles of carbon

2 Calculate the number of molecules, given the following number of moles:
   - a 1.3 moles of oxygen gas (O_2)
   - b 7 moles of water (H_2O)
   - c 0.2 mole of ammonia (NH_3)

3 Use your answers from question 2 to calculate the number of atoms in each of the three samples.

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Molar masses

From the periodic table, we know that the relative atomic mass of carbon is 12.01. So if we have 12.01 grams of carbon, we have 1 mole of carbon. To calculate the molar mass of a molecule, we must combine the masses of the atoms within that molecule. Oxygen gas has the formula O_2, so that means that to calculate the molar mass, we need to double the atomic mass of oxygen.

Example 1: Water

The molar mass of water can be calculated by adding the masses of 2 hydrogens and 1 oxygen.

molar mass of H_2O = $(2 \times 1.008) + 16.00$
= 18.016 g/mol

We use the units g/mol to show that we have that many grams per mole.

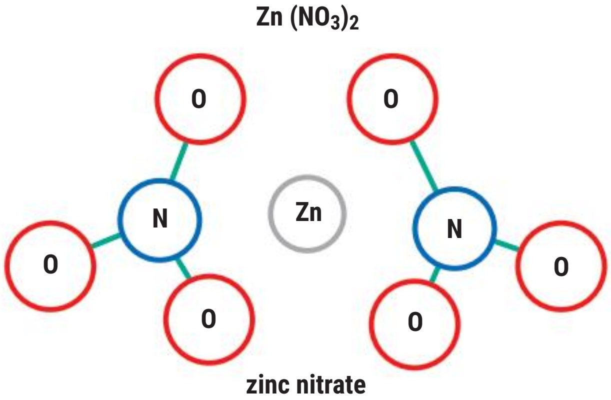
Example 2: Zinc nitrate

First we identify how many atoms of each element we have within the molecule. Zinc nitrate has the formula $Zn(NO_3)_2$, so we have 1 atom of zinc, 2 nitrogens and 6 oxygens.

Atomic masses:

zinc	65.38
nitrogen	14.01
oxygen	16.00

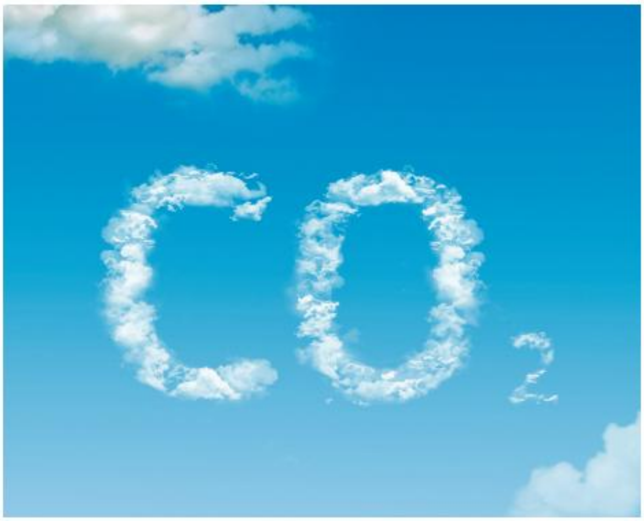
molar mass = $65.38 + (2 \times 14.01) + (6 \times 16.00)$
= 189.40 g/mol



Question

Calculate the molar mass of the following compounds:

a nitrogen gas (N_2)
b carbon dioxide (CO_2)
c copper sulfate ($CuSO_4$)
d acetic acid (CH_3COOH)
e ammonium sulfate $(NH_4)_2SO_4$



Mass to moles

Now that we can calculate molar masses, we can use this information to convert between number of moles and mass. This allows us to weigh a sample and instead of having to count out how many atoms are in it, we can calculate the number of moles instead.

For example, if we have 24.02 g of carbon, we can divide that by the molar mass (the same as the atomic mass for an element) to calculate how many moles we have.

$$\text{number of moles} = \frac{\text{mass of our sample}}{\text{molar mass}}$$

So the number of moles of carbon would be calculated as:

number of moles of carbon = 24.02 / 12.01 = 2

This allows us to convert between the mass of a substance and the number of particles.

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Example 1: Iodine

Calculate the number of moles in 469.5 g of iodine.

$$\text{number of moles} = \frac{\text{mass}}{\text{atomic mass}}$$
$$= 469.5 / 126.9 = 3.7$$

Example 2: Magnesium

Calculate the mass of 5 moles of magnesium

mass = number of moles × atomic mass
= 5 × 24.31
= 121.55 g

Example 3: Carbon dioxide

Calculate the number of moles in 300 g of carbon dioxide.

molar mass of CO_2 = 12.01 + 32.00 = 44.01

$$\text{number of moles} = \frac{\text{mass}}{\text{molar mass}}$$
$$= 300 / 44.01 = 6.82$$

Questions

1 Calculate the number of moles in the following:
  a 0.7 g of helium
  b 158 g of gold
  c 20 g of calcium oxide

2 Calculate the mass of the following:
  a 0.37 moles of sodium
  b 14.8 moles of xenon
  c 2.94 moles of methane (CH_4)
  d 0.1 mole of copper sulfate ($CuSO_4$)

The noble gas xenon is used in car headlights.

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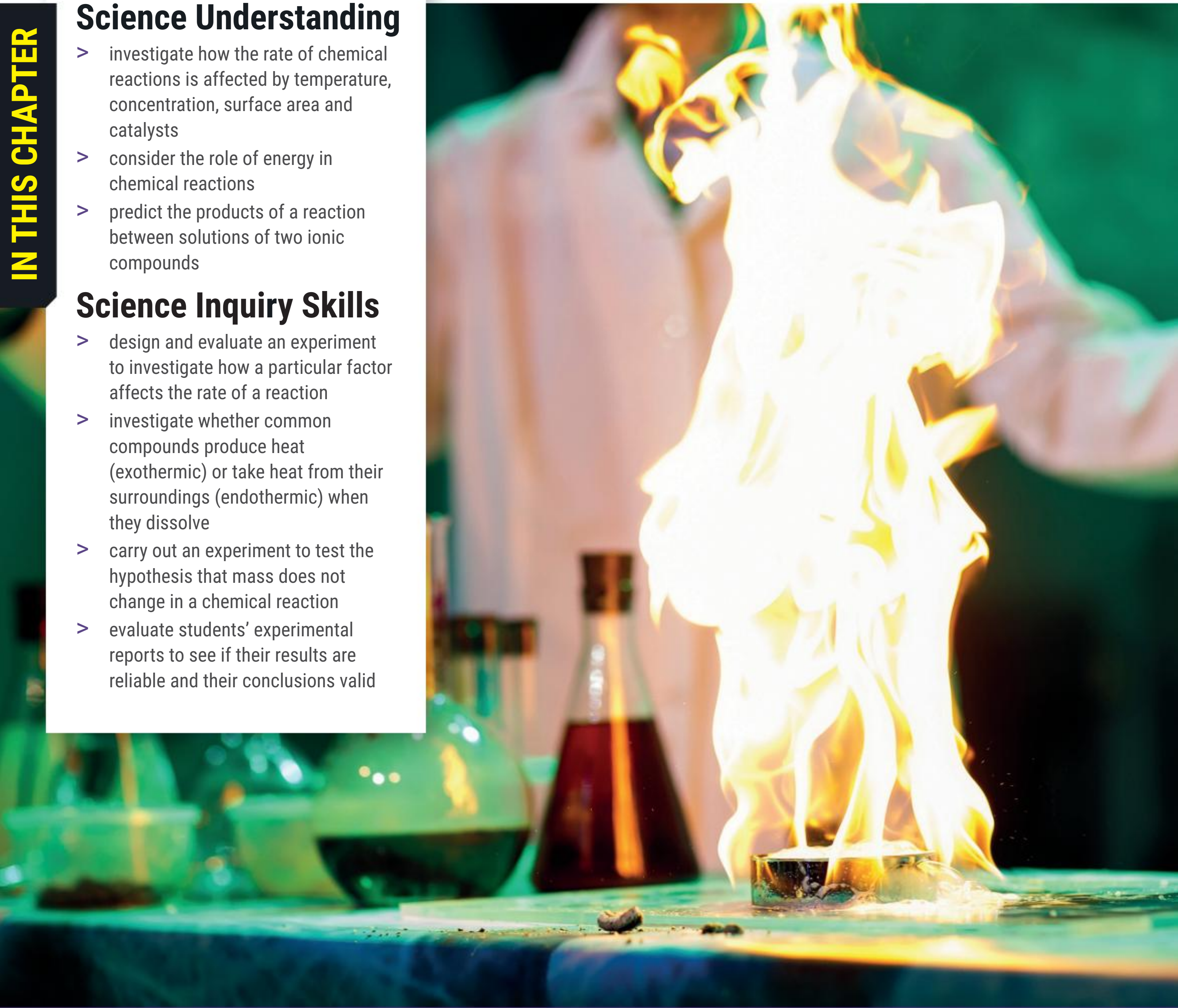
IN THIS CHAPTER

Science Understanding

- investigate how the rate of chemical reactions is affected by temperature, concentration, surface area and catalysts
- consider the role of energy in chemical reactions
- predict the products of a reaction between solutions of two ionic compounds

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



CH•3 Investigating reactions

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GET STARTED: *EXPLORE*

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.

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3.1 Predicting a reaction

When we observe chemical reactions happening, there are many factors that affect how that reaction is happening, or whether it will happen at all. We know that all reactions involve atoms, and that when a reaction occurs, there is a rearrangement of atoms. This means that bonds are broken and new ones formed. The newly formed substances are called products.

When carbon monoxide (CO) and oxygen gas react together, they form carbon dioxide (CO_2). In that process the O_2 molecules break apart, and each O atom bonds to a CO molecule to form CO_2, as shown below. To understand why this reaction does not occur every time the gases are mixed, we need to understand what conditions need to be met in order for a reaction to take place.

Collision theory

When trying to predict if a reaction will occur, we have to see if the reaction meets each of the conditions of the **collision theory**. This theory says that for a reaction to occur, atoms, ions or molecules must collide with the correct orientation and with sufficient energy. This means that in order for carbon monoxide and oxygen gases to react with one another, they need to collide in the right way, so that the O–O bonds break. They also need to collide with enough energy, so that the bonds can be broken. Whenever we observe a chemical reaction occurring, these two conditions of the collision theory must have been met.

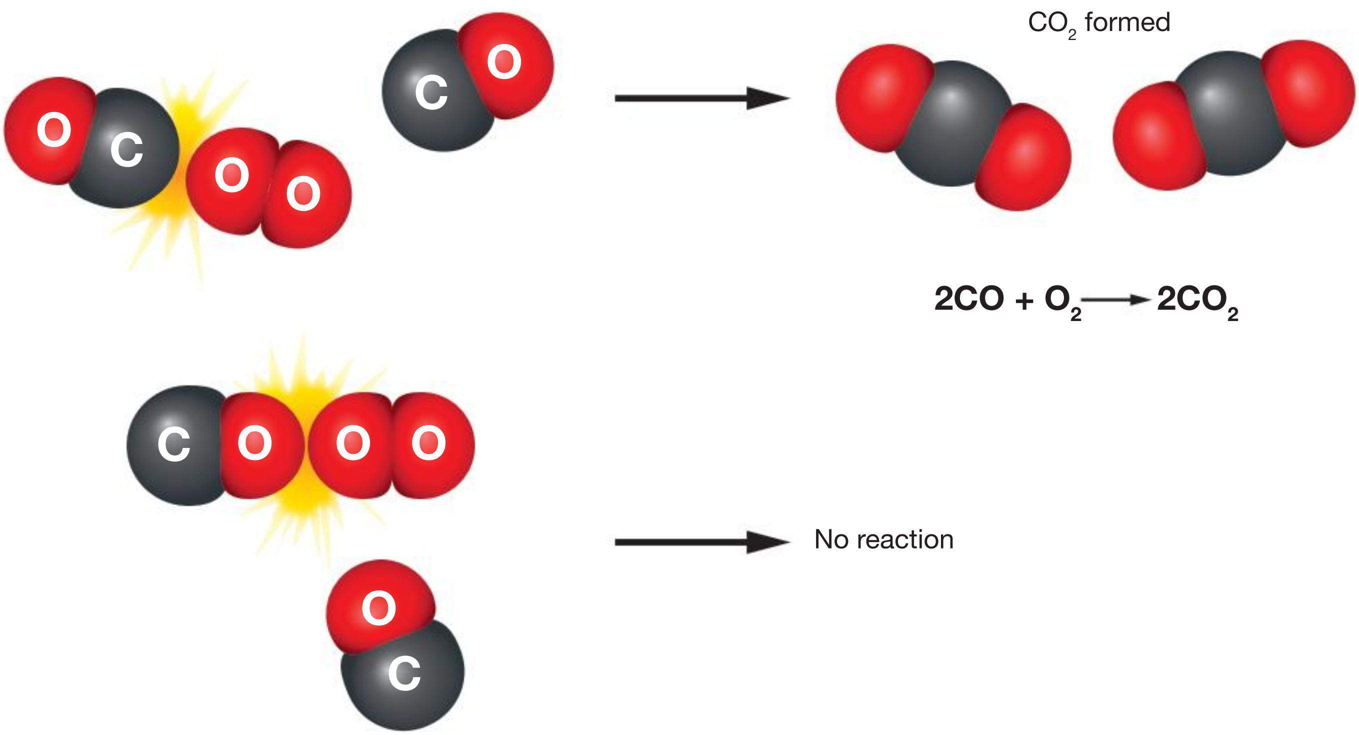

Figure 3.1 Carbon monoxide and oxygen won't react unless the molecules collide with the correct orientation (O atom hitting C atom, not O hitting another O atom) and with enough energy.

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A precipitation reaction

When new substances are formed in a chemical reaction, we know that the reactants must have collided in order to produce them. We will now look in detail at the reaction between solutions of potassium iodide and lead nitrate.

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 (Figure 2.5 on page 34). 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.

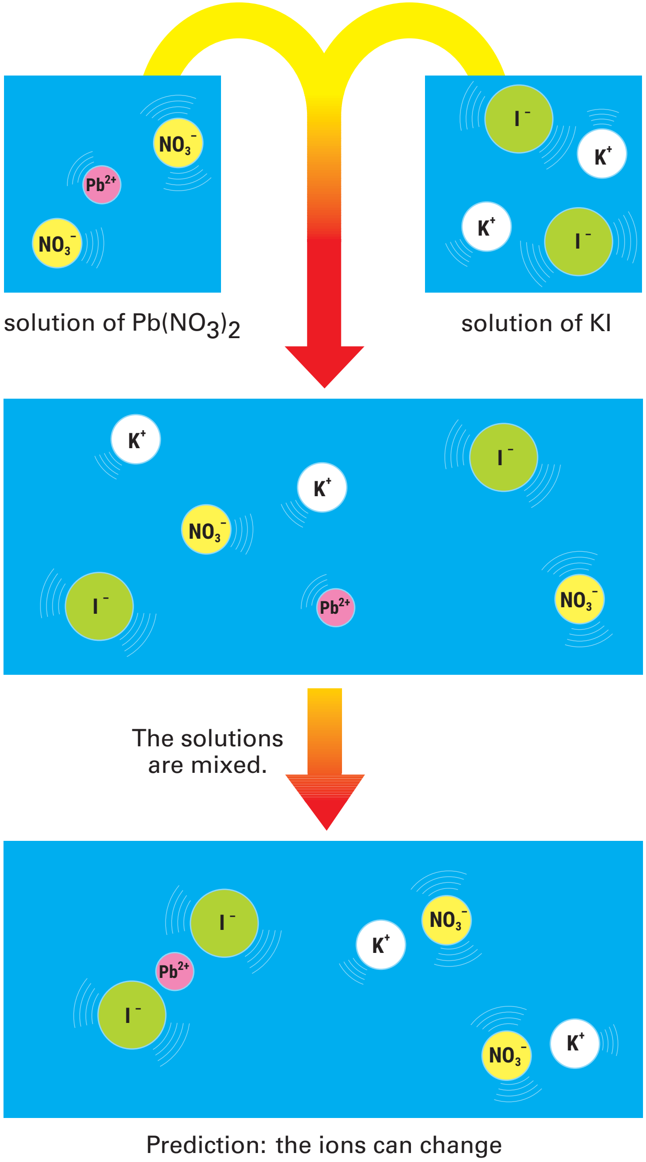

Figure 3.2 A precipitation reaction

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 3.1.

lead nitrate + potassium iodide → lead iodide + potassium nitrate

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INVESTIGATION 3.1 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)

Risk assessment and planning

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.

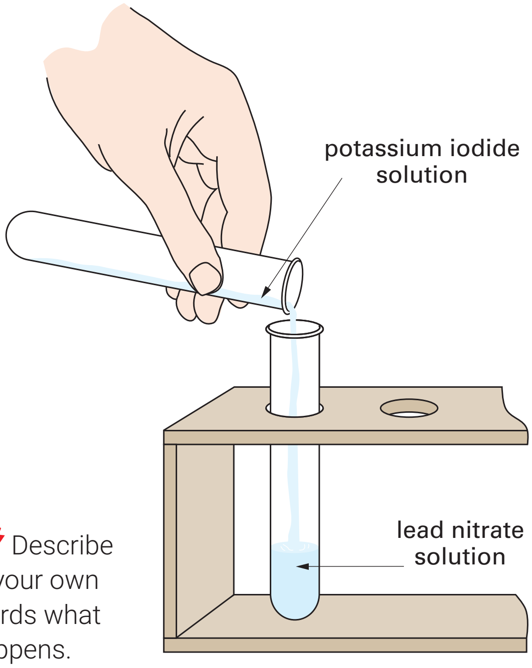
- How will you dispose of the lead and lead compounds?

Since iodine fumes are produced in Part B, step 2 should be done in a fume cupboard.

Method

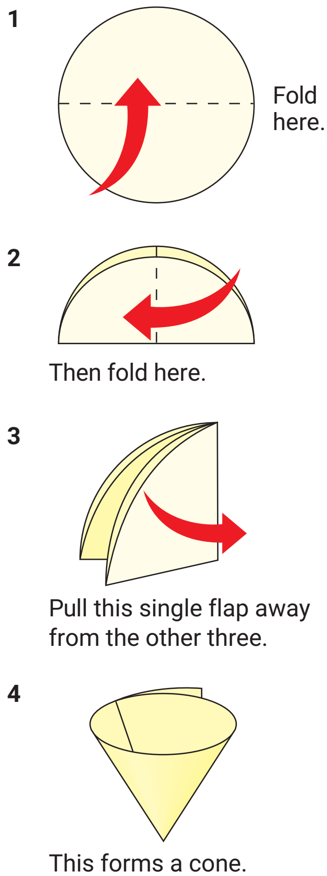
1 Quarter fill one test tube with lead nitrate solution, and the other with potassium iodide solution.

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.



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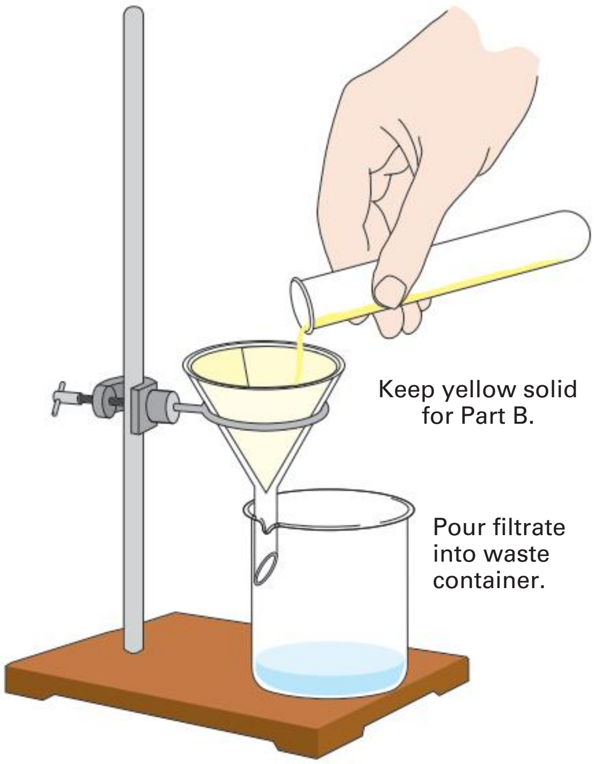
4 Place the cone into the filter funnel and use the wash bottle to wet the paper to hold it in place. Carefully pour the contents of the test tube into the funnel and collect the filtrate in the beaker. Pour this into a special waste container.



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 65, 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

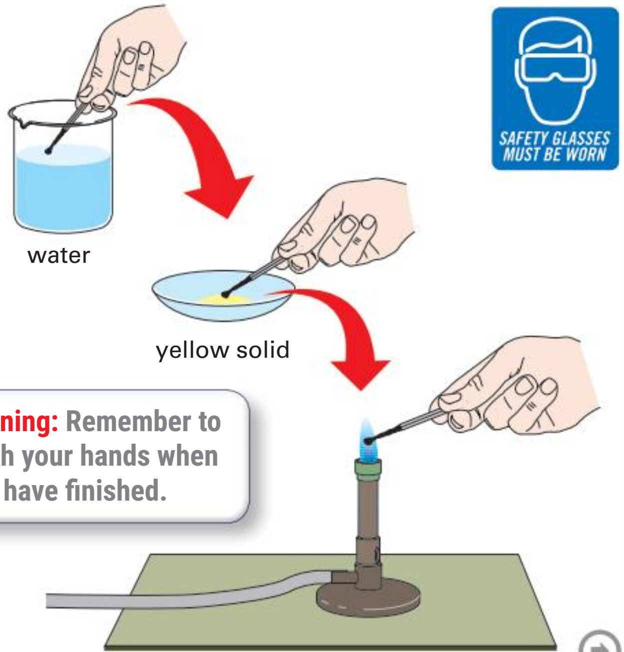
Method

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 Figure 3.2 on page 65. 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.

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

(Check the equation you wrote in Discussion question 3 above.)

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*.

$$Pb^{2+} + 2I^- \rightarrow PbI_2$$

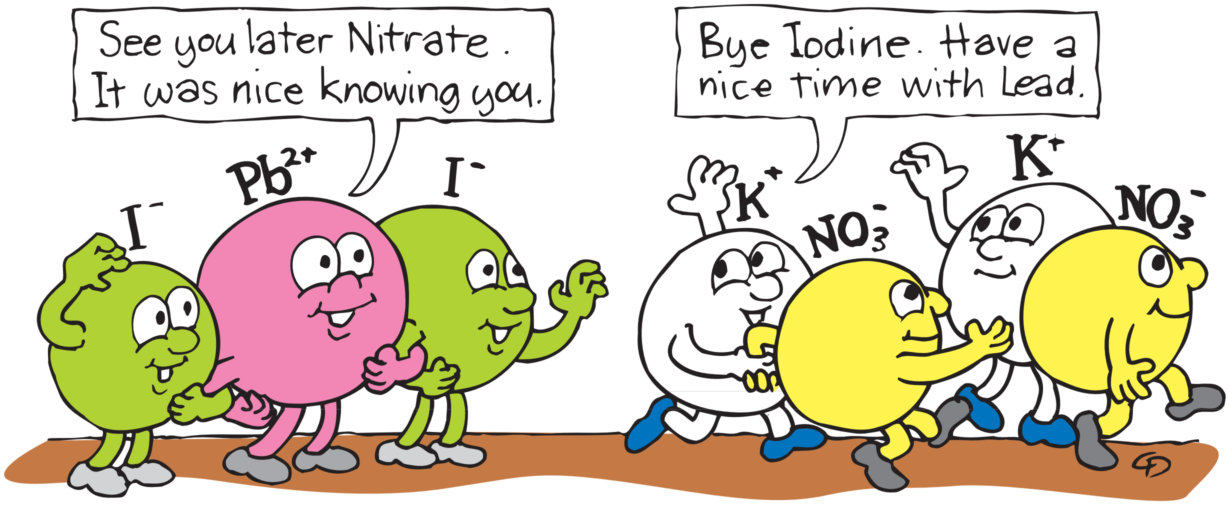


Figure 3.3 When lead nitrate and potassium iodide are mixed, the lead ions are more strongly attracted to iodide ions than they are to nitrate ions. So the ions change partners.

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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 top right 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.

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

a What is the solubility of:
- lead nitrate?
- magnesium carbonate?

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 65.)

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.

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3.2 Reaction rates

Figure 3.4 Slow to fast reactions

When you boil an egg, the egg looks and tastes different from the egg you started with. The boiling of the egg 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 in which 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 3.2 you can try this reaction yourself. The aim of the investigation is to find an answer to the research question.

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INVESTIGATION 3.2 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

Risk assessment and planning

- 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

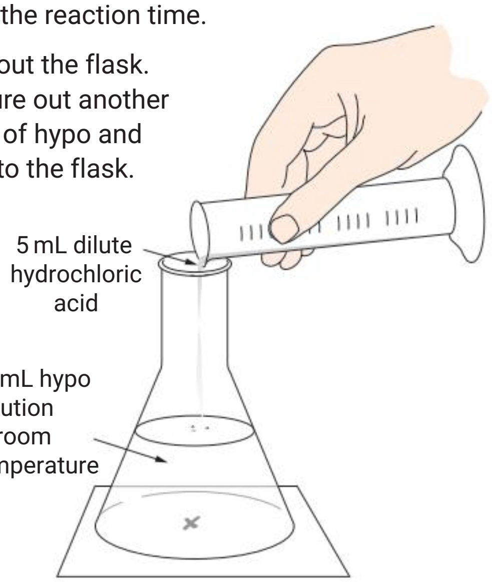
Method

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.



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

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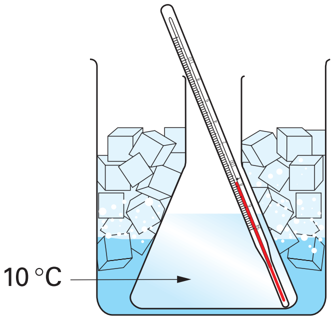
5 Put some water in a 500 mL beaker, and add some ice. Put the flask in the beaker of ice and let the hypo cool to about 10 °C.

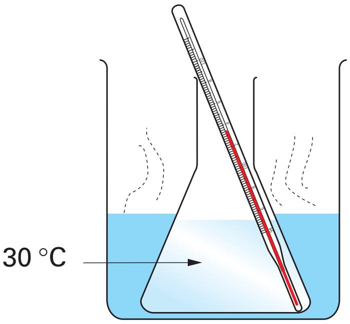


6 When the hypo has cooled, quickly take the flask out of the ice, wipe the water from the outside, and put the flask over the cross. Add 5 mL of acid immediately, start timing, and swirl the flask twice.

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?

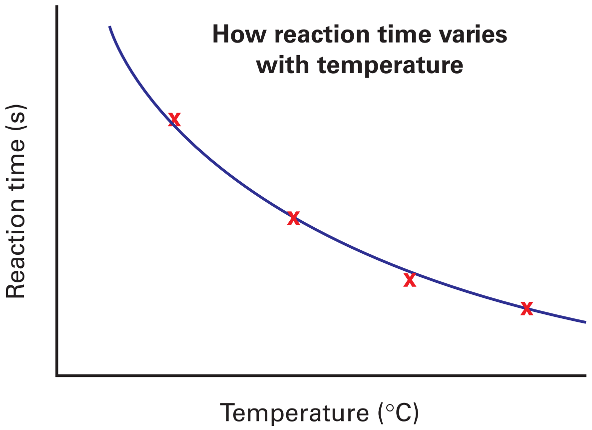
2 Use your results to decide whether your original hypothesis was correct. If necessary, rewrite it.

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—as 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?

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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, in which 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.

Figure 3.5 The tablet in hot water on the right reacted and dissolved faster than the one in cold water on the left.

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.

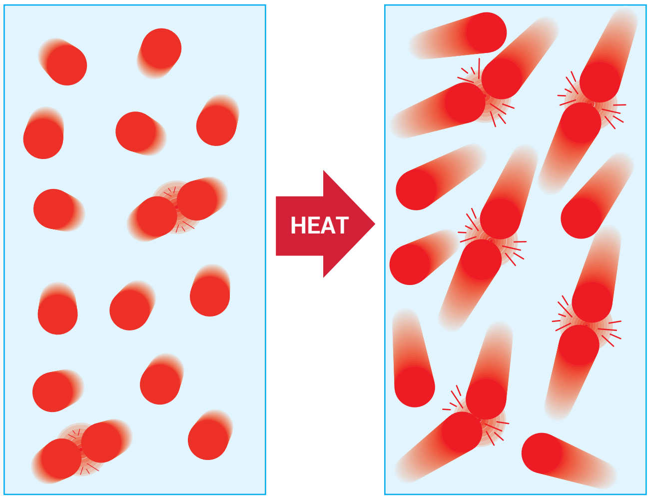

Figure 3.6 At higher temperatures the particles have more energy and collide more often and more violently. This is why chemical reactions are more likely to occur.

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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.

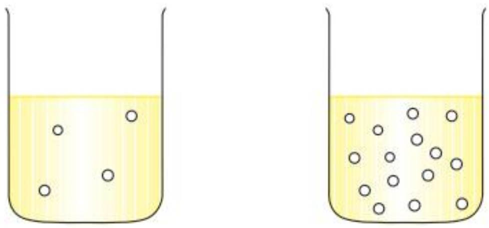


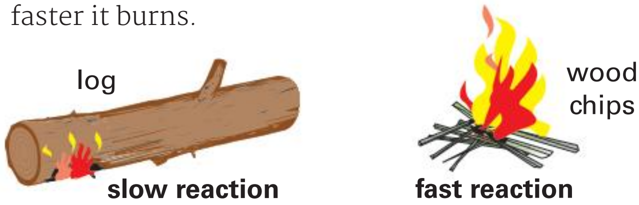
Figure 3.7 The difference between dilute and concentrated solutions

A higher concentration of a reactant usually increases the reaction rate. This is because the reacting particles are closer together and there are more collisions. 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' metal more rapidly than dilute acids.

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.

Figure 3.8 The beakers contain hydrochloric acid of different concentrations from dilute or concentrated. Marble chips are added to cause a reaction. Can you tell which beaker contains the most concentrated acid?

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SKILLBUILDER

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.

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EXPERIMENT 3.1 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

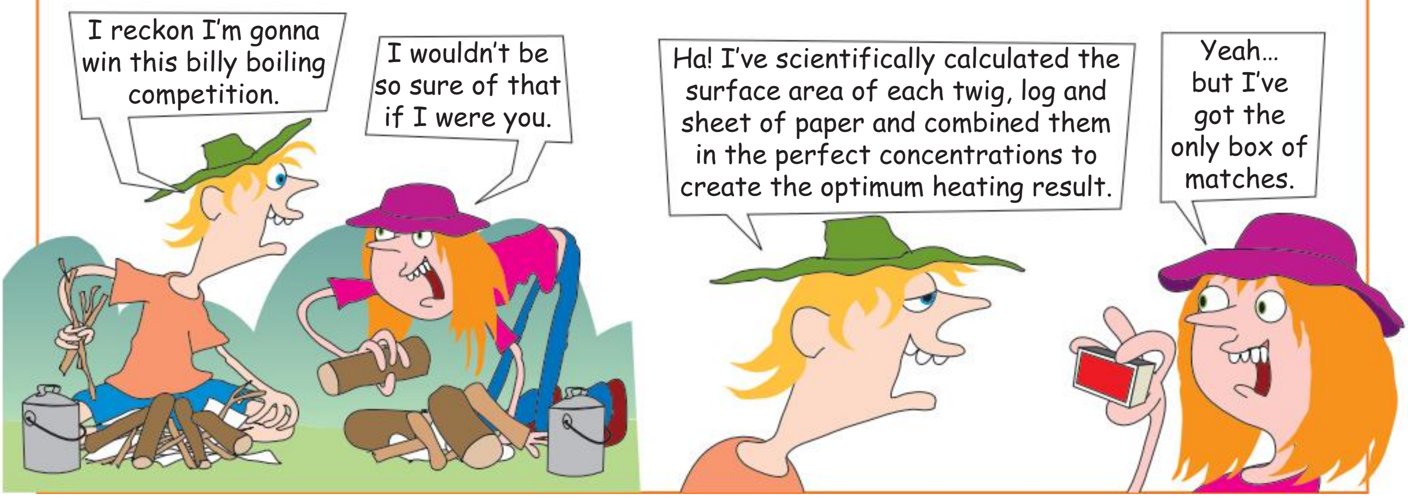
1 Decide which question you are going to investigate. Then plan your experiment carefully, keeping safety in mind. Read the following hints.

- To answer Question 1 you could use the reaction between hypo and hydrochloric acid (Investigation 3.2). 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.



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Catalysts

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.

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.

INVESTIGATION 3.3 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**

Risk assessment and planning

- Which substances will you test as catalysts?
- If you need a data table, design one.
- Make a list of risks for this activity

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.

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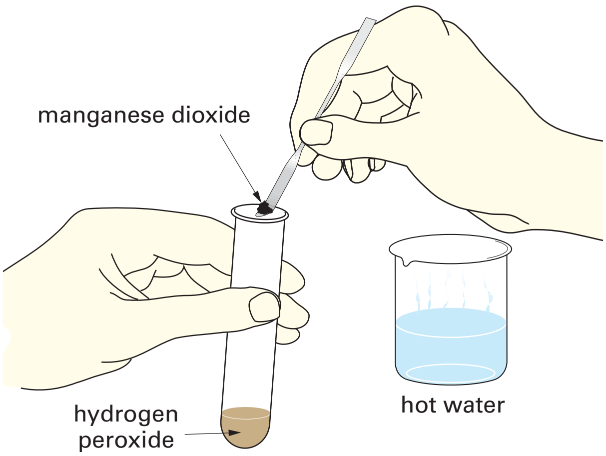
PART A

Method

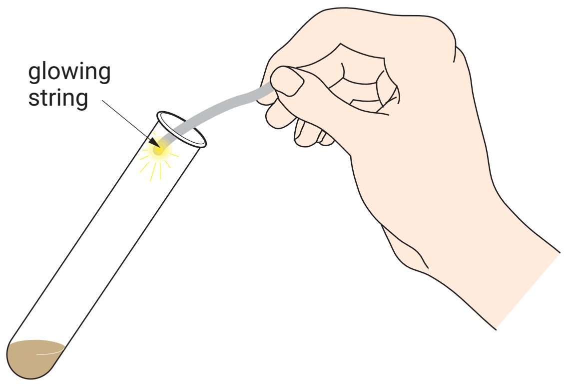
1 Add 2 mL of hydrogen peroxide to a test tube.
Is there any reaction at room temperature?

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 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?

PART B 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 might 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?

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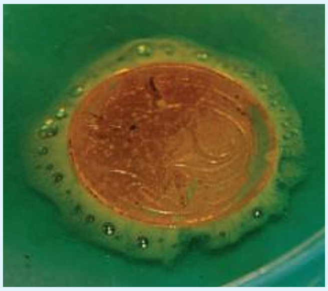
CHECK

1 The teacher added concentrated nitric 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 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.

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

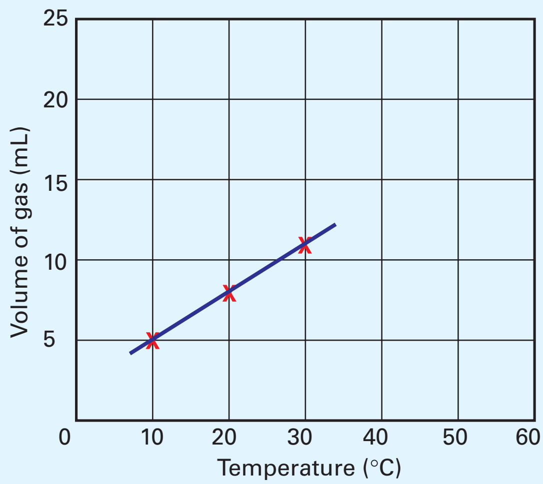
7 A scientist did an experiment to see how effective the following solids were as catalysts for the decomposition of hydrogen peroxide solution: copper oxide CuO, lead oxide PbO_2, manganese dioxide MnO_2. He obtained the results below in a series of experiments using equal volumes of hydrogen peroxide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

8 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.



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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 73 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?

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 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.

7 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.

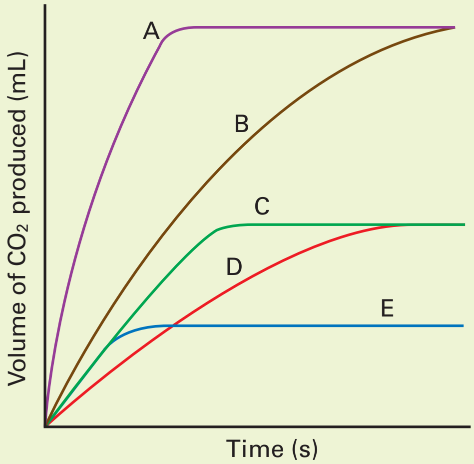
a Describe how you would carry out this experiment.

b What results would you expect?

8 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?

9 Magnesium powder burns very rapidly. Explain how you could slow down this reaction. Try to come up with two different solutions to this problem.

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3.3 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.

glucose + oxygen → carbon dioxide + water + ENERGY

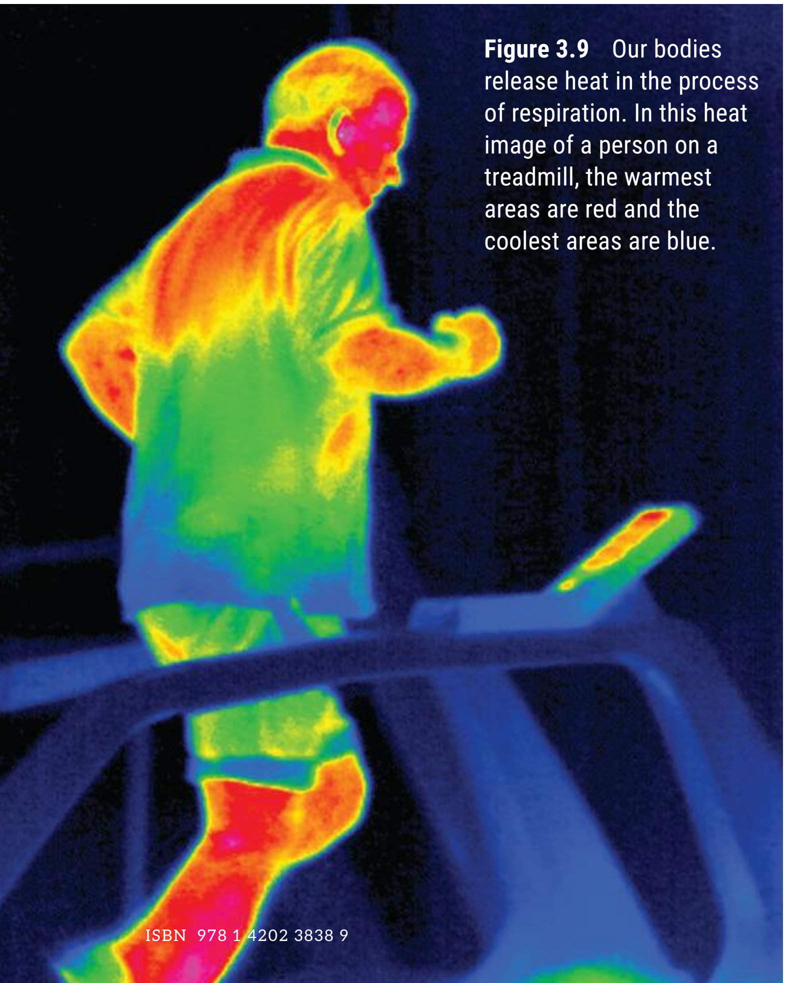

Figure 3.9 Our bodies release heat in the process of respiration. In this heat image of a person on a treadmill, the warmest areas are red and the coolest areas are blue.

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 in which 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.

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 (Figure 3.10), chemical reactions occur and silver moves from the rod to be deposited as a thin layer on the teapot.

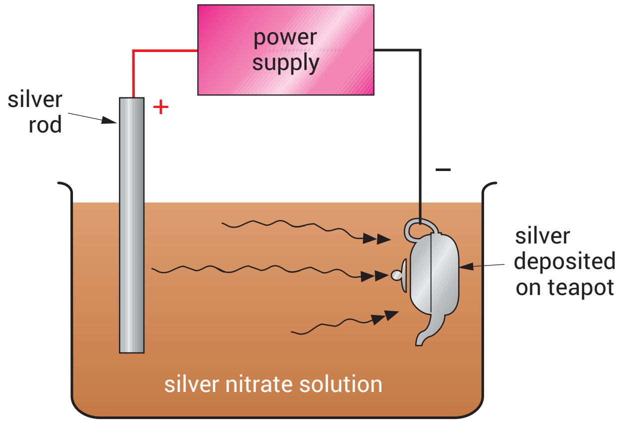

Figure 3.10 Electroplating a teapot

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INVESTIGATION 3.4 Exothermic or endothermic?

Research question

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

PART A

Materials

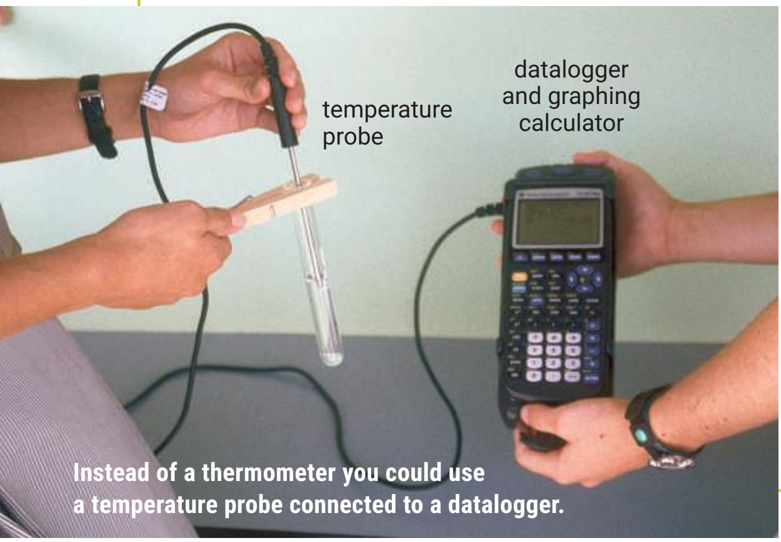
- 2 test tubes
- thermometer
- datalogger and temperature probe (optional)
- zinc
- sodium thiosulfate (hypo)
- dilute **hydrochloric acid** (1 M)

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

Risk assessment and planning

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 76.

PART C 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.

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EXTRA FOR EXPERTS

Graphing heat change, ΔH

Changes in heat in a reaction can be shown on a graph of reaction pathway against the potential energy.

Figure 3.11 shows an exothermic reaction. In this case the potential energy of the reactants is higher than the potential reaction energy of the products. You can see that energy has been given out by checking the difference in the potential energy.

The change in energy in the reaction is represented as delta H (ΔH), with delta meaning change. To find the change in energy you would use the equation:

ΔH = energy of products – energy of reactants

For this exothermic reaction ΔH is negative, as the value of energy in the products is smaller than that of the reactants, resulting in a negative value. For example:

ΔH = energy of products – energy of reactants

ΔH = 200 – 500 = -300 kJ of energy released

EXOTHERMIC REACTION

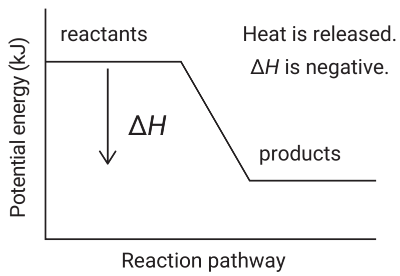

Figure 3.11 An exothermic reaction

Figure 3.12 shows an endothermic reaction. In this case the potential energy of the reactants is lower at the start, and after the reaction the potential energy is higher, so energy has been absorbed. As before, to find the change in energy you use the equation:

ΔH = energy of products – energy of reactants

For this endothermic reaction ΔH is positive, as the value of energy in the products is larger than that of the reactants, resulting in a positive value. For example:

ΔH = energy of products – energy of reactants

ΔH = 1500 – 500 = 1000 kJ of energy absorbed

In summary, a negative ΔH indicates an exothermic reaction, and a positive ΔH indicates an endothermic reaction.

ENDOTHERMIC REACTION

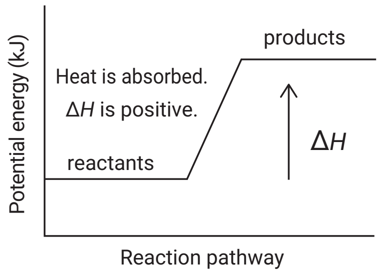

Figure 3.12 An endothermic reaction

Questions

1. Predict the sign of ΔH and state whether the reaction will be endothermic or exothermic for a:
   a. burning candle
   b. cold pack
   c. heat pack.
2. Calculate ΔH for the following reactions, and state whether they are endothermic or exothermic:
   a. A reaction has reactants with an energy of 457 kJ and products with an energy of 2350 kJ.
   b. In the reaction $H_2 + F_2 \rightarrow 2HF$, the energy of reactants is 1136 kJ and the energy of products is 594 kJ.
   c. In the reaction $2H_2 + O_2 \rightarrow 2H_2O$, the energy of reactants is 1852 kJ and the energy of products is 1368 kJ.
   d. In the reaction $2HBr \rightarrow H_2 + Br_2$, the energy of reactants is 629 kJ and the energy of products is 732 kJ.
3. a. Sketch a graph and label the products and reactants, and show the value for ΔH on the graph for the following reaction:
   $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
   with energy of reactants = 3338 kJ and energy of products = 2640 kJ.
   b. Is this reaction endothermic of exothermic?

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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.

The French scientist 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 the mass of the tin 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 ________.

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EXPERIMENT 3.2 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)

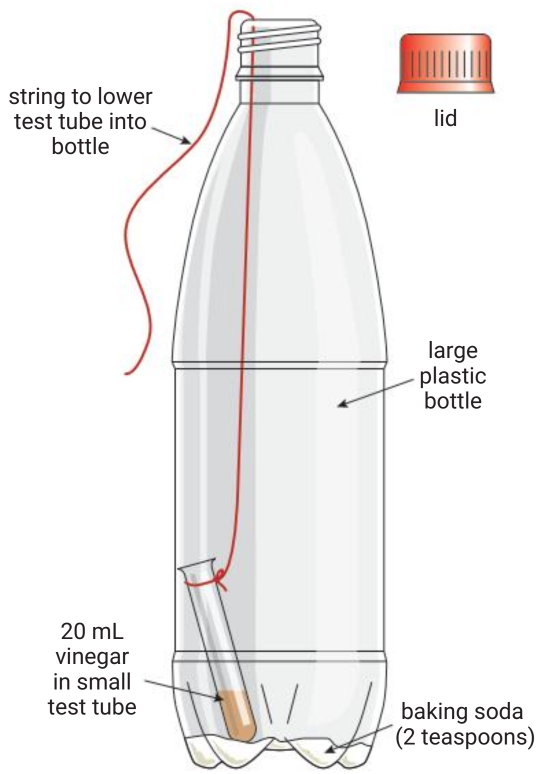
Risk assessment and planning

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 'Risk assessment and planning' box correct? In other words, do your results support the hypothesis that the total mass of the substances in a reaction does not change?

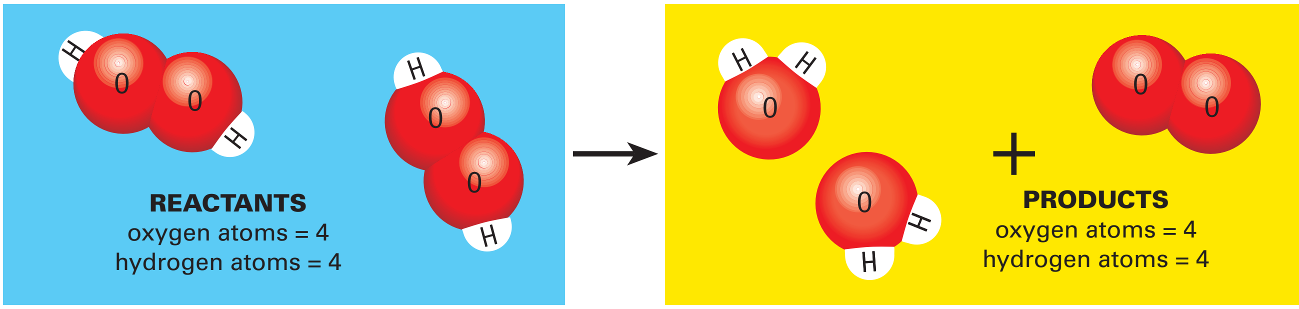
Law of conservation of mass

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

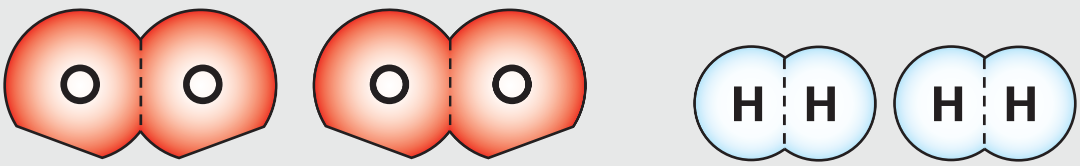


ACTIVITY

You can use cardboard cut-outs 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.

> **Tip**
> If you have a molecular model kit, you can make three-dimensional models. You may even be able to animate the equation models using computer software.



oxygen (O_2)

hydrogen (H_2)

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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 silver-plate 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 have been 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?

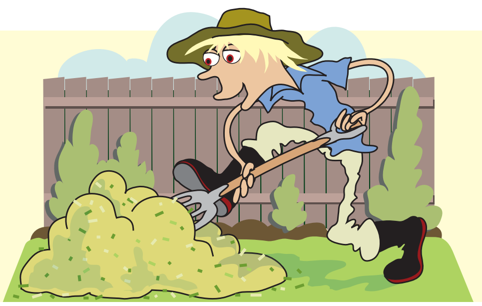
3 a Joseph Priestley produced oxygen by decomposing mercury oxide by heating. Write a word equation for this reaction.
  b Write a word equation for what happens when mercury is heated and reacts with air (oxygen).

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?

EXPLORE

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.



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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
products
endothermic
conservation
increases
rate
catalysts
concentration
temperature
exothermic

CH•3 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** the amount of product formed in a given time
- **B** how rapidly the solutions are mixed
- **C** the amount of heat given off in a certain time
- **D** how quickly the reactants are used up
- **E** how long it takes to observe a change

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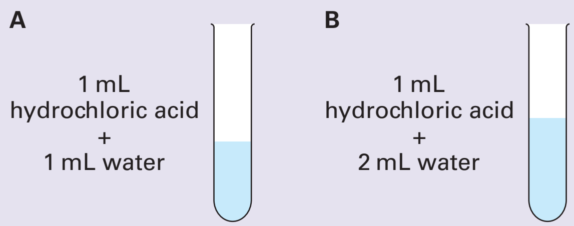
5 What effect does each of the following have on a chemical reaction (speeds it up, slows it down or has no effect)?

- **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.

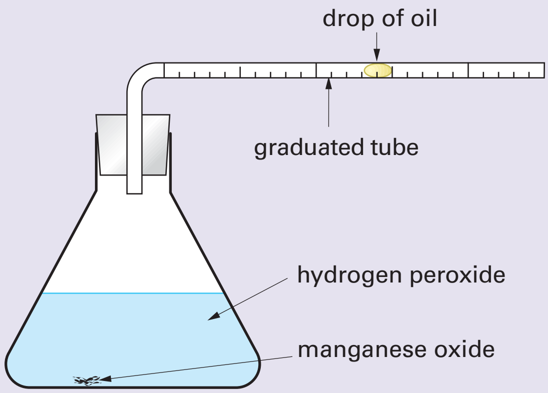
Test tube	Substance added	Height of foam produced (cm)
1	–	2
2	A	8
3	B	5
4	C	2

- **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 343.

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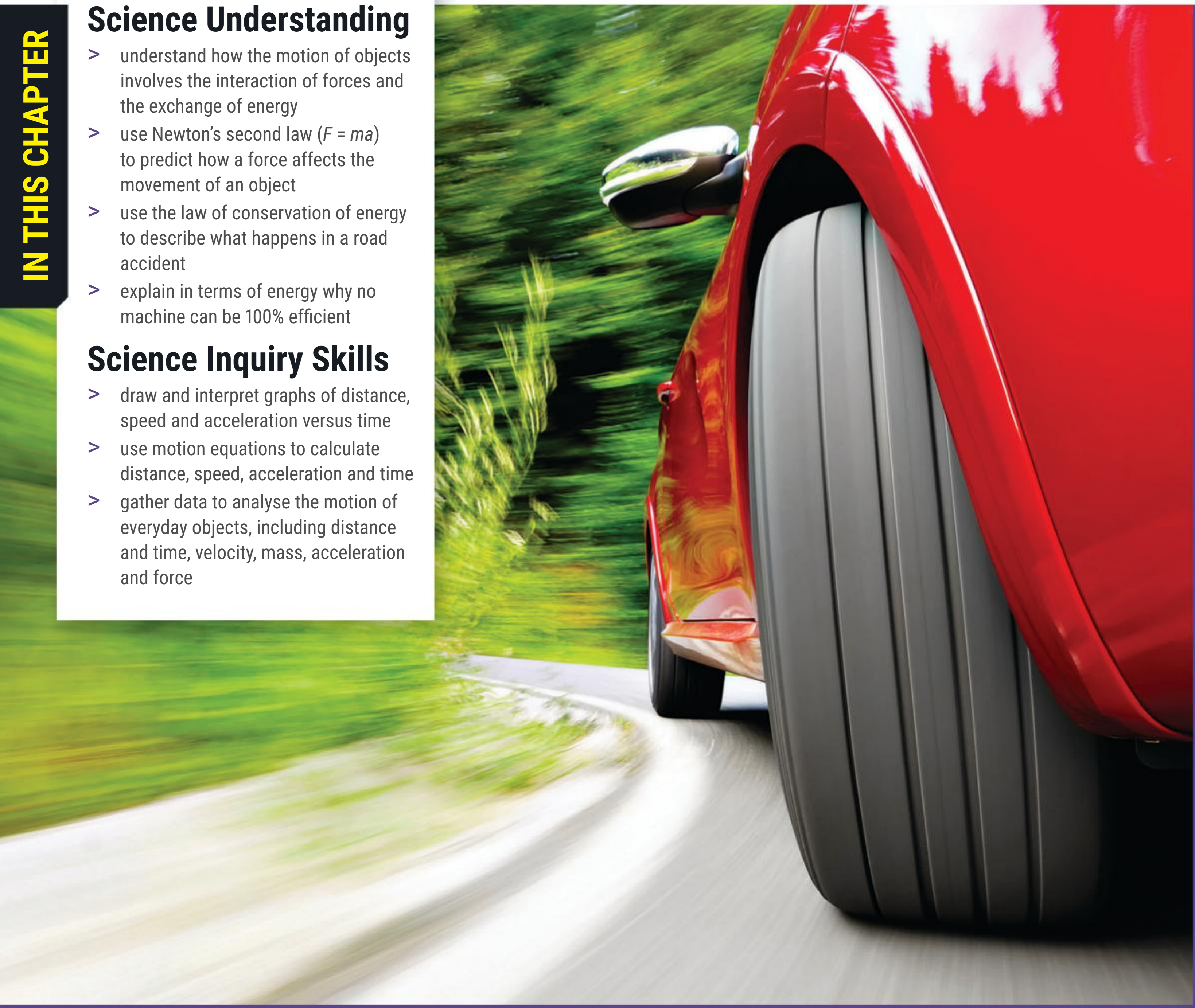
IN THIS CHAPTER

Science Understanding

- understand how the motion of objects involves the interaction of forces and the exchange of energy
- 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
- gather data to analyse the motion of everyday objects, including distance and time, velocity, mass, acceleration and force



CH•4 Road science

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GET STARTED: *QUESTION*

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 forwards when a car brakes suddenly?
6. What is friction and how is it involved in controlling a car?
7. Which parts of the car increase friction, and which are designed to decrease friction?
8. Draw a diagram to show the forces that act on a car moving at constant speed.
9. Which will take longer to stop, a car or a truck? Explain why.
10. What are the crumple zones in a car, and how do they work?
11. What other safety devices or systems are fitted to a modern car to help reduce accidents or injury in an accident? For each one you think of describe how it works.

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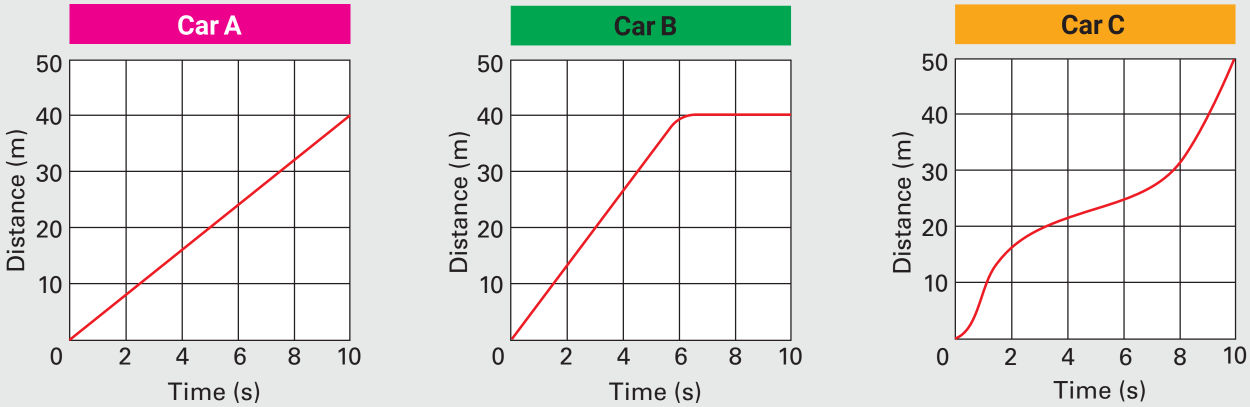
4.1 Speed and acceleration

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?



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Speed

Look at the graph for car A in Figure 4.1. The car 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).

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

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

$$= \frac{40\text{ m}}{10\text{ s}}$$

$$= 4\text{ m/s}$$

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

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

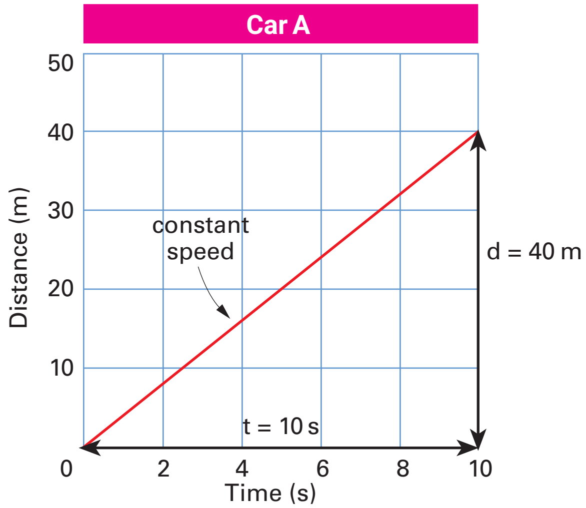
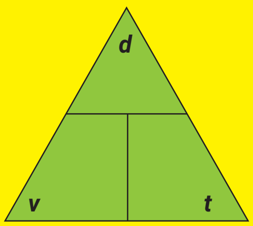


Figure 4.1 Distance–time graph for car A

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 in Figure 4.2. 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: the car had stopped.

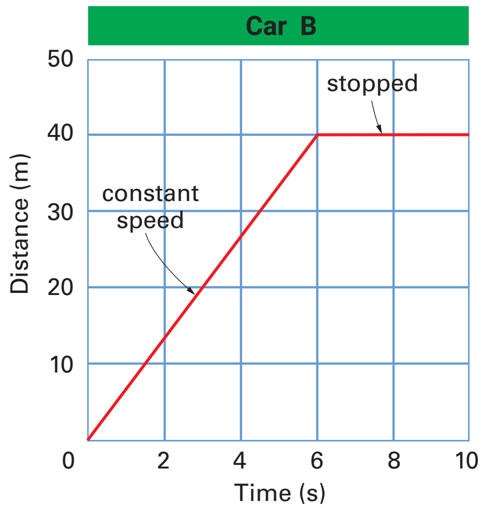


Figure 4.2 Distance–time graph for car B

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Finally, look at the graph for car C in Figure 4.3. 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). By 5 seconds it had slowed down (not so steep), and finally it speeded up again.

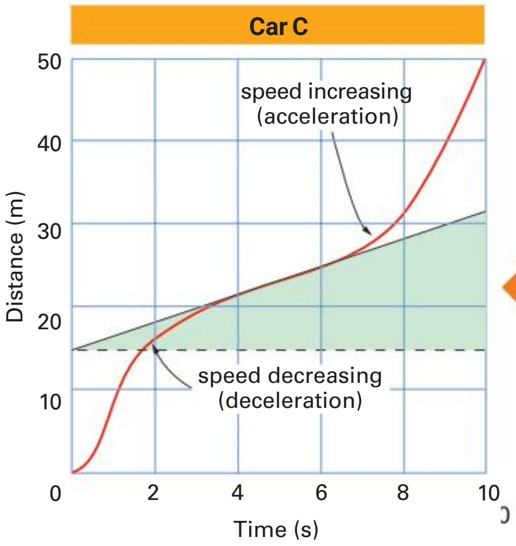


Figure 4.3 Distance–time graph for car C

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.

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

Figure 4.4 The slope of the distance–time graph gives the instantaneous speed at a particular time.

SCIENCE AS A HUMAN ENDEAVOUR

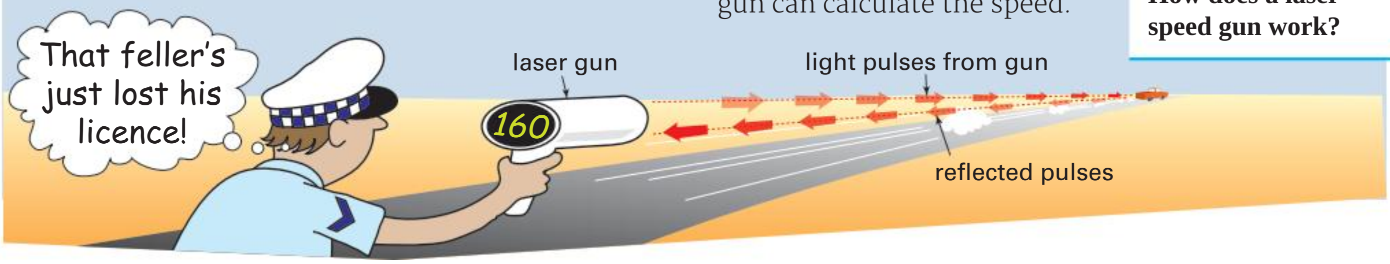
Radar and laser guns

Police use radar and laser guns to find the instantaneous speeds 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.

Check out the link to see how a laser speed gun works:

How does a laser speed gun work?



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Acceleration

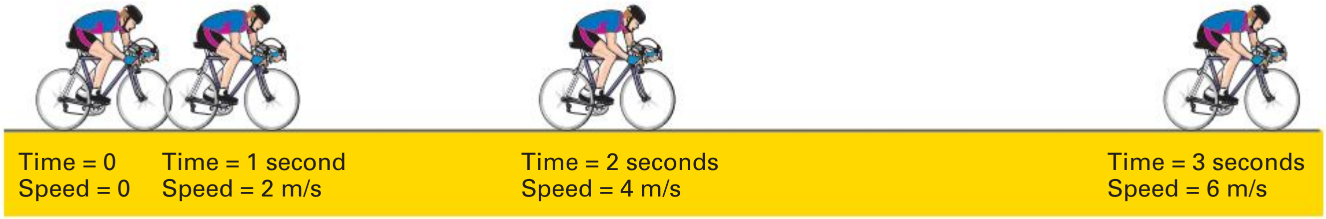

Figure 4.5 Acceleration is a change in speed over time.

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 Standing start to …	VW Golf R	Porsche 911 Turbo
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:

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

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

Figure 4.6 The parachutes increase friction, causing the dragster to decelerate.

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* (see Figure 4.6). 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.

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INVESTIGATION 4.1 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.

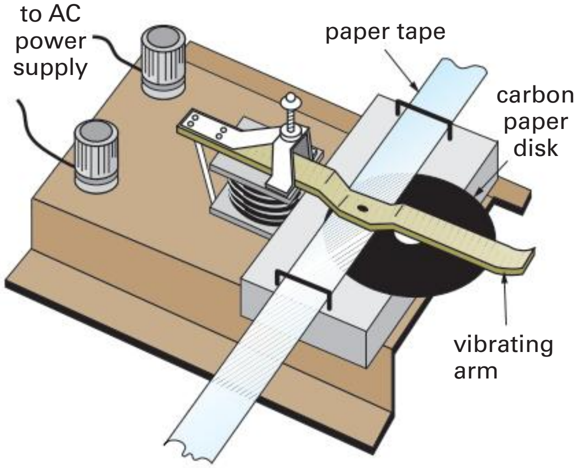
Risk assessment and planning

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.

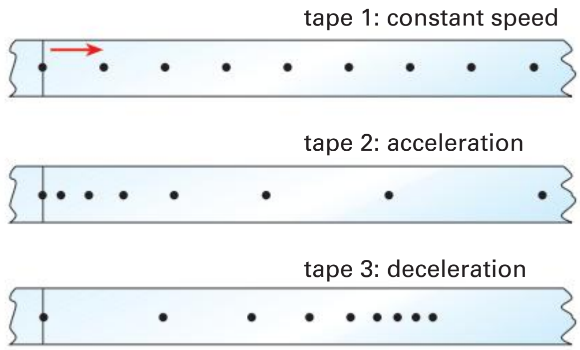
Teacher note: Depending on your school situation, you can do this experiment using ticker timers or a datalogger (Part B).

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, 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 disc
- 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 speeds, 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.

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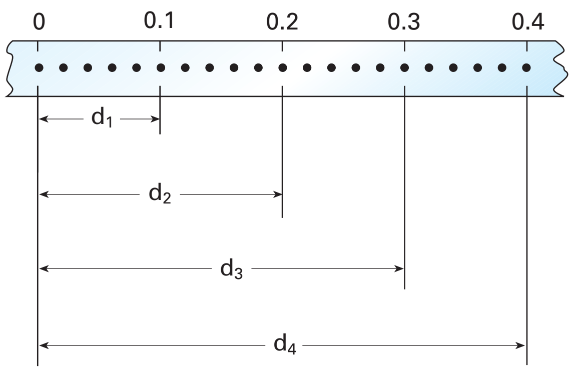
5 Select one of the tapes and mark a starting point. Count along the tape from the first dot, marking off every fifth dot, as shown below. Five dots represent 0.1 second.

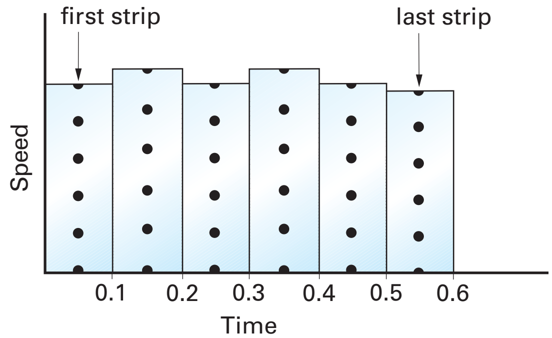


6 Measure the distances d_1, d_2, d_3, d_4, etc. and record them in a data table.

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 94), 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

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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

Method

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.

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.

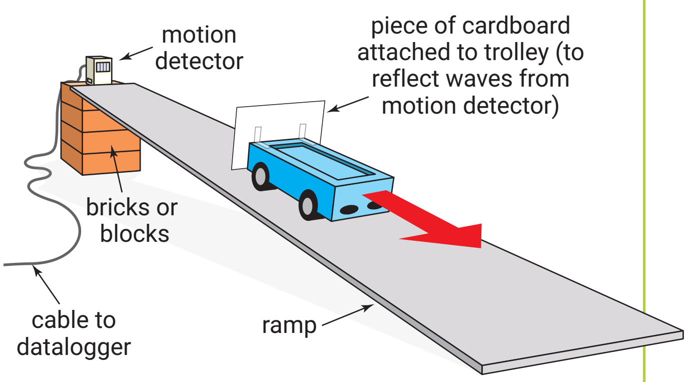
7 Now that you understand the distance–time graphs, look at the velocity–time graphs.
How can you explain the shapes of the graphs?

PART C 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.

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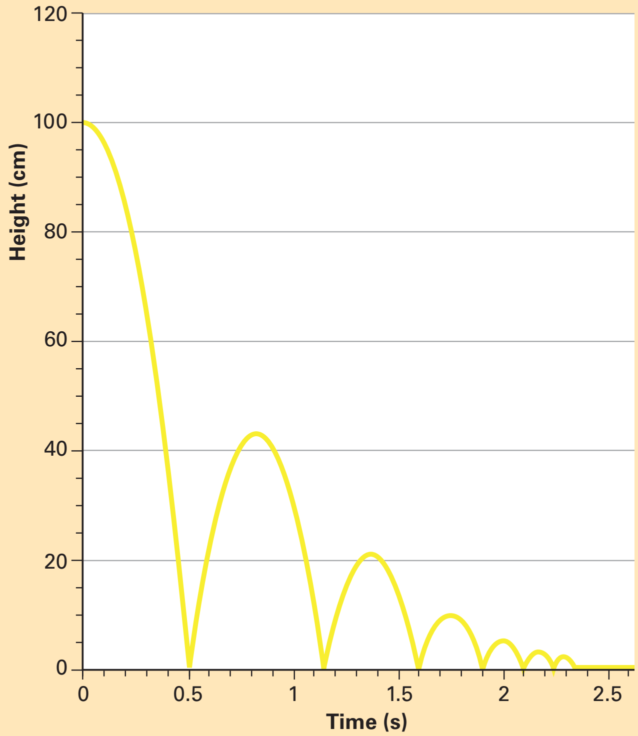
SKILLBUILDER

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 4.1 on pages 96–98 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 below 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?

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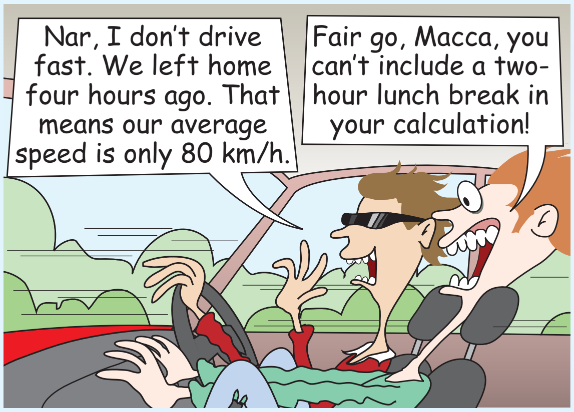
CHECK

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?

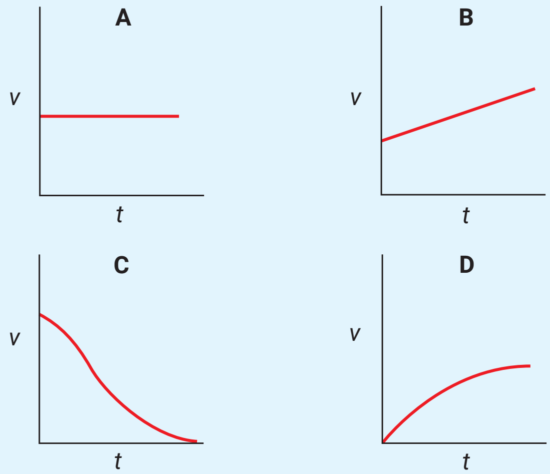
7 A bike coasts down a hill. Its acceleration is 3 m/s^2. How long does it take to accelerate from 5 m/s to 16 m/s?

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?

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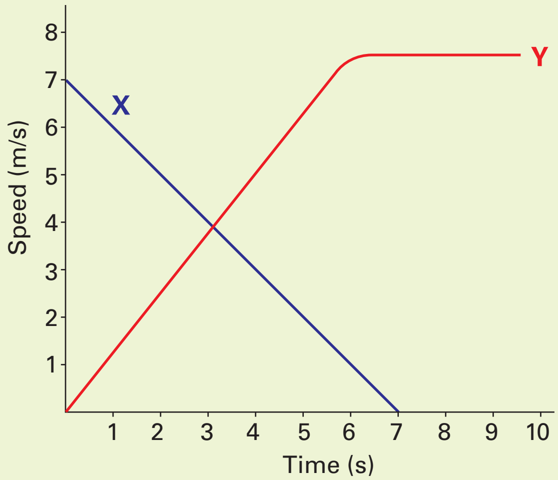
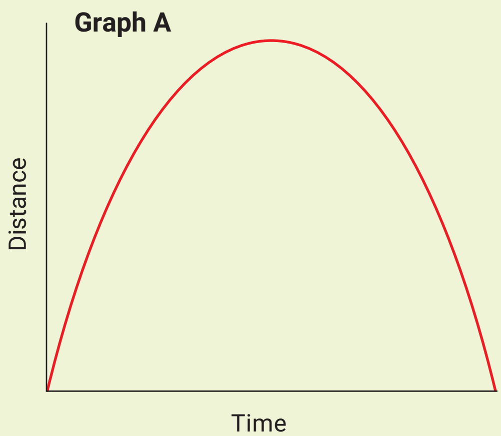
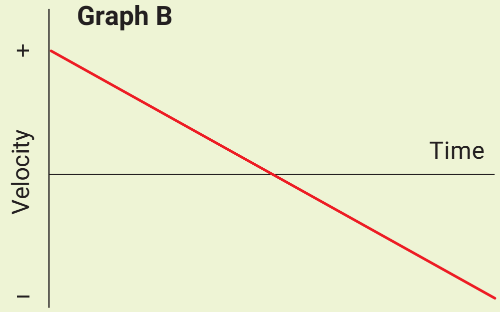
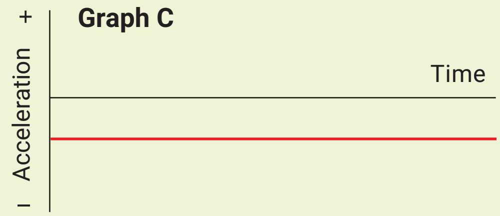
4 The graph below shows the motion of two objects, X and Y. Use the graphs to answer these questions.
- a What was the speed of X after 4 seconds?
- b What was the maximum speed of Y?
- c What happened to X at 7 seconds?
- d When did X and Y have the same speed?
- e Calculate the acceleration of X.
- 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.

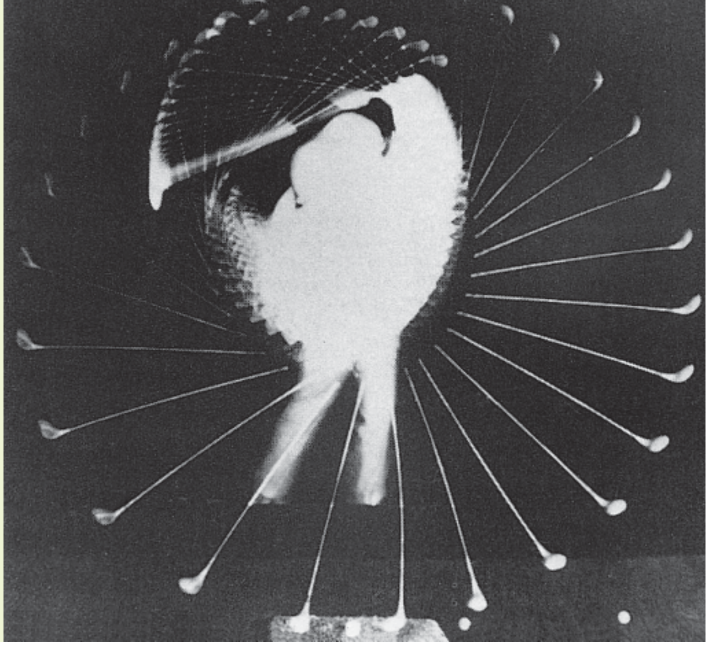






6 Look at the special photograph below of a golfer's swing. It was taken using a stroboscopic light that flashed 50 times per second (so that the time between flashes is 0.02 s).
- a What was the speed of the golf club just before and just after it struck the ball?
- b Suggest why these speeds are different.
- 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?

Figure 4.7 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 velocity,
u is the initial velocity,
a is the acceleration and
t is the time.

From this equation you can obtain a second equation:

$$d = ut + 1/2\,at^2$$

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/s² for 4 seconds. What was its final speed?

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

u = 15 m/s
a = 2 m/s^2
t = 4 s
v = ?

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

$v = u + at$
$= 15 + (2 \times 4)$
$= 15 + 8$
$= 23$ m/s

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?

u = 25 m/s
a = 1.6 m/s^2
t = 5 s
d = ?

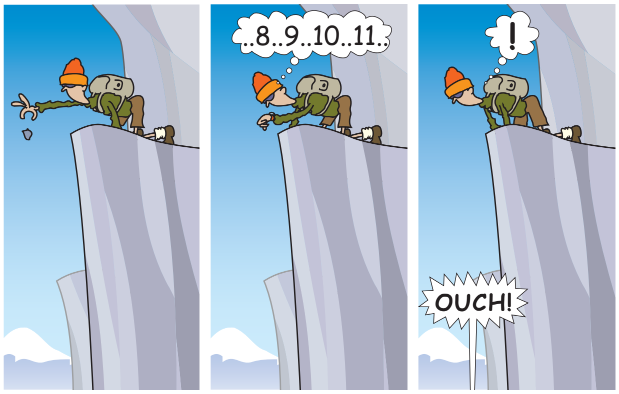
$d = ut + 1/2\,at^2$
$= (25 \times 5) + 1/2(1.6 \times 25)$
$= 125 + 20$
$= 145$ m

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?

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4.2 Stopping

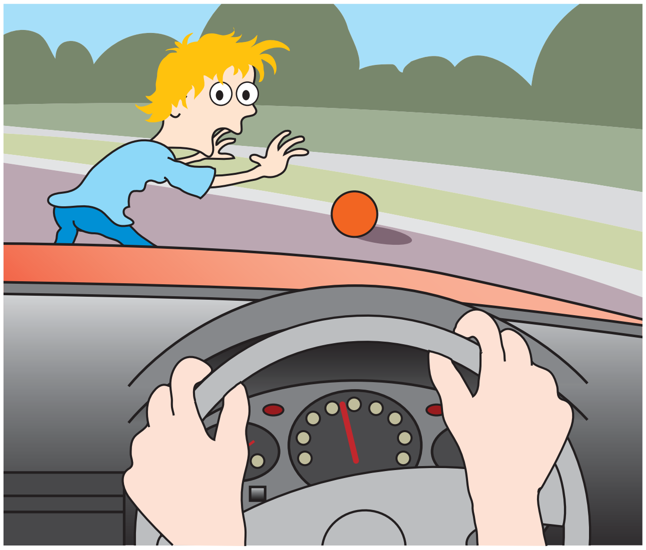
Imagine you are driving along a road and a child suddenly runs onto the road in front of you. You apply the brakes, and the car stops just in time.

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

Once 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 in Figure 4.8 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.

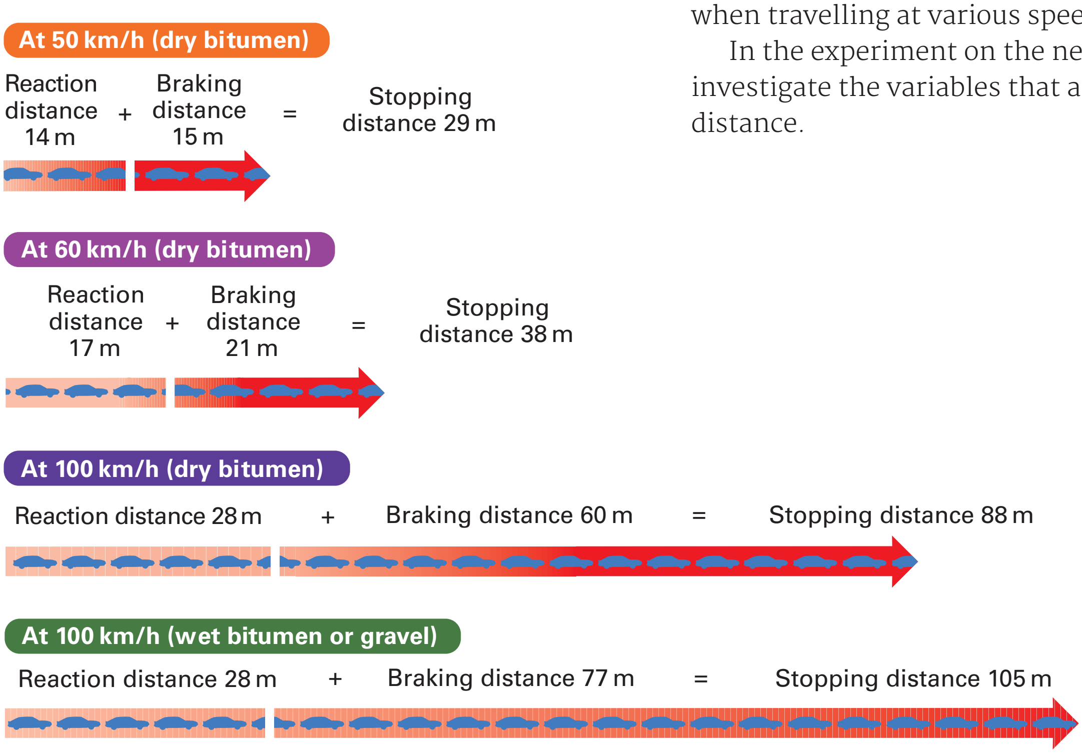


Figure 4.8 Stopping distance = reaction distance + braking distance

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EXPERIMENT 4.1 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

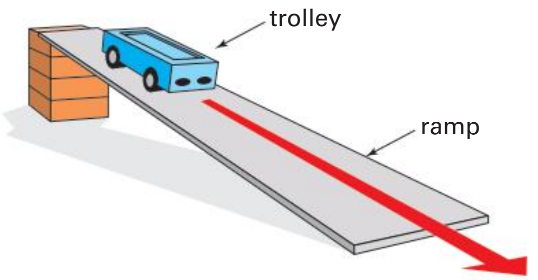
- How will you record your data? For example, can you put them into a spreadsheet such as Excel ?
- How will you work out the relationship between stopping distance and speed? Will you need to draw a graph? Will the spreadsheet do this for you?

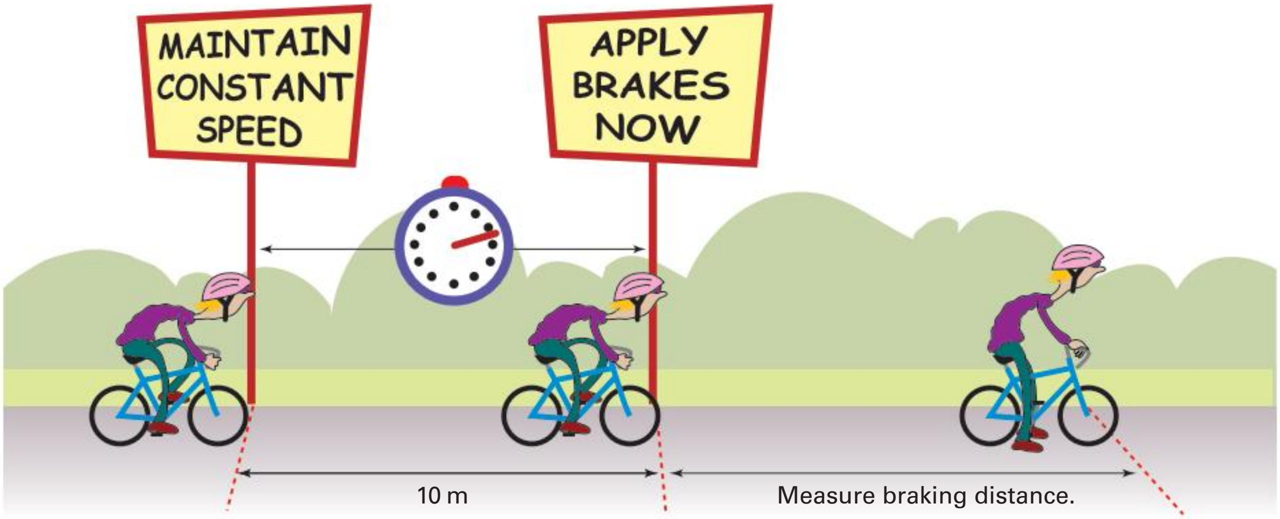
Evaluating the experiment

- 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.





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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 wheels 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 forwards. 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.

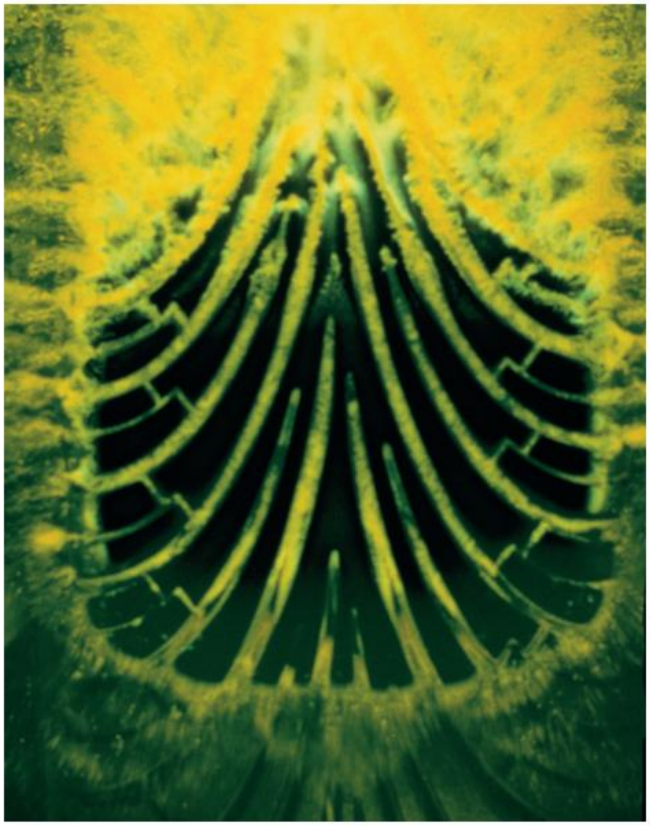

Figure 4.9 A tyre photographed at high speed through a wet glass roadway

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 in Figure 4.10. The wheel does not slide.

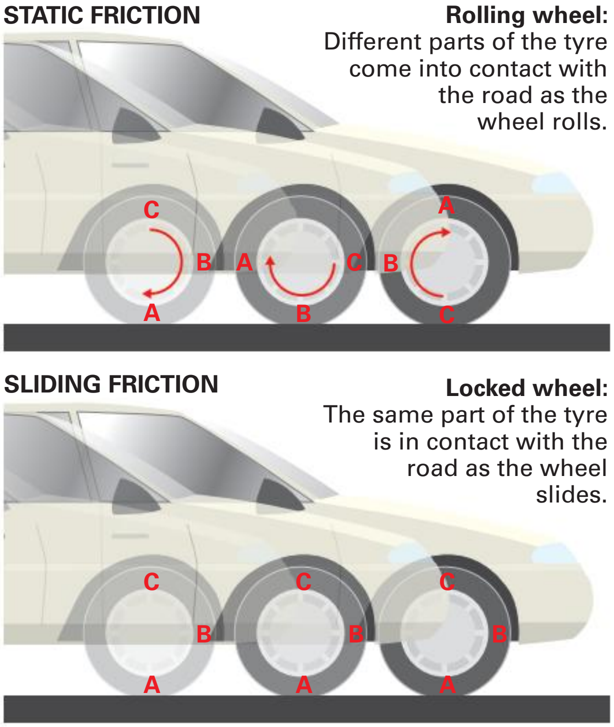

Figure 4.10 Static and sliding friction—which one stops a car faster?

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 anti-lock 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.

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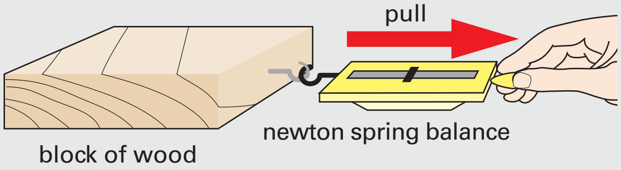
ACTIVITY

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?

SCIENCE AS A HUMAN ENDEAVOUR

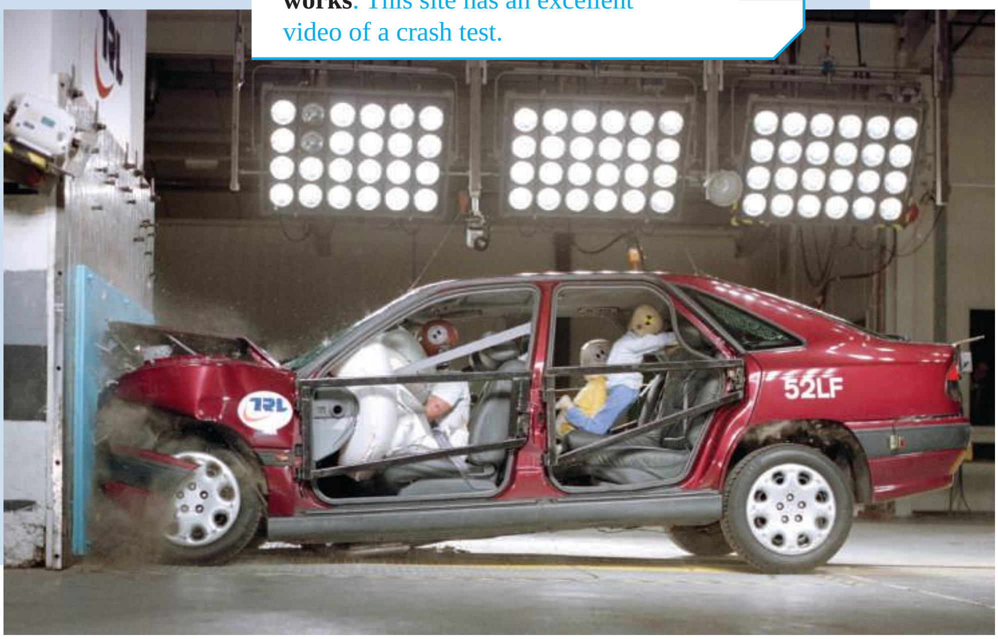
Crash tests

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, to show where various parts of the dummy make contact with the inside of the vehicle. 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.

For more information on crash tests follow the link to **How crash testing works**. This site has an excellent video of a crash test.



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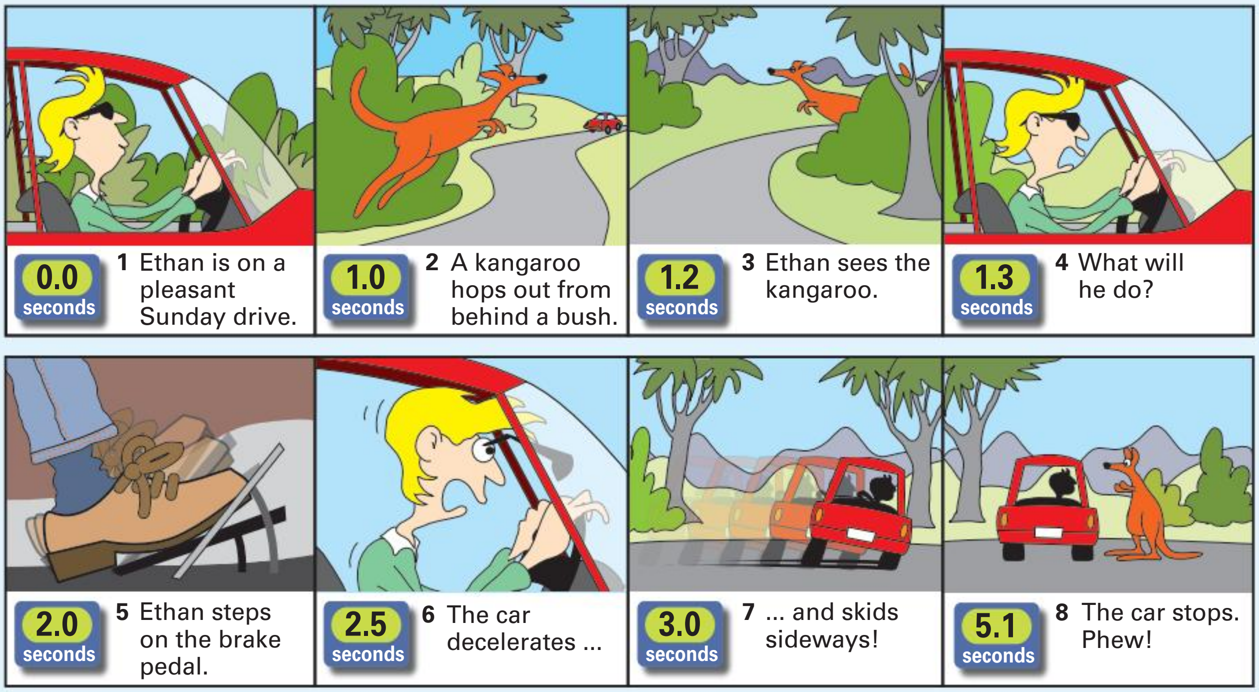
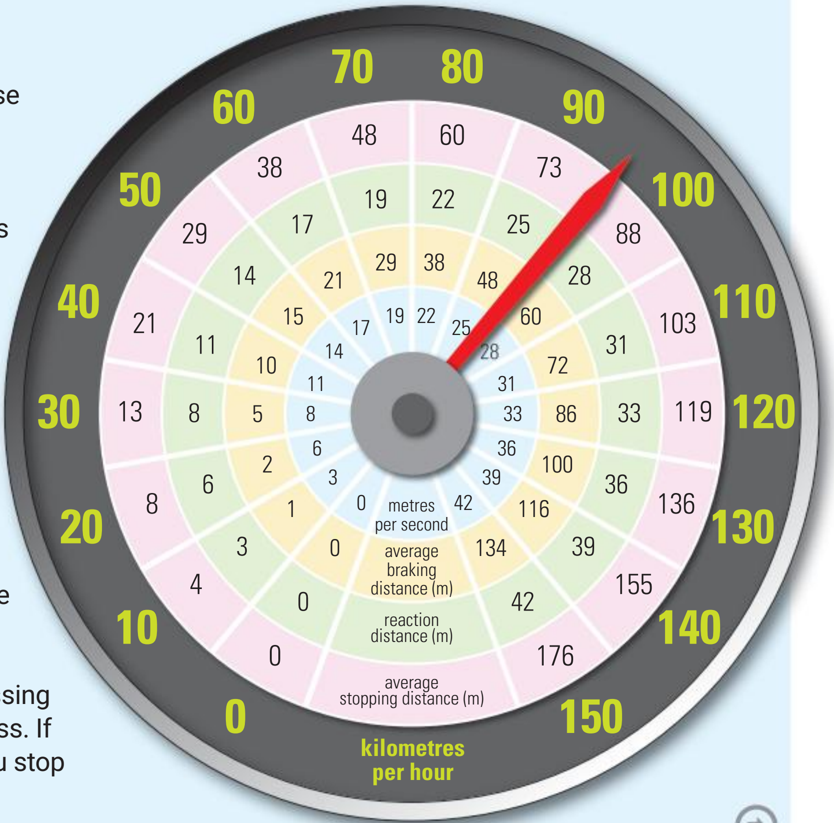


1 The cartoon strip above shows what happened to Ethan while driving in the country.
 a What is Ethan's reaction time?
 b What is his braking time?
 c What is his stopping time?

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 but the reaction time stays the same?

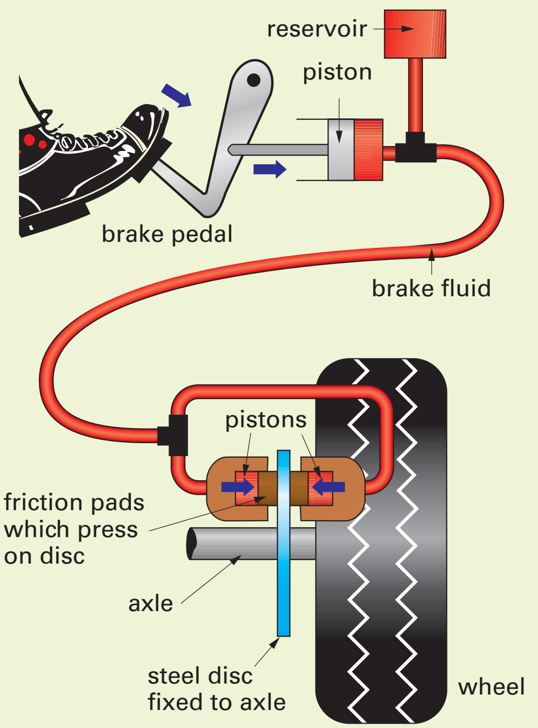
CHALLENGE

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 Look at the diagram on the right and write a paragraph explaining how disc 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?



EXPLORE

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.

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4.3 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.

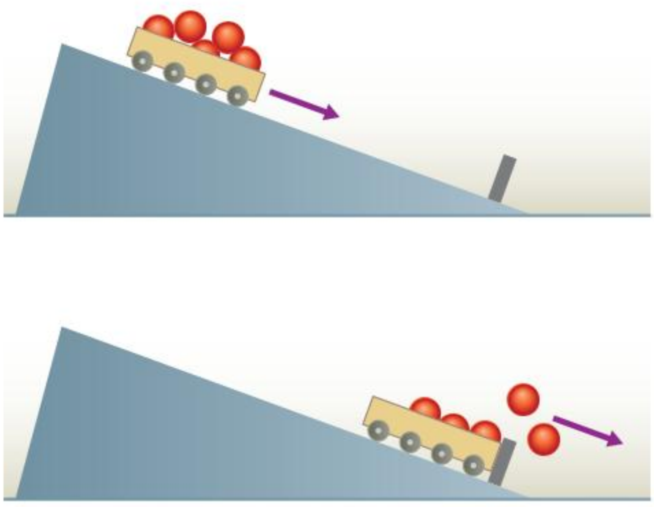
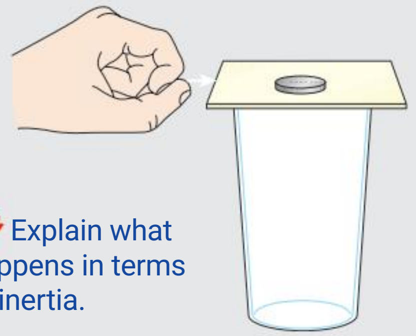


Figure 4.11 The inertia of the balls causes them to continue to move forward after the trolley has stopped.

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.

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.

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 Galilei 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:

$$p = mv$$

where p 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 4.2 you can investigate the effects of inertia and momentum in car accidents.

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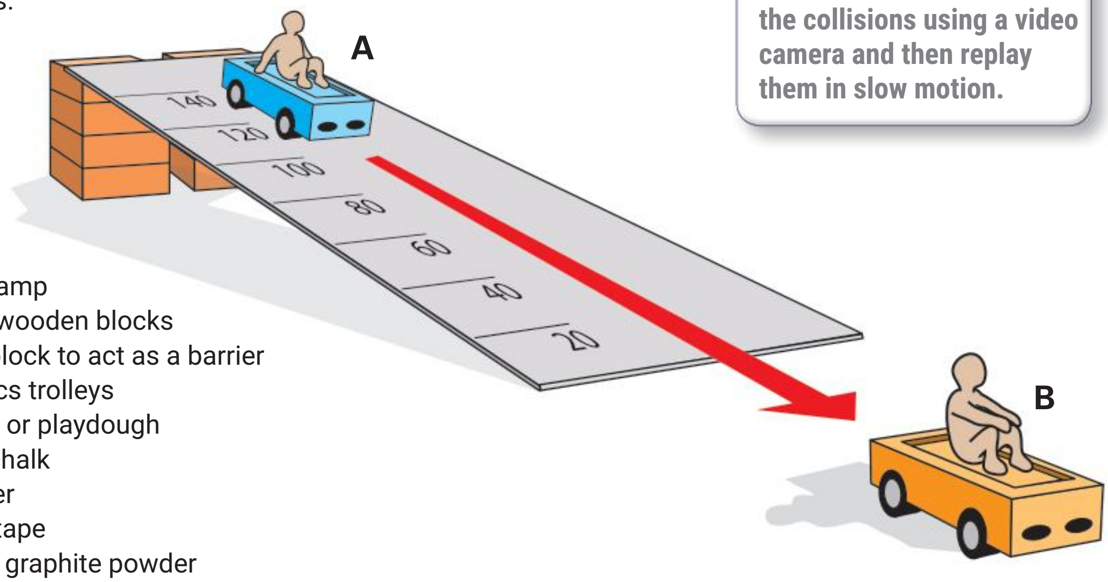
INVESTIGATION 4.2 Car accidents

Aim

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



Note: 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

Risk assessment and planning

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?

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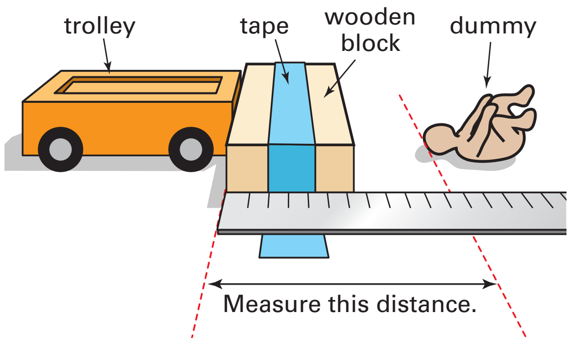
PART B

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?

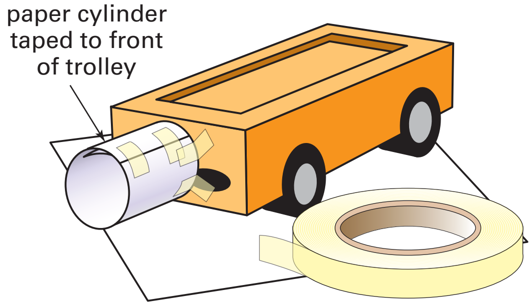
3 Use your graph to predict how far the dummy would be thrown if you released the trolley from one of the marks you have not used. Try it and check your prediction.

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

PART C 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.

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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!

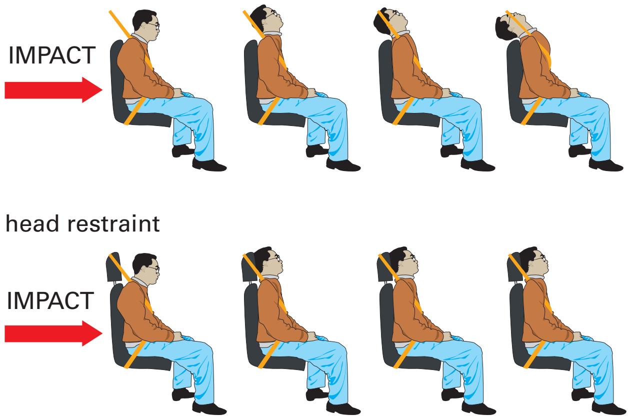

Figure 4.12 How head restraints work

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 forwards 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 mobile phone 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 Figure 4.12, where there is no head restraint. When the car is struck from behind, the person's body is moved forwards 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 under the rigid passenger compartment, and the steering column collapses so that the driver is not speared.

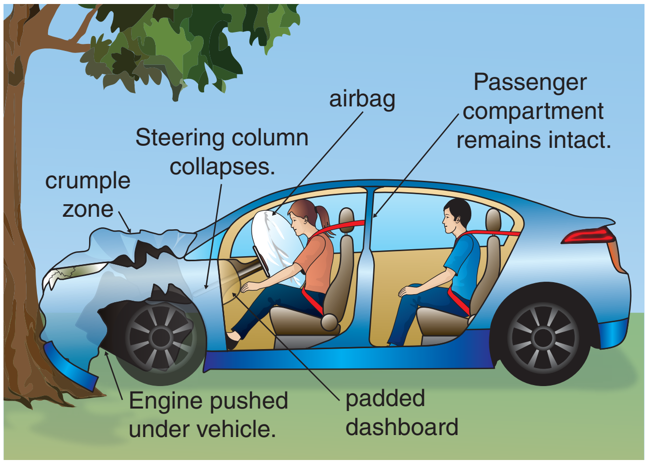

Figure 4.13 Safety features in a car

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 forwards 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

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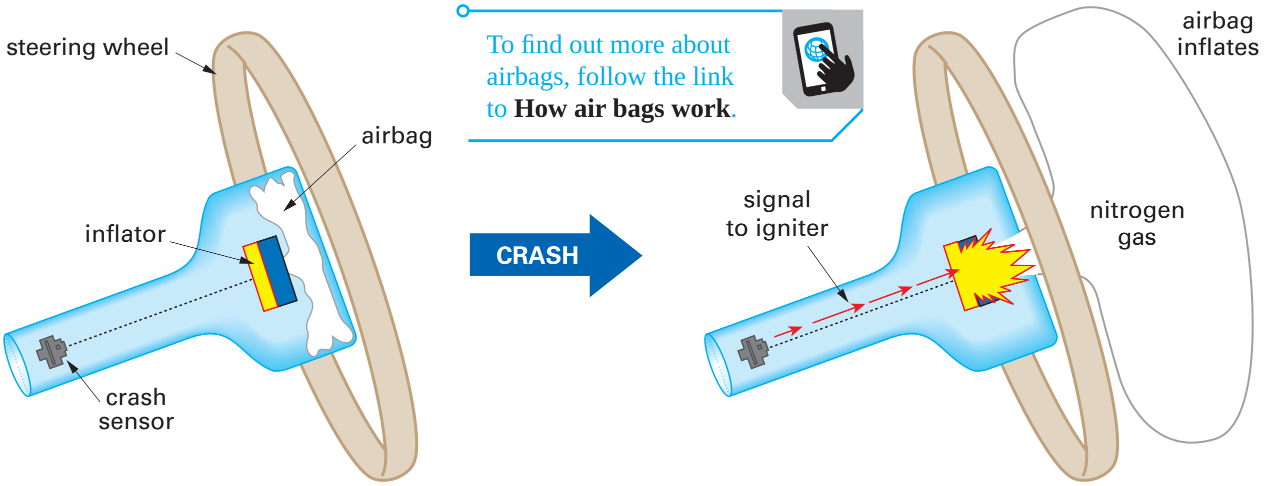


To find out more about airbags, follow the link to **How air bags work**.

Figure 4.14 How an airbag works

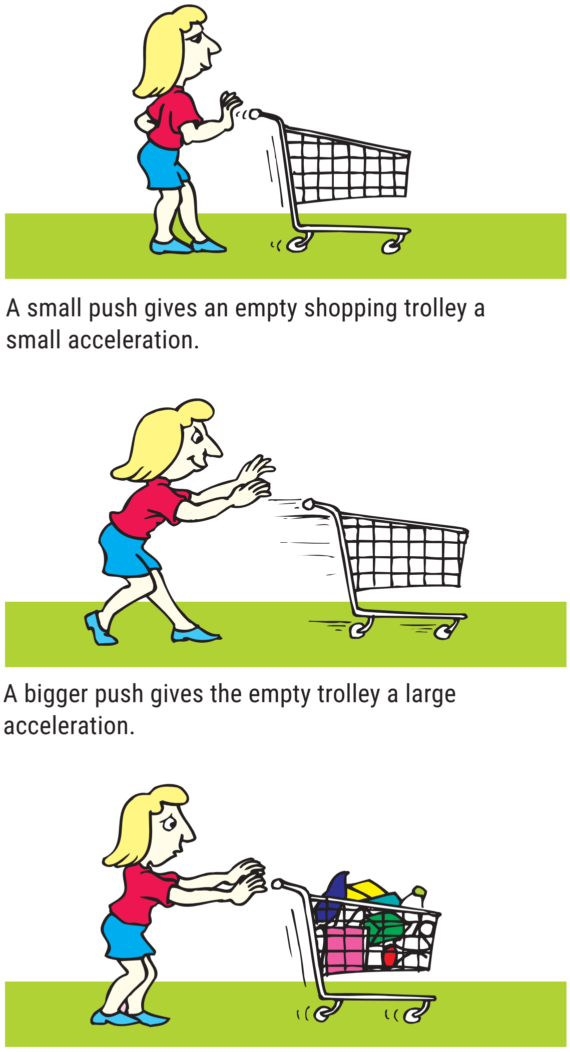
reaction that produces nitrogen gas and inflates the bag in about 0.3 seconds. A second later, the gas quickly escapes through tiny holes, thus deflating the bag so you can move.

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.



A small push gives an empty shopping trolley a small acceleration.

A bigger push gives the empty trolley a large acceleration.

But this same big push gives a full trolley only a small acceleration.

Figure 4.15 Newton's second law of motion

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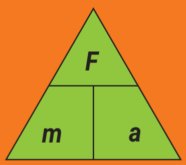
These two relationships between acceleration, force and mass can be combined as a single mathematical equation:

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

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. Because the car comes to a stop its final speed is zero. We can calculate the force exerted on the car as follows.

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

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 Figure 4.13 on page 112) 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.

Figure 4.16 These energy-absorbing wire ropes prevent vehicles crossing the median strip into the path of oncoming vehicles.

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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.

Figure 4.17 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 wheels 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 forwards but are restrained by their seatbelts. Loose objects in the car fly forwards.

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, so no machine can be 100% efficient, and perpetual motion machines are not possible. To keep things going, you have to keep putting energy in.

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ACTIVITY

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 (Figure 4.18). 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 judgement 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 Figure 4.19. 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 and not exceed 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 person have?

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

Figure 4.18 How many standard drinks?

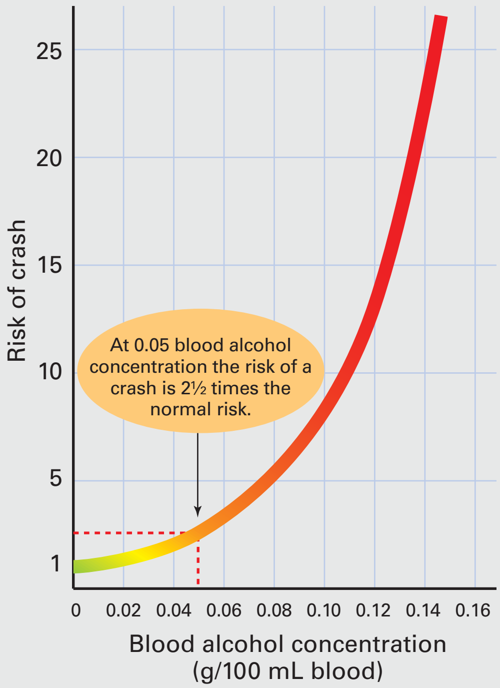

Figure 4.19 Relative probability of crashing at various blood alcohol concentrations

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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 golf ball 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 102, 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?

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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.

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

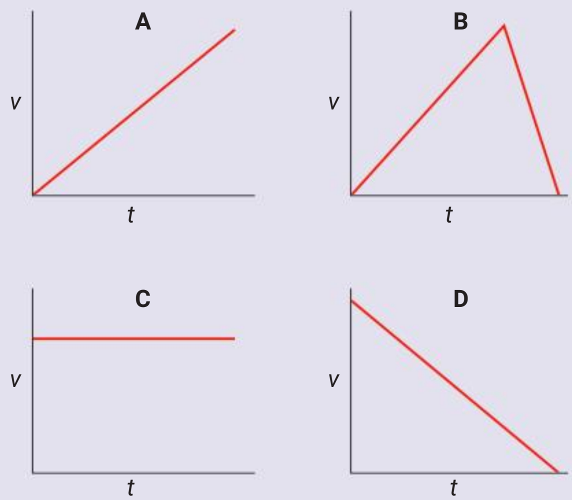
inversely
acceleration
speed divide
airbags
speed
force
inertia
mass
skid
reaction time
equation
slope

CH•4 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?



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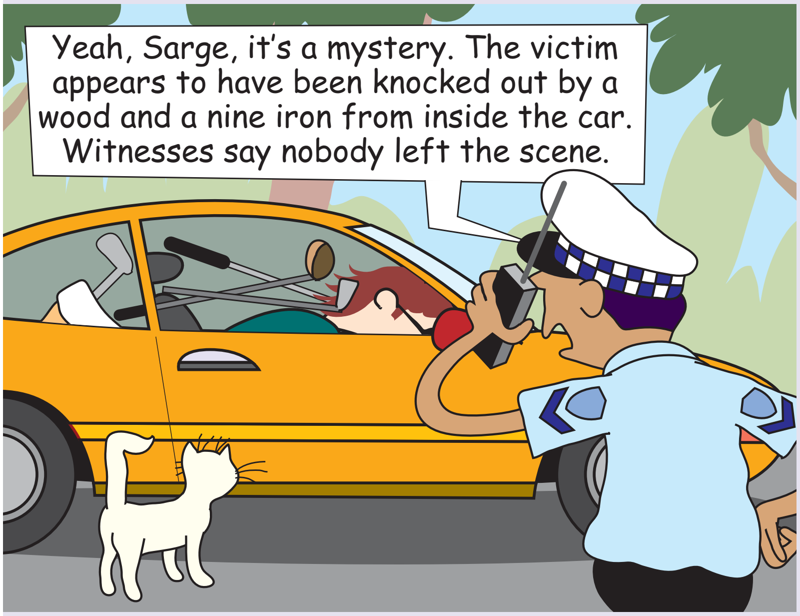
4 A sports car and a furniture van are both travelling at a speed of 60 km/h. Which vehicle would require more force to stop it? Why?

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



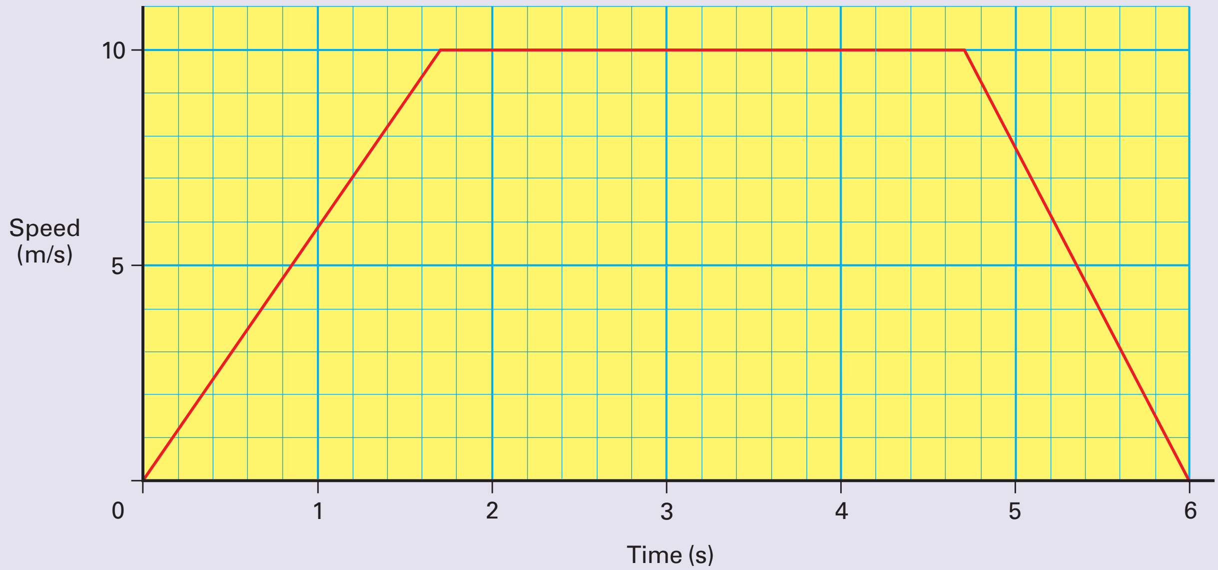
6 The same person drives a motorbike, a car and a semitrailer at 100 km/h. Compare his reaction distances and braking distances for the three vehicles if he has to stop suddenly.

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 wheels locked'?
- b What happens to the car when this occurs?
- c What have car designers done to solve the problem of wheels 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 344.

IN THIS CHAPTER

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
- gain an understanding of the requirements and problems of living in space

Science Inquiry skills

- use internet research to find out the latest on space exploration
- design an experiment to be carried out on the International Space Station

CH•5 Space engineering

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GET STARTED: *IMAGINE*

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 on the International Space Station 400 km above the Earth. You let go of the handrail. Will you fall back to Earth? Explain.
5. If you spent a long time in space what might happen to your body?

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5.1 Getting into space

How high can you jump 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.

Figure 5.1 The launch of the Atlas V rocket in September 2016 carries NASA's Origins mission craft that will sample an asteroid and return to Earth.

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 above the Earth's surface.

EXPLORE ONLINE

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

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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 4 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/s² is:

$$\begin{aligned} F &= ma \\ &= 10\,000 \text{ kg} \times 10 \text{ m/s}^2 \\ &= 100\,000 \text{ N} \end{aligned}$$

Figure 5.2 The force generated by a rocket's engines pushing downwards 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/s².

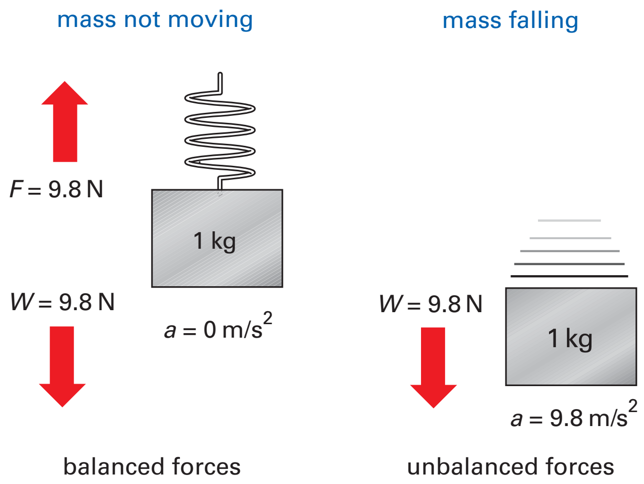

Figure 5.3 When the mass is hooked on the spring, the forces are balanced (in equilibrium) and there is no motion. When it is unhooked, it falls with an acceleration of 9.8 m/s².

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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 at top right 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.

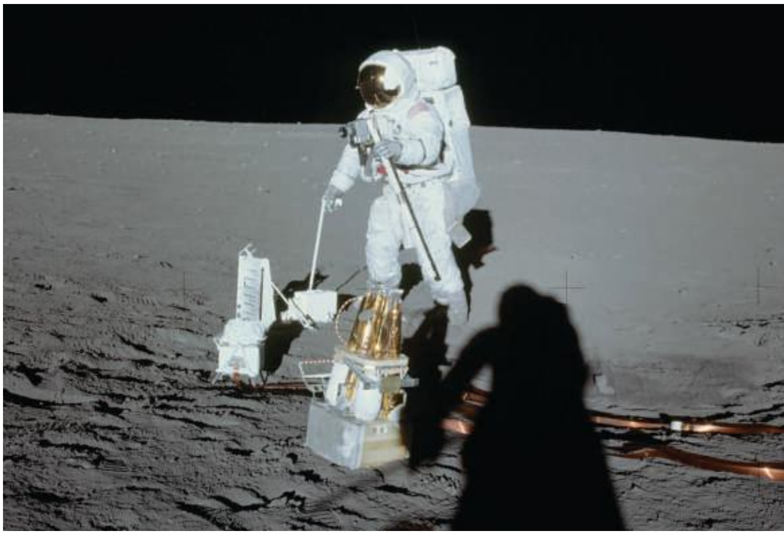

Figure 5.4 Astronauts on the moon have less weight than on Earth, even though their mass is the same. Can you explain why?

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

1 Use the formula $W = mg$ to find the acceleration due to gravity on planet X.

2 Suppose you took the four masses in the table back to Earth. Find the weights of the masses on the Earth's surface.

3 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.

4 Write a generalisation about the relationship between weight and gravity.

5 If the force of gravity is directly proportional to the mass of the planet, work out which of planet X, Jupiter or Earth has the smallest mass and which has the greatest.

6 How much would you weigh on planet X? How much would you weigh on Jupiter?

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Rocket science

The cartoon below illustrates *Newton's third law of motion*.

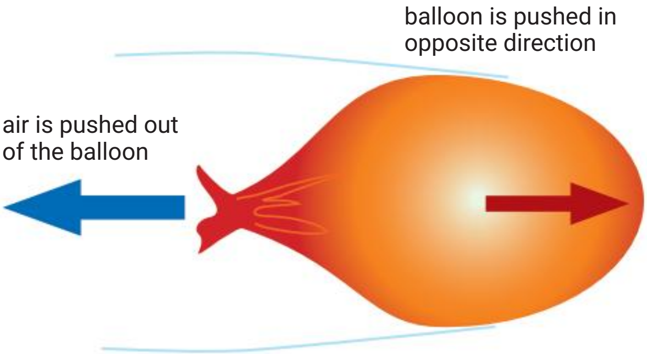

Figure 5.5 Newton's third law

When a balloon is let go, the balloon goes in one direction and the air goes 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.

Figure 5.6 A water jetpack 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 balloon 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.

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EXPERIMENT 5.1 Model rockets

Risk assessment and planning

- 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 for the first 5 metres.

You are to use simple materials in your test—balloons, drinking straws, adhesive tape and nylon fishing line.

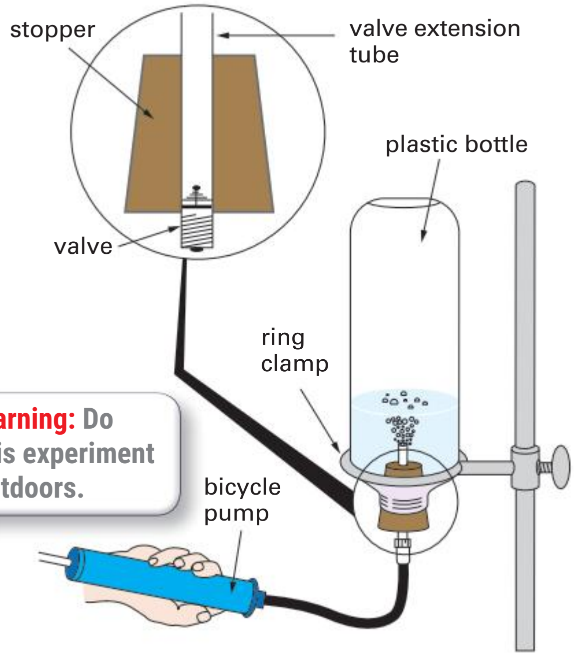
Discussion

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.

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Rocket motion

In Part A of Experiment 5.1 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 kg × 9.8 m/s^2
= 19 600 000 N

Thrust of engines = 69 600 000 N

Net force = thrust − weight of rocket
= 69 600 000 − 19 600 000 N
= 50 000 000 N

$$\text{acceleration} = \frac{\text{net force}}{\text{mass of rocket}}$$

$$= \frac{50\,000\,000\ \text{N}}{2\,000\,000\ \text{kg}}$$

= 25 m/s^2

Space engineers design engines that develop as much thrust as possible, and 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 fireworks skyrocket, it suffers one major disadvantage—once ignited it cannot be extinguished until the fuel has been used up.

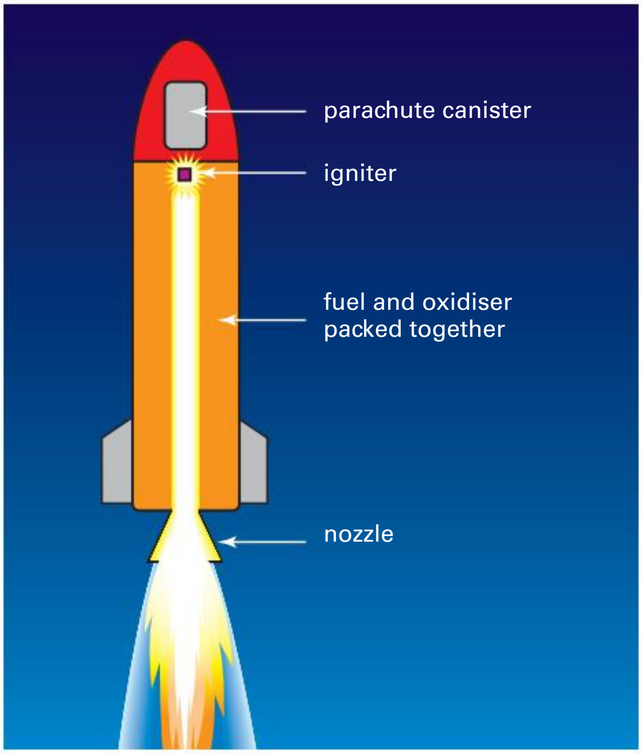

Figure 5.7 A solid-fuel rocket engine has solid fuel and oxidiser packed together. When ignited, the fuel burns, sending high-speed gases out through the nozzle. The parachute enables the rocket to be recovered for re-use.

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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.

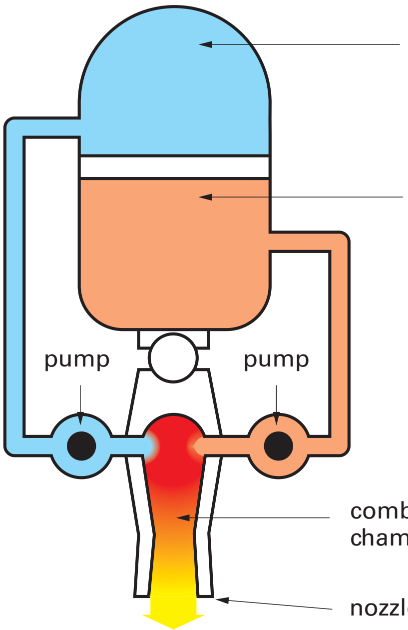

Figure 5.8 A liquid-fuel rocket engine. This engine is more complicated and expensive to build than the solid-fuel engine, but its thrust can be controlled.

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.

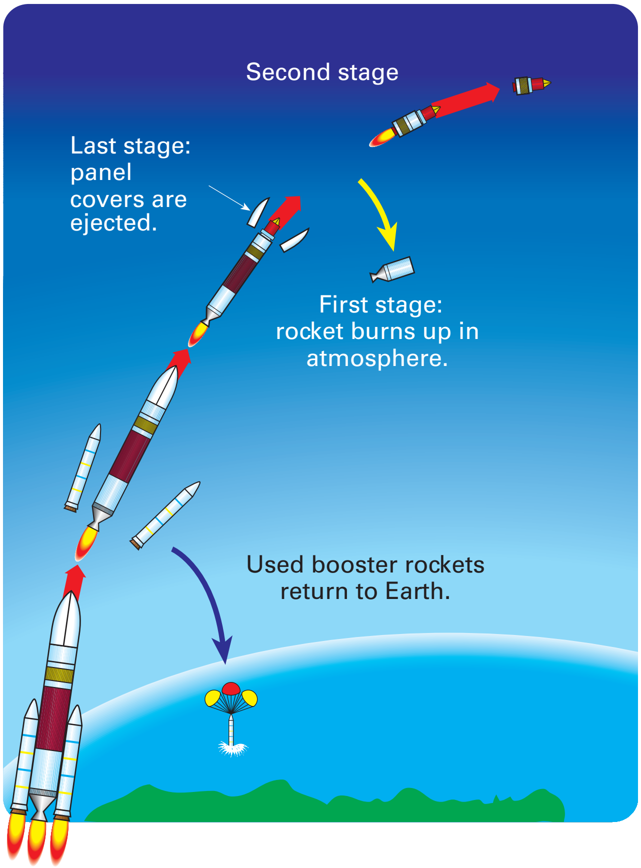

Figure 5.9 Sections of a multistage rocket detach and fall away after use. This helps to keep the mass of the rocket as small as possible while gaining maximum acceleration.

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 Get started on page 121.
   a What is the mass of the person?

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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 4 you have learnt Newton's three laws of motion. In your own words write down these three laws. Check pages 109, 114 and 125.

CHALLENGE

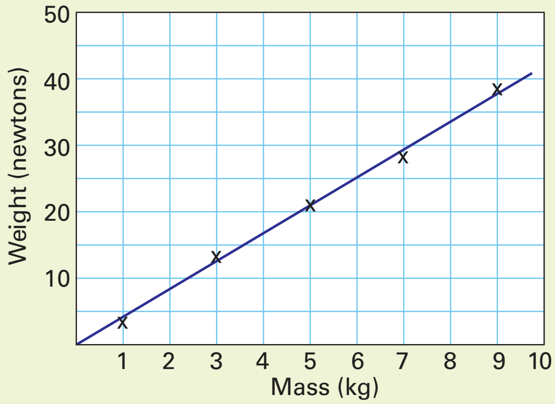
1 A man has a mass of 85 kg. Use the table on page 118 to calculate his weight:
a on Earth
b 1000 km above the Earth.

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 $g = 1.6$ m/s^2 on the moon, calculate the acceleration with which the lander leaves the moon's surface.

4 A rocket and a space vehicle 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 rocket 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 ($g = 1.6$ m/s^2), on Mercury ($g = 4.1$ m/s^2) or on Saturn ($g = 10.8$ 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.

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5.2 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 5000 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.

Figure 5.10 *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 5.1 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

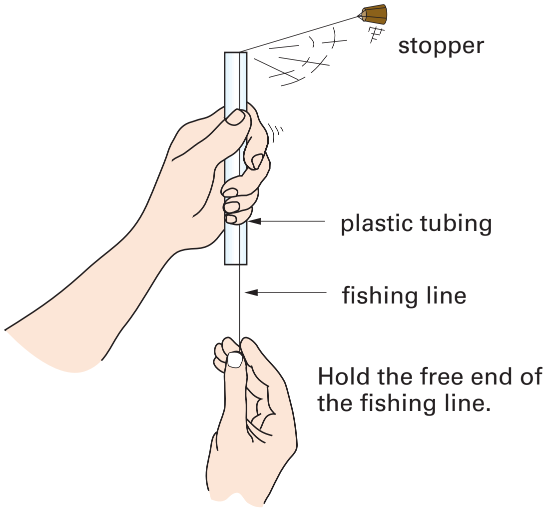
Risk assessment and planning

- 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.



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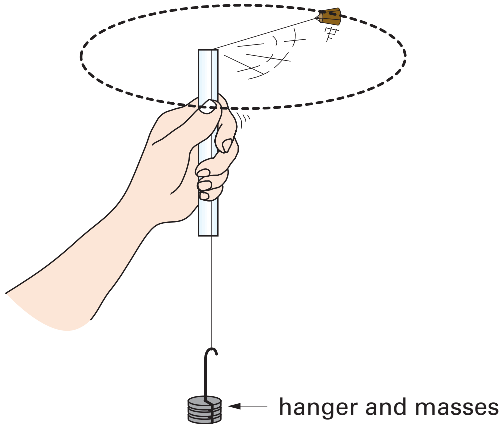
3 Thread the fishing line through the tubing again. Then tie the brass hanger to the free end.

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.

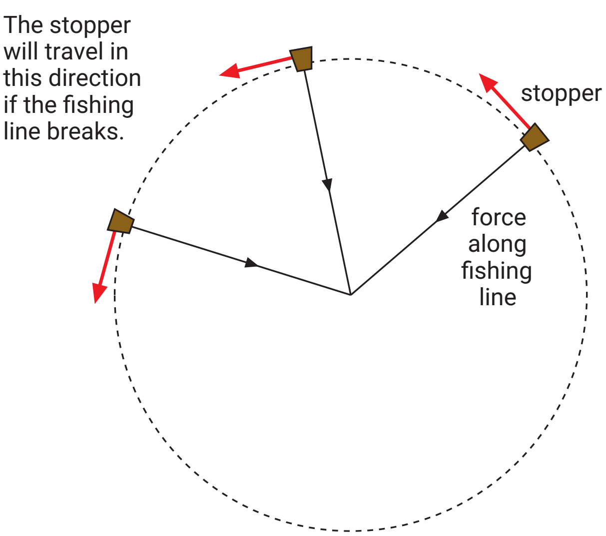


Figure 5.11 The inwards pulling force along the fishing line constantly changes the direction of the stopper's motion.

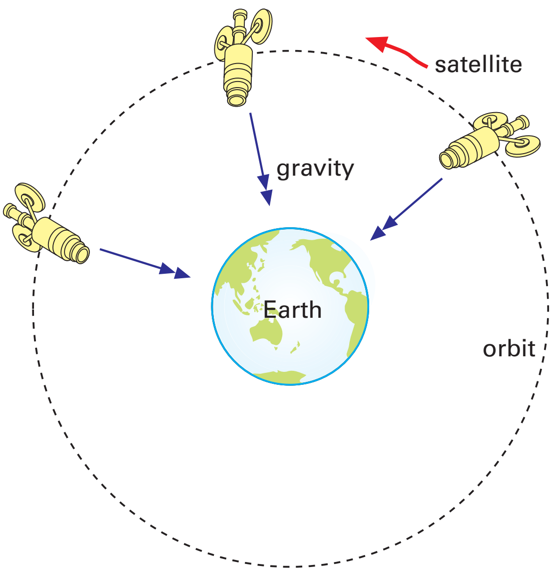


Figure 5.12 The satellite is being pulled towards Earth by the force of gravity, but its motion (inertia) keeps it in orbit.

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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 and even motorists driving along central Australian outback roads can find their position on the Earth's surface using a small portable receiver.

Such satellites are used in remote sensing to collect all sorts of data and images for scientific analysis. Remote sensing is the scanning of the Earth to obtain information about it. It is used to collect information such as weather, surface and ocean temperatures and atmospheric composition, and to search for minerals.

Polar orbiting satellites

Polar orbits are special LEOs that carry satellites in a circle over the North Pole and South Pole. These high-speed satellites complete about

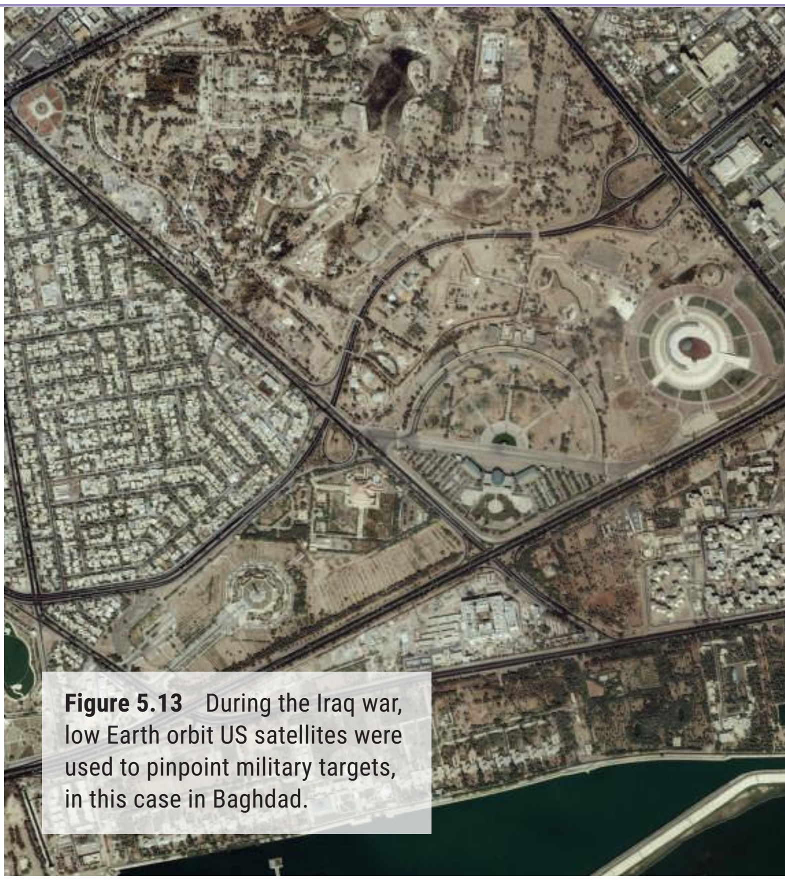

Figure 5.13 During the Iraq war, low Earth orbit US satellites were used to pinpoint military targets, in this case in Baghdad.

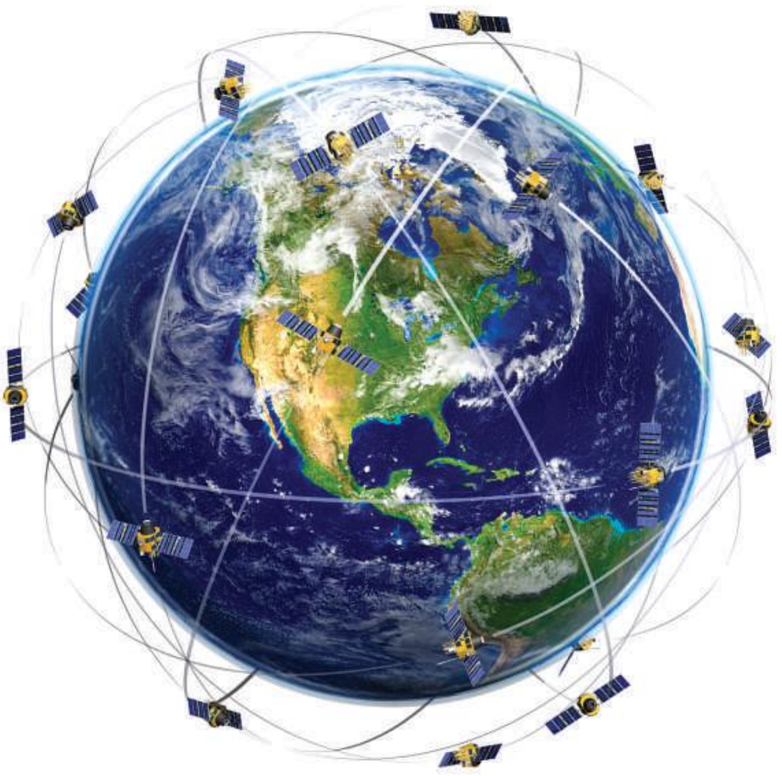

Figure 5.14 The GPS network relies on a network of 24 satellites. Signals from Earth to different satellites can pinpoint your position very accurately.

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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.

Figure 5.15 A typical low Earth orbit satellite

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.

Figure 5.16 Remote sensing satellites can capture images and collect data about the Earth, including monitoring this large hurricane.

EXPLORE ONLINE

1 WEATHER SATELLITES

You might like to look at some images from weather satellites. 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? Check out **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.

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ACTIVITY

In 2011, the NASA space shuttle fleet was retired and since then a new 'space race' has begun to imagine and create new ways to get into space. In time there will be many new technologies and replacements for the shuttles.

NASA has selected two companies, Boeing and Space X, to supply the next technology that NASA will use to get into space, calling them 'space taxis'. Both are capsules that will launch on top of a rocket, and then return astronauts to Earth after docking with the International Space Station. There are also other companies with solutions for getting into space. In time, this will lead to space tourism, and cheaper ways to get people and materials into space. Your task is to research one of these technologies and outline what it is, its benefits and risks, and potential uses. Produce a short summary including images to explain the technology you select. Here are some ideas to get you started, although you may select other technologies.

Space X

Space X is building a capsule called Dragon v2 that will launch on top of a rocket. They are focused on reusable technology to reduce the cost and time for getting into space. Space X has been able to build a rocket that after launch can land back on Earth ready for reuse. This is the first time this has been achieved.

Boeing

Boeing's CST-100 space capsule will transport astronauts to the space station. Boeing is also working with a company called Bigelow Aerospace to create expandable space habitats that may one day be used for space tourism or private space exploration.

NASA

NASA is creating its next generation rocket called the Space Launch System (SLS), powerful enough to get astronauts into deep space and eventually to Mars. It is the most powerful rocket ever designed.

Sierra Nevada corporation

The Dreamchaser is more like a mini-shuttle, and will launch on top of a rocket, but glide back to Earth much like the space shuttle. It is already being tested and is expected to fly into space in 2017.


Space X Dragon v2

Boeing CST-100


NASA Space Launch System (SLS)

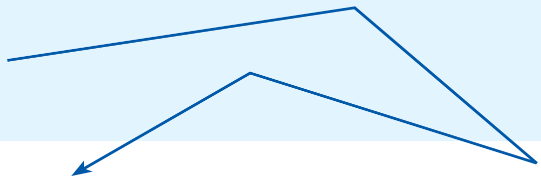

Dreamchaser

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 three times during its movement. Copy the path in your notebook and show, using arrows, the direction of the forces acting on the ball.



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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?

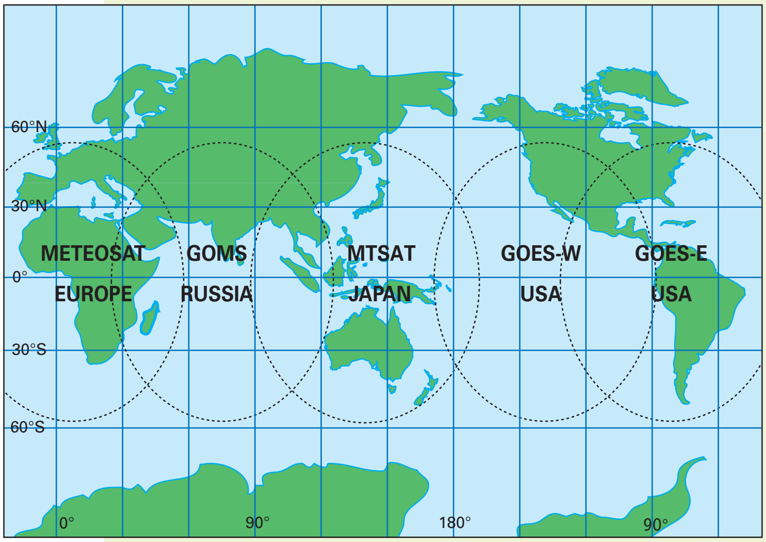
5 a A low Earth orbit (LEO) is usually about 400 km above the Earth's surface but very rarely below this altitude. Why?
  b Why do satellites in LEOs have to have high orbital speeds?
  c What is the main advantage of placing a satellite in a LEO?

6 How is a polar orbiting satellite different from a geostationary satellite? What are the advantages of placing satellites in polar orbits?

7 Research the space shuttle.
  a What was its purpose?
  b What caused the temperature on the shuttle's surface to rise on re-entry?
  c 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. Assume 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.

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5.3 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. Here are some of the problems of living in space.

Figure 5.17 Fresh fruit arrives on a supply mission to the International Space Station.

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.

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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 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 or solar panels. 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. Your eyeballs can also go out of shape.
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 other machine.
4. The most serious problem for space travellers is the demineralisation of bones. Weight-bearing 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.

Figure 5.18 Japan Aerospace Exploration Agency astronaut Koichi Wakata, flight engineer, gets a workout on the Advanced Resistive Exercise Device (ARED) in the Tranquility node of the International Space Station.

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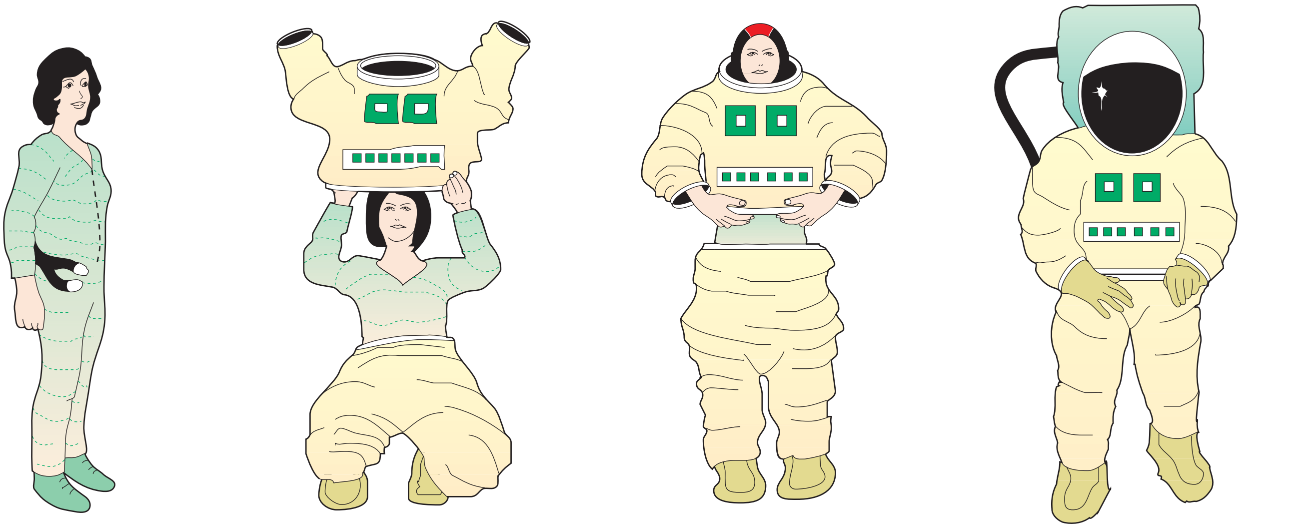
Heat and radiation

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. Spacesuits also protect astronauts from space dust, which although may be small, can travel faster than a bullet and can be very dangerous. Special gold-lined visors also protect eyes from bright sunlight.

Follow the link to check out the NASA prototype for their Z-2 spacesuit. What are the advantages of this new design over existing designs?

Figure 5.19 How a spacesuit works



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. It may also contain boosters enabling it to 'fly' in space.

ACTIVITY

Astronaut's diary

Use the information on pages 136–138 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, such as 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.

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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 400 km, and orbits the Earth every 92 minutes.

Figure 5.20
(*top*) The International Space Station in orbit 400 km above the Earth's surface.
(*bottom left*) On 24 August 2016 Commander Jeff Williams became the first astronaut to spend over 534 days in space.
(*bottom right*) Astronaut Kate Rubins aboard the ISS.

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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.

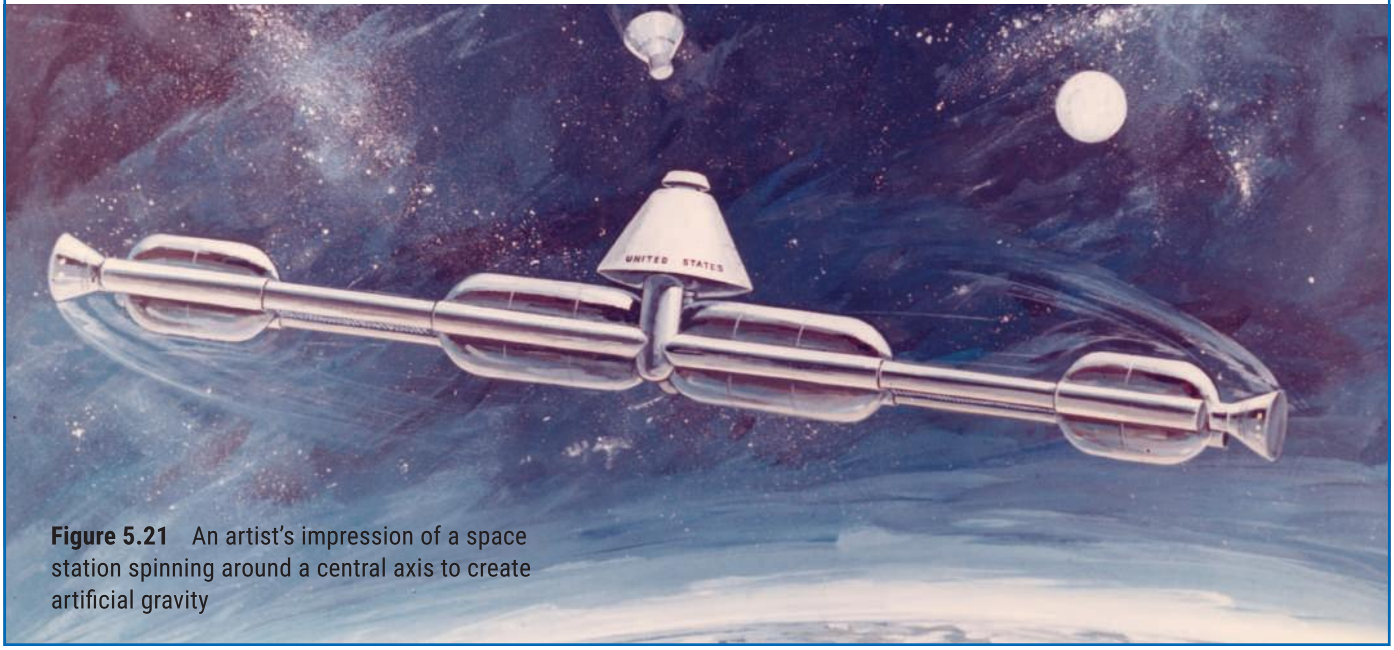

Figure 5.21 An artist's impression of a space station spinning around a central axis to create artificial gravity

ACTIVITY

Your task is to design a space station that will generate artificial gravity and 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?

EXPLORE ONLINE

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

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SKILLBUILDER

Space experiment

A major task for the crew of the International Space Station is to conduct experiments in space. They spend much of their time completing experiments related to medicine, physiology, biology, Earth science, physics, electrical engineering and technology, fluid dynamics, chemistry and many other areas of science and engineering. 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 the webs 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.

Currently a STEM company named Cuberider (Quberider) is working with schools to get Australian payloads into space and onto the ISS. The payloads, which are the size of a coffee mug, will be launched aboard the Space X Falcon 9 rocket, and will carry dozens of software experiments developed by nearly 1000 students from 40 high schools across New South Wales. These experiments, carried on a microcomputer, will collect data and perform experiments aboard the ISS. Using various sensors including gyroscopes, infrared, temperature, magnetism and luminosity sensors, students are to test many ideas, including variations in the Earth's magnetic field, Einstein's theory of relativity, and exposure to radiation. Students have even created music and art using data patterns.

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.

Figure 5.22 This plant growth experiment is exploring how plants grow in microgravity.

Figure 5.23 NASA is currently testing a 3D printer in space, which will enable missions to create their own spare parts.

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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. The three crew members 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*.

EXPLORE ONLINE

For more information about Andy Thomas, follow the links to these websites:

Andrew S.W. Thomas

Mission Specialist Andy Thomas

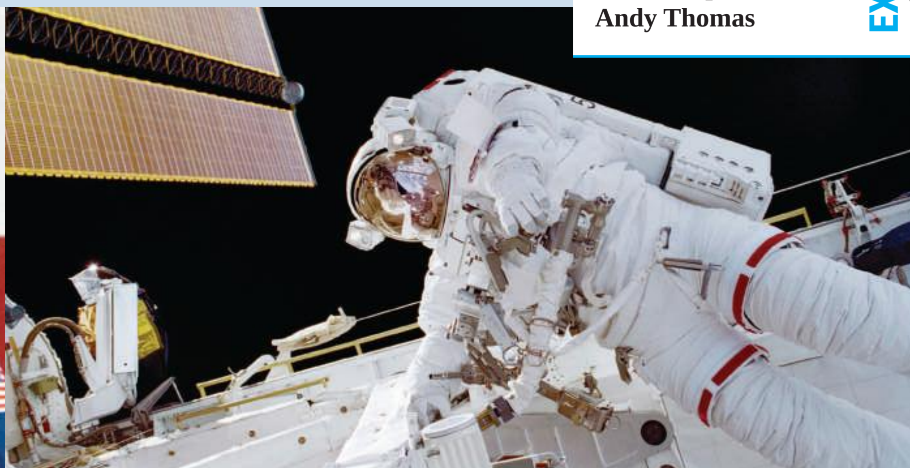

Figure 5.24 Andy Thomas gathers equipment in the cargo bay of space shuttle *Discovery* at the end of his space walk in March 2001.

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?
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?

Figure 5.25 Getting a haircut on the ISS involves using suction to collect hair as it is cut.

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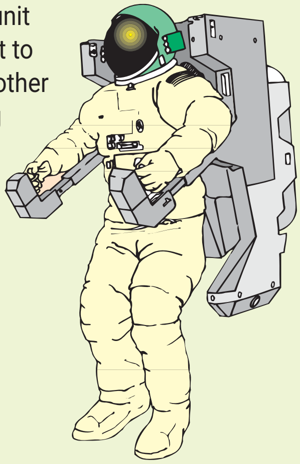
6 Why is the level of carbon dioxide in the air of the crew compartment monitored carefully?

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 when it is released into space from a spacecraft.

6 The International Space Station has cost more than $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.

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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.

gravity
reaction
action
mass
satellites
force
microgravity
inertia
decreases
radiation
orbital speeds
thrust
weight

CH•5 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 these 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.

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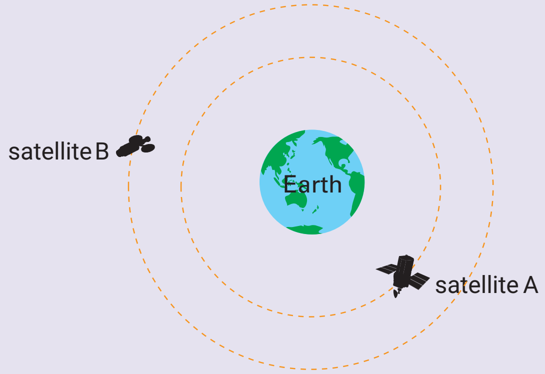
5 Two satellites are in orbit around the Earth. Satellite A is at an altitude of 400 km while satellite B is at an altitude of 900 km. Explain why satellite A has to have a greater orbital speed than satellite B.



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 a space shuttle going to the International Space Station. You made the following observations; write an inference for each one.

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 shuttle glowed red hot.

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 Earth’s moon?

Check your answers on page 345.

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IN THIS CHAPTER

Science Understanding

- investigate series and parallel circuits and measure voltage drops across and currents through various components
- investigate household circuits, and explore electrical safety
- investigate the movement of a magnet and a wire to produce electricity
- explore electricity generation and transmission
- compare the impact of coal burning and nuclear power stations on the environment
- understand how technological advances are enabling the development of solar cars

Science Inquiry Skills

- interpret graphs of electrical power demand
- use equations to calculate voltage, current, resistance and power

CH•6 Using electricity

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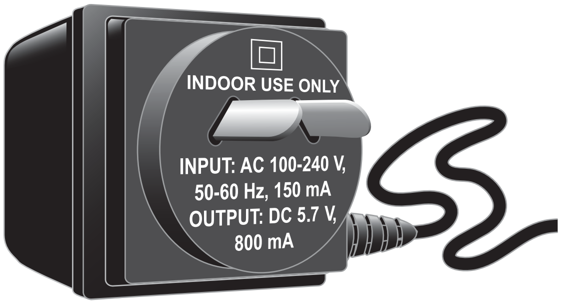
GET STARTED: *QUESTION*

Find a mobile device charger for your phone, tablet or laptop and use it to answer the following questions:

1 Look at the transformer that is part of the charging cable. Write down what it says on it about:
   a the input
   b the output
   c the frequency (Hz).
2 The input will be in AC, and the output in DC. Discuss what you think these terms mean.
3 What is purpose of the transformer?
4 Which is the more dangerous form of electricity, AC or DC? Why do you think so?
5 What do these units V, A or mA stand for?
6 What is the difference between V and A in terms of electricity in a circuit?
7 Is AC or DC electricity used in your home circuits?
8 Can you remember what a circuit is? Can you draw a simple circuit?
9 Try to draw a series and a parallel circuit to explain how they are different.



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6.1 Electrical safety

AC and DC

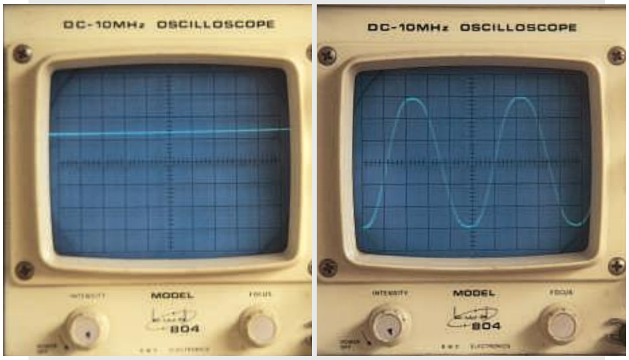
Caitlin has just unpacked the mobile phone she received for her birthday. She notices that it has a rechargeable battery, and it has a cord so she can plug it into a power point to recharge it. However, she is not sure what the things on the recharging plug mean.

When Caitlin connects her mobile phone to a power point, she is using the *mains supply*, with a voltage of 240 volts (or 240 V) AC. AC stands for *alternating current*, since the current changes direction 50 times a second (50 hertz or 50 Hz). The electric current flows first in one direction and then in the opposite direction. Mains power is dangerous because the high voltage can drive large currents, which can kill you. The recharger converts the 240 V AC to 5.7 V DC to charge the battery. DC stands for *direct current*, since the electric current flows in one direction only.

ACTIVITY

If your school has a cathode ray oscilloscope (CRO), your teacher may show you the difference between DC and AC.

1. If you connect a 1.5 volt battery to the CRO, you see a straight line.
2. If you connect an AC power supply, you see a wave shape. Above the horizontal axis the current is in one direction, and below the axis it is in the opposite direction.



DC AC

Electricity in the home

Mains electricity is supplied to your home by two wires covered with plastic insulation. The wires are often enclosed in a single cable. One of the wires carries AC electricity into the house and is called the *active* or *live* wire. It alternates between +240 volts and −240 volts. The *neutral* wire (zero volts) completes the electric circuit from the house back to the power station.

Both the live and the neutral wires are connected to a meter box, which contains the electricity meters, main switch and circuit-breakers or fuses. The meter measures how much electricity is used in the house. From the meter box, the live and

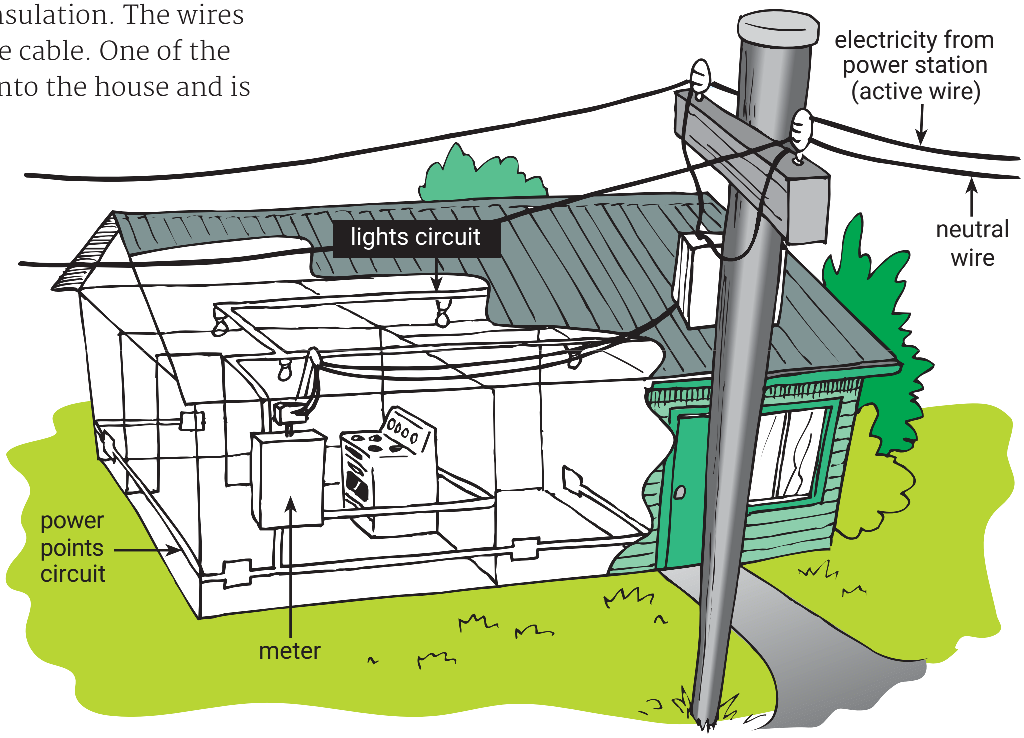


Figure 6.1 Circuits in the home

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neutral wires branch out to make several different circuits. These circuits carry electricity to the lights, power points, stove and hot water system. Switching on an appliance allows AC electricity to move from the active wire through the appliance and back through the neutral wire.

Houses are usually wired using parallel circuits, as in Figure 6.2. The advantage of this is that all the circuits can be connected separately to the mains power supply. For example, if a light bulb in one room 'blows' (that is, the circuit is broken), all the other lights in that parallel circuit can still operate.

The meter box also contains circuit-breakers or fuses, which are safety devices in case there is a short circuit. In Investigation 6.1, you can see how a fuse works.

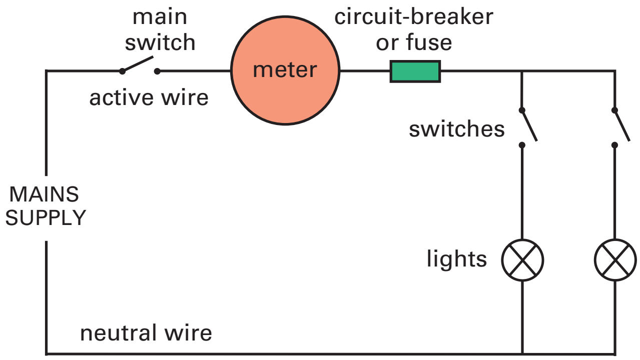

Figure 6.2 If one bulb blows in this parallel lights circuit, the other bulb continues to work.

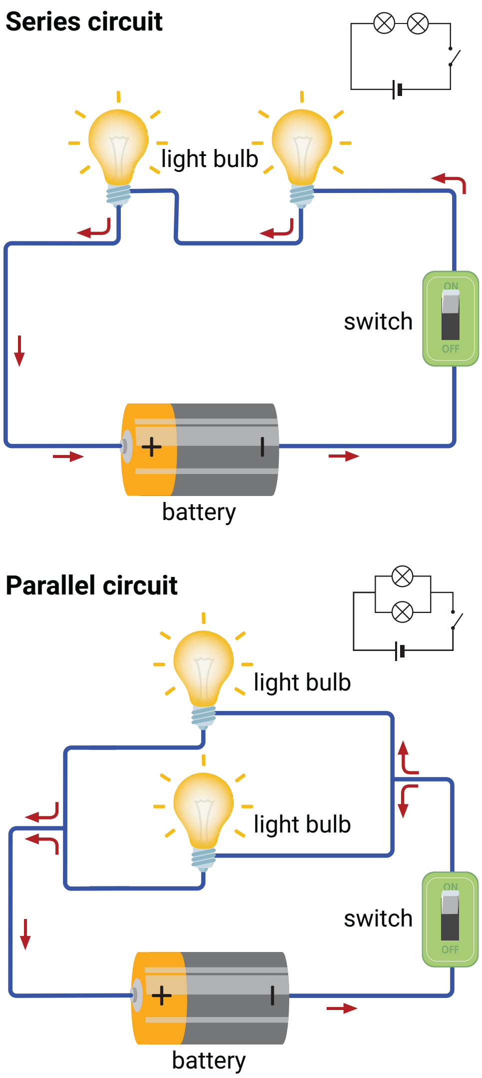

Figure 6.3 Series and parallel circuits

INVESTIGATION 6.1 Short circuits and fuses

Aim

To investigate what causes a short circuit and how a fuse works.

Materials

- power pack or battery
- 4 connecting wires
- switch
- torch bulb in holder
- screwdriver or other conductor
- large rubber stopper
- 2 large pins
- strands of steel wool
- heatproof mat

Risk assessment and planning

Discuss with your teacher the safety precautions necessary when using a power pack.

Suggest why the circuit has a switch in it.

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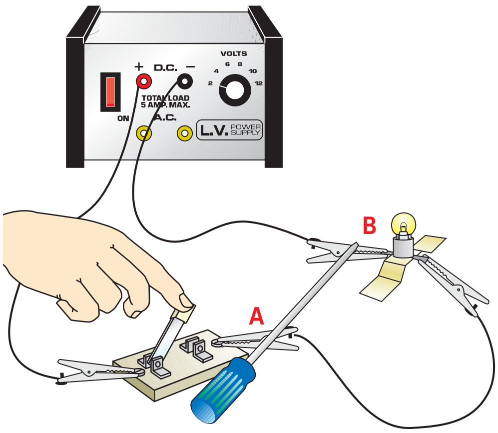
PART A A short circuit

Method

1 Connect up the circuit shown here, with a power pack, a switch and a bulb in series. Set the power pack on 2 volts DC.



2 Close the switch. Then carefully touch a screwdriver or other conductor across the alligator clips at A and B. *Immediately you see what happens, take the screwdriver away.*

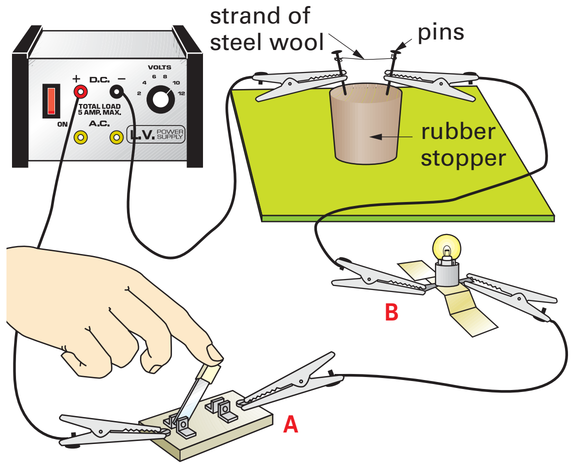
Discussion

1 What you have observed is a short circuit. Describe it in your own words.

2 Infer the path of the electric current:
 a without the screwdriver
 b with the screwdriver.
 Why do you think the path through the screwdriver is called a short circuit?

PART B Making a fuse

1 Make a simple fuse from a large stopper, two pins and a strand of steel wool. Put it on a heatproof mat as shown.



2 Connect your home-made fuse into the circuit you used in Part A, and close the switch.

3 Again short the circuit across A and B with the screwdriver.
 Observe what happens.
 If nothing happens, increase the power pack voltage slightly.

Discussion

1 Why did the fuse blow in step 3 but not in step 2?

2 Why do you think you used a rubber stopper to make the fuse?

Fuses and circuit-breakers

In Investigation 6.1, the metal screwdriver was a better conductor of electricity than the strand of steel wool. It had less electrical resistance. The current therefore took the easier path and flowed through the screwdriver. This path is called a **short circuit**.

Short circuits are very dangerous. If two bare wires touch, there may be a spark. Or the wires may become so hot that they cause a fire. So when short circuits occur, you need to cut off the electricity using a fuse or a circuit-breaker.

A **fuse** is a safety device containing a piece of wire that melts if too great a current passes through it. Fuses are used mainly in cars and electronic appliances. They are usually thin strips of metal inside a plastic or glass cartridge, and they snap into clips. Ask an adult to show you the fuse box in a car. It is usually on the driver's side under the dashboard.

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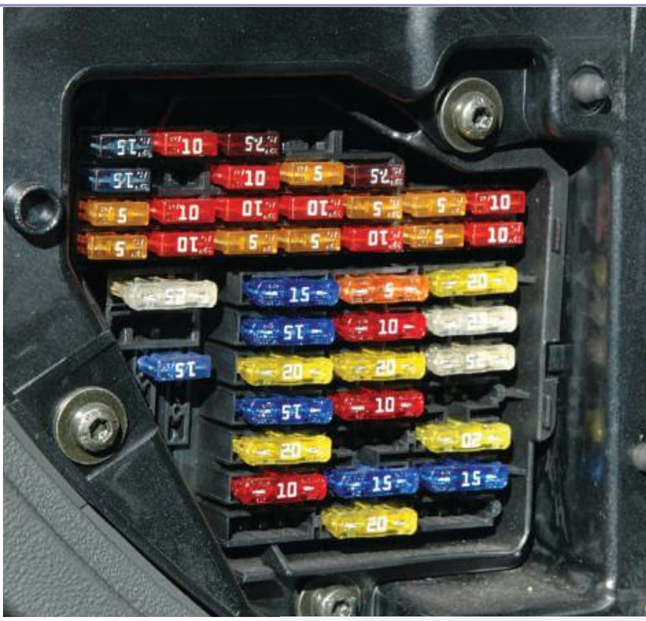


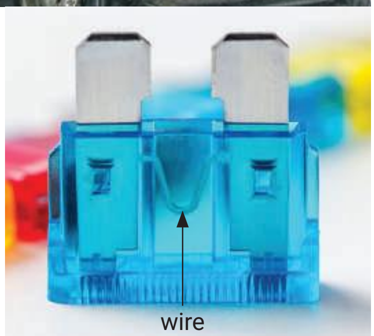
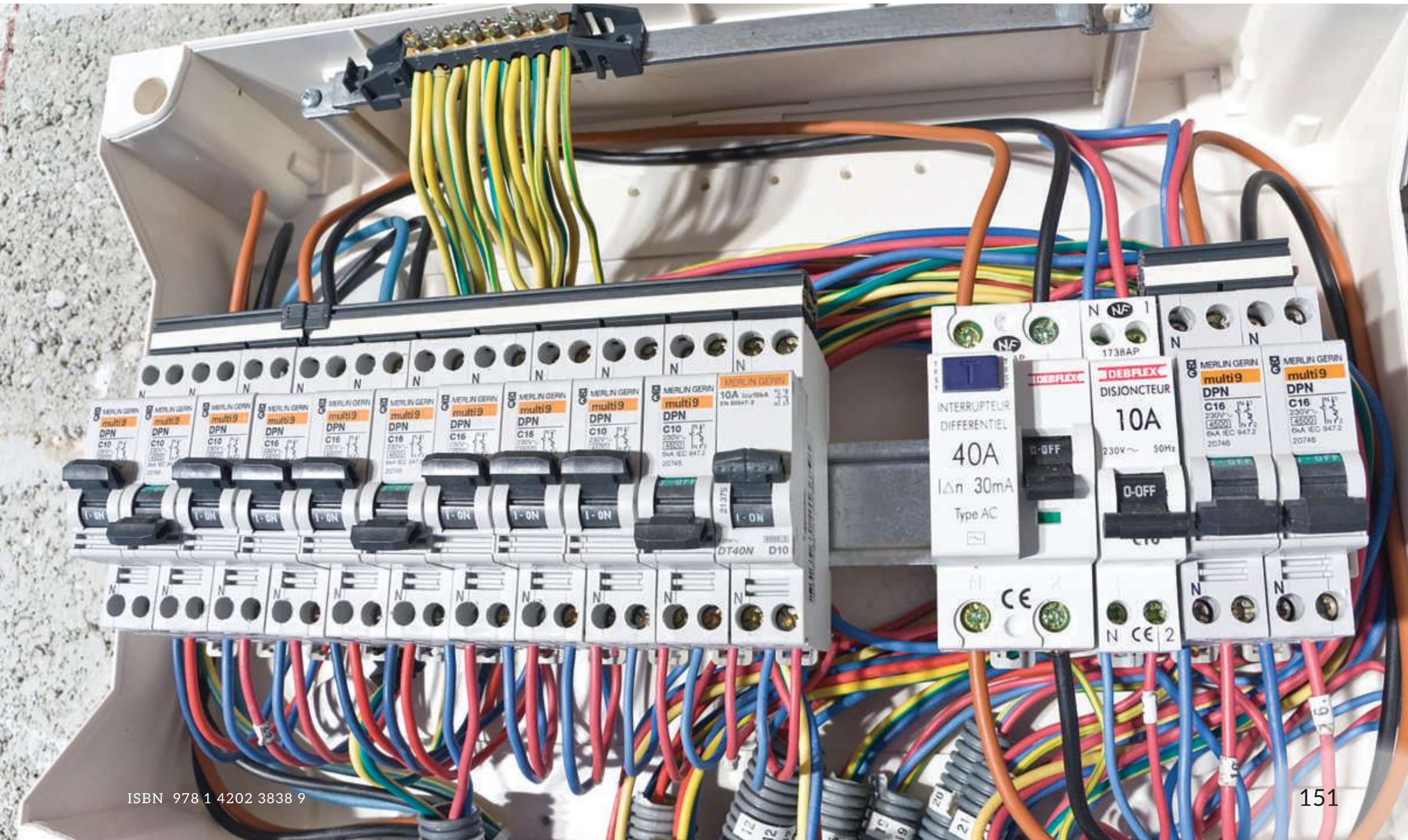


Figure 6.4 The fuse box in a car. Notice that there are different fuses for different circuits. There are also several spare fuses. In the close-up you can see the wire that melts between connections.

Note that there are different fuses for different circuits such as lights (10 A), cigarette lighter (15 A), and heater (25 A). A 10 amp fuse will allow a current of up to 10 amps to flow through it before it fuses (melts). A 25 amp fuse will allow a current up to 25 amps. The thicker the fuse wire, the more current it will take before it 'blows'. If a fuse blows, you simply replace it with one of the correct value. If it keeps blowing, there is probably a fault in the circuit that needs fixing.

Most homes now have **circuit-breakers** (Figure 6.5) instead of fuses. If too much current flows, the circuit-breaker automatically turns off the electricity. This happens if a household circuit becomes overloaded; for instance, when you are already using several appliances, then plug in another such as an electric heater. Circuit-breakers are more convenient than fuses since you do not have to replace any wires. Once the cause of the short circuit has been fixed, you simply switch the circuit-breaker on again.

Figure 6.5 The circuit-breakers in a meter box. If there is a fault in a particular circuit, that switch automatically turns off.



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Earthing

Most electrical appliances have three-pin plugs. The longer pin is called the *earth*, because it is connected to the ground (earth). You may be able to find the **earth wire** connected to a metal water pipe or stake outside or under your house somewhere.

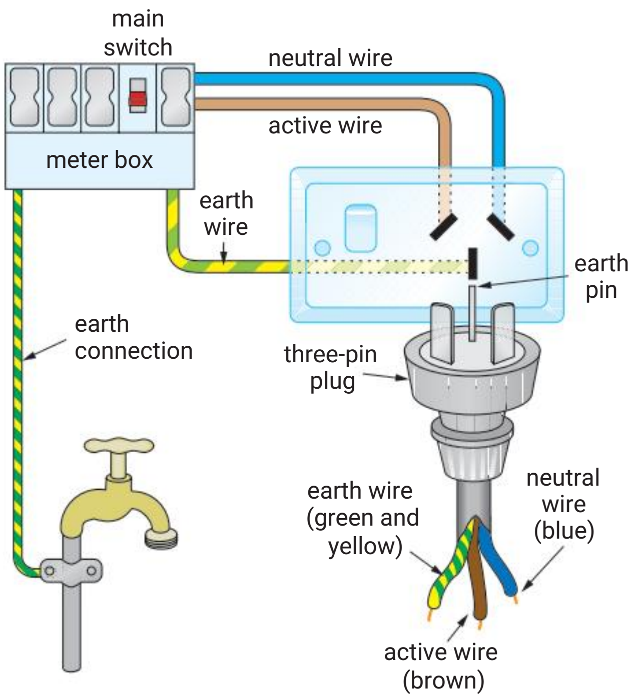

Figure 6.6 A three-pin plug and power point showing how the earth wire is connected

Because metals are such good conductors of electricity, electrical appliances with a metal case, such as washing machines and toasters, must be earthed to protect you from electric shocks. If there is no earth wire and the live wire loses its insulation and touches the metal case, current will flow through the live wire via the case and through your body, and you will receive an electric shock. The earth wire is attached to the metal case and normally carries no current. But if there is a short circuit, current flows harmlessly from the live wire through the earth wire to the ground and you don't receive an electric shock. The circuit-breaker in the meter box will probably switch off, since too much current flows through the appliance.

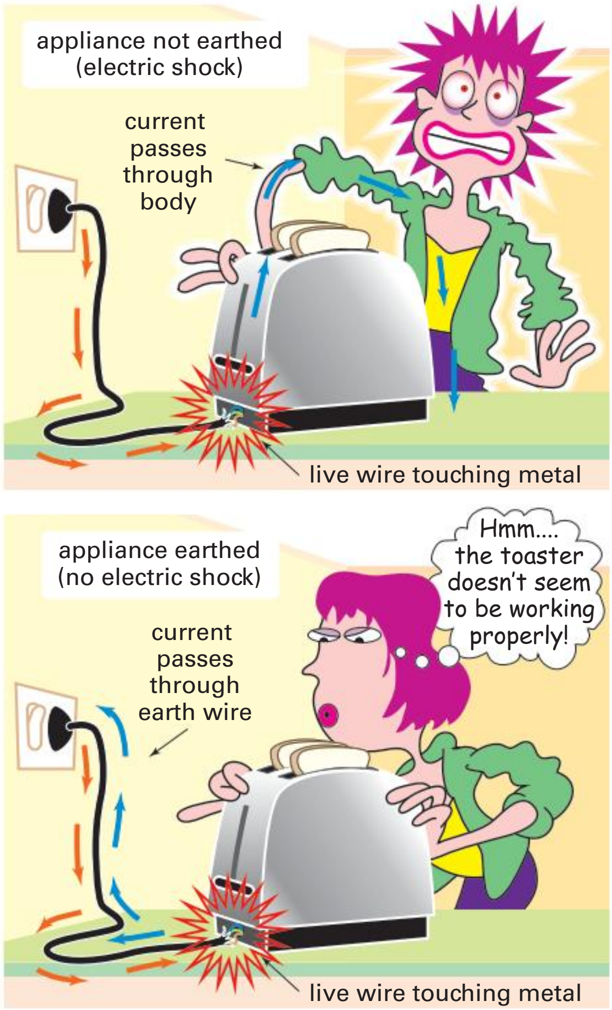

Figure 6.7 Earthing appliances keeps us safe.

Many appliances such as portable radios and hair dryers are made with no external metal parts. They are instead totally surrounded by plastic, which is an insulator. This insulation is sufficient to protect you even if a fault occurs. Such appliances are said to be *double-insulated*, and have the double-insulation symbol ⧈ marked on them. (See the plug on page 147.) These appliances do not need an earth and have a two-pin plug instead of the normal three-pin plug.

You should also keep in mind when using electrical appliances that water will conduct electricity. For this reason, you must be extra careful using electrical appliances in places where water is likely to be spilt, such as in the kitchen, laundry or bathroom.

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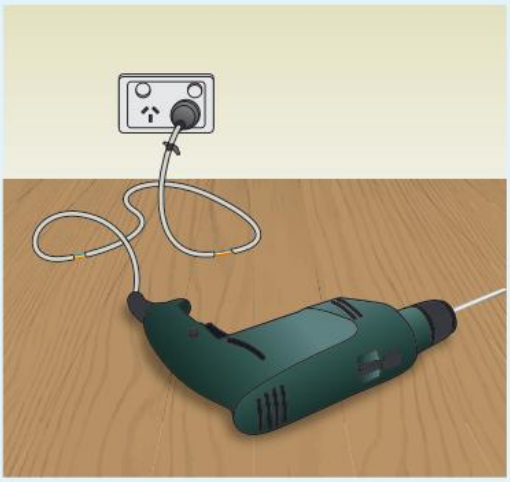
CHECK

1 Explain what is dangerous about each of the situations shown.

a

b

c



d

2 a Why do some appliances have a three-pin plug and some have a two-pin plug?
  b Suppose a toaster has a metal case. Would you expect it to have a three-pin plug or a two-pin plug? Explain.
  c To which part of the toaster would you expect the earth wire to be connected?

3 What is the meaning of the number 15 marked on a fuse or circuit-breaker?

4 What would happen if the live wire in a double-insulated hair dryer touched the plastic case?

5 Light circuits usually have an 8 amp circuit-breaker, and power circuits a 15 amp one.
  a What might happen if you put an 8 amp circuit-breaker in a power circuit?
  b What might happen if you put a 15 amp circuit-breaker in a light circuit?
  c Which mistake would be more dangerous—**a** or **b**? Why?

6 What is the advantage of having Christmas tree lights connected in parallel?

7 Stupid Sparky said: ‘Fix a broken car fuse with anything—a nail, a piece of wire or a coin. It’s too much trouble to get the proper fuses. And they don’t blow again when you put thick wire or nails in them.’ Explain why Stupid Sparky is being so stupid.

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CHALLENGE

1 When Jordan plugs a toaster into a power point and turns it on, the power goes off. He finds that the circuit-breaker has switched off, so he turns it back on. He then turns the toaster on again, but the circuit-breaker switches off again. What should Jordan do next? Why?

2 The diagram below shows a kettle with a fault: the active wire is touching the metal case, causing it to be live. Copy the diagram and add two safety devices that would protect someone using the kettle.

3 Draw a circuit containing an AC power source (symbol —⊝—) and five light bulbs:

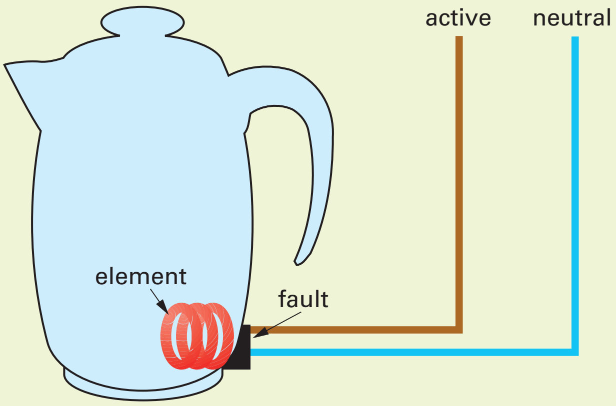
a in series

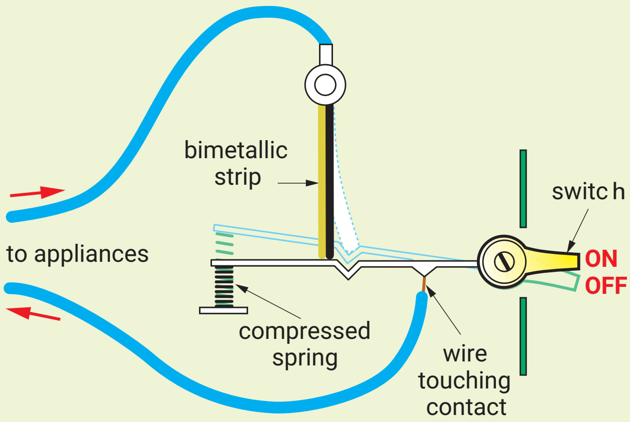
b in parallel

c some in series and some in parallel.

For **b**, put in switches to turn each light on and off independently, and one that will turn them all on and off together.

4 Use the diagram below to explain how this type of circuit-breaker works. The bimetallic strip consists of two different metal strips, one of which expands more than the other when it becomes hot.



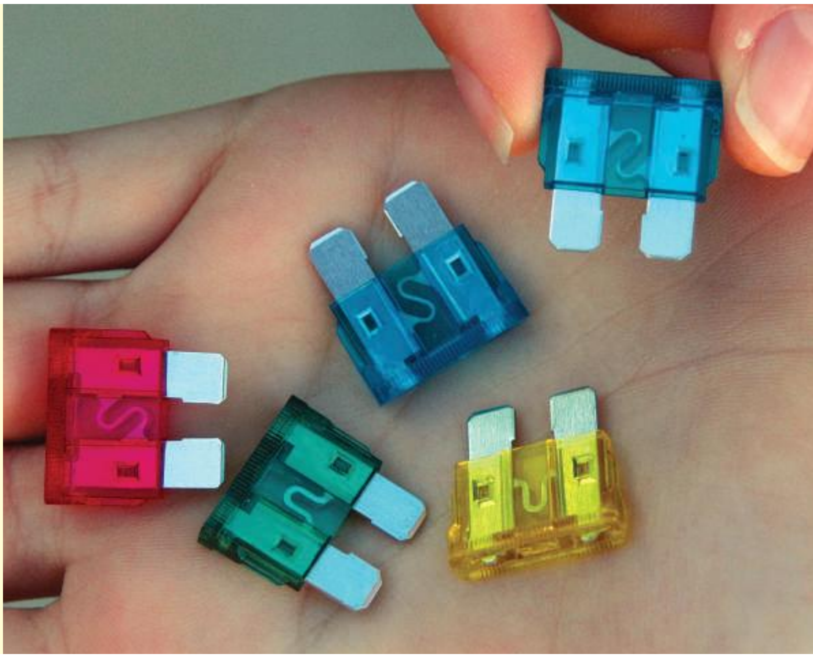


EXPLORE

1 Obtain some old electrical plugs, sockets and switches that are no longer being used. Examine them carefully and try to explain how they work. You could also pull apart an old electrical appliance such as a toaster, iron or radio—*with its 240 V plug removed*. See if you can identify any of the parts. Can you put the appliance back together correctly?

2 Look at some car fuses or fuse wires. Note the relationship between the thickness of the wire and the current that will pass through it.

3 Design a poster to draw people's attention to the hazards in using mains electricity.



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6.2 Measuring electricity

Current, voltage and resistance

Before you can measure the electrical energy used by household appliances, you need to be able to measure the current and voltage in a circuit. The diagrams below show how you can use the flow of water through pipes for a swimming pool as a *model* to explain the flow of electricity in an electric circuit.

In the water circuit, you can measure the rate of flow of the water. In the electric circuit you can measure the electric current (*I*), which is a movement of electrons. Electric current is measured in amperes (or amps for short) using an ammeter. One ampere is about 6 000 000 000 000 000 000 electrons moving past a point every second. The electric current is the same everywhere in the circuit, so it does not matter where you connect the ammeter, so long as it is in series with the resistance and the battery.

In the water circuit, the pump pushes the water around the circuit and has to overcome the resistance of the pool filter. In the electric circuit the battery supplies the electrical 'pressure' (voltage *V*) to push the current through the light bulb. The higher the voltage, the more current is forced around the circuit. As the electrons are pushed through a resistor (such as a bulb or a piece of wire), they lose some of their energy as light and heat. As a result, there is a drop in voltage across the resistor. This is measured in volts using a **voltmeter**. Note that because you are measuring a *difference* in voltage, you must connect the voltmeter in parallel across the part of the circuit where you want to measure the voltage.

Insulators (plastic, for example) do not allow an electric current through them easily. They have a high resistance. In contrast, metals and other conductors have a low resistance, although some metals have a higher resistance than others. For example, the nichrome wire used in heating elements and the thin tungsten wire used in light bulbs have a higher resistance than the copper wire used in electrical wiring. The resistance of wire also depends on its length, thickness and temperature. When measuring resistance, you use a unit called the **ohm**. (Ohm rhymes with 'home' and its symbol is the Greek letter omega Ω.)

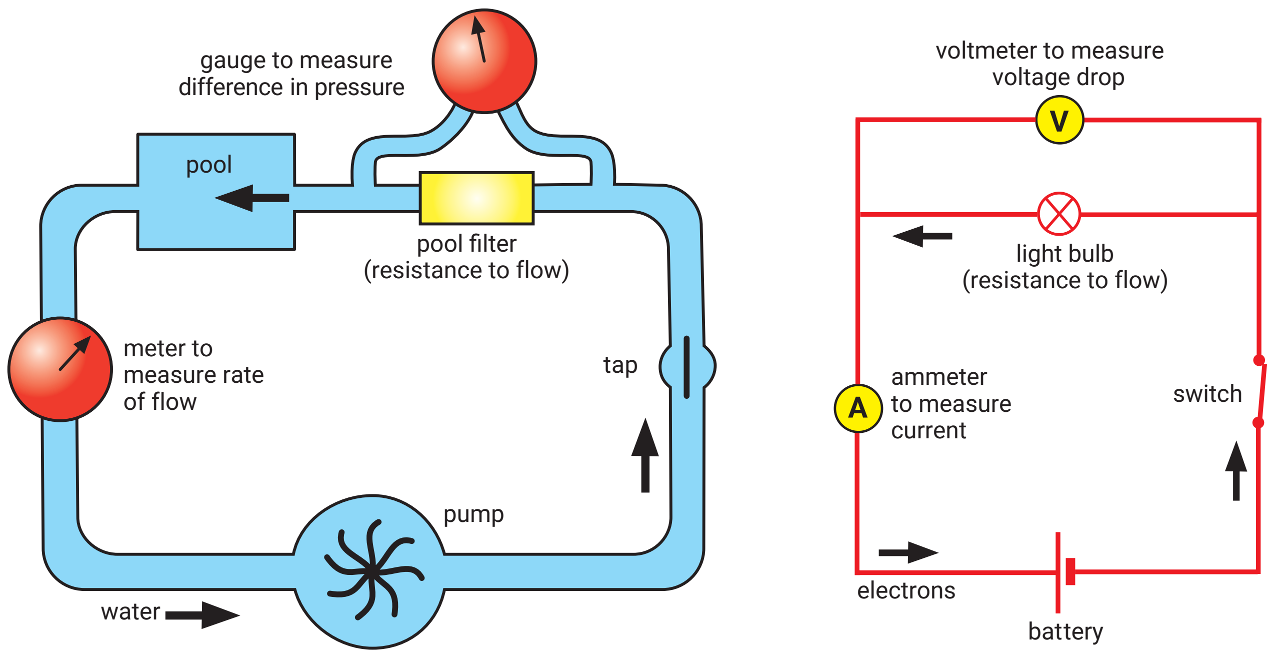

Figure 6.8 A water circuit for a swimming pool is similar to an electric circuit.

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Ohm's law

In 1826, the German scientist Georg Ohm investigated how voltage, current and resistance in an electric circuit are related. He discovered that if you double the voltage across a conductor, twice as much current will flow through it. Three times the voltage produces three times the current, and so on. This discovery came to be called **Ohm's law**. *The current flowing through a conductor is proportional to the voltage difference between its ends.*

For a given conductor, the ratio *V*/*I* is constant. This ratio is the resistance (*R*) of the conductor. It is the resistance of the conductor that determines whether the current in a circuit is large or small. Ohm's law can be written as an equation:

$$\frac{\text{voltage}}{\text{current}} = \text{resistance} \quad \text{or} \quad \frac{V}{I} = R$$

This can be rearranged to give $V = IR$

A simple way to rearrange equations is to write the three variables in a triangle as shown. Cover the symbol that stands for what you want to find, and the other two symbols tell you how to calculate it. Other maths equations can be rearranged in the same way.

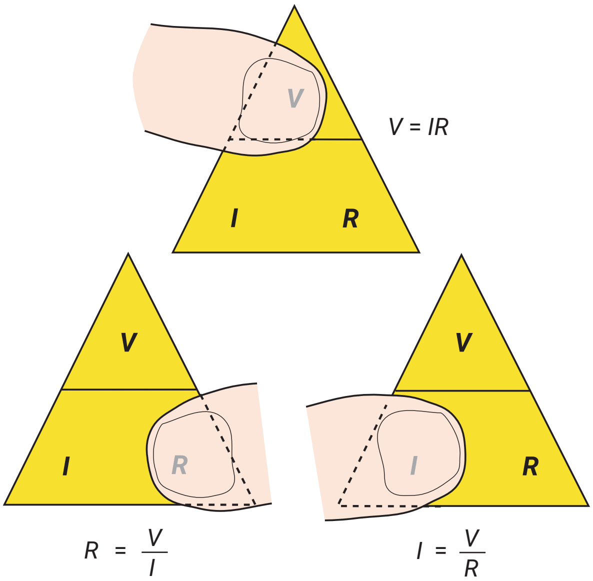


Figure 6.9 Rearranging Ohm's law is easy.

Suppose you have a 4 ohm resistor connected to a 12 V battery. You can find the current in the circuit as follows:

$$I = \frac{V}{R} = \frac{12 \text{ volts}}{4 \text{ ohms}} = 3 \text{ amps}$$

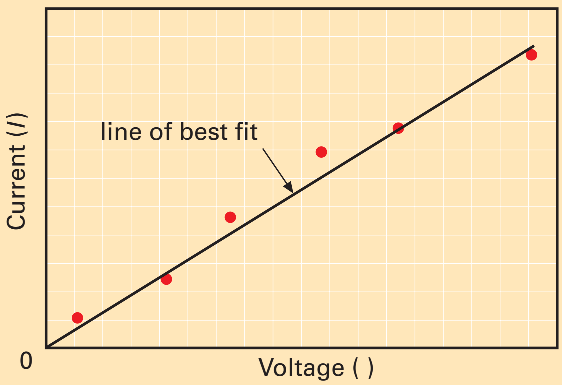
In Investigation 6.2, you can test Ohm's law for yourself.

SKILLBUILDER

Drawing lines of best fit

Suppose you graph your results from an investigation into the relationship between two variables, as shown. In this case, the points lie roughly on a straight line. For this reason, it is better to draw a line of best fit, rather than joining all the points. A line of best fit averages out any errors in your measurements. It shows the general trend of all the measurements.

Drawing lines of best fit takes practice. The line need not go through all the points, but it should pass as close as possible to all the points. As a guide, there should be about as many points above the line as below it. To draw the line, use a plastic ruler that you can see through. Also, use a pencil so you can rub the line out if you are not happy with it.



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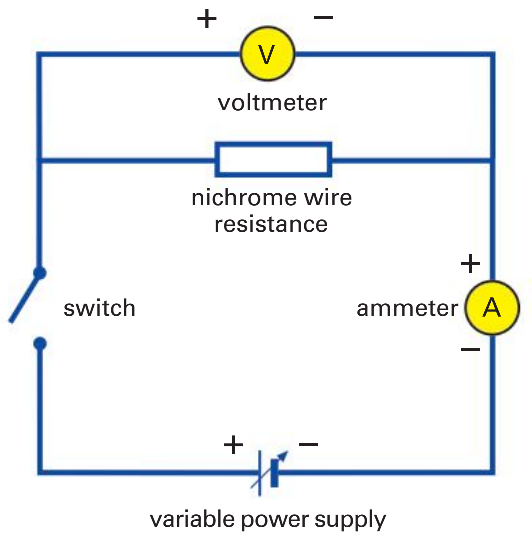
INVESTIGATION 6.2 Ohm's law

Aim

To find out how voltage, current and resistance in an electric circuit are related.

Materials

- power pack
- piece of nichrome wire (jug element wire) about 50 cm long or small resistor (e.g. 20 Ω)
- voltmeter and ammeter or 2 digital multimeters
- switch
- 6 connecting wires, with alligator clips
- heatproof mat



Warning: Do not turn on the power pack until your teacher has checked your circuit.

Risk assessment and planning

You must prepare well for this investigation, so read it carefully before you start.

- Discuss with your partner(s) how you will connect the voltmeter in the circuit.
- How will you connect the ammeter?

Draw up a data table like the one below.

Power supply setting (volts)	*V* Voltmeter reading (volts)	*I* Ammeter reading (amps)	$\frac{V}{I}$ (ohms)

Method

1 Set up an electric circuit as shown top right, with the nichrome wire on a heatproof mat. Connect the ammeter in series with the nichrome wire. Connect the voltmeter in parallel with it. Make sure that the positive terminals of the ammeter and voltmeter are connected to the positive side of the power pack as shown.

2 Set the power pack to 4 volts DC. Close the switch and read the voltmeter and ammeter as quickly as possible. (If you leave the switch closed for too long, the nichrome wire becomes hot, and this changes its resistance.)
Record the voltage *V* and current *I* in your data table.

3 Repeat the measurements for a number of different power pack settings less than 4 volts: say 3, 2, 1.5, 1 and 0.5 volts. Allow plenty of time between readings for the wire to cool.
Record all results.

4 Plot current *I* (vertical axis) against voltage *V* (horizontal axis) on graph paper.

Discussion

1 If you increase the voltage, what happens to the current? If you double the voltage, what happens to the current?

2 Use your graph to predict the current for some voltages you did not test, e.g. 2.5 volts, 5 volts. Test your predictions.

3 Complete the data table by calculating the values for voltage divided by current. As the voltage and current change, what do you notice about *V*/*I* ?

4 Suggest why the plotted points are not all exactly on a straight line.

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Electric shocks

An electric shock is caused by an electric current passing through your body. The muscles in your body are triggered by small voltages in the nerves. Your nervous system cannot cope with larger voltages and currents, and the muscles suddenly contract or spasm. Your heart may also spasm or even stop.

The larger the current, the more painful and serious the shock. In general, if there is a large voltage and a small resistance, then the current will be large. The mains voltage is always 240 V, but the resistance of the human body varies. The diagrams on this page show three different situations.

In Figure 6.10 the person touches the live wire with one hand and the neutral wire with the other hand. If his hands make good contact, he will have a low resistance and the current through his body will probably be fatal. This is called *electrocution*.

In Figure 6.11 the person touches the live wire with one hand and a good conductor such as a metal pipe with the other. The current that flows through her body will again probably be fatal.

People normally get shocks when they touch just the live wire, as in Figure 6.12. If the person is wearing rubber shoes or standing on a plastic floor, her resistance could be as high as 10 000 ohms. This means the current through her body would be 0.024 amps.

$$I = \frac{V}{R} = \frac{240}{10\,000} = 0.024 \text{ amps}$$

However, if she is barefoot and standing on a concrete floor, her resistance could be as low as 1000 ohms, giving a fatal current of 0.24 amps. The severity of the shock also depends on which part of your body the electricity travels through. A current of 0.01 amps can flow harmlessly from one finger to another, but the same current through your heart is nearly always fatal. The presence of water reduces resistance and so increases the danger of serious shocks.

If you see someone who has suffered an electric shock, it is essential that you don't get shocked yourself. First switch off the electricity and push the person away from the appliance or wire using an insulator such as a wooden broom handle. If the person is unconscious, call an ambulance. If their breathing or heartbeat has stopped, they must be given mouth-to-mouth resuscitation and heart massage.

Figure 6.10 Electrocution

Figure 6.11 Shocked again!

Figure 6.12 Just shocking!

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Paying for electricity

Electricity is just one form of energy. What we consume when we use electrical appliances is not voltage or current, but energy. So, when we pay for electricity, we are charged for the amount of electrical energy we have converted into other forms. Electricity is sold in energy units called **kilowatt-hours** (**kWh**). The number of kilowatt-hours that you use at your house is measured by the electricity meter. Most meters are now digital, but you can still find meters like those in Figure 6.13.

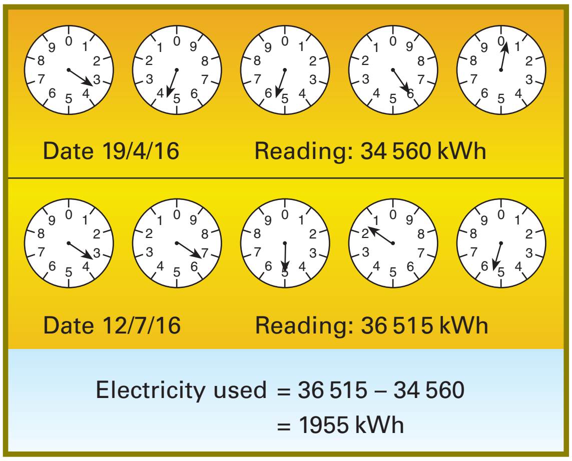

Figure 6.13 An old electricity meter

Figure 6.14 Electricity meters come in many different forms.

Different electrical appliances use different amounts of electrical energy, as shown in the table. The rate at which an appliance uses energy is called its **power**, and this is measured in **watts** (**W**, joules per second). The higher the wattage of an appliance, the more it adds to your electricity bill. For example, a 1000 watt bar heater uses electrical energy twice as quickly as a 500 watt heater. One kilowatt is 1000 watts, so a kilowatt-hour is 1000 watts used for 1 hour (or 500 watts used for 2 hours).

Appliance (operating at 240 volts)	Power rating (watts)
calculator	0.0003
clock	5
portable radio	12
light bulb	60
personal computer	100
television set	200
refrigerator	400–500
electric drill	500
toaster	1000
bar heater (small)	1000
hair dryer	1500
hotplate (on stove)	2000
dishwasher	2500
hot water system	3000

Figure 6.15 Appliances have a label to tell you how efficient they are.

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SKILLBUILDER

Using equations

The price charged for electricity depends on how much you use and when you use it. The night rate is much cheaper because the demand for electricity is less then. To calculate the energy used by an appliance, you use the equation:

energy = power × time *or* $E = Pt$

Note that you must use the correct units for the variables. If you want the energy in kilowatt-hours, then the power of the appliance must be in kilowatts (not watts), and the time the appliance is used must be in hours (not minutes or seconds).

Suppose a 200 watt television set is used for 5 hours. The energy used by this appliance is calculated as follows:

P = 200 watts = 0.2 kilowatts

t = 5 hours

E = Pt = 0.2 kilowatts × 5 hours

= 1 kilowatt-hour

The voltage and power rating marked on appliances allow you to calculate the operating current, using the equation:

power (watts) = voltage (volts) × current (amps)

***or* $P = VI$**

As an example, a microwave oven operating at 240 volts has a power of 600 watts. To calculate the current it uses, you need to rearrange the equation as follows:

$$I = \frac{P}{V} = \frac{600 \text{ watts}}{240 \text{ volts}} = 2.5 \text{ amps}$$

Appliances such as electric stoves use electrical energy very quickly, using large currents. They therefore need thicker wiring and larger amperage circuit-breakers. Some appliances such as a spa or home heater need to be directly wired into the fuse box on their own circuit for this reason.

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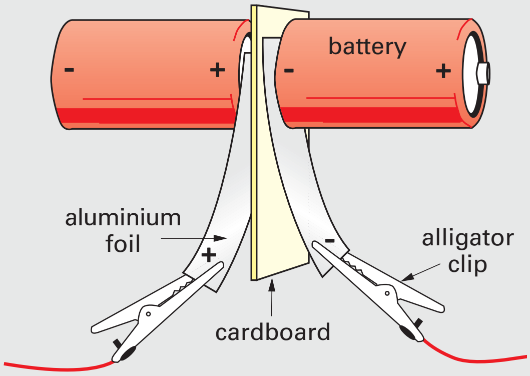
ACTIVITY

You can measure the power of a portable radio as follows.

1. Count the number of batteries to find the DC voltage of the radio.
2. Cut a piece of aluminium foil about 20 cm × 8 cm. Fold it three times lengthwise to give it extra thickness. Then cut it in half to give two strips each 10 cm long. Finally cut a piece of cardboard about 10 cm × 2 cm.
3. Put one piece of foil on either side of the cardboard strip. Have someone push and hold apart two of the batteries in the battery compartment of the radio. Push the strips into this gap.
4. Pull the aluminium strips apart and use alligator clips to connect them to an ammeter. (Remember to connect positive to positive.)
5. Switch on the radio and measure the current with:
   - **a** no station tuned in
   - **b** a station on low volume
   - **c** a station on high volume.
6. Use the equation $P = VI$ to calculate the power under these different conditions.
7. If the radio has a CD player, you could also measure the power needed to play CDs.



CHECK

1. Copy and complete this table.

	Symbol	Unit	Measured using ...
voltage			
current			
resistance			

2. Copy and complete the following sentences.
   - **a** All materials offer some ______ to the flow of electricity.
   - **b** A conductor has ______ resistance and an insulator has ______ resistance.
   - **c** If the resistance in a circuit is increased, the current ______.
3. Copy and complete the following table using Ohm's law.

Voltage (volts)	Current (amps)	Resistance(ohms)
–	5	3
6	3	–
240	–	20
110	–	19

4. A toaster connected to the household 240 volt supply has a current of 4 amps flowing through it. What is the resistance of the heating element in the toaster?

5. How many kilowatt-hours of electricity are used by the following appliances:
   - **a** a 120 W ceiling fan, used for 12 hours
   - **b** two 60 W electric blankets, used for 9 hours
   - **c** a dozen 40 W fluorescent lights, used for 5 hours
   - **d** a 1500 W hair dryer used for 10 minutes.

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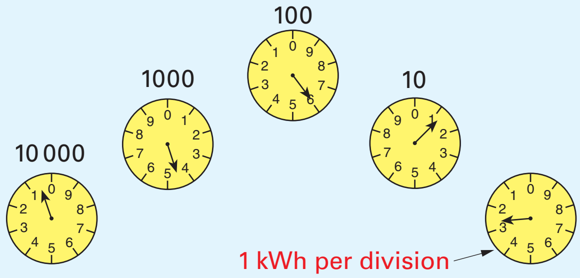
6 Use the table on page 159 to answer these questions.
   a Which appliance uses the most electrical energy per second?
   b Which is more expensive to leave on for the same length of time—a light, a TV or a bar heater?
   c Which appliances are run by batteries? What do you notice about their power consumption?
   d Why do stoves and hot water systems have their own circuit and circuit-breaker?

7 When cooking dinner, Kaori used four hotplates (each 2000 watts) for 30 minutes. How much electricity did she use (in kWh)?

8 What is the reading on this electricity meter?



9 A family turns their TV set on for about 3 hours per day. The power rating of the TV is 300 watts. On the basis of a cost of 15 cents per kWh, calculate the cost of running the TV for a year.

CHALLENGE

1 Explain why the element in a toaster becomes red hot, while the wires connecting the toaster to the mains power supply remain cool.

2 An electric blanket connected to the household 240 V supply has a current of 0.5 A flowing through it. What is the resistance of the heating element in the blanket?

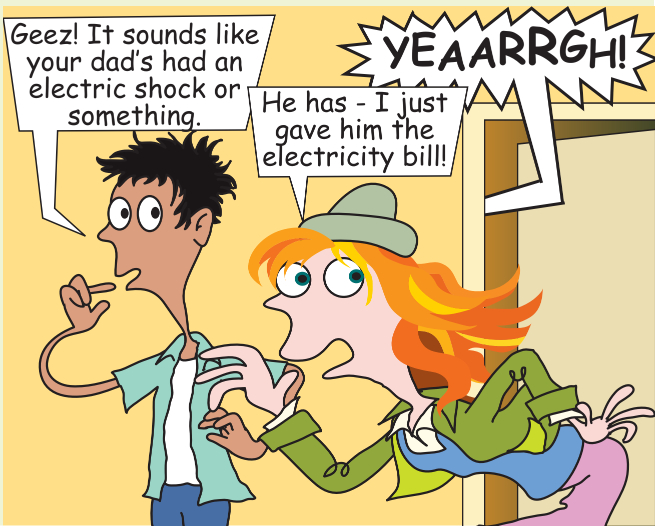
3 Ohm's law says that current is *proportional* to voltage. Use examples to explain what this means.

4 Which is cheaper to run over 5000 hours—a 15 W compact fluorescent light bulb with a lifetime of 6000 hours and costing $8, or an equivalent 35 W halogen energy-saver bulb with a lifetime of 3000 hours and costing $5? Assume 1 kWh of electricity costs 20 cents.

5 a A person with wet hands has a resistance across his chest of 2500 ohms. Would it be dangerous if he touched the terminals of a 12 V battery with both hands? (Assume that a current of 0.01 amps through your heart is fatal.)
   b If his hands are dry, then the resistance is about 100 000 ohms. Would he still be in danger?
   c A person with sweaty hands has a resistance across her chest of 2400 ohms. If she touched a 240 V live wire, would she be in danger?
   d Draw a person's body and in colour show a path that a current of 0.1 amps might take in an accident that would not be too dangerous.
   Use a different coloured pen to show a path that would be very dangerous. (Hint: See page 158.)

6 The Jones family has just received its quarterly electricity bill, and they have used 2000 kilowatt-hours of electricity. The electricity tariff is as follows:
- first 1020 kWh . . . . . . 14.47 cents per kWh
- balance . . . . 15.27 cents per kWh

   a Calculate the Jones' electricity bill.
   b Suggest a reason for this type of tariff.
   c During summer, the Jones' 750 watt swimming pool filter runs for 8 hours each day. Calculate the cost of running the filter for a month.



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7 In an experiment to measure the resistance of a piece of nichrome wire, the following apparatus were used: a battery, an ammeter, a voltmeter, a switch, the nichrome wire and connecting wires.

a Draw a circuit diagram to show how the apparatus would be set up.

b When the switch is closed, the voltmeter reads 6 V and the ammeter 0.5 A. What is the resistance of the wire?

c If a nichrome wire twice as long was used, what do you think its resistance would be?

d What would the ammeter read now?

8 What is the power of an appliance that uses:

a 0.5 kilowatt-hours in 2 hours?

b 1.5 kilowatt-hours in 30 minutes?

9 A 1200 watt microwave oven uses 5.2 amps of electric current. Use the formula $P = I^2R$ to calculate the electrical resistance of the oven.

10 A car has four headlights, each with a rating of 36 watts. Two tail-lights, a numberplate lamp and a dashlight are all rated at 6 watts.

a What is the total power needed for the car's lights?

b What current will be drawn from a 12 volt battery?

c What happens when you turn the car's engine off but leave the lights on? Why?

11 Thomas did an experiment to test Ohm's law. His results are shown on the right.

V (volts)	*I* (amps)
0	0
1.5	0.12
3.0	0.15
3.5	0.25
4.5	0.30
6.0	0.42

a Thomas thinks one of the current values is wrong. Which one do you think it is? (There are two ways to work this out.)

b What is the resistance of the wire he used?

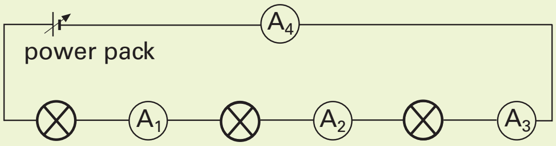
12 The circuit below contains three lamps, each marked 80 W, and four ammeters. The bulbs all glow with equal brightness, and ammeter 1 (A_1) reads 1 amp.

a What do A_2 and A_3 read?

b What does A_4 read?

c What is the voltage drop across each lamp?

d What is the voltage of the power supply?



13 A 40 W bulb is replaced in a reading lamp with a 60 W bulb to get a brighter light.

a Will the electric current through the bulb increase, decrease or stay the same?

b How does the resistance of the 60 W bulb compare with that of the 40 W bulb?

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6.3 Where does electricity come from?

You can't make electricity from nothing. However, DC electricity can be released from batteries or by using solar cells. AC electricity can be generated using magnets.

Using batteries

Some chemical reactions produce electricity. For example, in a torch battery, there is a reaction between the zinc case and the chemical paste it contains. This reaction makes the zinc case negatively charged and the top terminal positively charged. When the cell is connected in a circuit, electrons are pumped out of the cell as shown in Figure 6.16. The electric current is simply a flow of electrons around the circuit. The electrons lose energy as they pass through the bulb and get it back again in the battery.

When the reaction is finished, no more electricity is produced and the battery is 'flat'. If the cell is rechargeable, you can pass electricity through it to reverse the reaction. The battery can store this energy until you use it again.

Using solar cells

A **solar cell** (or photovoltaic cells) is made of almost pure silicon. It produces a small electrical voltage (about 0.5 volts) when exposed to sunlight. If you connect many solar cells together, you can generate enough electricity to power outback telephones, spacecraft, automatic lighthouses, even cars. Solar cells are still fairly expensive, and you need a lot of them, but they are becoming cheaper and more widely used.

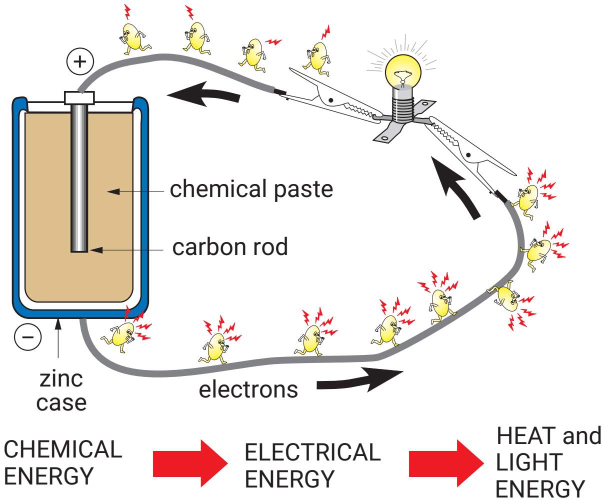

Figure 6.16 The chemical reaction in a torch battery causes electrons to flow in a circuit.

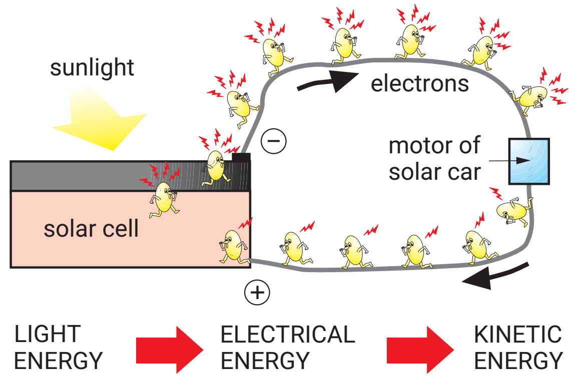

Figure 6.17 How a solar cell works

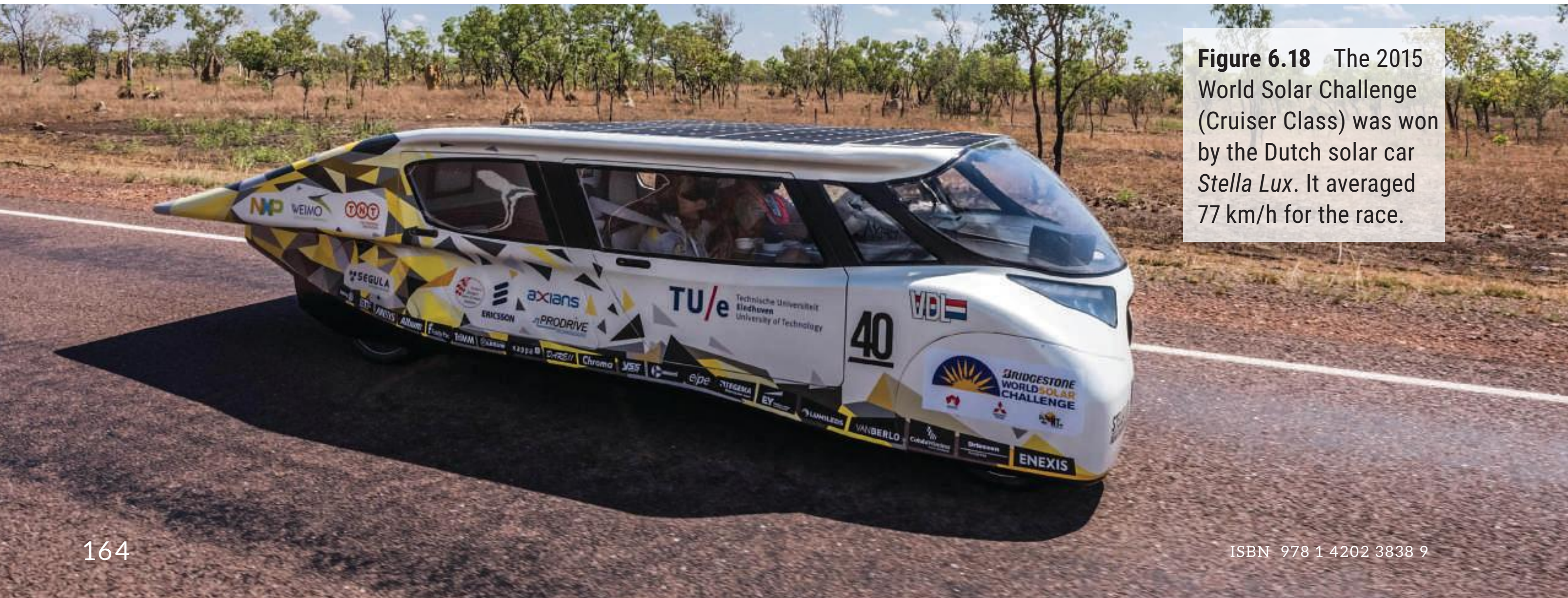

Figure 6.18 The 2015 World Solar Challenge (Cruiser Class) was won by the Dutch solar car *Stella Lux*. It averaged 77 km/h for the race.

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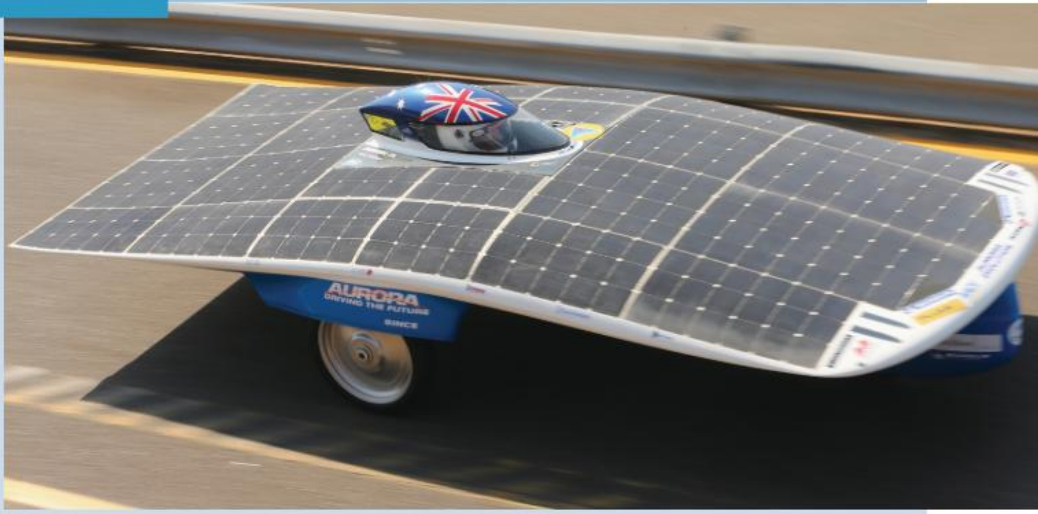
SCIENCE AS A HUMAN ENDEAVOUR

Solar cars



The photo on the right shows the Australian-built solar car *Aurora Evolution* which won the 2013 World Solar Challenge (Adventure Class). It travelled 3000 km from Darwin to Adelaide using only the power of the sun.

1 How do solar cars work?
2 List as many differences as you can between solar cars and normal cars.

The photovoltaic effect was discovered in 1839 and the first solar cell was made in 1883. It was only 1% efficient—it only converted 1% of the solar energy into electricity. However, it wasn't until 1905 that Albert Einstein explained how the photovoltaic effect works. Since that time scientists and engineers have improved solar cells so they are more efficient.

In 1998, Martin Green and Stuart Wenham, two Australian scientists from the University of New South Wales, made a solar cell that was 25% efficient—a world record. To do this, they etched the top of their solar cells into tiny upside-down pyramid shapes, using a laser, as shown below. This pyramid design traps and bounces the sunlight around the cell, extracting as much solar energy as possible.

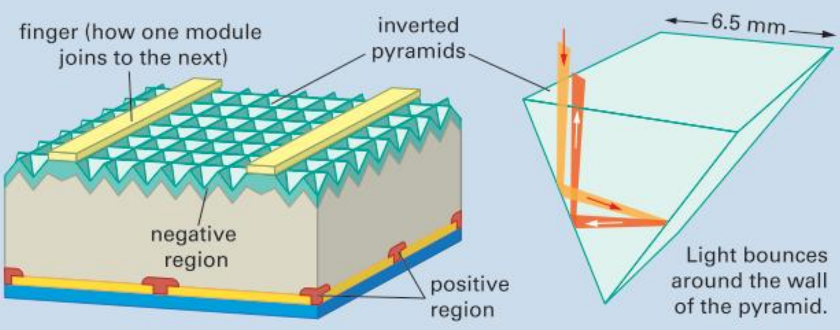
Even more efficient triple-junction solar cells were developed for use in space. These have red, green and blue cells stacked on top of each other. Each cell is designed to convert the red, green or blue parts of light into electricity. More recently, solar cells have been made more cheaply by coating them onto a thin flexible film.

The efficiency of cars in the World Solar Challenge has also been increased by a motor that sits inside the wheels. It was designed in Australia by CSIRO engineers, and is 98% efficient. The motor was used by *Aurora Evolution*.

Solar cars can manage speeds of over 100 km/h even on cloudy days. Much more research is needed before we will use them for everyday travel, but it may not be long before small hybrid cars have solar panels on the roof to improve their efficiency.

3 Why do most solar cars have a cockroach shape?
4 Why do they usually have only three narrow wheels?
5 What scientific concepts and principles have been used in the development of solar cars?

Search the internet for 'Virtual World Solar Challenge', where you can design and race your own solar car.



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Using magnets

An electromagnet is a temporary magnet made from a coil of wire wound around a piece of iron. When electricity flows through the wire, it creates a magnetic field around the iron core. But can a magnet be used to produce electricity? You can find out in the activity below.

Moving a magnet through a coil induces (produces) an electric current in the coil. This process is called *electromagnetic induction*, because the moving magnetic field induces the electrons in the wire to move. Moving the magnet in the opposite direction reverses the direction of the current. In this way, you can produce alternating current (AC). You can produce a larger current if you increase:

- the strength of the magnet
- the number of turns of wire in the coil
- the speed of movement of the magnet or coil.

ACTIVITY

1. Make a coil by winding two or three metres of thin, insulated wire around a cardboard tube. Hold the wire in place with adhesive tape. Alternatively, use a ready-made coil.
2. Connect the bare ends of the wire to a multimeter or galvanometer. This can measure the direction as well as the size of small electric currents.
3. Plunge a bar magnet into the coil. Then quickly pull the magnet out of the coil.

   Record your observations of how the reading on the multimeter changes when the magnet is moving in, when it is still, and when it is moving out. Does it matter how quickly you move the magnet?

   

   Write a hypothesis to explain all your observations.
4. Use your hypothesis to predict what will happen if you hold the magnet still and move the coil up and down. Test your prediction.
5. Predict what will happen if you reverse the magnet so that the other pole goes in first. Try it.

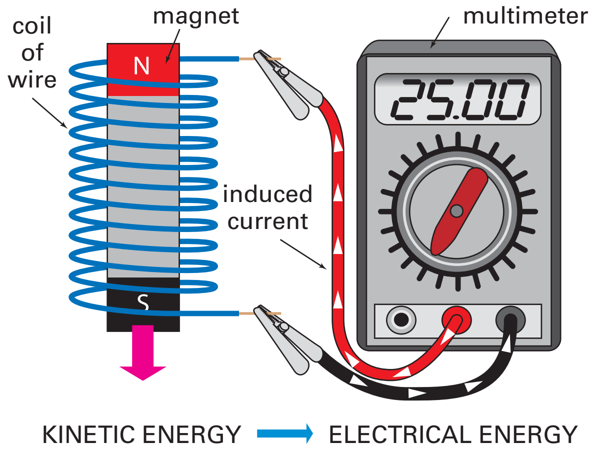

Figure 6.19 A magnet moving inside a coil of wire can produce electricity.

Electric generators

Most electric **generators**, such as the one in a car, have a coil of wire that is rotated between the poles of a magnet. However, the huge AC generators in power stations are designed differently. They use electromagnets that rotate inside the coil, as shown. There are special connections to the electromagnet so the wires don't tangle.

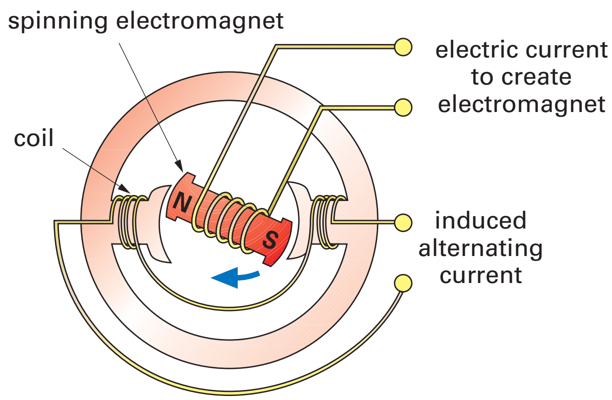

Figure 6.20 A generator

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Power stations

The generators in a power station are turned by turbines with fan-like blades that are spun at 50 cycles per second by jets of high-pressure steam. After leaving the turbines, the steam is condensed back to water and returned to the boiler. Vast amounts of water are needed for the condenser, and this normally comes from a nearby lake and into a cooling tower (see Figure 6.22). Most Australian power stations burn coal to produce the steam; however, it can also be produced by burning natural gas or oil.

About 5% of Australia's power is generated in hydro-electric power stations (see Figure 6.22). Here it is the kinetic energy of falling water rather than the pressure of steam that drives the turbines and generators. The greater the height the water falls, the more electricity is produced.

Hydro-electric power stations are cheaper to run than coal-burning power stations, and they can be started up or closed down much more quickly. Coal-burning power stations operate 24 hours a day, and when more electricity is needed, the hydro-electric stations are brought into operation. This usually occurs at the beginning and end of a working day, when people are using electric trains, lights, stoves etc.

Figure 6.22 A hydro-electric power station in the Snowy Mountains. Water flows from the reservoir at the top, down the pipes to the power station at the bottom.

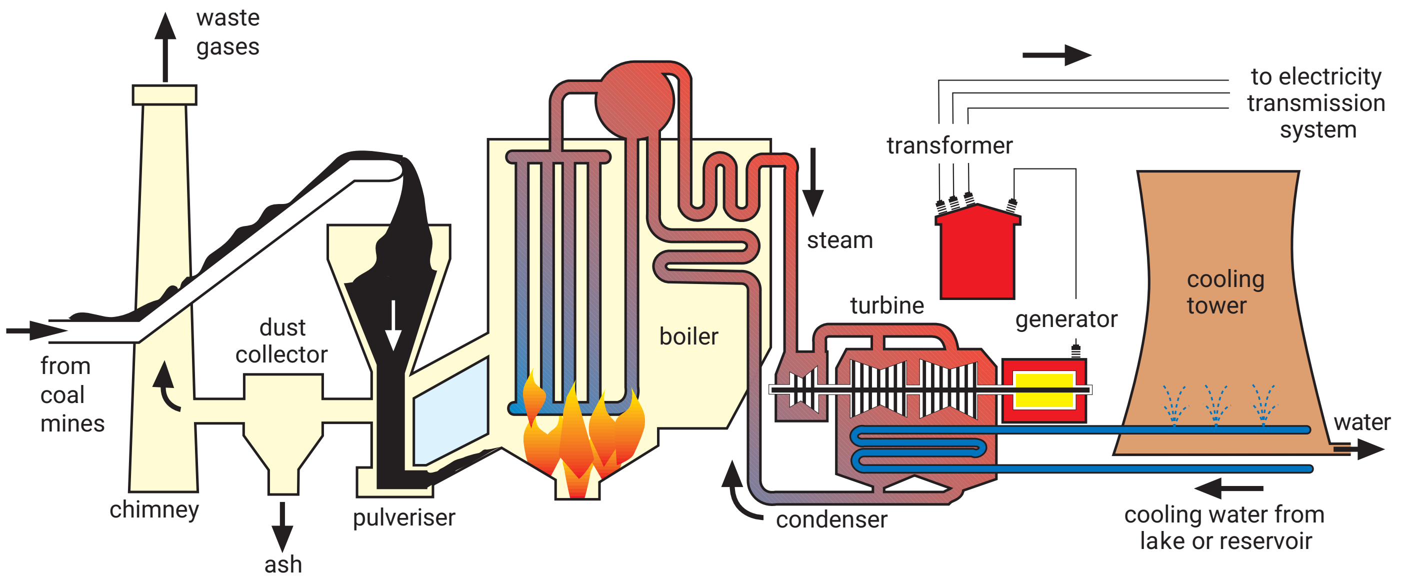

Figure 6.21 How a coal-burning power station works

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Problems with power stations

A major problem with coal-burning power stations is that they release carbon dioxide, a greenhouse gas, into the atmosphere. One possible solution to this problem is *geosequestration*, in which the CO_2 is compressed and injected into rocks 1–3 km underground. This idea is being tested near Warrnambool in south-western Victoria.

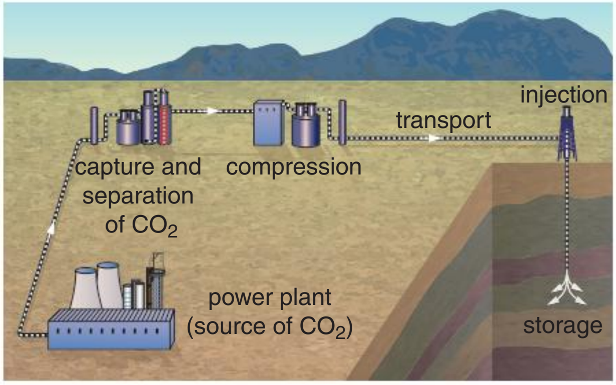

Figure 6.23 Geosequestration of carbon dioxide

Nuclear power stations do not produce greenhouse gases, but they have several major disadvantages. First, there have been several serious accidents at nuclear power stations. The most recent of these was at the Fukushima nuclear plant in Japan. It was damaged in a 9.0 magnitude earthquake and subsequent tsunami on 11 March 2011. There was a partial meltdown in three of the reactors and radioactive material leaked into the surrounding area.

The second major problem with nuclear power stations is what to do with the spent fuel rods after use in a nuclear reactor. They are extremely radioactive and are stored under water for a couple of years until their radiation decreases. They are either reprocessed to make new fuel rods or transported to a disposal site for long-term storage, but they remain radioactive for thousands of years.

Follow the links to explore all types of power stations, including nuclear, coal, hydro and even batteries.

Figure 6.24 The damaged Fukushima nuclear plant in Japan, March 2011

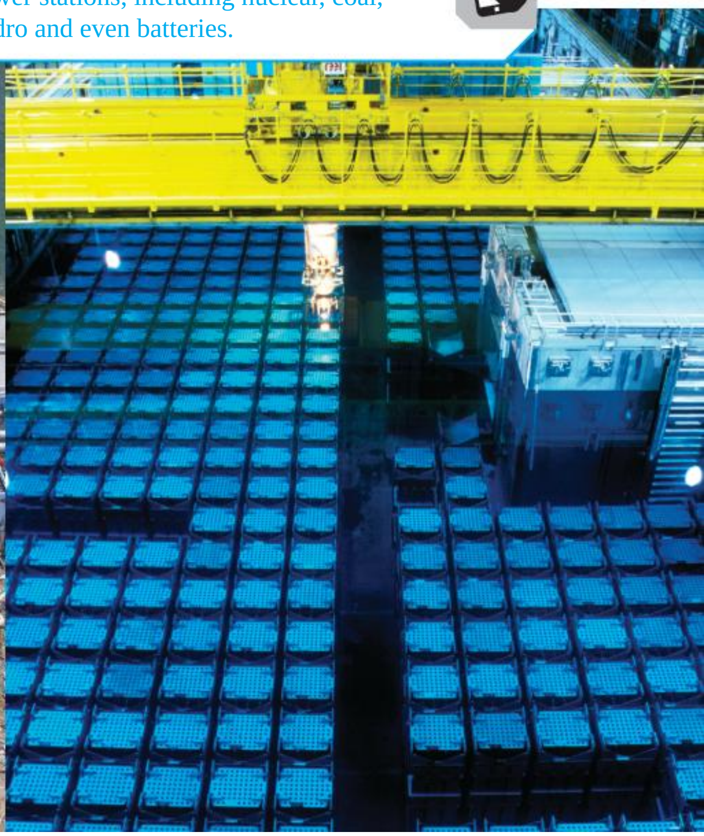

Figure 6.25 Radioactive spent fuel rods stored under water

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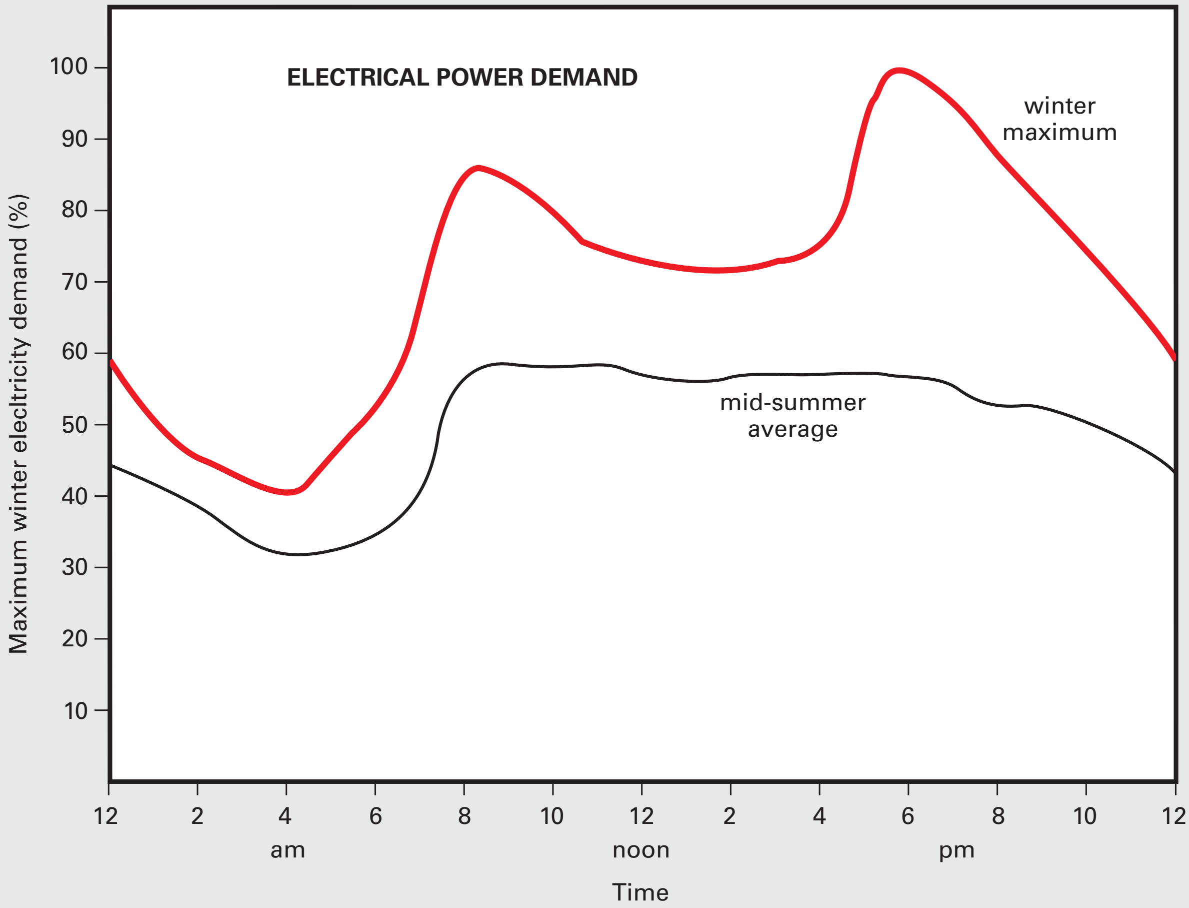
ACTIVITY



The graph above shows the typical demand for power in Australia on a week day. Use the graph to answer these questions.

1 What units have been used on the vertical axis of the graph?

2 At what time of the day does the peak (maximum) demand occur in winter?

3 There is also a demand peak in the morning in winter. When does this occur?

4 Explain the shape of the winter graph in terms of our use of electricity over 24 hours.

5 Why is the demand for electricity greater in winter than in summer?

6 If the peak demand on a winter's day is 10 000 megawatts, what is the minimum demand on that day?

7 Even at 4 am we still use considerable amounts of electricity (a bit less than half the peak demand). How can you explain this?

8 Why is it that the summer graph has only one peak while the winter graph has two peaks?

9 The night rate electricity tariff (cost) is about half the normal rate. Suggest a reason for this.

10 Given that electricity cannot be stored, how is it possible to meet the changing demand for electricity over a 24-hour period?

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Transmitting electricity

Electricity is transmitted from the power station to your home through power lines. However, some electrical energy is always lost as heat when it travels through wires, and the greater the current, the more heat that is lost. To reduce this heat loss, you can increase the voltage and thereby decrease the current.

The voltage can be changed in devices called **transformers**. A transformer contains an iron core and two coils of wire called the *primary coil* and the *secondary coil* (Figure 6.26). The alternating current in the primary coil creates a magnetic field. Because the current changes direction 50 times per second, the magnetic field also changes. This changing magnetic field interacts with the secondary coil and induces a current in it.

If the secondary coil has more turns of wire than the primary coil, it is called a *step-up transformer*. The voltage induced in the secondary coil is greater than that in the primary coil, but the current is lower. If the secondary coil has fewer turns of wire than the primary coil, it is called a *step-down transformer*. This produces a lower voltage but higher current than that in the primary coil.

Before leaving the power station, the voltage is stepped up (increased) to as much as 500 000 volts. This is done to reduce the current in the wires. Then, before it reaches your home, the voltage is stepped down to 240 volts.

There are transformers in many of the appliances in your home. Many devices, such as portable radios, run on batteries yet can be plugged into the mains. It is better to use mains electricity than batteries because it is cheaper. The appliance must therefore have a step-down transformer to reduce the voltage from 240 volts to 9 volts or whatever the appliance uses.

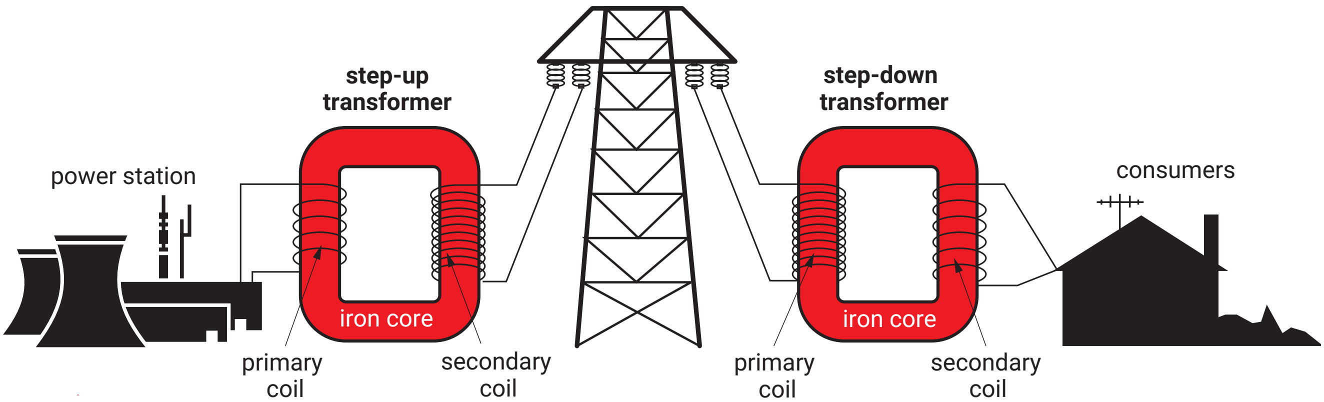

Figure 6.26 Transformers are used to increase and decrease the voltage from a power station.

CHECK

1 Copy and complete the table below by putting in the type of energy from which the electrical energy is formed.

Energy	Electrical energy formed from …
battery	
solar cell	
electric generator	

2 Suggest why solar cells rather than batteries are used in spacecraft.

3 What must be brought near a rotating coil of wire if an electric current is to be generated in the coil?

4 Ik Jin connects a coil of wire to a multimeter. When he pushes the *south pole* of the magnet into the coil, the voltage is positive. Will the voltage be positive or negative when Ik Jin:

- **a** pulls the south pole of the magnet out of the coil?
- **b** pushes the north pole of the magnet into the coil?
- **c** holds the magnet steady inside the coil?

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d holds the magnet steady and moves the coil towards the south pole of the magnet?

5 a Use Figure 6.21 to try to explain what happens in each part of the power station.

b Draw an energy chain to describe the energy changes that take place.

6 What are the similarities between nuclear power stations and coal-burning power stations? What are the differences?

7 What is the difference between a step-up trnasformer and a step-down transformer?

EXPLORE ONLINE

Follow the links to the websites below.

Fuelling the 21st century

Use this as a starting point to research fuel cells.

An electric motor

Make your own simple electric motor and demonstrate it to the class. There are many variations to explore.

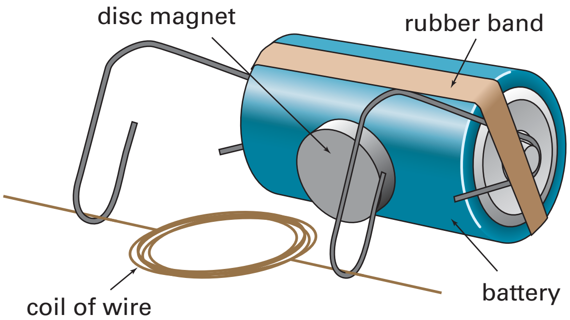


Figure 6.27 One design for a simple electric motor

CHALLENGE

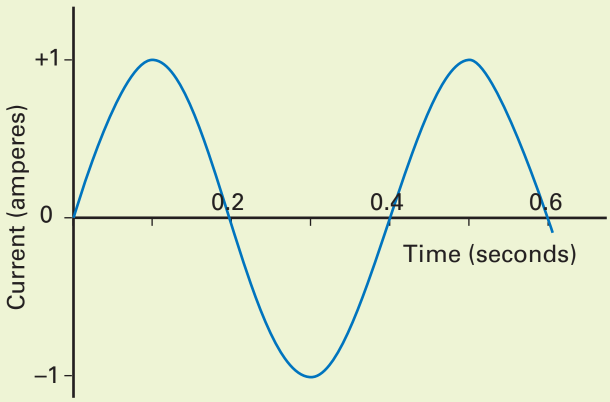
1 Suggest three ways of making an electric generator produce a larger current.

2 The graph below shows how the current produced in an electric generator varies with time.

a What is the maximum current generated?

b How long does it take for the coil of the generator to rotate once?

c Suppose you connected a light bulb to the generator. Would you expect the brightness of the bulb to vary? Explain.



3 What are the advantages and disadvantages of the following types of power stations?

a coal-burning

b hydro-electric

c nuclear

4 Suggest why there are no nuclear power stations in Australia.

5 Why is electric power transmitted at very high voltages over long distances?

6 How is an electric generator like an electric motor? How is it different?

7 The readings in the table were obtained from a transformer.

	Voltage (V)	Current (A)
primary coil	200	1.00
secondary coil	1000	0.19

a Does the transformer step the voltage up or down?

b Calculate the power of each coil.

c How much power is 'wasted' by the transformer?

d What happens to this wasted power?

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MAIN IDEAS

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

1 ______ current (DC) is a flow of electrons in one direction only. ______ current (AC) is a flow of electrons that continuously reverses direction. Mains supply is 240 volt AC.

2 A ______ occurs when the electric current takes a 'short cut' along a path of lower ______.

3 Circuit-breakers and ______ wires are essential for safety in electric circuits.

4 The electric current flowing in a circuit depends on the electrical resistance in the circuit and the ______. The relationship between voltage *V*, current *I* and resistance *R* can be shown by the formula $V = IR$ (______).

5 ______ is the rate at which energy is produced or used. It is measured in ______ (joules per second).

6 Electrical energy is sold in ______. It can be calculated using the following equation:

energy (kilowatt-hours) = power (kilowatts) × time (hours)

7 A ______ and a coil of wire, in motion relative to each other, can produce an electric current. This is how ______ in power stations work.

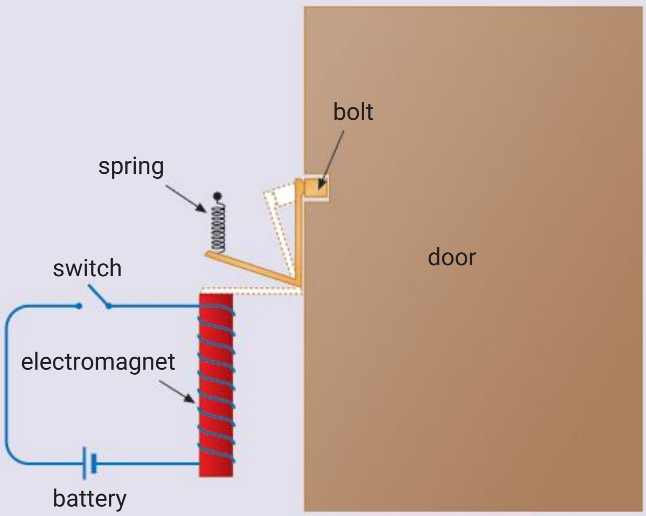
8 ______ can increase or decrease the voltage of alternating current.

transformers
direct
alternating
earth
watts
generators
magnet
kilowatt-hours
Ohm's law
resistance
short circuit
power
voltage

CH•6 REVIEW

1 The number of watts printed on an appliance tells you:
- **A** the rate at which the appliance uses energy.
- **B** the voltage at which the appliance operates.
- **C** the electrical resistance of the appliance.
- **D** the heat the appliance gives off.

2 The diagram on the right shows an electric door-bolt, which is used to lock a door. Write a paragraph explaining how this device works.



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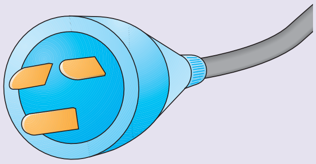
3 Look at the diagram of a three-pin plug.

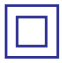


- **a** Which is the earth pin?
- **b** What is the purpose of an earth wire?
- **c** Why do some electrical plugs only have two pins?

4 A plate on the plastic case of a portable radio–CD player has the following information:

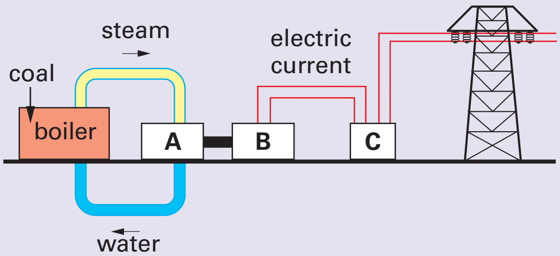
AC: 240 V ~ 50 Hz 12 W

DC: 9 V ---- ('D' SIZE × 6)



- **a** What does AC stand for?
- **b** What is the power of the radio?
- **c** How many batteries does it need?
- **d** Would you expect the radio to have a two-pin or a three-pin plug? Why?
- **e** Would you expect the radio to contain a transformer? Explain.

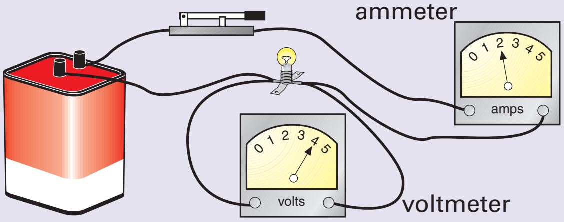
5 The diagram shows the layout of a coal-burning power station (in simplified form).



- **a** What happens in A?
- **b** What energy change occurs in B?
- **c** What is C? What is its purpose?
- **d** What must happen to the electricity passing through the power lines before it can be supplied to your home?
- **e** Which part of the diagram would be different for a nuclear power station?

6 An electric radiator has a small plate on the back that reads '240 V, 1500 W'. If the cost of electrical energy is 15 cents per kilowatt-hour, how much would it cost to run this radiator for 3 hours?

7 Here is a diagram of an electric circuit containing an ammeter and a voltmeter.



- **a** What is the size of the current flowing through the light bulb?
- **b** What is the voltage drop across the bulb?
- **c** What is the resistance of the bulb?

8 Juanita did an experiment similar to Investigation 6.2. Here are her results.

	Voltage (volts)	Current (amps)	Resistance (ohms)
Trial 1	6	1	6
	12	2	6
	24	4	6
Trial 2	6	2	3
	12	2	6
	24	2	12
Trial 3	6	0.5	12
	6	1	6
	6	2	3

- **a** What were the three variables in Juanita's experiment?
- **b** Which variable did she control in trial 1?
- **c** What happened to the voltage when the resistance stayed the same and the current was doubled?
- **d** What happened to the voltage when the current stayed the same and the resistance was doubled?
- **e** What happened to the voltage when the current was doubled and the resistance was halved?
- **f** Write a mathematical equation that summarises Juanita's results.

Check your answers on page 346.

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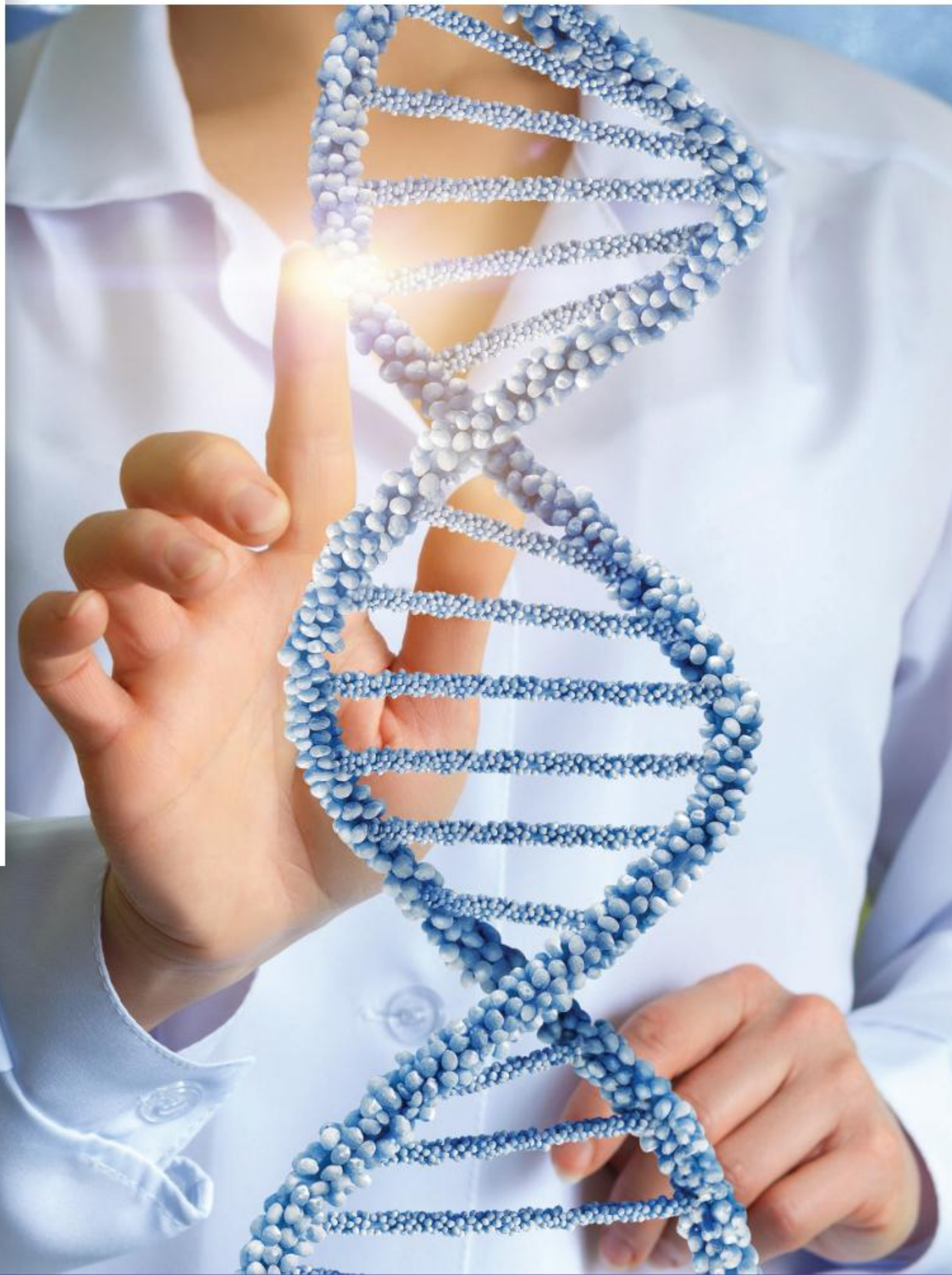
IN THIS CHAPTER

Science Understanding

- describe the role of DNA as the blueprint for controlling the characteristics of organisms
- use a model to represent the relationship between DNA, genes and chromosomes
- 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
- describe mutations in relation to DNA, and the causes of mutations
- 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



CH•7 Inheritance

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GET STARTED: *IMAGINE*

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

The forensic scientist in the photo is collecting evidence from material found at a crime scene. Forensic scientists look for sources of DNA, which may be from the victim or potential suspects.

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?

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7.1 DNA

All cells contain a substance called **deoxyribonucleic acid** or **DNA** for short. It is the DNA in the nucleus of your cells 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 Figure 7.1).

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.

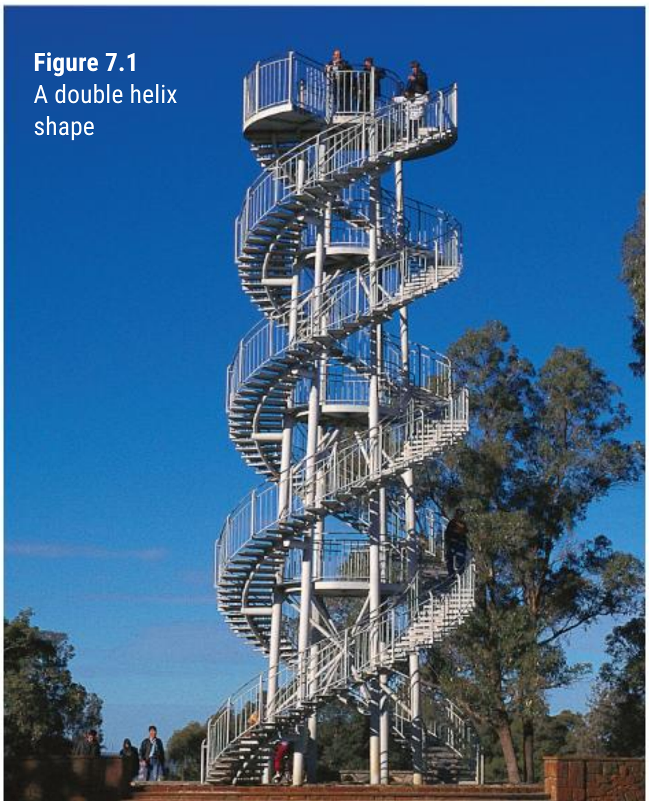

Figure 7.1 A double helix shape

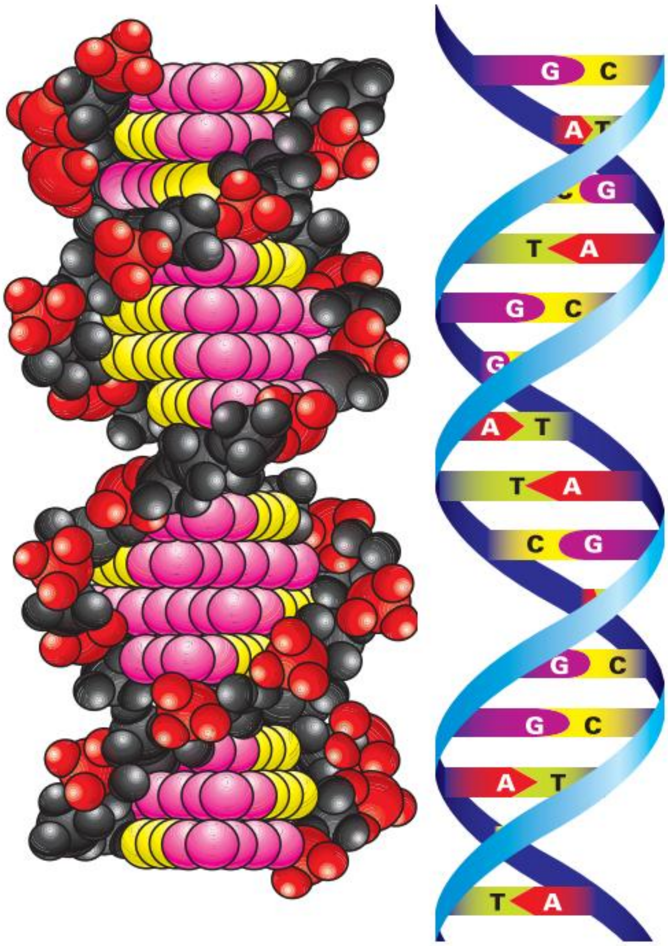

Figure 7.2 A model of DNA and a simplified structure on the right. The weak bonds between the matching base pairs on each strand hold the DNA molecule in its helical shape.

Genes

Organisms are different because the proteins in their cells are different. The DNA within the nucleus of each cell contains the instructions as to which proteins the cell should make. These instructions are in the form of **genes**. A gene is a section of the DNA strand that codes for a protein. The sequence of bases in the section (gene) determine which particular protein is made (Figure 7.3).

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.

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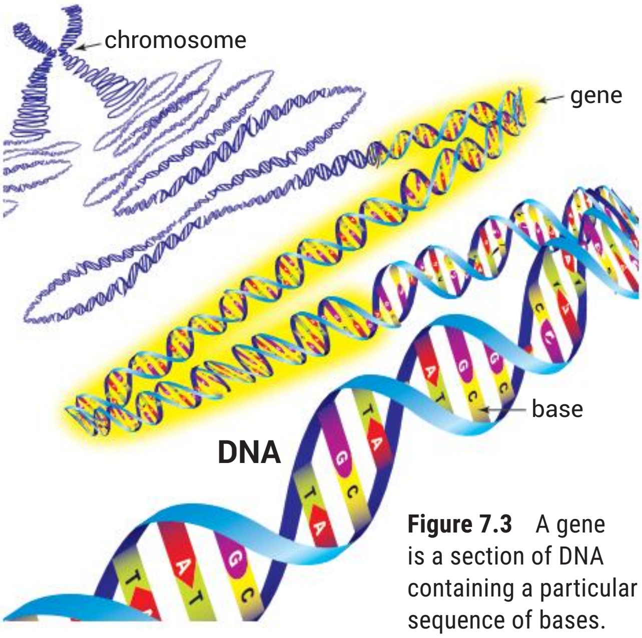
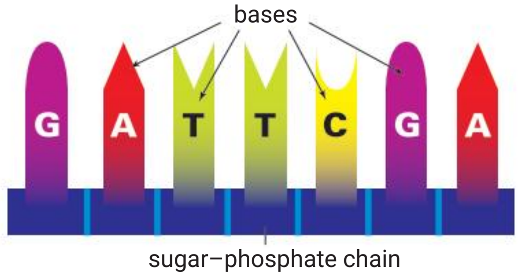


Figure 7.3 A gene is a section of DNA containing a particular sequence of bases.

Figure 7.4 Base codes in a DNA strand



The DNA code

If the two strands in the molecule of DNA separated, part of a single strand would look like the structure in Figure 7.4. 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 table below).

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 more than 50 000. DNA molecules contain millions of bases. Hence, a DNA molecule can code for thousands of proteins.

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/	GTG	
TCT	serine	CCT	proline		START	GCT	alanine
TCC		CCC		ACT	threonine	GCC	
TCA		CCA		ACC		GCA	
TCG		CCG		ACA		GCG	
TAT	tyrosine	CAT	histidine	ACG		GAT	aspartic acid
TAC		CAC		AAT	asparagine	GAC	
TAA	STOP	CAA	glutamine	AAC		GAA	glutamic acid
TAG		CAG		AAA	lysine	GAG	
TGA		CGT	arginine	AAG		GGT	glycine
TGT	cysteine	CGC		AGT	serine	GGC	
TGC		CGA		AGC		GGA	
TGG	tryptophan	CGG		AGA	arginine	GGG	
				AGG			

Figure 7.5 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.

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DNA replication

Most cells of the body regularly undergo cellular division. Prior to cell division, DNA in the nucleus copies itself. This process is called **replication** as the DNA copy is an exact replica of the cell's original DNA.

The DNA is made up of building blocks called *nucleotides* (see Figure 7.6). 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.

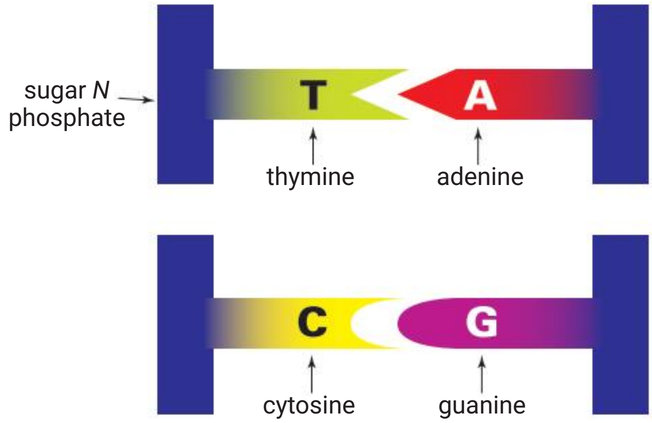

Figure 7.6 Nucleotides are the building blocks of DNA. They consist of sugar, phosphate and base molecules.

Figure 7.7 DNA replication

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

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

3 An identical copy of the original DNA has been made.

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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.

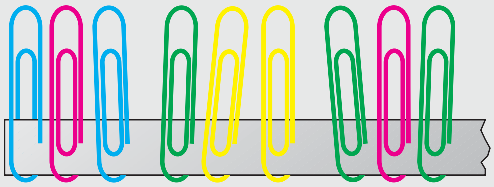

Figure 7.5 on page 177 shows the codes for the 20 amino acids that are found in the body. Notice that most amino acids have two or more alternative triplet codes. Notice that there are also codes for STOP and START.

4. Use Figure 7.5 on page 177 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.

Mutations

The fawn (baby deer) in the photo 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**. These alterations mean there is a change to the original sequence of bases.

Some mutations can be detrimental to the organism, and most are fatal, causing death. 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 strand had the following sequence of bases:

AATCAACCTTCA

For convenience, let's separate the triplets.

AAT CAA CCT TCA

Using Figure 7.5 on page 177, this would code for the following amino acids:

asparagine glutamine proline serine

Figure 7.8 An albino fawn (baby deer)

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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 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 179.

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.

EXPLORE ONLINE

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.

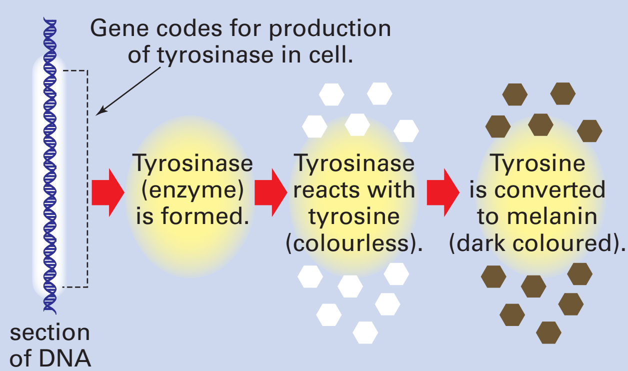
SCIENCE AS A HUMAN ENDEAVOUR

Why there are albinos

Scientists have unravelled the secrets of DNA to understand many disorders. 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.

Figure 7.9 An albino South African boy



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Genomes

In 1916, after years of experimenting, American biologist Walter Sutton inferred that the inherited characteristics of fruit flies were carried in the DNA of 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**.

Figure 7.10 Fruit fly, *Drosophila melanogaster*, has 250 million bases in its DNA.

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 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 coordinated 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 multinational 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?

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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 related to genetic research. 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.

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 can 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.

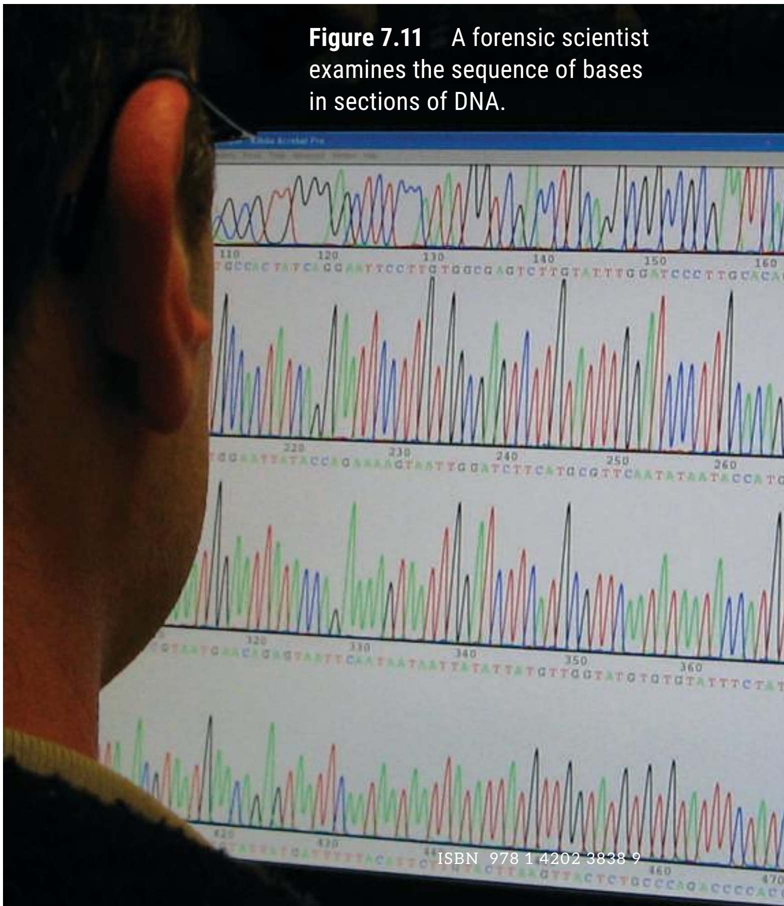

Figure 7.11 A forensic scientist examines the sequence of bases in sections of DNA.

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SCIENCE AS A HUMAN ENDEAVOUR

DNA testing

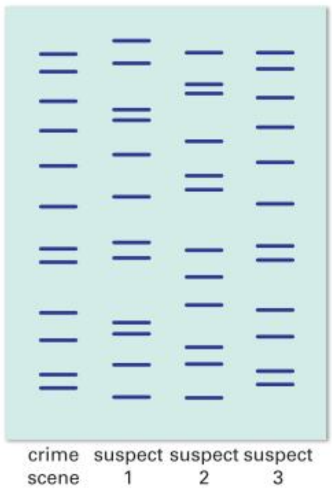
Look at the photo on page 182 which shows a DNA profile or 'fingerprint'. Profiles like this can be used to identify people.

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 of 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 below. 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?

1



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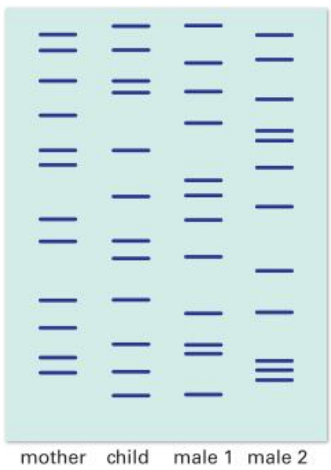

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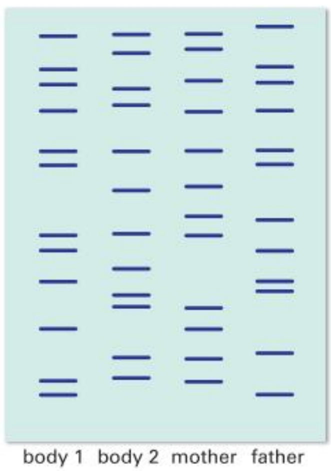

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CHECK

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 Figure 7.5 on page 177 to work out the amino acid sequence.

7 Explain, by using the base sequence in Question 6 and Figure 7.5 on page 177, 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.

EXPLORE ONLINE

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.

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7.2 Chromosomes

In about 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. The 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.

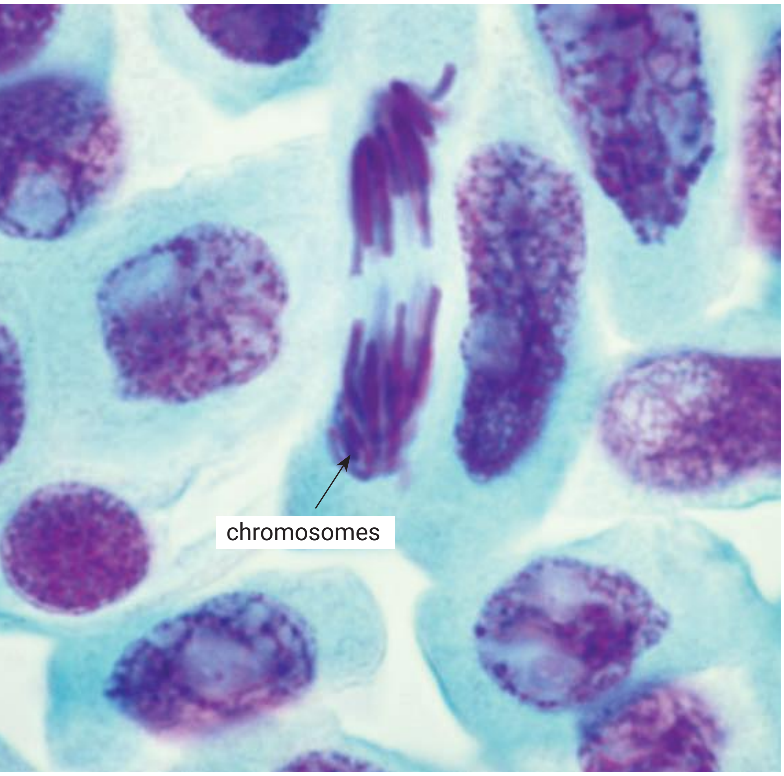

Figure 7.12 You can see chromosomes during cell division.

Figure 7.13 shows a simplified version of mitosis. When the cell is not undergoing division, the chromosomes cannot be seen as they are in the form of chromatin inside the nucleus. Remember, before cell division can begin, DNA replication must occur. The replicated DNA then coils tightly together to form double-stranded chromosomes. The two strands of each chromosome are identical, and each is known as a **chromatid** (CRO-ma-tid).

During mitosis, the double-stranded chromosomes are pulled apart, and two new cells are formed. These cells are referred to as daughter cells, and each is genetically identical to the original cell.

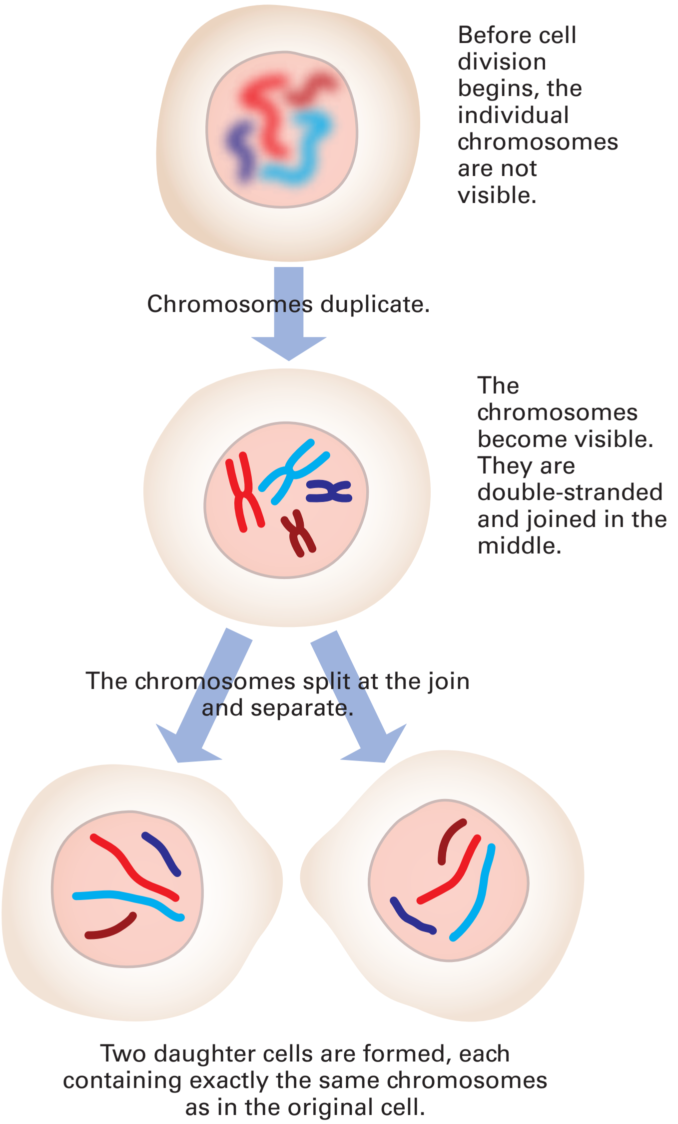

Figure 7.13 The process of cell division is called mitosis.

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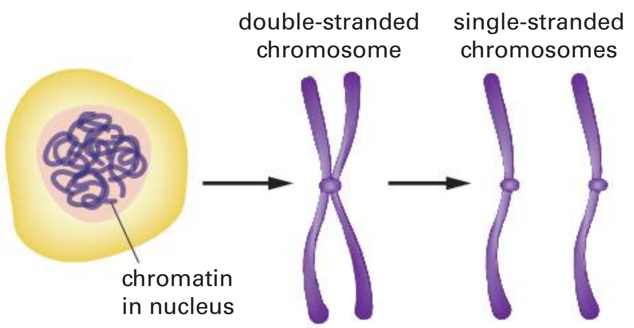
EXTRA FOR EXPERTS

Chromatin, chromosomes and chromatids

When a cell is not dividing, the DNA is in the form of chromatin. Chromatin is formed when the strands of DNA are wound around special proteins called histones. This allows large quantities of DNA to be efficiently packaged into a small volume.

After DNA replication, in preparation for cell division, the DNA coils and condenses into double-stranded chromosomes. These are X-shaped and consist of two sister chromatids that are joined together by their centromeres. A centromere is a region of DNA in the middle of the chromatid. Each sister chromatid is identical; this means that a double-stranded chromosome is simply two copies of the one chromosome.

When the double-stranded chromosome is pulled apart during cell division, the two chromatids are separated. Once separated, each chromatid is referred to as a (single-stranded) chromosome.



Chromosomes in cells

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

In Figure 7.14, the 46 chromosomes in a human have been placed in pairs from largest to smallest (except the sex chromosomes).

All body cells in an organism contain the same number of chromosomes. In humans this is 23 chromosome pairs. These cells are referred to as *diploid* cells: *di* means two and *ploid* refers to the chromosome number.

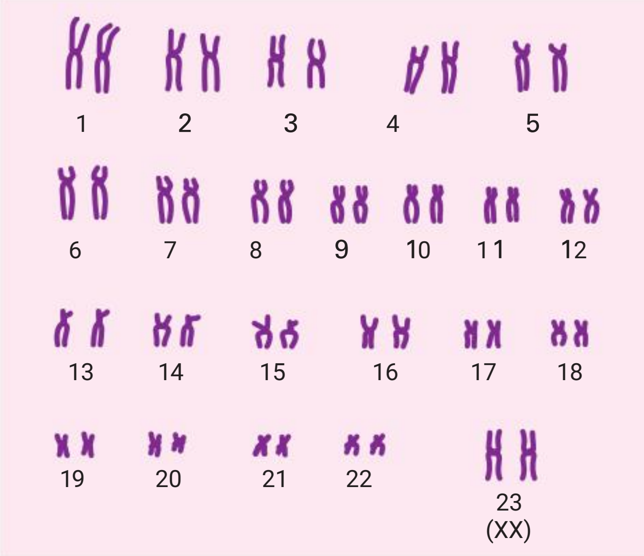


Figure 7.14 The 46 chromosomes in a human female are arranged in pairs based on size. The pair numbered 23 contains the sex-determining genes.

Meiosis

Sex cells (sperm and eggs) are produced through a different form of cell division, which is known as **meiosis** (my-OH-sis). The nuclei of sex cells contain only half as many chromosomes as the nuclei of other body cells. Why is this? During fertilisation, the sperm and egg nuclei fuse together to form one nucleus that contains 23 pairs of chromosomes.

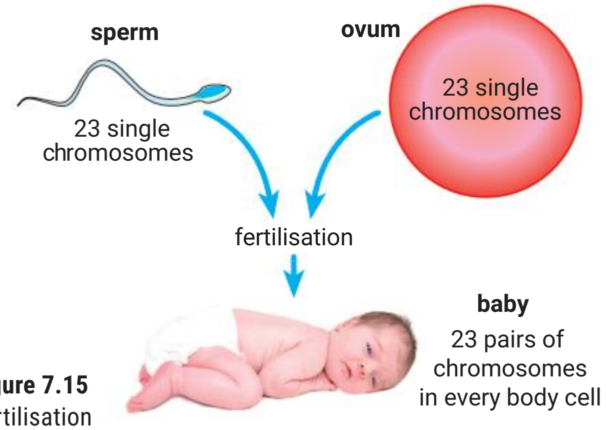


Figure 7.15 Fertilisation

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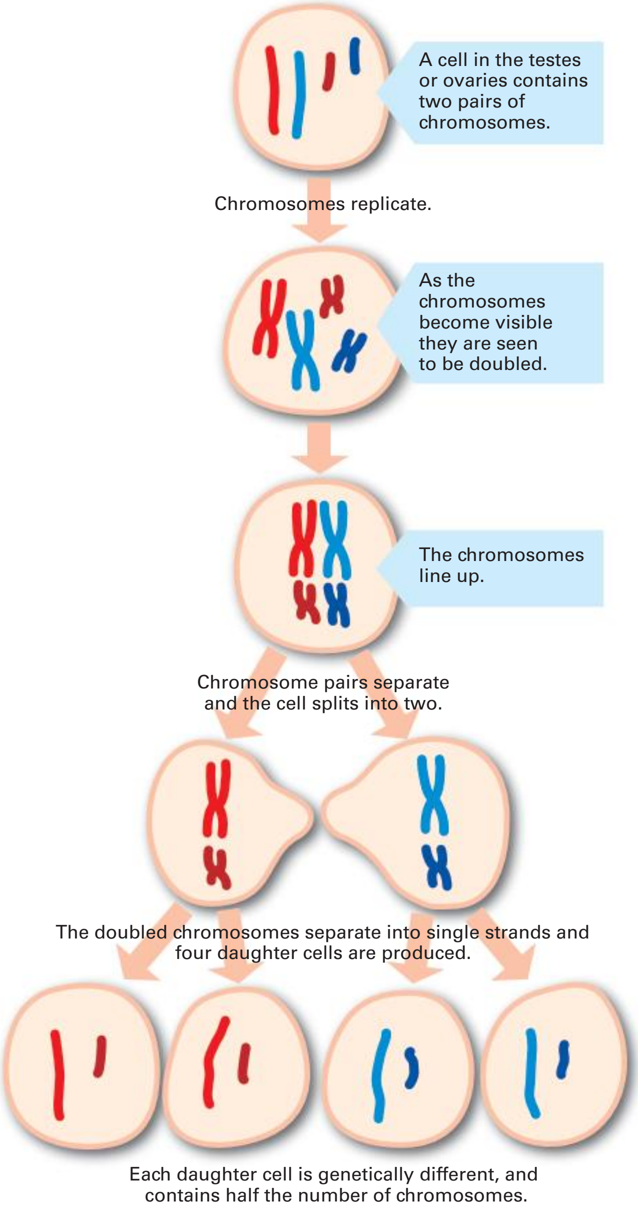
During meiosis, the pairs of chromosomes are separated, so that each sex cell only receives 23 single chromosomes, instead of 23 pairs of chromosomes. As each sex cell only has one chromosome from each pair, they are called *haploid cells*. Meiosis only occurs in special cells in the testes and ovaries in animals, and in the anthers and ovaries in plants.

In mitosis, two identical daughter cells are produced. However, in meiosis, four different daughter sex cells are produced, as shown.

Figure 7.16 The process of meiosis produces sex cells with half the number of chromosomes of a body cell.



ACTIVITY

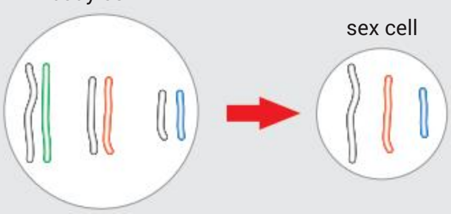
Meiosis

1. Meiosis can be thought of as having two cell divisions. Describe how the first division is different from the second one.
2. There is another way the chromosomes can be arranged in line 3 of Figure 7.16. Using red and blue pens, draw this arrangement. Draw the sex cells this arrangement will produce. How are they different from Figure 7.16?
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? Explain your answer.
4. Find out about the phases of meiosis. Name and explain each phase.

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.



One possible selection

4. How many different sex cells can you make? Use coloured pencils to draw the three single chromosomes in each of the sex cells.

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Determining sex

The chromosomes on the right are from a human male. How are they different from the chromosomes in a female in Figure 7.14 on page 186?

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. 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.

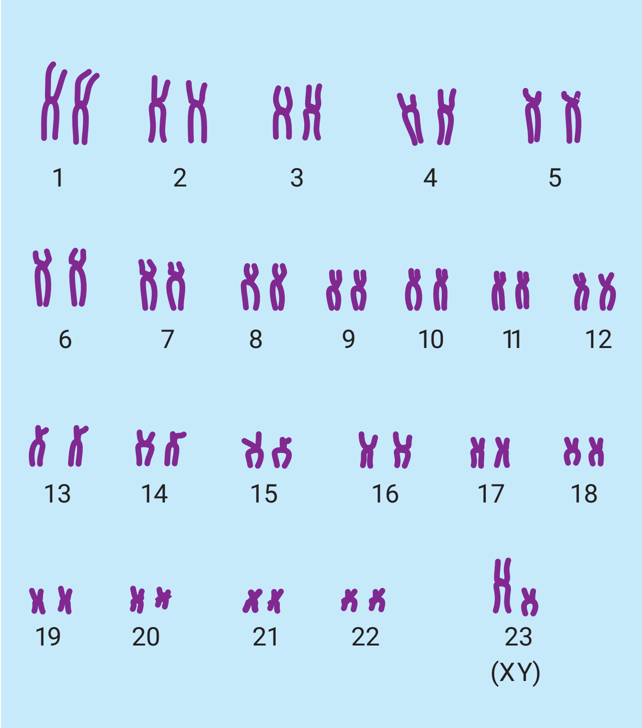

Figure 7.17 The chromosomes from a human male

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 discs for this activity.

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

   Record whether the result is a boy or a girl.
6. Replace the disc 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 results in step 6.

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

   In 1 mL of human 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?

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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 information on page 186 to work out how many chromosomes there are in:

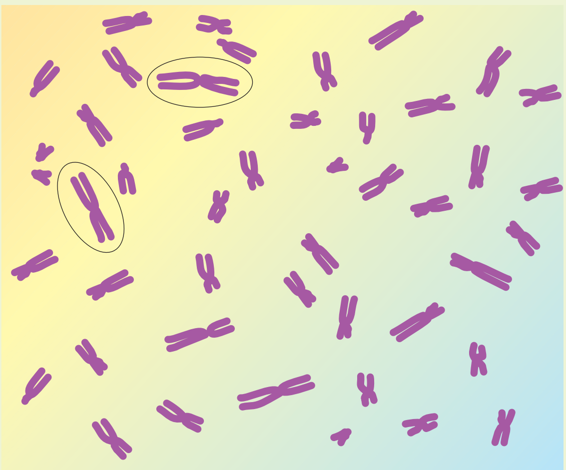
- a a fruit fly's ovum.
- b the pollen of a corn plant.

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

9 Notice that the three organisms listed on page 186, under the heading Chromosomes in cells—humans, fruit flies, corn—all have even numbers of chromosomes. 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 information on page 186 to justify your answer.

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

Figure 7.18 Identical twins (top) and fraternal twins (bottom)

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a Explain in terms of chromosomes why identical twins are always the same sex, yet fraternal twins can be the same or different sex.

b Explain why one member of fraternal twins can have blue eyes while the other has brown eyes, yet identical twins 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 Figure 7.19 and Figures 7.14 and 7.17 on pages 186 and 188 to work out:

a which chromosome pair is affected

b whether the person whose chromosomes are shown in Figure 7.19 is a male or a female.

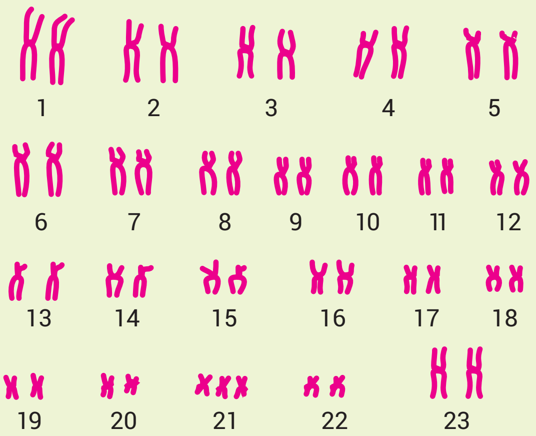

Figure 7.19 Chromosome map

6 Use the information in Figure 7.19 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 the 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?

Figure 7.20 Hydrangea flowers grown in acidic soil (blue) and basic soil (pink)

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7.3 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).

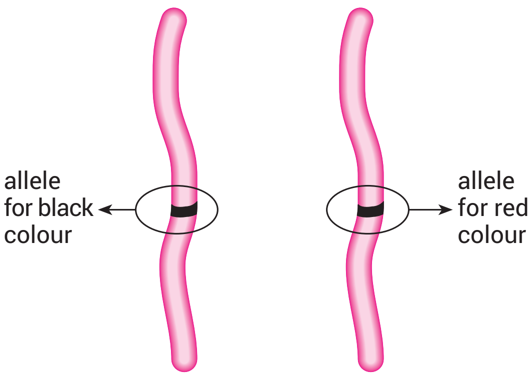

Figure 7.21 The colour of the fish's skin is controlled by two alleles of the same gene. Each allele is found at the same location on each of the chromosomes in the pair.

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, i.e. **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.

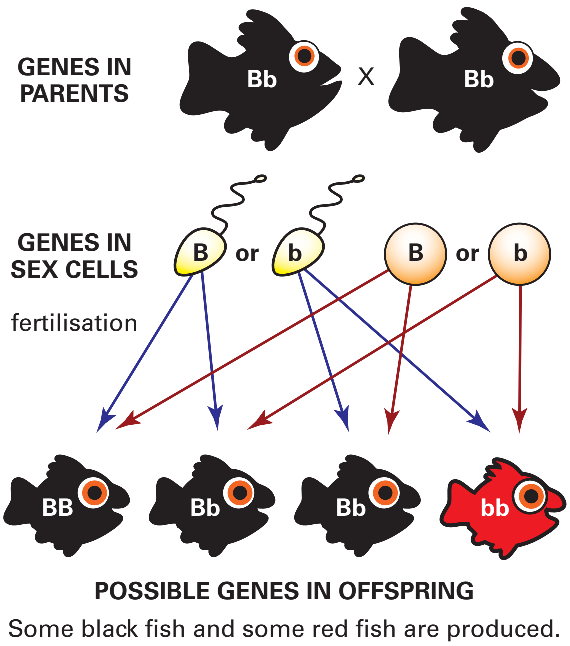

Figure 7.22 Inheritance of genes in offspring

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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.

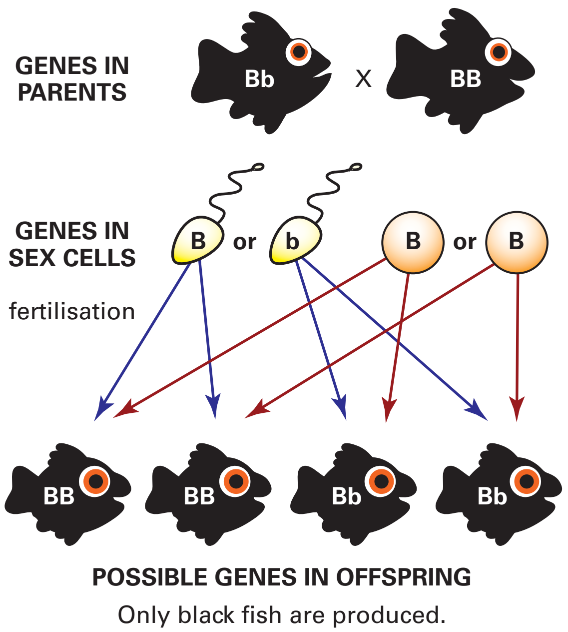

Figure 7.23 Another variation showing all dominant genes in the offspring

ACTIVITY

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 page 191, 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 discs and 20 red discs for this activity. (You can use other colours, or coins, if you wish.)

1. Place 10 black discs and 10 red discs in a small container. These discs represent the ova carrying the colour genes. Label this container 'Female'.
2. Place the remaining discs in another container labelled 'Male'. These discs represent the sperm carrying the colour genes.
3. Without looking, select a disc 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 discs 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.

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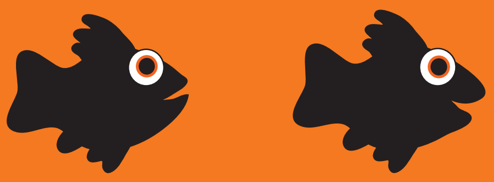
Some genetics terms

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 the 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 top right, 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

Figure 7.24 Punnett squares are used to predict the genotype and phenotype of offspring.

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Pedigrees

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

Figure 7.25 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.

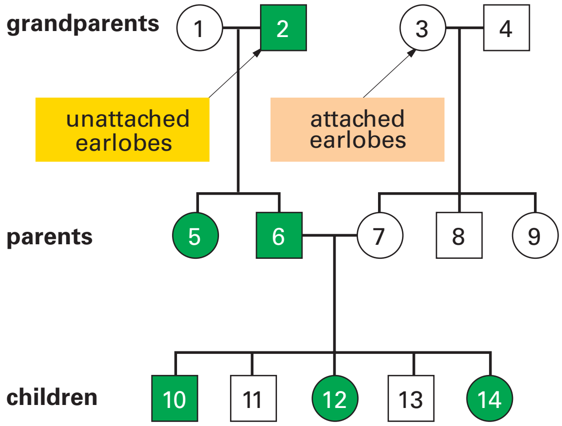

Figure 7.26 A pedigree

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.

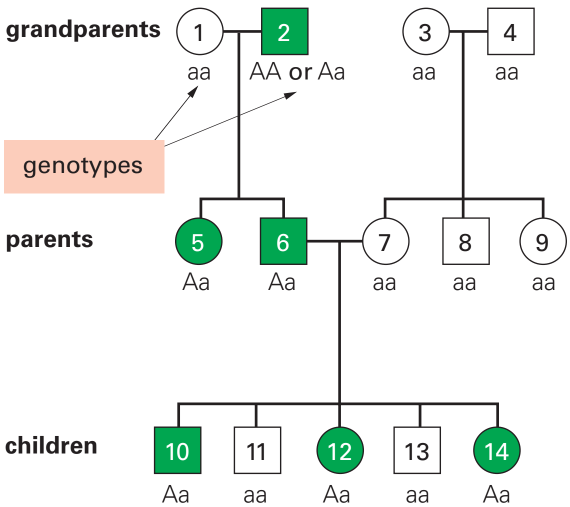

Figure 7.27 Pedigrees can show the genotypes as well as the phenotypes of individuals.

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EXTRA FOR EXPERTS

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 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.

Questions

1. What was lucky about Mendel's experiments?
2. What are alleles?
3. What are two of the characteristics controlled by a single gene?
4. Is it easy to explain how blue and brown eye colour is determined? Explain why and give an example. Use Punnett squares to show how blue and brown eye colour could be inherited.
5. Why are green and grey eye colours harder to predict?
6. Melanin is found in our skin and determines how dark our skin is. How is melanin related to eye colour?

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.

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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.

Figure 7.28 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.

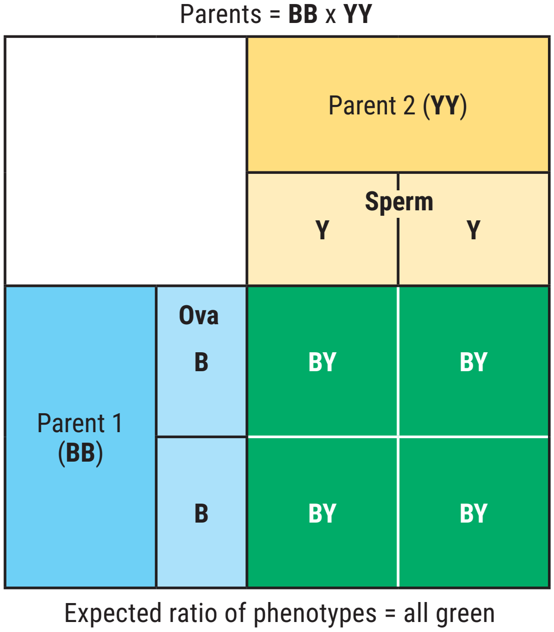

Figure 7.29 An example of incomplete dominance

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

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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 these foreign molecules 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

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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.

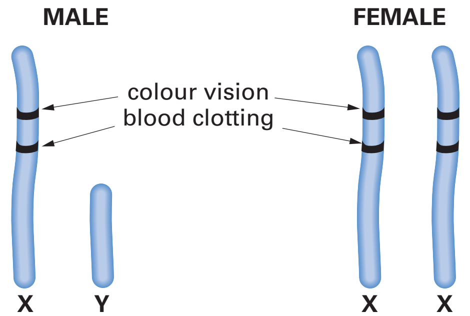
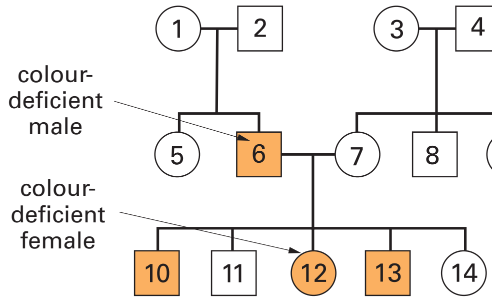


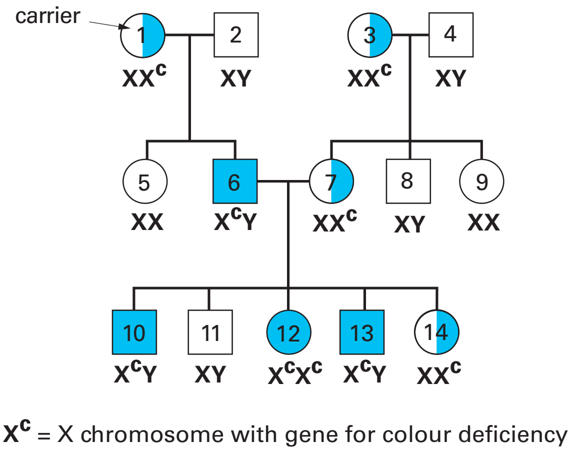
Figure 7.30 The genes for colour vision and blood clotting are found on the X chromosome. Females have two alleles for each characteristic but males have only one because there are none on the Y chromosome.

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. In contrast, 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.



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

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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 causes 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.

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 Construct a list of pros and cons for gene testing after completing some research into this topic.

Figure 7.31 The boy, diagnosed with Duchenne muscular dystrophy, will get a service dog of his own soon.

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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 and 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

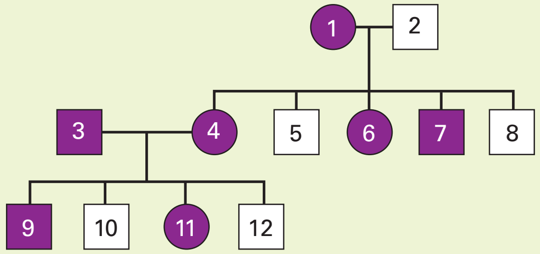
1 Suppose that the allele that controls right-handedness is dominant over the one for left-handedness. A heterozygous right-handed male and a left-handed female have four children, three who are left-handed and one who is right-handed.
  a If the allele for right-handedness is called R, use a Punnett 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 below, the shaded circles and squares show people with long eyelashes.



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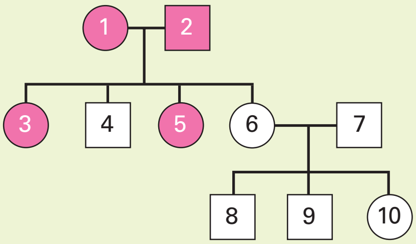
a Use appropriate symbols to work out the genotypes of the members in the pedigree.

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?

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
dominant
chromosomes
bases
genes
Y chromosome
mutations
genome
phenotype
radiation
DNA
sex cells
X chromosomes
genotype

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CH•7 REVIEW

1 Chromosomes are found in the nucleus of:
- **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 177 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.

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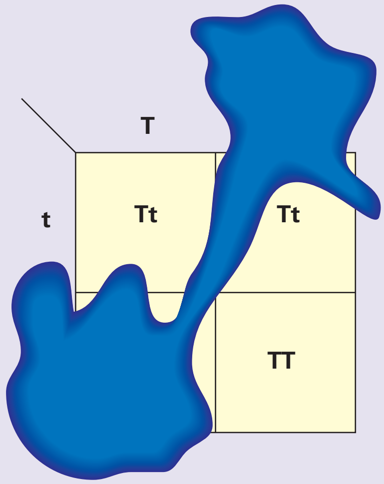
7 The Sloans have just had a baby boy. They also have another son and a daughter. Mrs Sloan is blood type O while her husband is blood type A.
  a Which parent is definitely homozygous for blood type?
  b If the daughter has O type blood, what blood genotype does Mr Sloan have?
  c What are the chances 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?

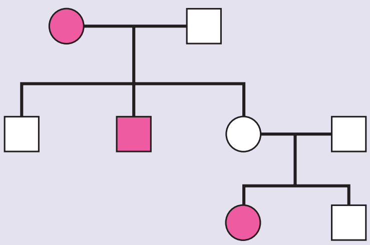
9 A couple has four children—three girls and a boy. The father, mother and two of the daughters can roll their tongue, while the other daughter and son cannot. Tongue rolling is controlled by a single gene. If the allele for tongue rolling is dominant, use a pedigree to work out the possible genotypes and phenotypes of all the members in the family.

10 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.



11 Colour deficiency is an X-linked characteristic. Use a Punnett square 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 347.

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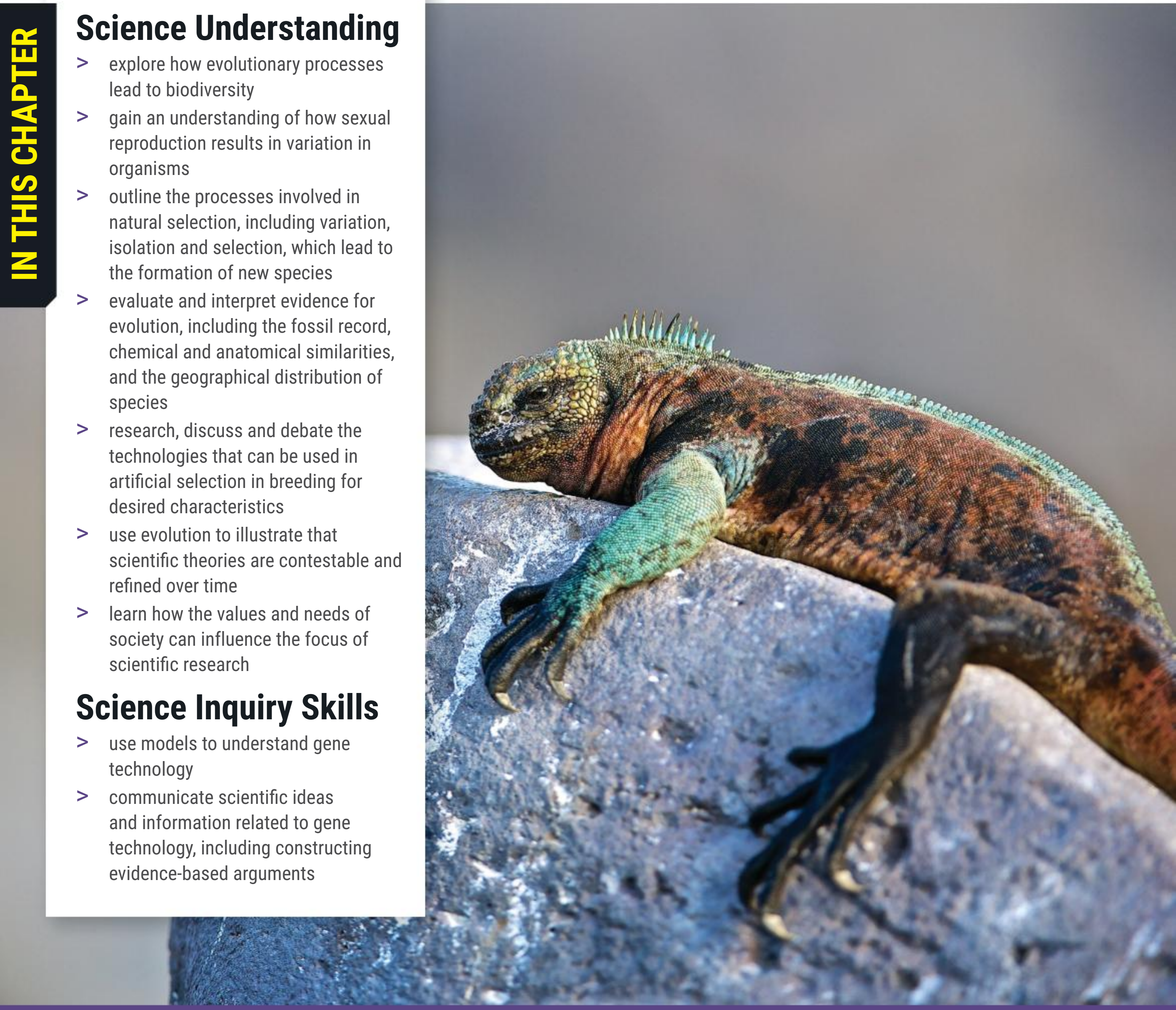
IN THIS CHAPTER

Science Understanding

- explore how evolutionary processes lead to biodiversity
- gain an understanding of how sexual reproduction results in variation in organisms
- outline the processes involved in natural selection, including variation, isolation and selection, which lead to the formation of new species
- evaluate and interpret evidence for evolution, including the fossil record, chemical and anatomical similarities, and the geographical distribution of species
- research, discuss and debate the technologies that can be used in artificial selection in breeding for desired characteristics
- use evolution to illustrate that scientific theories are contestable and refined over time
- learn how the values and needs of society can influence the focus of scientific research

Science Inquiry Skills

- use models to understand gene technology
- communicate scientific ideas and information related to gene technology, including constructing evidence-based arguments



CH•8 Evolution of life

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GET STARTED: *QUESTION*

Form 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 dibblers. These tiny marsupials have been classified as endangered since 1996. They are found only in coastal habitats of the Fitzgerald River National Park in south-west Western Australia, and on Boullanger and Whitlock islands off the coast near Jurien Bay.

   What does *endangered* mean?

   Why do you think the population of the dibbler is now very small?

   If you want to find out more, check out Perth Zoo's **Dibbler breeding program**.
4. Which do you think has a greater biodiversity: a coral reef or a desert ecosystem? Explain your answer.

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8.1 Biodiversity and variation

Biodiversity

Biodiversity is the combination of all life on Earth: the plants and animals, the genetic information they contain and the ecosystems they live in and interact with.

Biodiversity is often studied from three perspectives, all of which contribute to biodiversity.

Genetic diversity

Genetic diversity refers to the range of genes a particular species contains. Having a wide range of genetic diversity is important, as it allows a species to adapt to changing environments. To maintain strong diversity, different communities of the same species are often required, and populations must be large enough to allow for the exchange of genes. Genetic diversity decreases if populations are isolated or small, as inbreeding within the species increases.

Figure 8.1 The genetic diversity within a species produces different genotypes and phenotypes.

The genotypes are expressed as phenotypes, which can be influenced by the environment in which an organism lives.

Species diversity

Species diversity refers to the variety of species that exist, each with its own genetic diversity, within a habitat or ecosystem. Some ecosystems, such as a coral reef, have more diversity of species than others, such as a desert.

Figure 8.2 Coral reefs have a high level of species diversity.

Ecosystem diversity

Ecosystem diversity refers to the variety of ecosystems that exist. You may remember that an ecosystem is a community of species or organisms that live in a physical environment and interact with each other. This is sometimes called *functional diversity*, as scientists study the function of an organism in its ecosystem. Each species has a function that it performs and has an impact on the ecosystem in which it lives.

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Figure 8.3 Ecosystem diversity helps maintain different species, each species having a different function in that ecosystem. What is the 'function' of the leopard?

Figure 8.4 Variation in hair colour is controlled by many genes.

Variation

The genes an organism inherits determine many of its observable characteristics. In humans, examples of characteristics controlled by genes include the colour of your hair, eyes and skin.

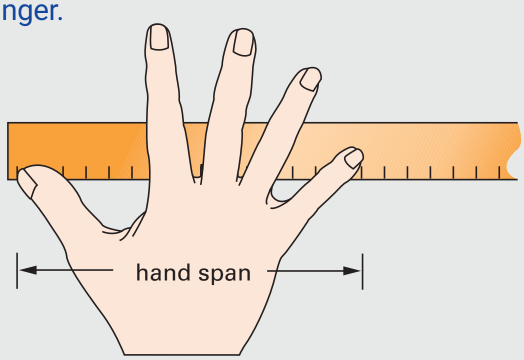
Some characteristics, like earlobe attachment, are controlled by a single pair of genes. However, most characteristics are controlled by more than one pair of genes. This produces a much wider variation in phenotypes. For example, the colour of your eyes is controlled by at least three pairs of genes on different pairs of chromosomes. Some other genes may turn these genes off and on. The way all of these genes combine determines the exact colour of your eyes. And it is this combination that creates the wide variation in human eye colour.

Variation in a species is very important, because it means that if environmental conditions change, some individuals within the population may have characteristics that allow them to survive. A species that exhibits little variation is in danger of becoming extinct if extreme environmental changes occur.

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.

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The source of variations

Some organisms produce offspring using *asexual* reproduction. This form of reproduction involves an organism producing clones of themselves; each offspring is genetically identical to the parent. This means that no variation is produced during asexual reproduction. The horticulturalist in the photo below is taking cuttings from a plant; she knows the daughter plants will produce exactly the same flowers as the parent plant.

Figure 8.5 A horticulturist takes cuttings from the parent plant. These cuttings will grow into plants identical to the parent plant.

Most organisms will generate offspring through sexual reproduction, which involves the formation of sex cells through the process of meiosis. Genetic variation is created in sex cells in three main ways:

- *independent assortment* of chromosomes during meiosis
- *recombination* of genes in chromosome pairs during meiosis
- *mutations* in the DNA in the cells of 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.

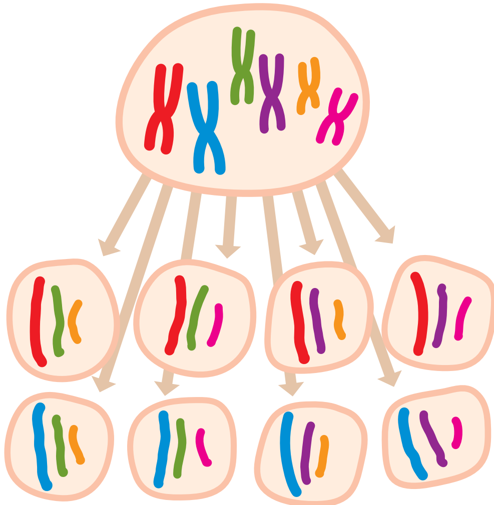

Figure 8.6 An organism with three pairs of chromosomes can produce eight different types of sex cells.

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.

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Recombination

During meiosis, chromosome pairs line up in the cell to be separated. Before the pair is separated, they exchange genetic material, which results in different arrangements of genes on each of the chromosomes.

In the diagram below, the top section of the DNA on a pair of chromosomes is exchanged. This process is known as *crossing-over*, and it results in a **recombination** of genes in a pair of chromosomes.

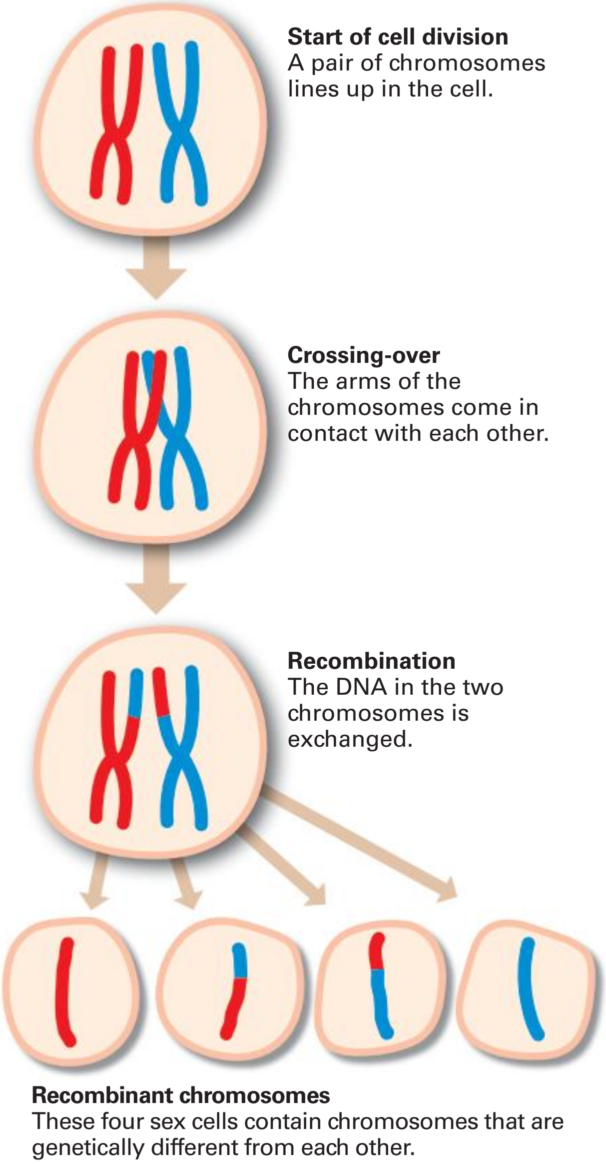

Figure 8.7 Crossing-over produces a different combination of genes in the chromosomes in the sex cells.

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 Figure 8.7 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.

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.

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Figure 8.8 Oranges in one location can grow differently to those in another location due to environmental conditions.

Figure 8.9 Environmental conditions, including a lack of food, have determined some of the characteristics of this child.

Effects of the environment

The orange tree above is loaded with sweet, juicy oranges. About 100 km away, orange trees bear very few, fairly dry fruit. Why is this, when all the orange trees came from the same stock? The juicy oranges 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 oranges. The other area has had unusually warm weather.

Even though the orange 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 Figure 8.9 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.

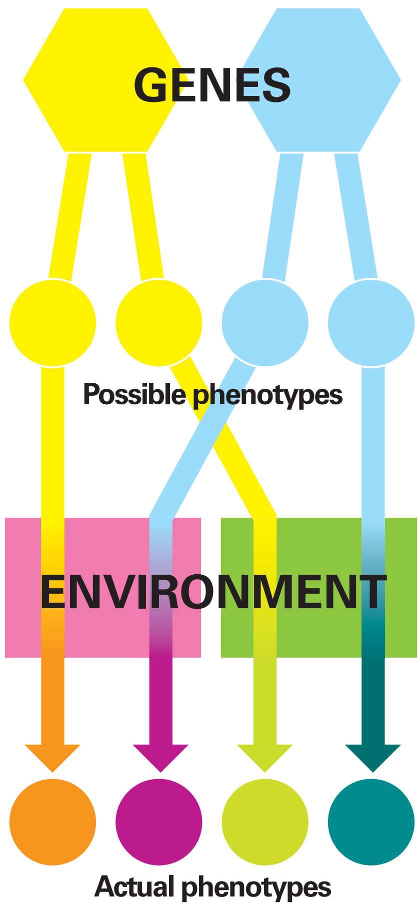

Figure 8.10 The characteristics of a population of organisms are determined by the environment as well as by the organisms' genes.

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CHECK

1 a What is biodiversity?
 b Outline the three types of diversity that contribute to overall biodiversity.

2 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?

3 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.

4 What is crossing-over? Use a diagram to show how it is a source of variation in organisms.

5 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.

6 Explain how variations in a population are caused by genetic factors as well as by environmental factors.

7 Explain, giving an example, how a particular environmental factor can affect the phenotype of an organism. (Do not use the examples in this book.)

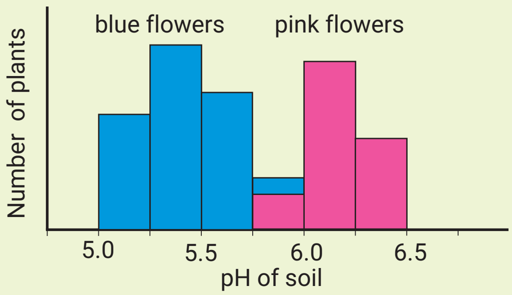
CHALLENGE

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 a different chromosome. 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?

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8.2 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 that 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 Investigation 8.1 you will use a model to help you understand how natural selection works.

Figure 8.11 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.

Figure 8.12 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.

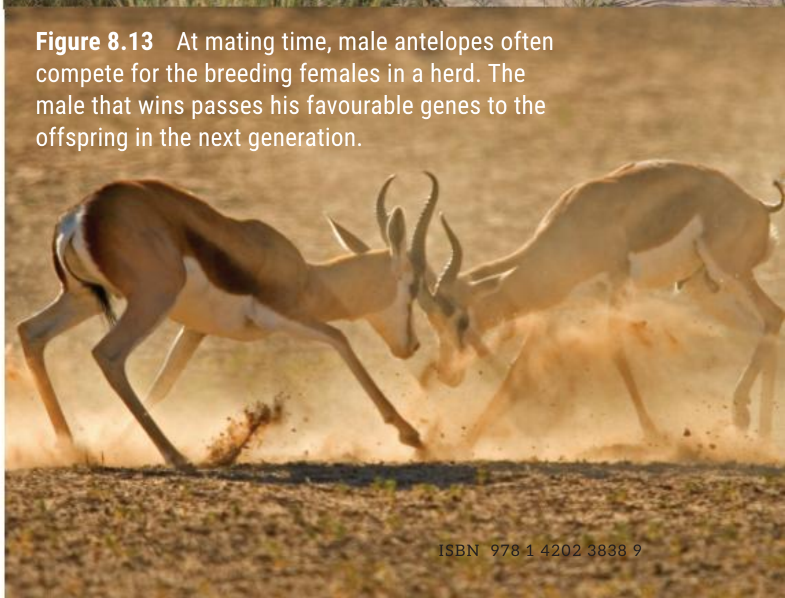

Figure 8.13 At mating time, male antelopes often compete for the breeding females in a herd. The male that wins passes his favourable genes to the offspring in the next generation.

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INVESTIGATION 8.1 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 on the book's website.**

Risk assessment and planning

- 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

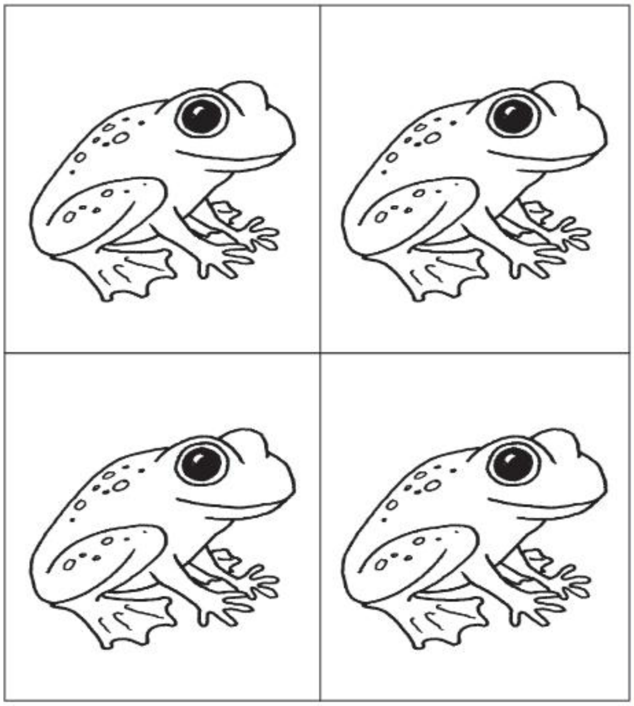
Method

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.



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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 × red	=	red
yellow × yellow	=	yellow
red × yellow	=	green
red × green	=	some red, some green—see Table 2
green × green	=	some red, some green, some yellow—see Table 2
green × yellow	=	some green, some yellow—see Table 2

Table 2

Number on die	Colour of offspring		
	red × green parents	green × green parents	green × 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

Results: Pond

Year	Red frogs	Green frogs	Yellow frogs
1	10	10	10
2			
3			
4			
5			

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.

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*.

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SCIENCE AS A HUMAN ENDEAVOUR

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) that turns the normally concave disc-shaped red blood cells into sickle-shaped cells.

The abnormal haemoglobin allele is recessive to the allele that codes for normal haemoglobin.

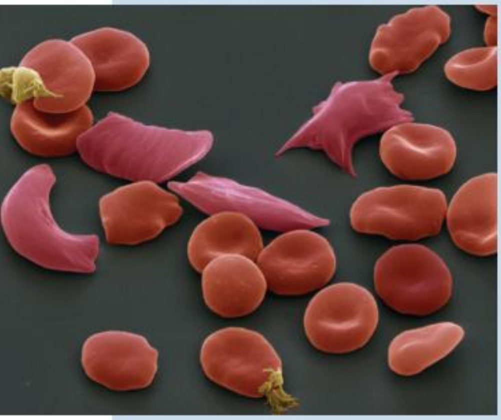

Figure 8.14 Normal red blood cells are rounded, in contrast with the distorted sickle-shaped cells (pink).

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 196) 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. Figure 8.15 shows the percentage of people in the population with the allele for abnormal haemoglobin.

Figure 8.16 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.

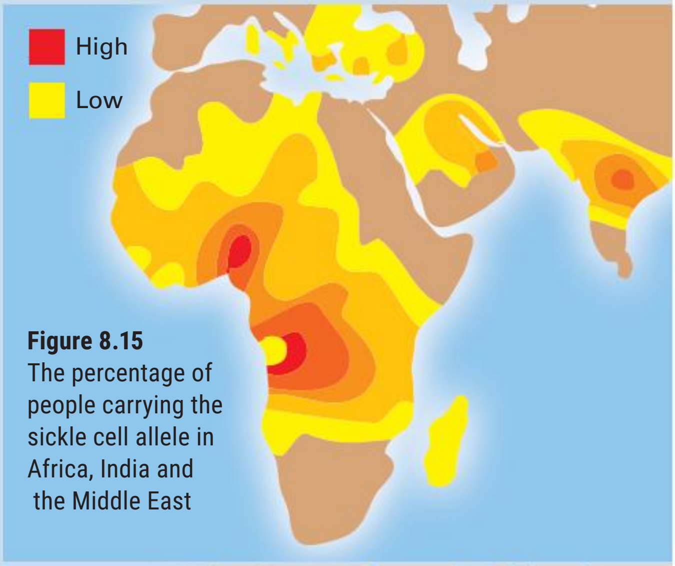

Figure 8.15 The percentage of people carrying the sickle cell allele in Africa, India and the Middle East

Figure 8.16 Areas in Africa, India and the Middle East where malaria is prevalent

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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?

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8.3 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.

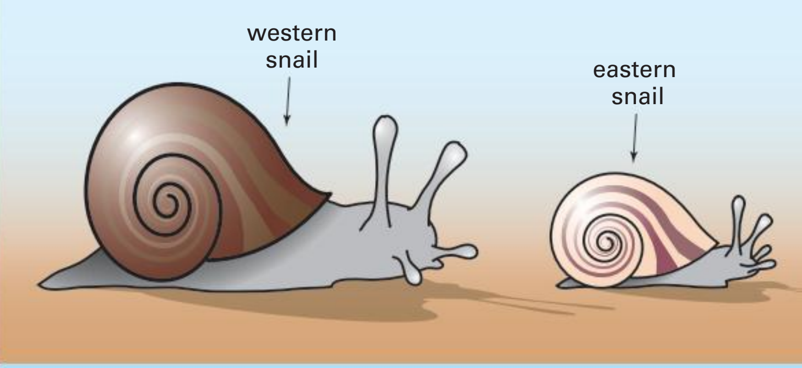
Over thousands of years, the climate changes. The creeks and wet areas in the valley dry up and the snails are no longer able to travel from one side of the valley to the other. The forest on the eastern side of the valley becomes drier than the forest on the western side. The eastern forest also contains 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 interbreed under natural conditions to produce fertile offspring. The eastern and western snails are considered to be different species as they have different mating seasons and behaviours, and therefore do not interbreed.

Figure 8.17 A land snail in the moist forest

Figure 8.18 The western and eastern snails



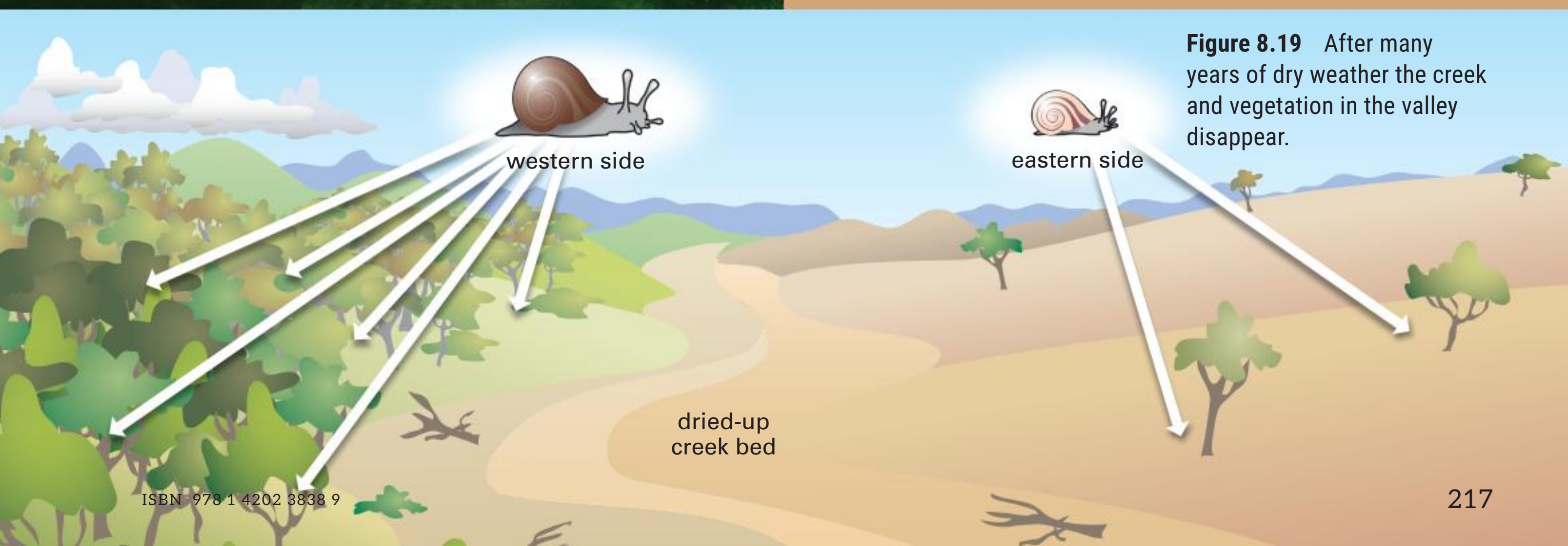


Figure 8.19 After many years of dry weather the creek and vegetation in the valley disappear.

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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.

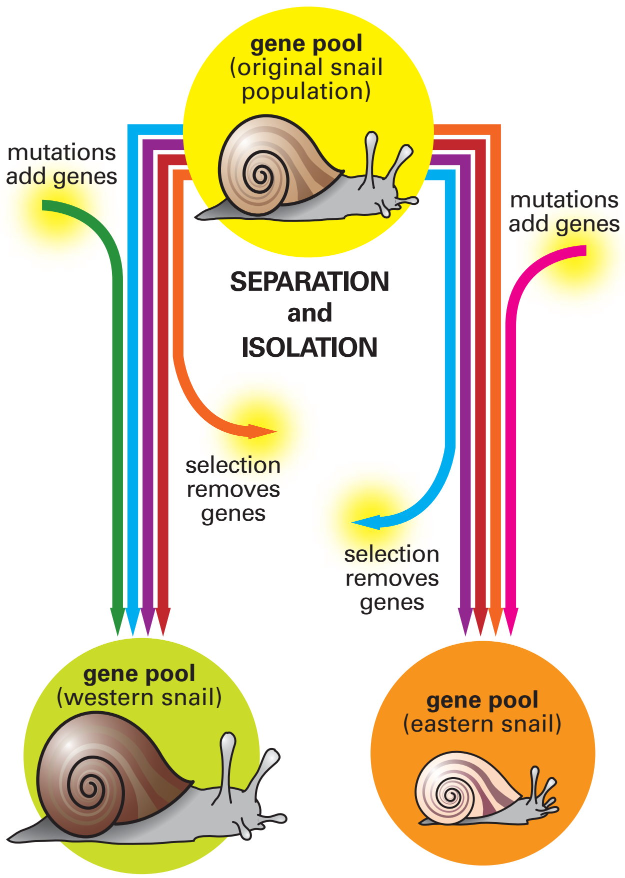

Figure 8.20 New species can be formed by separation and isolation of the gene pools.

Evolution—inferences and theories

Figure 8.21 Charles Darwin

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.

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 had no knowledge of genetics and could not explain the cause of the variations or 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, much longer than one human lifetime. Consequently, it is usually impossible for biologists to directly observe species evolution or formation to test their inferences.

As new discoveries and inferences are made, the theory of evolution is modified accordingly.

Biodiversity and evolution

Biodiversity is an outcome of evolution. In other words, evolution produces and maintains biodiversity. The selection pressures applied to organisms by the environment, the changing gene pools due to mutations and natural selection, and separation and isolation all lead to genetic diversity, species diversity and ecosystem diversity. All of this maintains overall biodiversity.

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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.

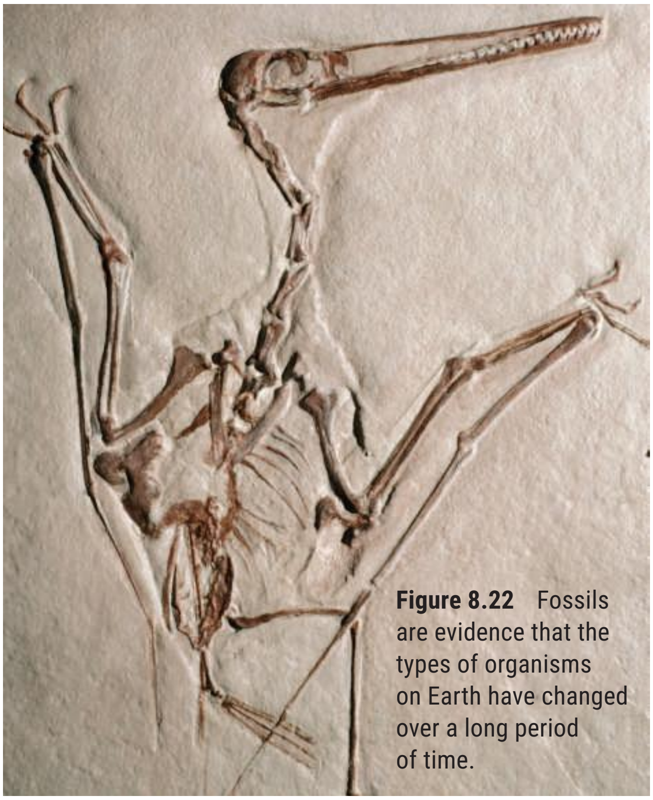

Figure 8.22 Fossils are evidence that the types of organisms on Earth have changed over a long period of time.

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		
	first primates	
70		
	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	

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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.

Figure 8.23 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.

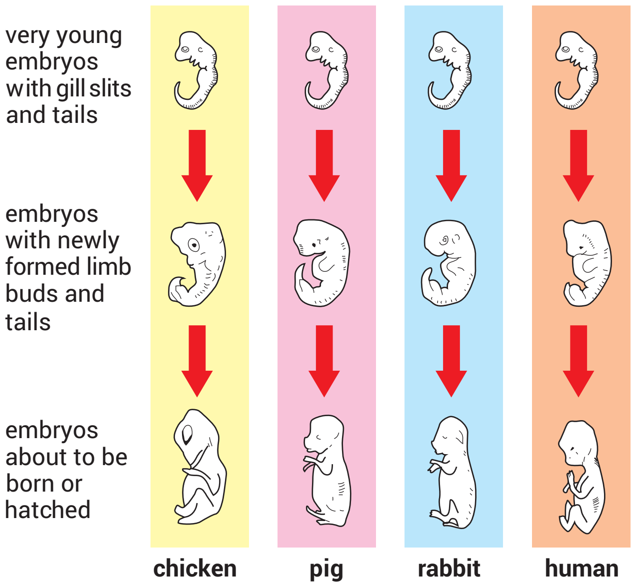

Figure 8.24 These vertebrate embryos are very similar at an early stage, suggesting that they might share a common ancestor.

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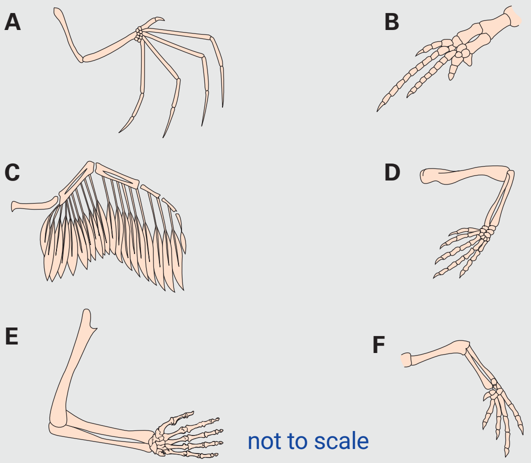
ACTIVITY

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	frog
whale	human
bird	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.

Figure 8.25 Strands of DNA from humans, chimpanzees and orang-utans show a great degree of similarity, suggesting that these animals have a common ancestor.

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SCIENCE AS A HUMAN ENDEAVOUR

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. The platypus and its relative the echidna 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.

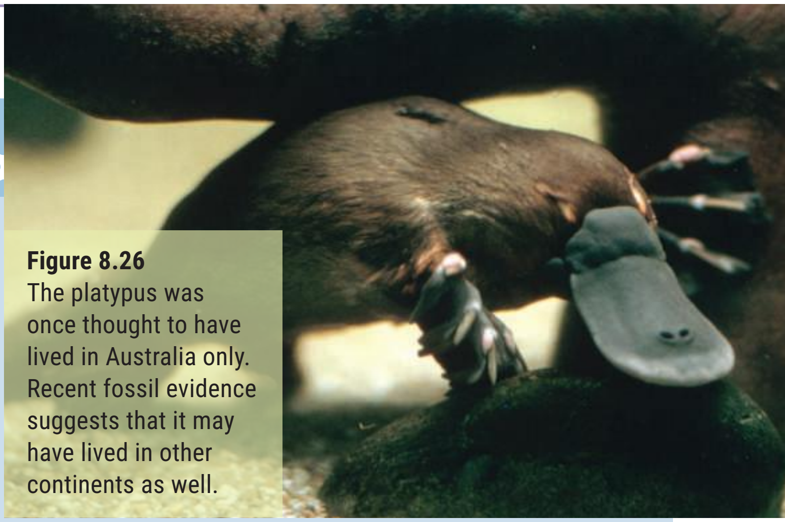

Figure 8.26 The platypus was once thought to have lived in Australia only. Recent fossil evidence suggests that it may have lived in other continents as well.

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 217 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.
10. Explain how biodiversity and evolution are interrelated.

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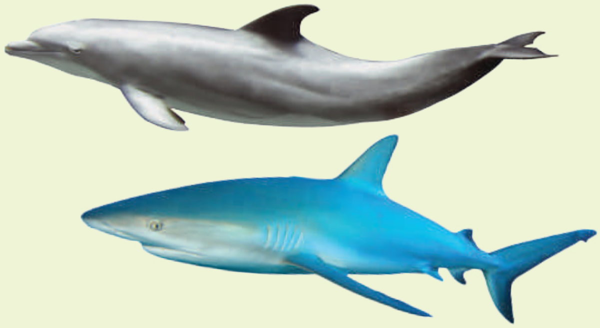
CHALLENGE

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.

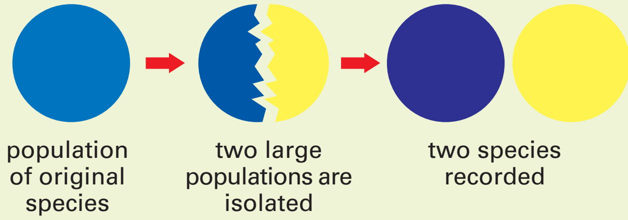
b Suggest what could happen to the frog populations in the two different locations over a period of time.

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.

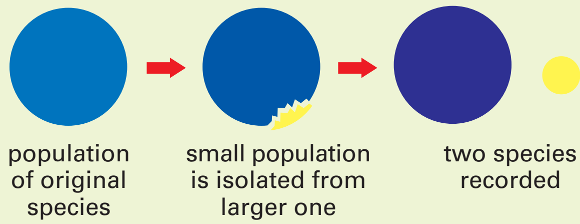
4 Do you think that organisms stop evolving in environments that change very little over long periods of time? Explain your answer.

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 become 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.

Model 1



Model 2



EXPLORE ONLINE

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.

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8.4 Biotechnology

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 more than a wild form of goldfish.

Figure 8.27 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.

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).

Artificial selection has also been used in farming. This has been used to produce crops that are resistant to disease, to produce new fruits and vegetables, and to create varieties of plants that produce more fruits or seeds per plant. Most of our modern fresh foods have been selectively bred over many years. Think of all the varieties of apples now available.

Figure 8.28 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.

Figure 8.29 These tomatoes have been selectively bred to have more flavour and to maximise the number of tomatoes per plant.

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Genetic engineering

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.

Figure 8.30 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.

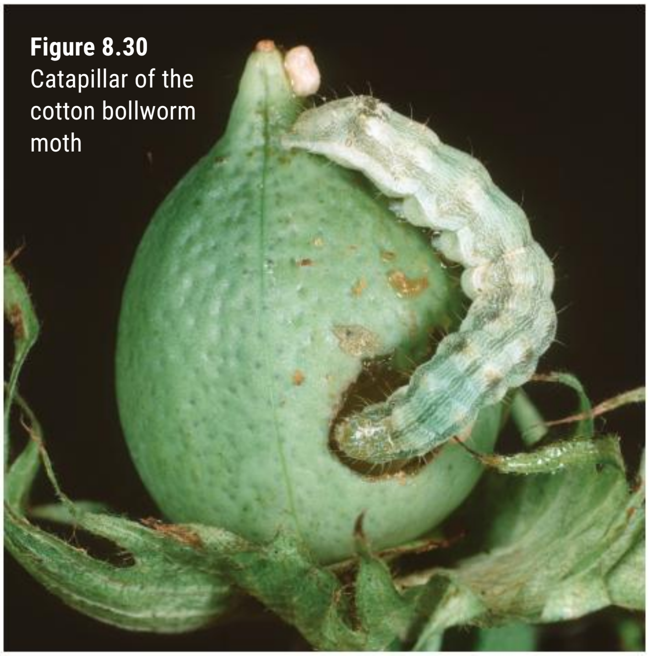

Figure 8.30 Catapillar of the cotton bollworm moth

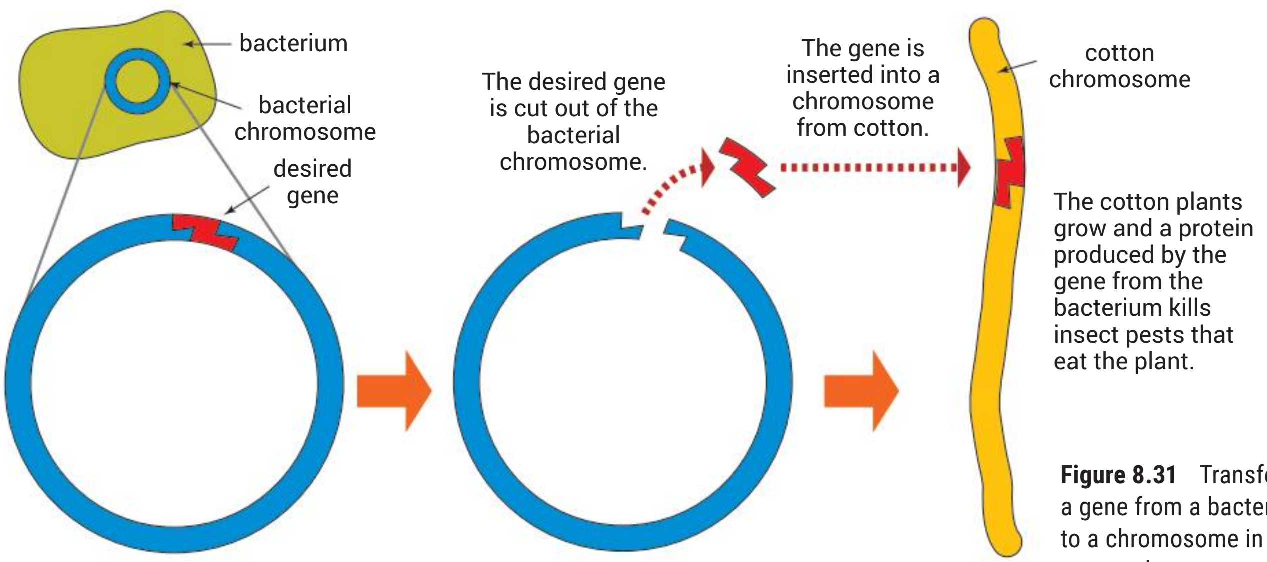

Figure 8.31 Transferring a gene from a bacterium to a chromosome in a cotton plant

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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.

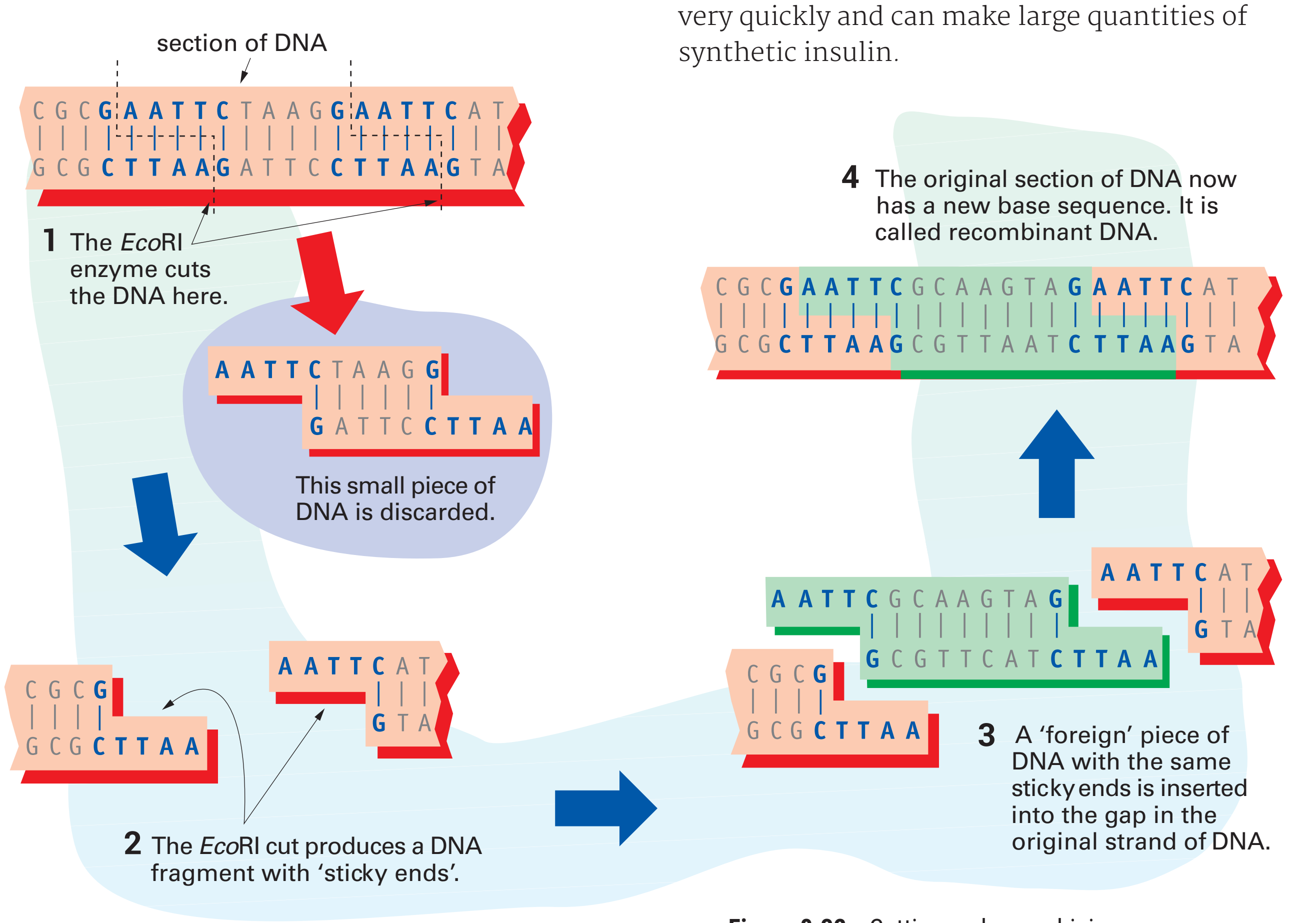

Figure 8.32 Cutting and recombining genes

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INVESTIGATION 8.2 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 × 50 cm
- scissors

Risk assessment and planning

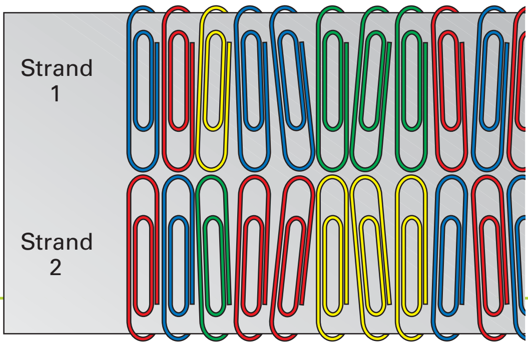
- In the activity on page 179 in Chapter 7 you made a model of DNA using coloured paper clips. The same model is used in this investigation. The four colours of the paper clips represent the four types of bases in DNA. Blue = A, red = T, yellow = G and green = C.
- Read through the Method carefully. You will need to refer to the table on page 177 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 177 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?

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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 foods 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 the 'pest' as well as beneficial insects. It is also possible that 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. Research the Australian Food Standard 1.5.2 which requires the labelling of GM foods.
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 transgenic organisms. Your teacher might organise you into groups for a class debate.

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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*. Figure 8.33 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 heart, lungs, liver and kidneys.

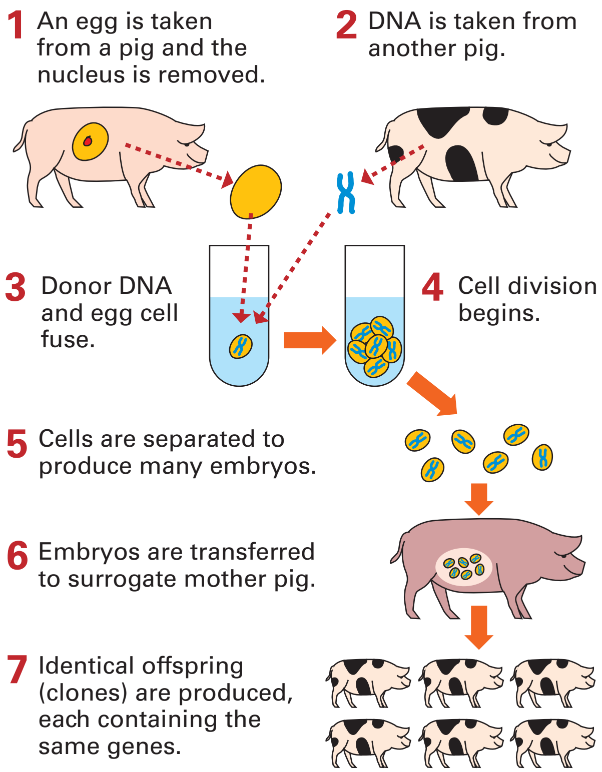

Figure 8.33 Cloning pigs

Figure 8.34 This baby gaur, a wild ox from India, was born in 2001 and was the first endangered animal to be cloned.

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 think that her premature death was just a natural occurrence, not a result of the cloning procedure.

Before developing arthritis, Dolly had given birth to six healthy lambs as a result of natural mating.

Follow the links to the websites below.

Cloning fact sheet

How cloning works

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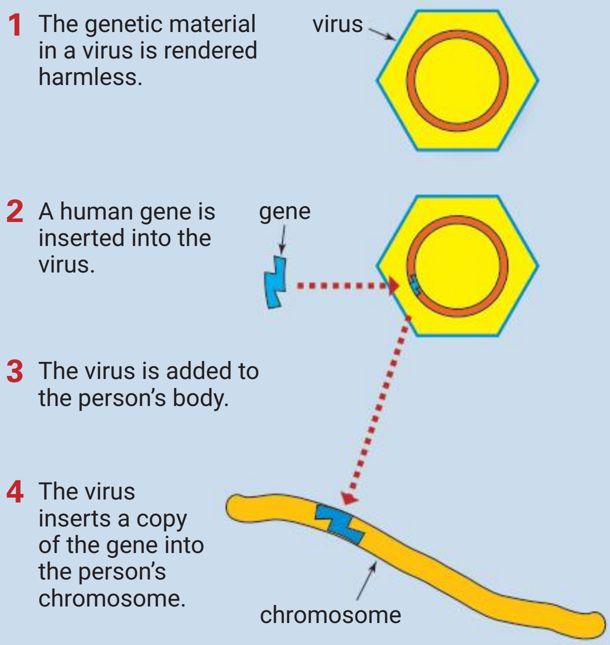
SCIENCE AS A HUMAN ENDEAVOUR

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 of the virus. 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.



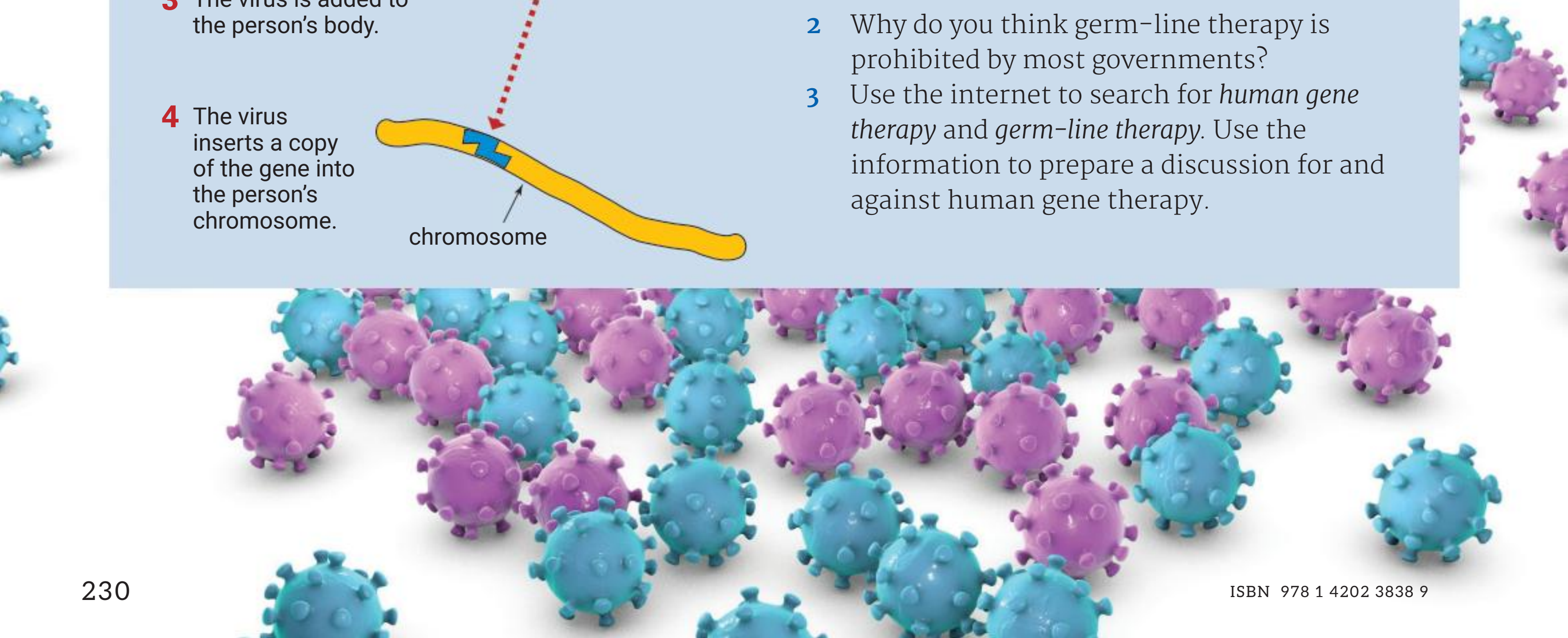
Germ-line gene therapy—creating designer people?

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 human gene therapy.



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CHECK

1 How does artificial selection differ from natural selection?

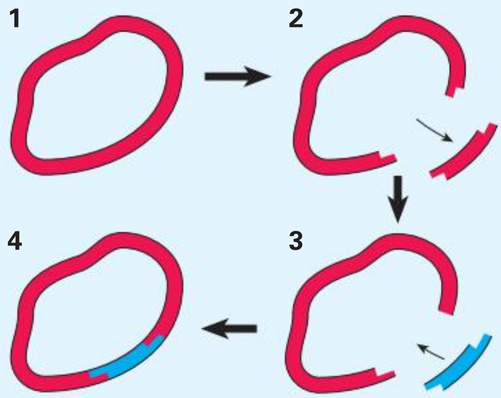
2 Genetic engineering is called recombinant DNA technology. Explain in simple language why these terms are interchangeable. (Hint: Refer to page 225.)

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 Cotton plants can be made transgenic.
 a What does the word *transgenic* mean?
 b Why are some people worried about the effect on the environment of GM crops like this cotton?

CHALLENGE

1 The diagrams show 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 the ancestral corn should not be allowed to become extinct. Suggest why.


ancestral corn


modern corn

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 Figure 8.33 on page 229 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.

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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.

9 ______ is the combination of all life on Earth including the organisms, the genetic information they contain and the ecosystems they live in and interact with.

10 Biodiversity is ______ and maintained by the process of evolution.

environmental
artificial selection
phenotypes
evolution
competition
genes
genetic engineering
population
independent assortment
gene pool
mutations
variations
natural selection
biodiversity
selection agents
produced

CH•8 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 are over 100 different breeds of domestic dog, yet wild dogs have very few variations (e.g. jackal, wolf, dingo). How can you explain this?

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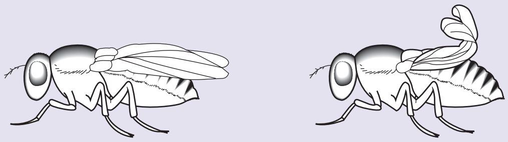
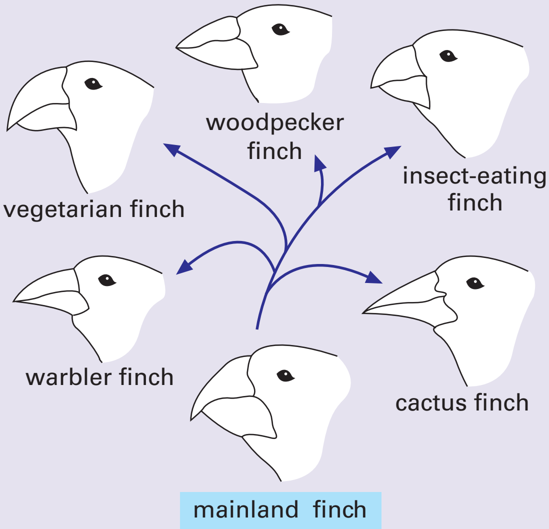
5 An organism's genotype is not the only factor that determines its characteristics (phenotype). The environment also plays an important part in how the organism's genes are expressed. Explain, giving an example, what this statement means.

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

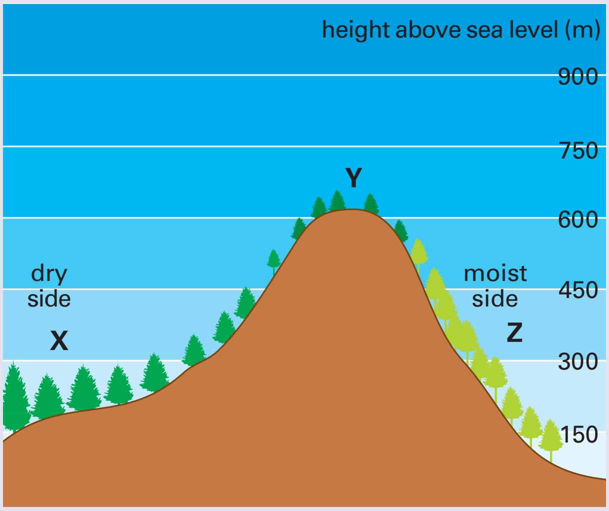
8 The diagram below shows the five species of finches that Charles Darwin observed when he visited the Galapagos Islands. It also shows the finch that lived on the mainland of South America, which Darwin inferred was the ancestor of the Galapagos Islands finches. Suggest how modern DNA testing techniques 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 349.

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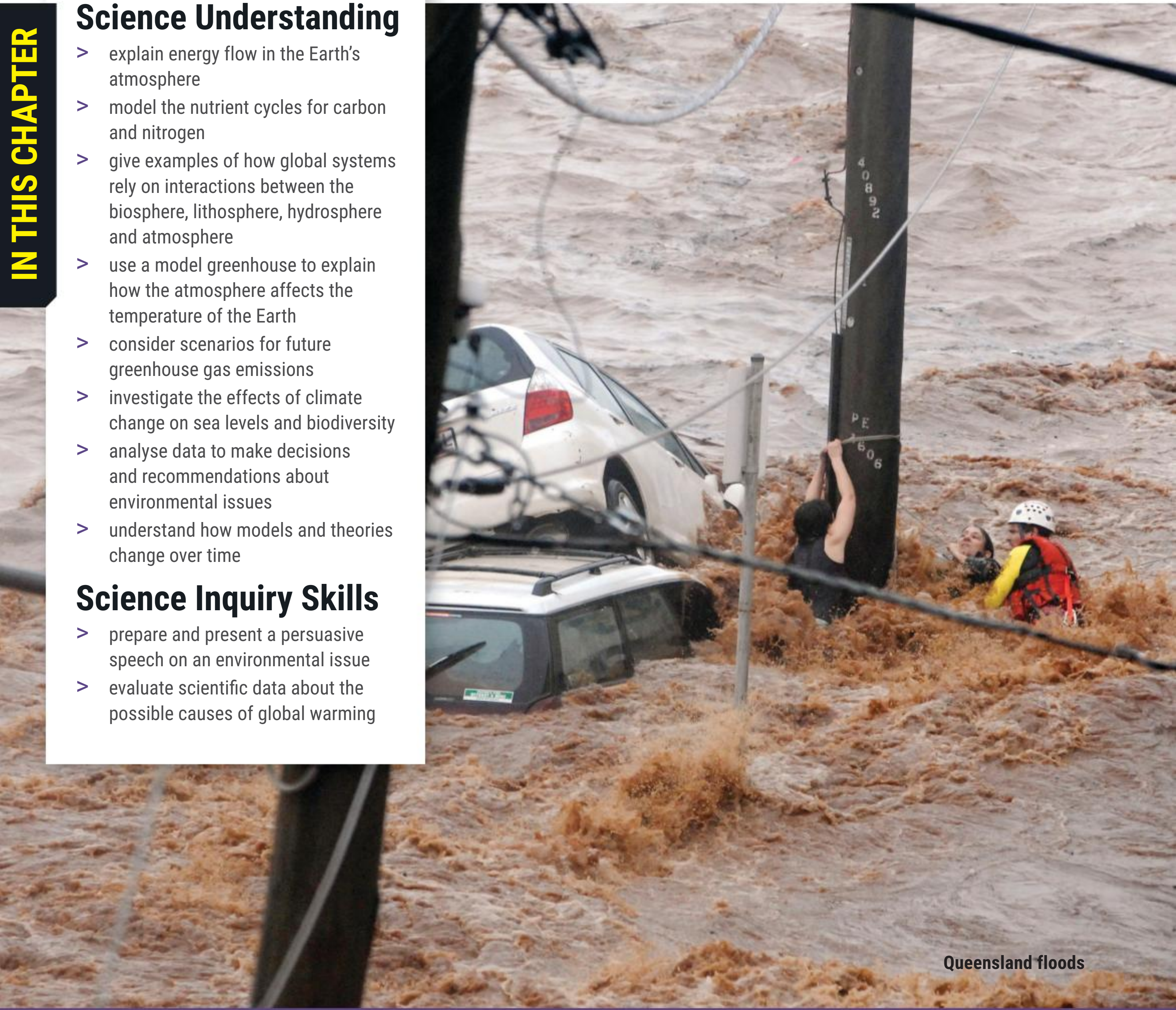
IN THIS CHAPTER

Science Understanding

- explain energy flow in the Earth's atmosphere
- model the nutrient cycles for carbon and nitrogen
- 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
- investigate the effects of climate change on sea levels and biodiversity
- analyse data to make decisions and recommendations about environmental issues
- understand how models and theories change over time

Science Inquiry Skills

- prepare and present a persuasive speech on an environmental issue
- evaluate scientific data about the possible causes of global warming



Queensland floods

CH•9 Earth systems

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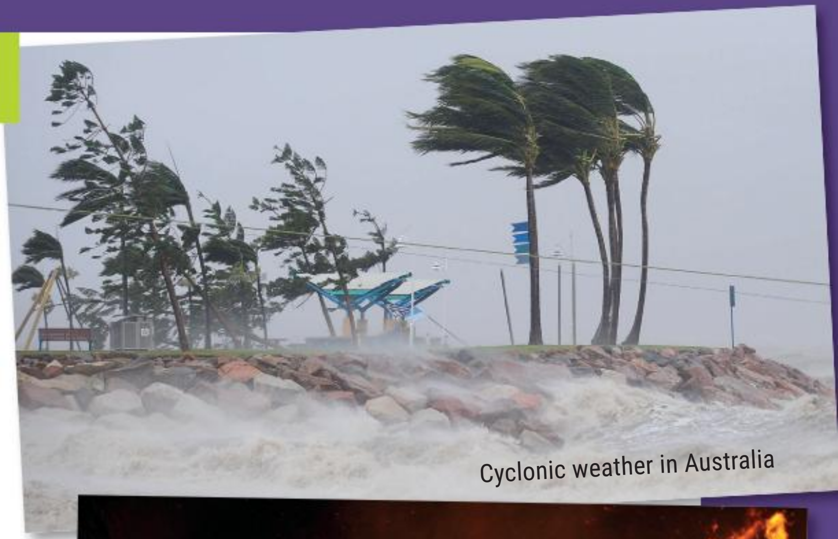
GET STARTED: *EXPLORE*

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.

1. List some of the factors or issues that may have been a cause of some of these weather-related events.
2. 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 the incidence of skin cancers.
3. Keep your answers for later on in this chapter (page 258).



Cyclonic weather in Australia

Bushfires have increased in Australia.

Melting sea ice in the Arctic Ocean

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9.1 The Earth's cycles

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**. The biosphere 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 9.3.

Figure 9.1 The Earth's four spheres

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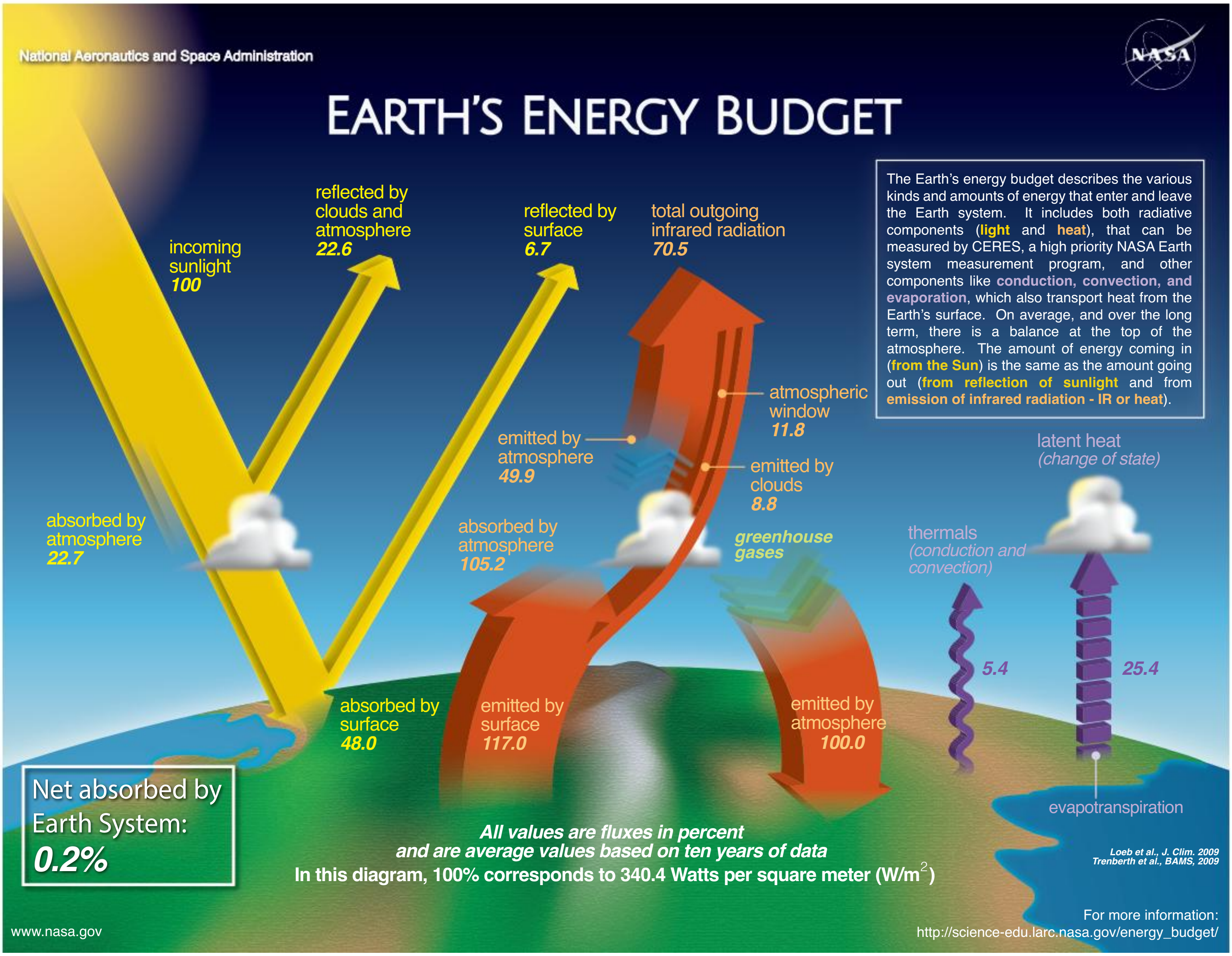

Figure 9.2 The energy cycle of the Earth's atmosphere

The cycling of energy

The Earth is a massive system of energy and energy changes. Energy is transformed from one form to another as it is transferred through Earth's atmosphere. Figure 9.2 shows the energy cycle for the Earth. You can see that 100% of the energy comes from the sun, our sole source of energy on Earth. The arrows show that a large proportion, 48% of the energy, is absorbed by the Earth's surface. Eventually most of the energy, in fact 99.8%, is lost back into space. This occurs through refection of the light, and through loss of infrared radiation (heat) into space. In effect there is a balance. The energy coming in is very nearly the same as the energy going out, so the Earth's energy budget is balanced.

Because of global warming (covered in Section 9.3), the Earth retains a little more energy from the sun than actually escapes. As shown in Figure 9.2, 0.2% of the energy received by the Earth does not escape back into space. During an ice age more energy would escape from the Earth than is retained, so the Earth would cool down. In this diagram, *fluxes* means energy flows or movements.

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Local effects

Localised effects on the Earth's energy cycle can be measured. In central Australia, between 2002 and 2009, NASA monitored the heat radiated from the ground over a 2 million square kilometre region. During these years a drought had reduced vegetation, due to decreased rainfall. Prior to the drought this area of Australia was an absorber of heat, but during the drought it was an emitter of heat. Once the drought broke and vegetation and soil moisture returned, the area again became an overall absorber of heat energy.

Each area of the Earth will absorb and emit heat differently due to the present conditions there. Changes in the Earth's surface, such as land clearing will also have an effect on the heat reflected, absorbed and radiated from those regions.

Cloud effects

Clouds also have a major effect on the Earth's energy cycle. High clouds tend to warm the Earth, as they are usually quite thin and do not reflect much energy back into space. Instead they let it pass through to the Earth's surface. High clouds also reflect heat back towards the Earth, stopping much of it from escaping into space. Low clouds tend to cool the Earth because they are quite thick and reflect more energy back into space before it reaches the Earth's surface. They are also lower in the atmosphere, where it is warmer, and so emit more heat into the atmosphere—into space as shown in Figure 9.2 on page 237, and also to the ground. But their overall effect is to return more heat to space than they retain.

Evaporation and condensation of water also transfer energy to and from the Earth's surface as energy is absorbed and released during changes of state.

EXTRA FOR EXPERTS

Carbon

You have probably heard about carbon trading schemes in which 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.

Question

To check that you understand how this is done, calculate how much carbon there would be in a tonne of methane gas (CH_4).

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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 Figure 9.3) 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.

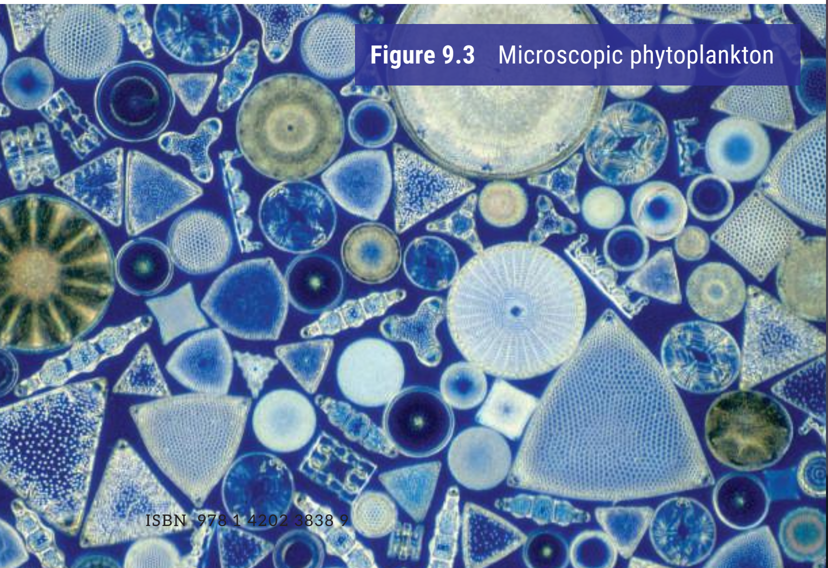

Figure 9.3 Microscopic phytoplankton

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.

Figure 9.4 This volcano in Chile erupted in 2011, sending an ash cloud around the world.

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ACTIVITY

The carbon cycle

In *ScienceWorld 9* you learnt about the **carbon cycle**, in which 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 (coal and oil) 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. Nitrogen 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 part of the **nitorgen cycle** is called *fixing* nitrogen.

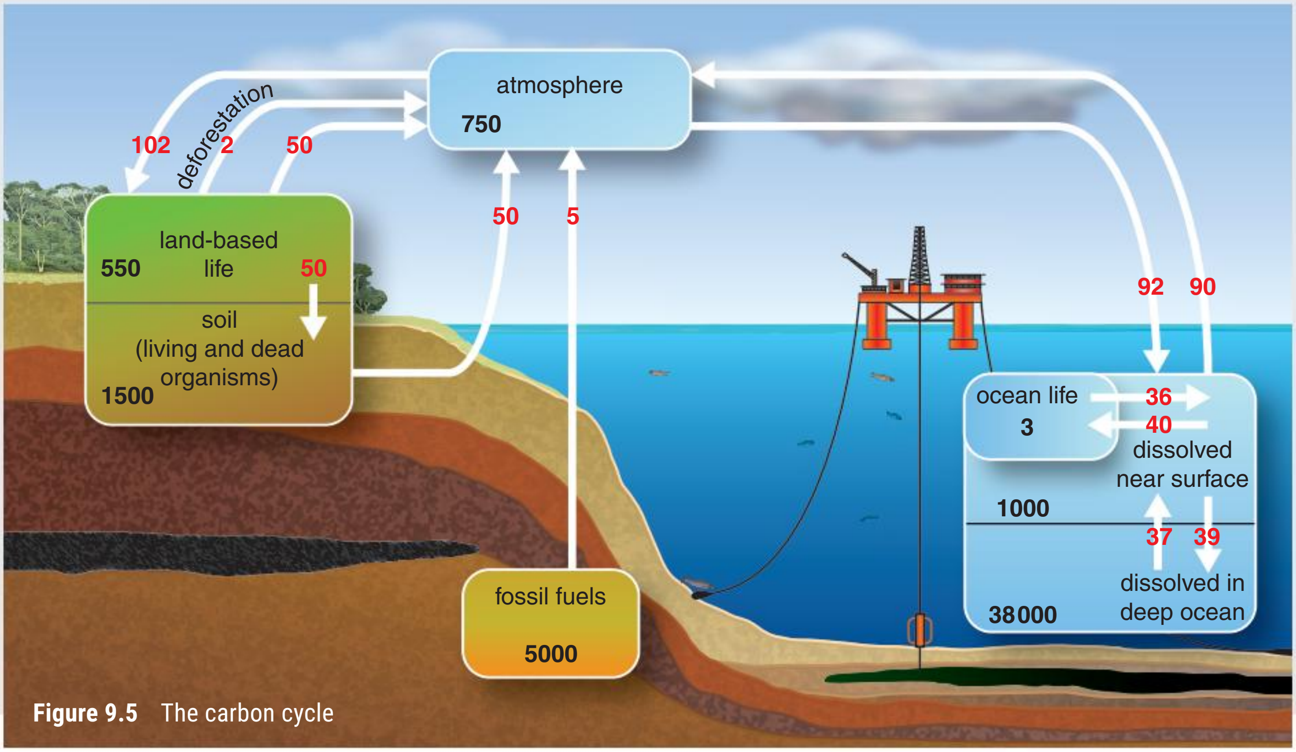

Figure 9.5 The carbon cycle

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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 43):

$$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$$

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.

Figure 9.6 The nitrogen cycle

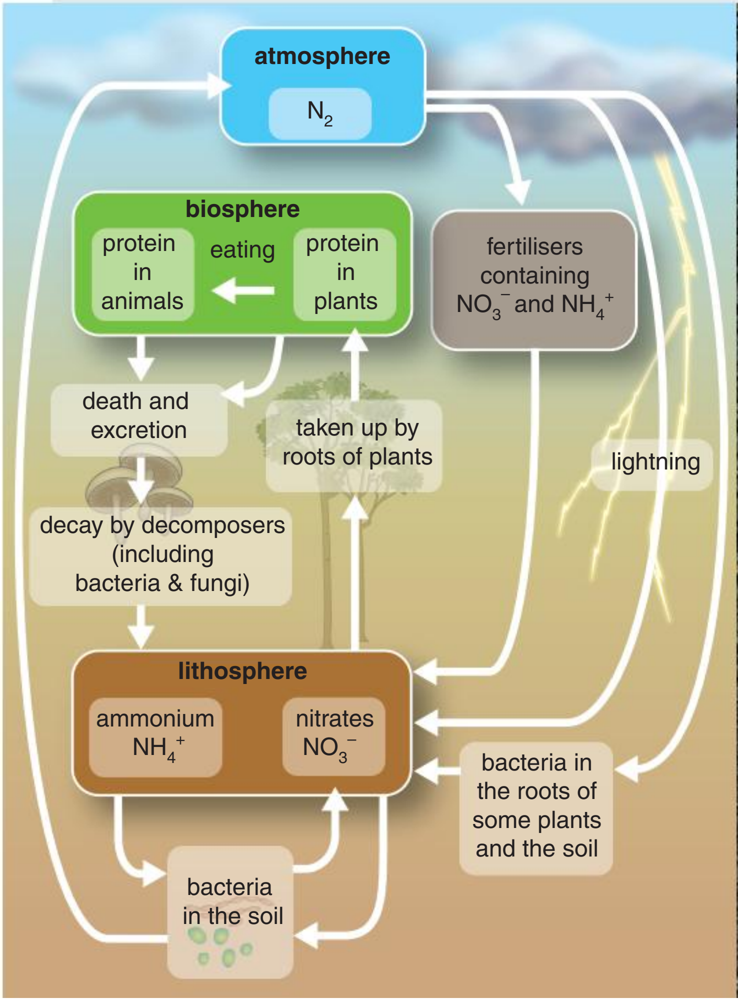

Figure 9.7 Nitrogen-fixing bacteria are found in root nodules on certain plants like this pea plant.

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CHECK

1 a How much of the Earth's energy comes from the sun?
  b Describe the current overall energy balance of the Earth according to Figure 9.2 on page 237.
  c Describe what the energy balance of the Earth would be like in an ice age.

2 What effect do low clouds have on energy flow in the Earth's atmosphere?

3 a Which process removes carbon dioxide from the atmosphere?
  b Which processes return carbon dioxide to the atmosphere?

4 What are phytoplankton? What role do they play in the Earth's ecosystem?

5 Which organisms are responsible for making nitrogen from the air available to plants?

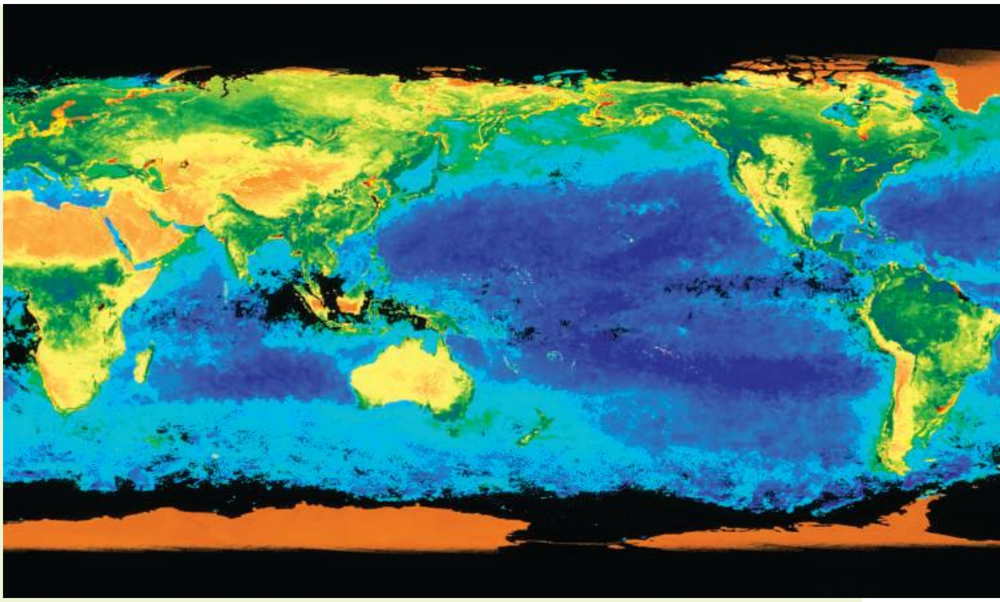
6 Why does soil become less fertile if crops are grown and harvested in the same place year after year?

7 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.

8 Why are the oceans becoming more acidic?

CHALLENGE

1 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.



2 Describe the effect that each of the following activities would have on the reflection or radiation of energy from the Earth's surface in a particular location.
  a clearing of the rainforests in Sumatra and other parts of Indonesia
  b a severe drought in central Australia
  c melting of the polar ice cap in the Arctic
  d replanting of plantation forests in Western Australia's state parks

3 a Compare and contrast the effect of low and high clouds on the Earth's energy cycle.
  b If global warming caused weather changes that increased the amount of low cloud, what would be the effect on the atmosphere? What effect would this have on global warming?

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9.2 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, for example 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 in Figure 9.8 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.

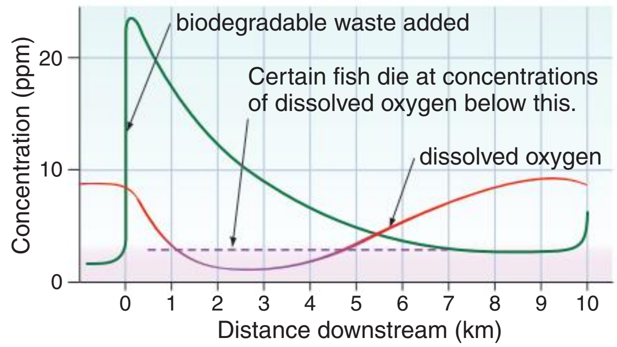

Figure 9.8 Concentration of oxygen in a polluted river

Figure 9.9 Fish will die if the dissolved oxygen concentration falls below a certain level.

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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.

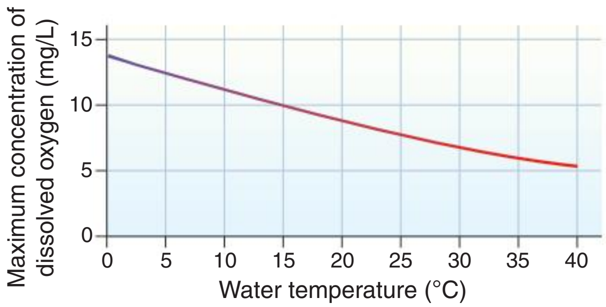

Figure 9.10 The concentration of dissolved oxygen in water at different temperatures, when the water is in contact with air

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, for example 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, such as humans, are more likely to be affected by the pollutant than plants or animals at lower feeding levels.

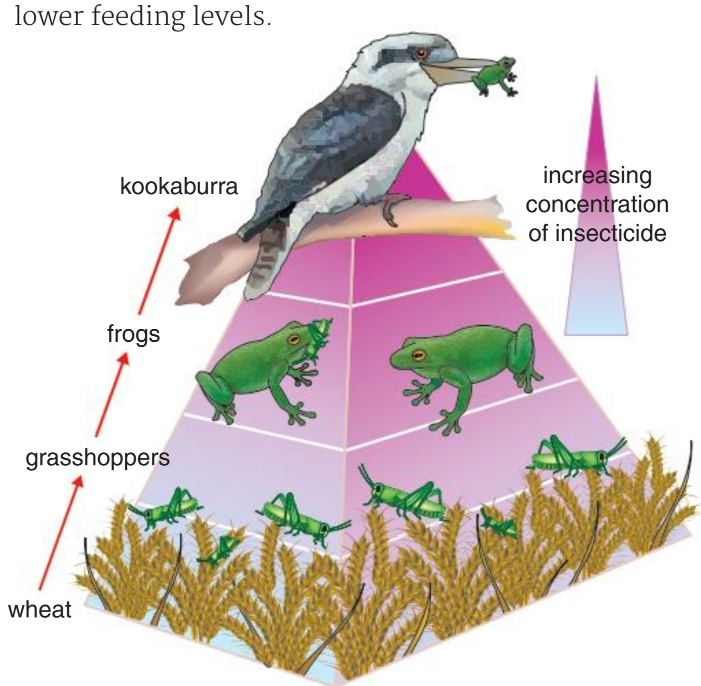

Figure 9.11 In biomagnification, the concentration of a non-biodegradable pollutant increases as you go up a food chain.

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*.

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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.

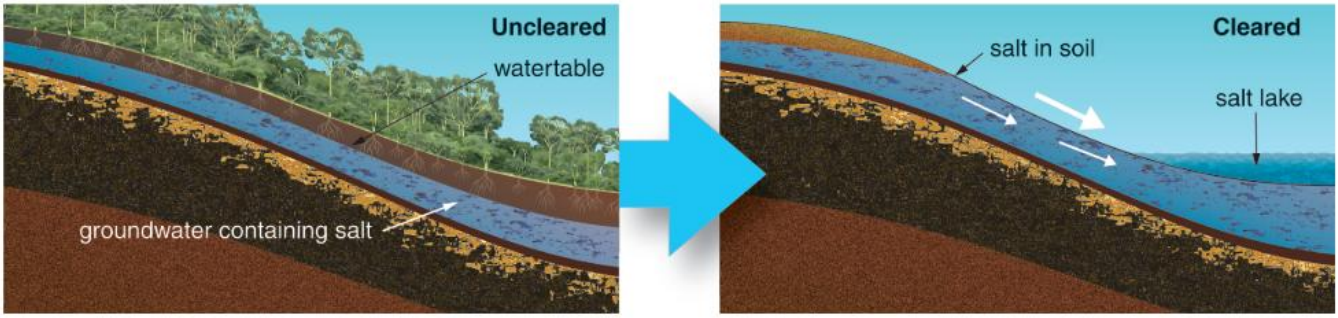
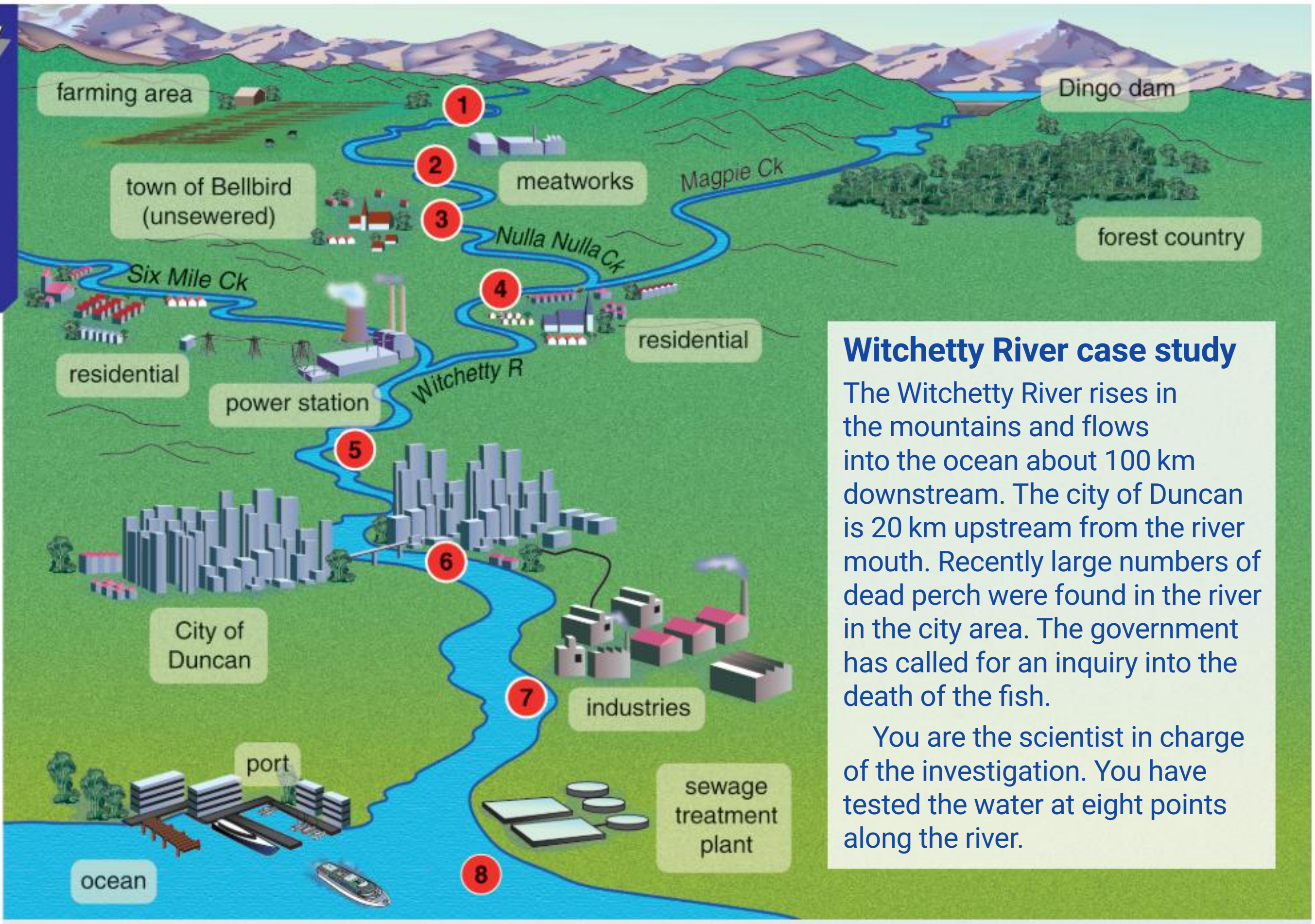


Figure 9.12 As the watertable rises, it brings salt to the surface.

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 in the table 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.

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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.

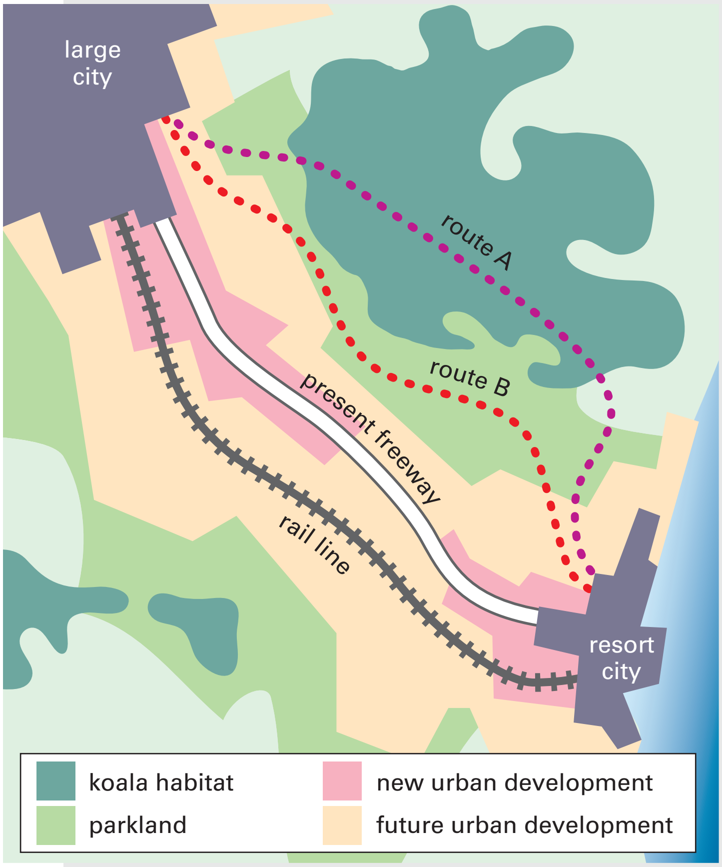

Figure 9.13 Map of the area showing the koala habitat and the proposed freeways

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.

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?

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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 243 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 the 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.

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9.3 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.

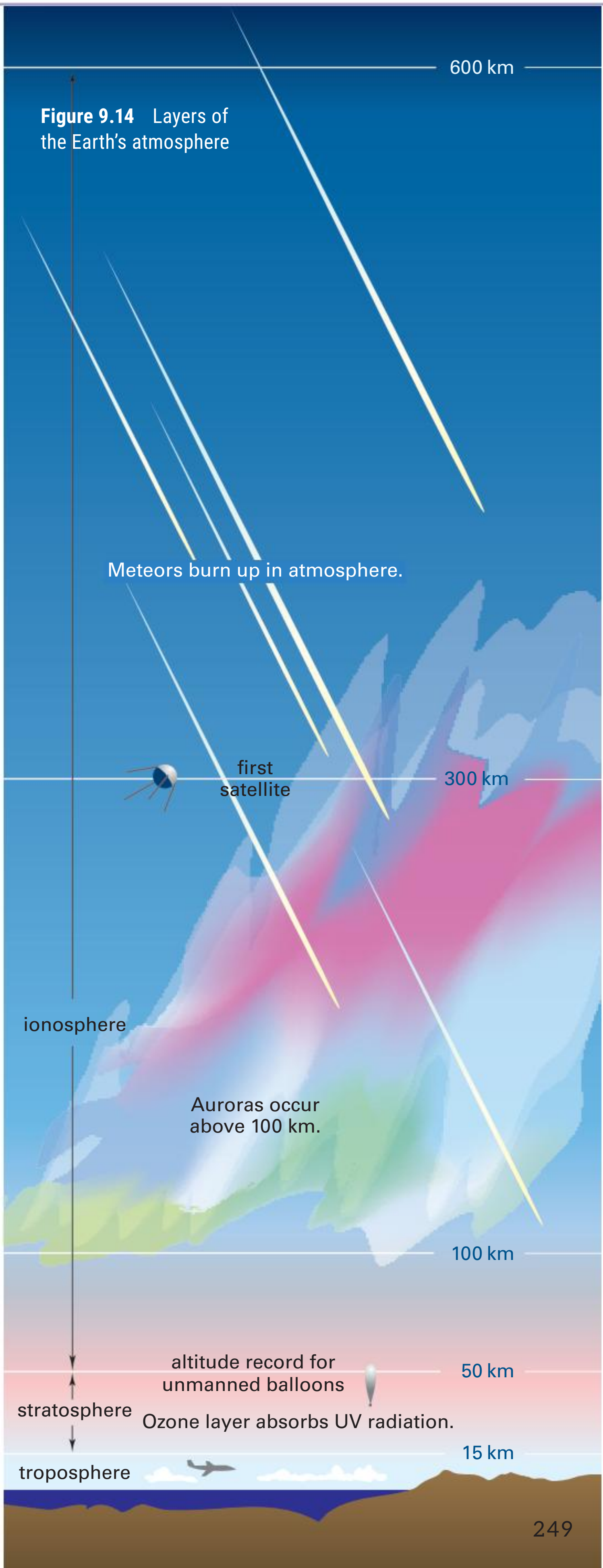

Figure 9.14 Layers of the Earth's atmosphere

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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—it 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**, and is a natural phenomenon.

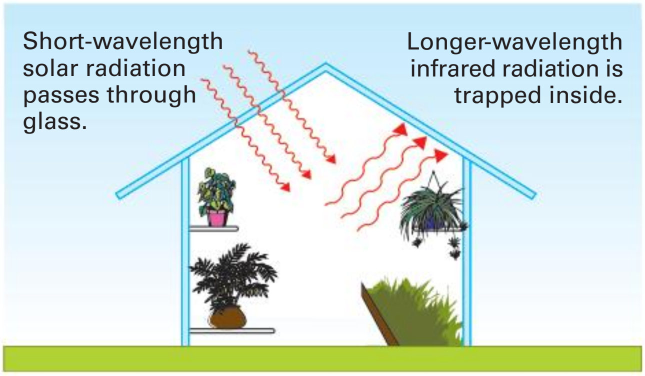
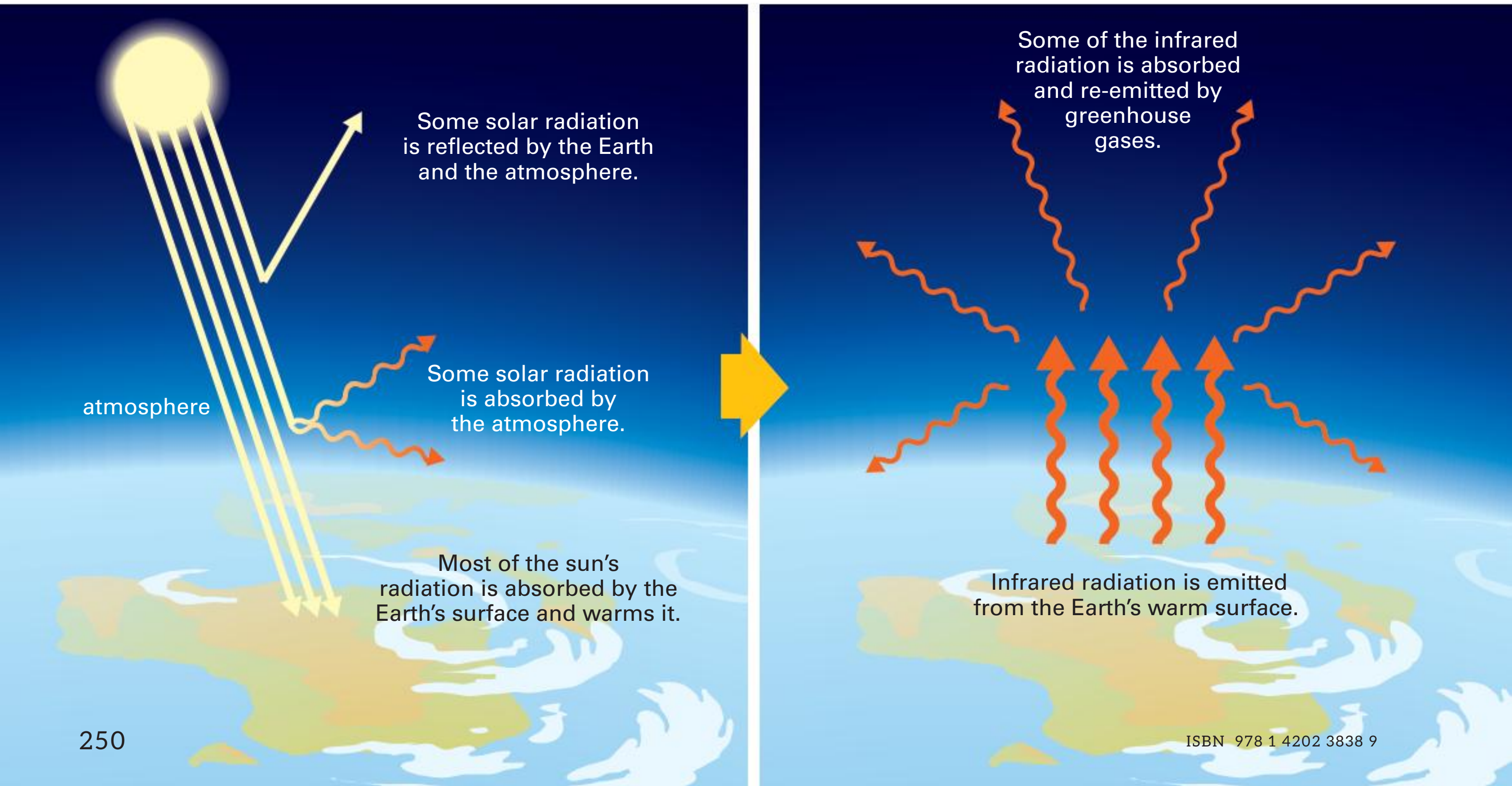


Figure 9.15 How a greenhouse works

Figure 9.16 Greenhouse gases in the atmosphere absorb infrared radiation and re-emit it back to Earth.



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INVESTIGATION 9.1 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

Risk assessment and planning

- Read through the Method carefully. You will need to leave your equipment in the sun for at least 20 minutes or, if it is overcast, you will need to set up lights.
- Prepare a data table for your results.

Method

1 Lay the two slides side by side and tape them together. Cut a hole in both boxes as shown.

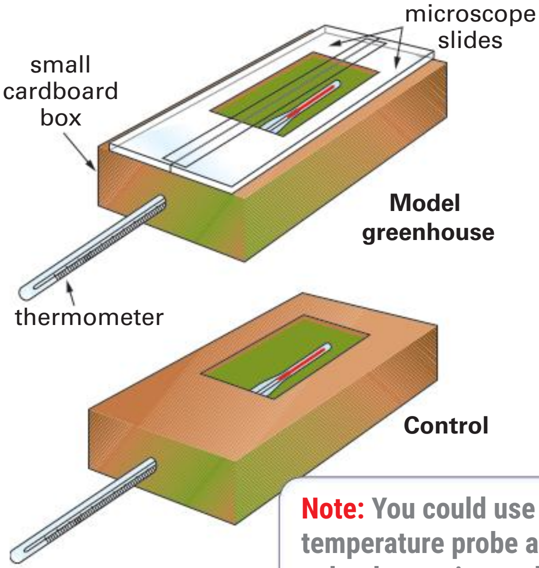
2 Lay the slides over the hole in one of the boxes. Punch a hole in one end of the box to insert a thermometer. This is your model greenhouse.

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.



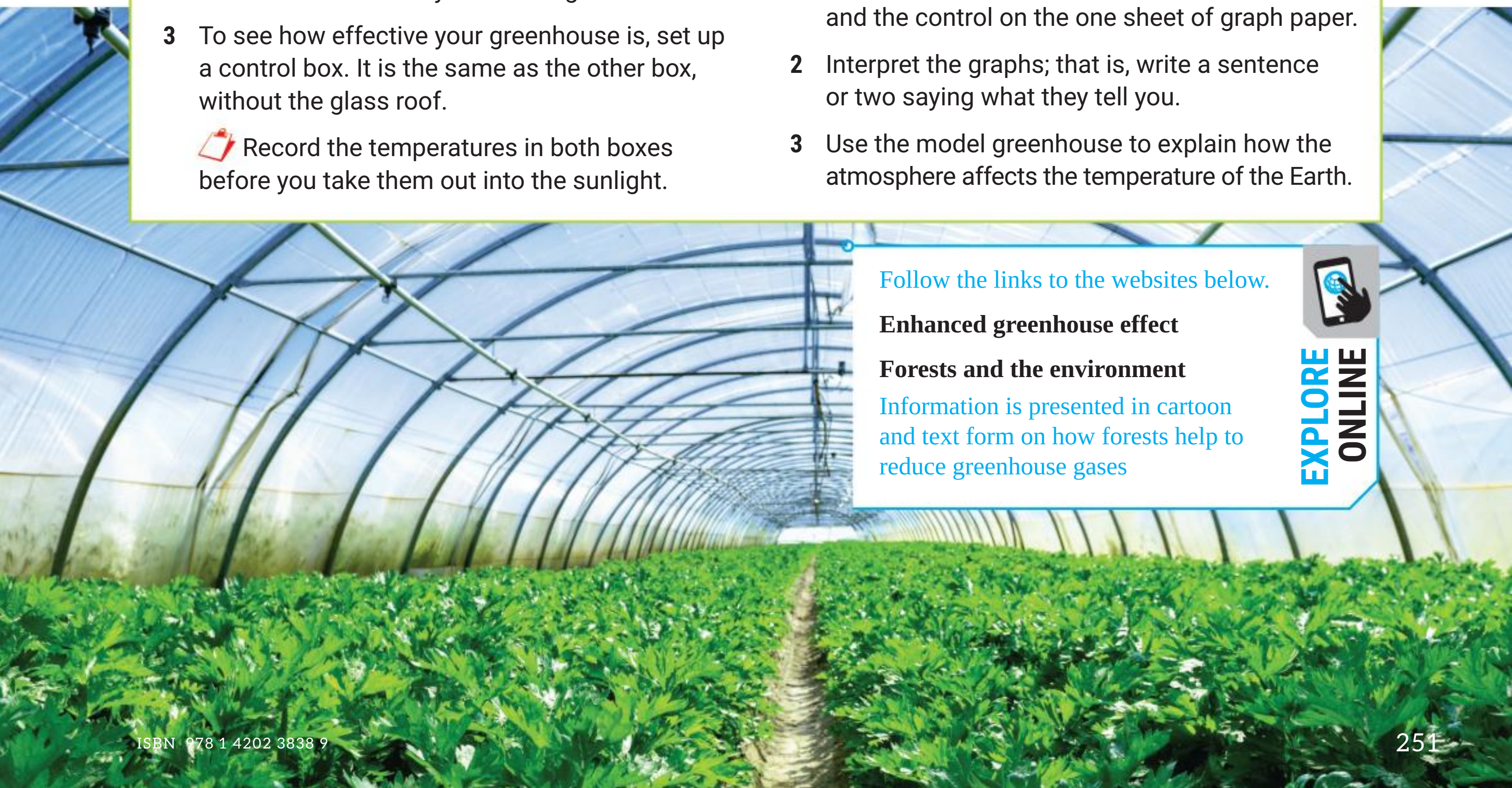
Note: You could use a temperature probe and a datalogger instead of thermometers.

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.



EXPLORE ONLINE

Follow the links to the websites below.

Enhanced greenhouse effect

Forests and the environment

Information is presented in cartoon and text form on how forests help to reduce greenhouse gases

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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** (e-kwil-LIB-ree-um) by the carbon cycle. (See the diagram on page 240.)

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 (coal and oil) 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 greenhouse gases in the atmosphere. Greenhouse gases 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 of gases called CFCs or chlorofluorocarbons. These CFCs were discovered in the 1920s and became widely used in refrigerators, air conditioners, 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

Greenhouse gas and sources	Atmospheric concentration before 1750 (ppm)	Atmospheric concentration in 2016 (ppm)	Yearly increase (ppm)	Atmospheric lifetime (years)	Global warming effect
carbon dioxide (CO_2) burning fossil fuels and forests	280	399	2	100–300	1
methane (CH_4) cows & sheep, swamps, rice paddy fields, natural gas leakage, rubbish dumps	0.7	1.81	0.004	28	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	0.33	0.0006	121	298

Source: Carbon Dioxide Information Analysis Centre (CDIAC), updated April 2016. Website: http://cdiac.esd.ornl.gov/pns/current_ghg.html

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levels and changes in temperature for the last 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 255.)

There has been an increase of 0.74 °C in global surface air temperatures over the last 100 years, with 2005, 2010, 2015 and 2016 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.

Various international treaties and agreements are now in place, and are revised regularly to set targets for decreasing emissions, and to try to control the enhanced greenhouse effect.

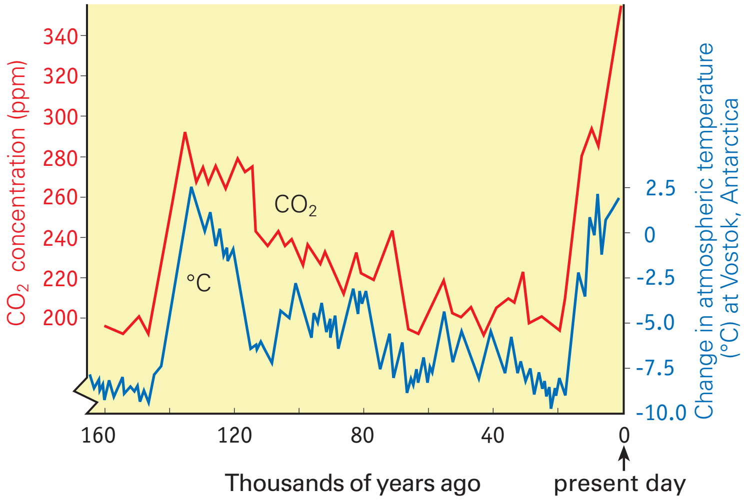


Figure 9.17 How the carbon dioxide content of the atmosphere and the global temperature have changed over the past 160 000 years (Intergovernmental Panel on Climate Change).

ACTIVITY

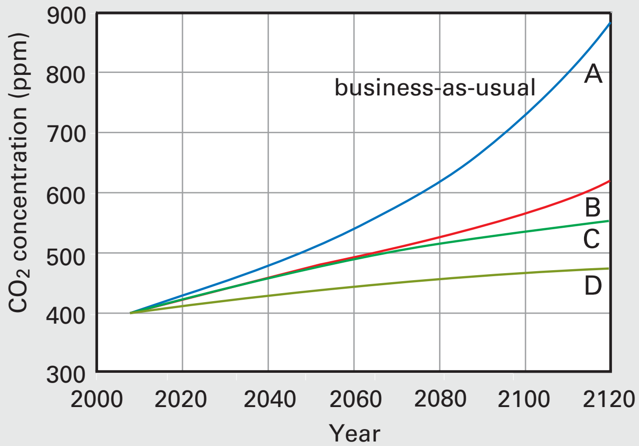
Predicting the future

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.

Global warming and biodiversity

Changes in the Earth's temperature can have an effect on biodiversity. That is, a change in temperature in an environment or ecosystem can change the distribution of an organism, and reduce or increase its chances of survival. This could, in turn, increase or decrease the biodiversity, depending upon the ecosystem and the organisms involved. An entire ecosystem could potentially be changed substantially or wiped out if a large change in temperature occurred.

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Think about the process of evolution you learnt about in Chapter 8. Global warming is a biotic factor (temperature increase) that puts selection pressure on a species. Global warming could therefore have the following effects on biodiversity:

- There may be a change in the distribution or area in which an organism can live, if it is temperature sensitive. This could increase or decrease the size of the habitat available for the organism to live in, and therefore either increase or decrease biodiversity.
- Natural selection and survival of the fittest will select for the most suitable characteristics to survive in a changing ecosystem. This means that some species will adapt to higher temperatures. If there are variations in the population more suited to surviving in a higher-temperature ecosystem, these will be selected for. This could increase or decrease biodiversity.
- In some cases, organisms will not adapt well to the temperature change and their survival will be threatened, possibly leading to extinction and reduced biodiversity.
- If one animal or plant becomes extinct, due to its inter-relationships and the complexity of food webs, many other organisms may also be affected. This could reduce biodiversity.
- Changes to the environment might cause further mutations, either increasing or decreasing biodiversity.

ACTIVITY

Answer the questions in each scenario about how global warming might affect an ecosystem and influence biodiversity.

Scenario 1: Alpine snow gums

Australian alpine environments are sensitive places. The snow gum (*Eucalyptus pauciflora*) grows at altitudes between 1300 and 1800 metres. Its habitat is quite small given that Australia has limited alpine areas.

1. Explain what you think would happen to the snow gum's available habitat if the temperature of the Earth rose due to global warming.
2. What effect would this have on the size of the population of snow gums?
3. How would this change affect the biodiversity of the snow gum?
4. Global warming causes more forest fires, and in many cases more extreme ones. How would this affect the survival of snow gums and their habitat?

Scenario 2: The Great Barrier Reef

The Great Barrier Reef is a world-famous, yet sensitive ecosystem. Coral reefs require a specific set of conditions to survive. This includes temperatures of 20–32 °C, and clear water to ensure enough sunlight reaches them. As you go deeper into the water, sunlight decreases. Global warming is increasing the temperature of the oceans, and melting the polar ice caps.

1. What effect could increasing ocean temperatures have on the Great Barrier Reef? Explain your answer.
2. What effect could melting polar ice caps have on the Great Barrier Reef? This is a complex situation and you will need to research it fully.
3. How would these changes affect the biodiversity of the reef, currently one of the richest and most biodiverse ecosystems on Earth? Research a food web for such an ecosystem, and use it explain how the effects of a change would be felt through the entire system.

Scenario 3: Inquiry

Research an example of how global warming could lead to an *increase* in biodiversity. Explain the organisms involved and the scenario that leads to the increase in biodiversity.

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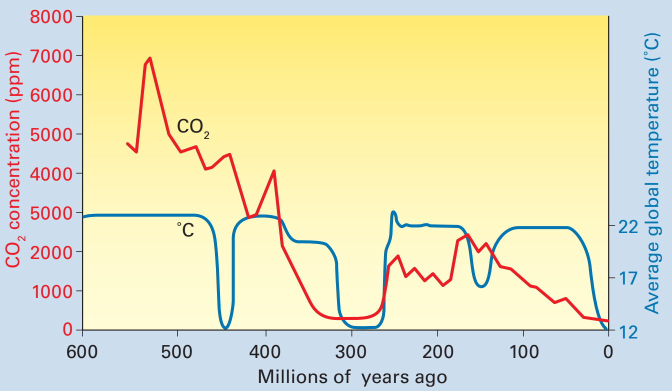
SCIENCE AS A HUMAN ENDEAVOUR

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 Figure 9.17 at the top of page 253. Some scientists say we should instead look at the graph below.



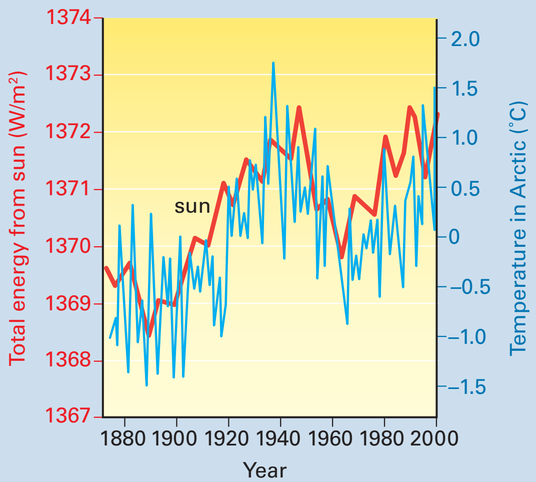
1 According to this graph, what has happened to the concentration of CO_2 over the last 600 million years? How is this different from what Figure 9.17 tells you?
2 What has happened to the average global temperature over the past 600 million years? When did the Earth experience ice ages? Is today's temperature above or below the Earth's average temperature?

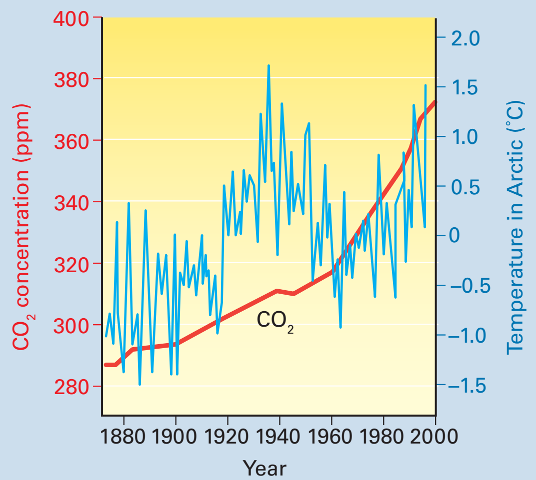
Figure 9.17 clearly shows a **correlation** between CO_2 concentration and global temperature. If one variable increases or decreases, so does the other. However, this does not necessarily mean that global warming is caused by an increase in CO_2.

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 might not exist. What do you think?





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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.

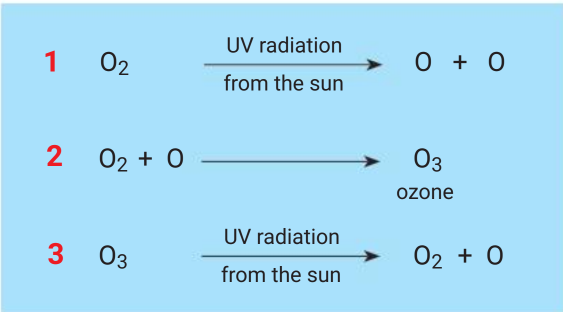

Figure 9.18 Ozone is formed when oxygen molecules in the stratosphere absorb UV radiation from the sun.

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 been 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.

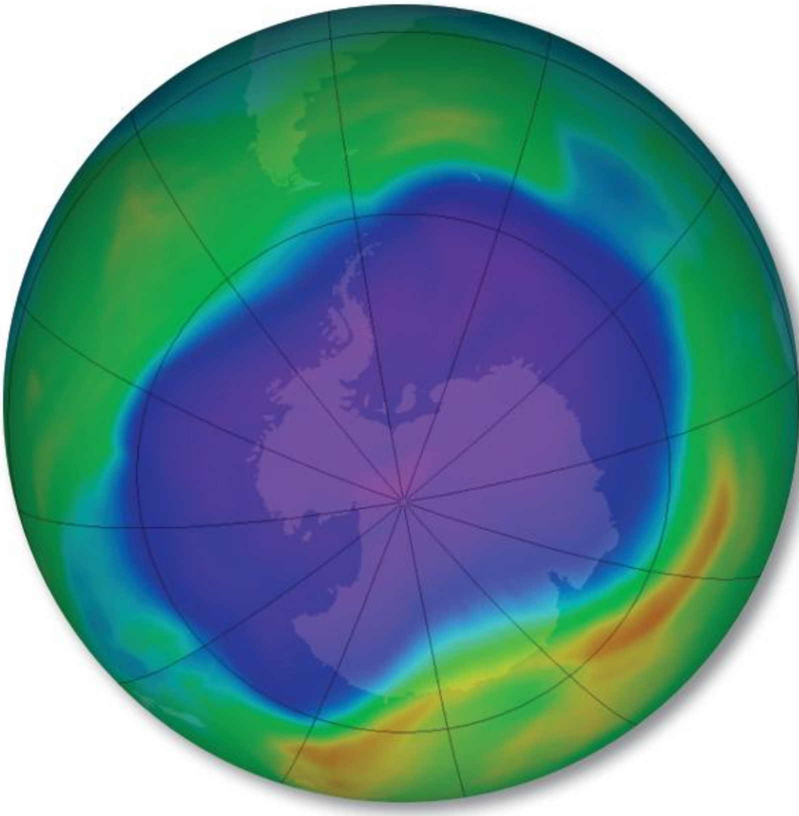

Figure 9.19 The largest hole in the ozone layer occurred in September 2006. The blue area is where the ozone has thinned most.

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.

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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.

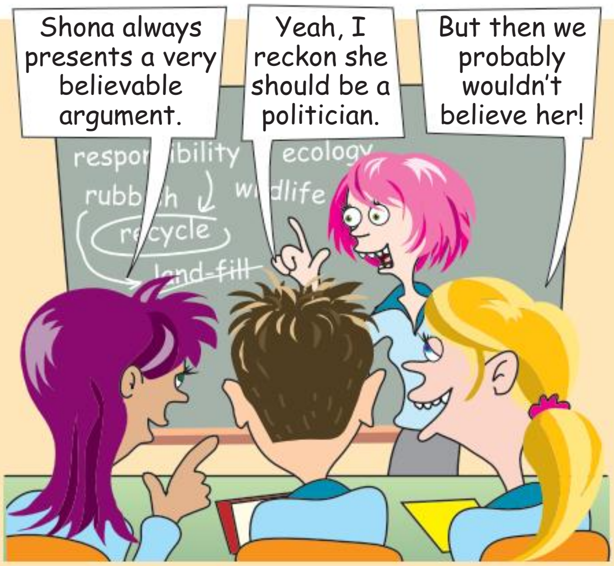
1. Search the internet using the words *household recycling*, or just *recycling*. You can also use library books, magazines and brochures.
2. Scan the information and decide how useful it is.
3. If the information is relevant to the topic, read it carefully and make notes. Do this by summarising in 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 responsibility 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.

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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.
5. Biodiversity is affected by global warming.

Follow the links to the websites below.

Tropical deforestation

Using energy wisely

Global warming—frequently asked questions

Fossil fuels

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 252 to answer these questions about greenhouse gases.
   - a What are the sources of methane?
   - b Which gas increased in concentration the most rapidly in 2016?
   - 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 2016 was 399 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 Get started activity on page 235 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?

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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 Figure 9.18 on page 256 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 (399 ppm CO_2)
- double CO_2 levels (798 ppm CO_2).

Leaf area was measured every 5 days and recorded.

a Plot the data on graph paper.

b Write a conclusion for the experiment.

Days	Leaf area (cm^2)	
	399 ppm CO_2	798 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

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 by 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 $$CCl_3F \xrightarrow[\text{from the sun}]{\text{UV radiation}} CCl_2F + \underset{\text{chlorine atom}}{Cl}$$

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.

Figure 9.20 Nickel refinery at Kwinana, south of Perth

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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.

8 The ultimate source of Earth's energy is the ______.

9 The Earth's energy is in ______. The energy from the sun that enters the Earth's system, is very nearly equal to the energy that ______ into space.

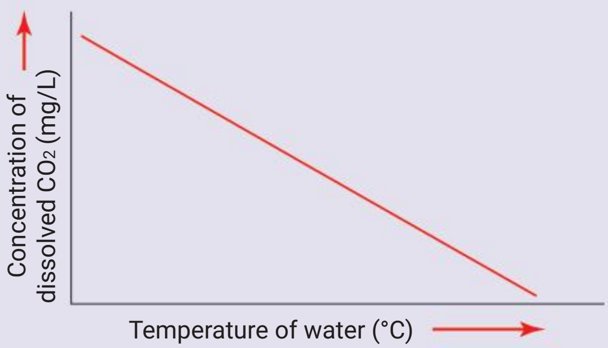
atmosphere
UV radiation
biomagnification
oxygen
balance
CFCs
fixing
sun
global warming
lithosphere
greenhouse effect
carbon cycle
insecticides
escapes
living
hydrosphere
ozone layer
eutrophication

CH•9 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.



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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.

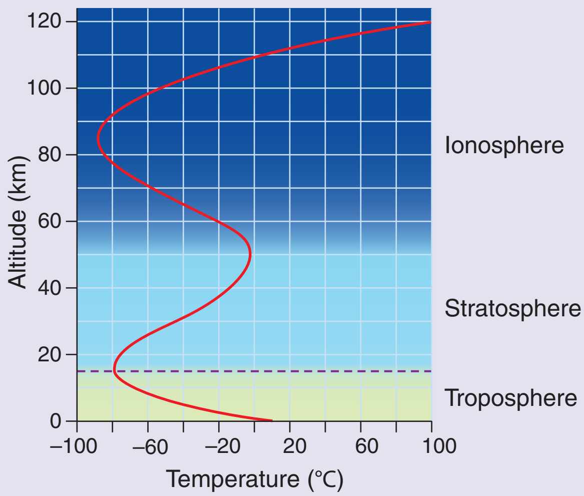
4 Below is a list of organisms in a food chain. Copy and complete the table by writing the name of each organism next to the concentration of DDT you predict it would have in its body.

- 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?

8 **a** Explain how global warming affects sea levels.
b What may be the effect of global warming on biodiversity? Give an example.

Check your answers on page 350.

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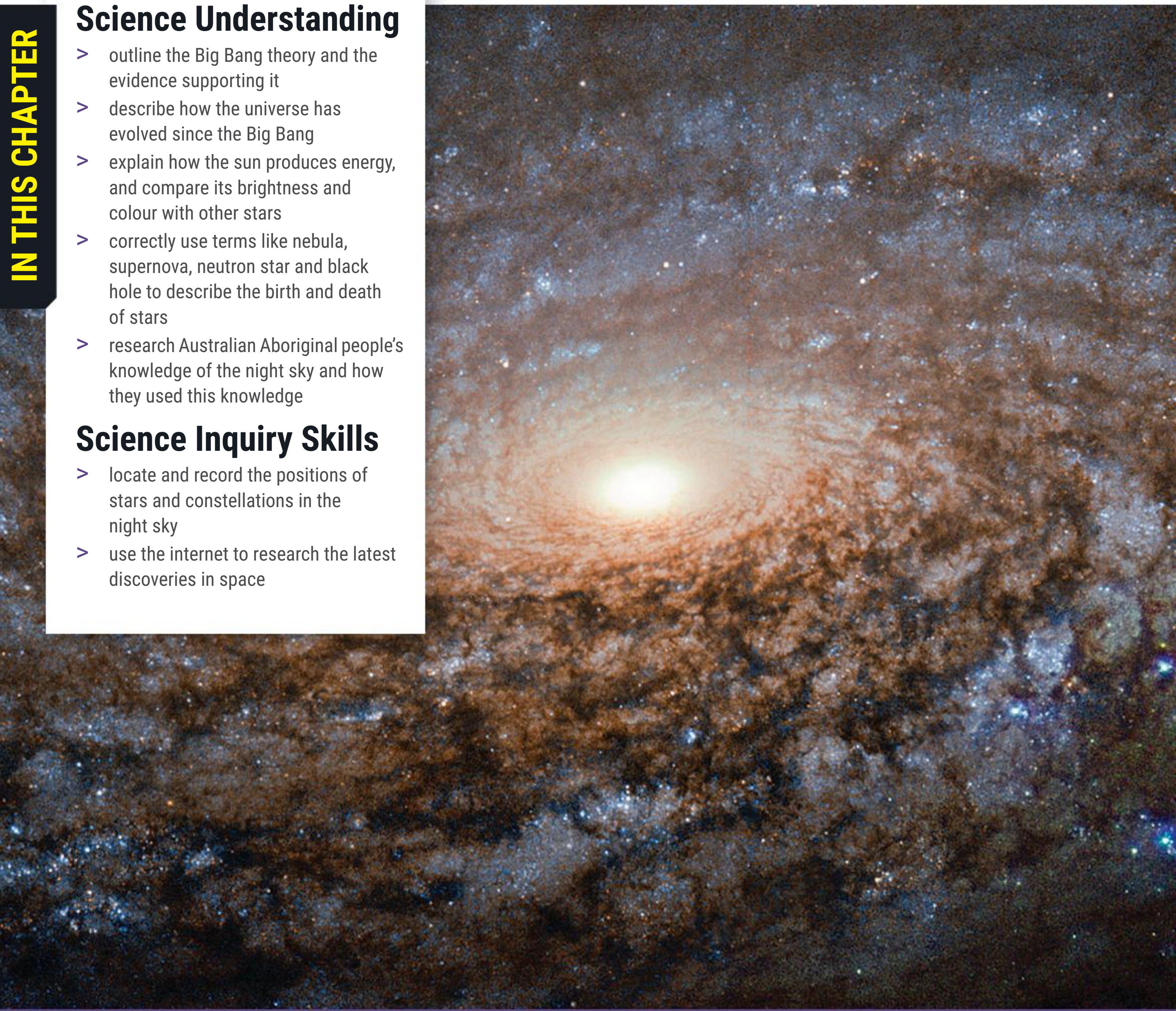
IN THIS CHAPTER

Science Understanding

- outline the Big Bang theory and the evidence supporting it
- describe how the universe has evolved since the Big Bang
- 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
- 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



CH•10 Origin of the universe

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GET STARTED: *IMAGINE*

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. Do you think they would be human-like in appearance?
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?
6. Where did the universe come from?

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10.1 The night sky

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 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, but, as the Earth revolves around the sun, you see some constellations on summer nights and others in winter.

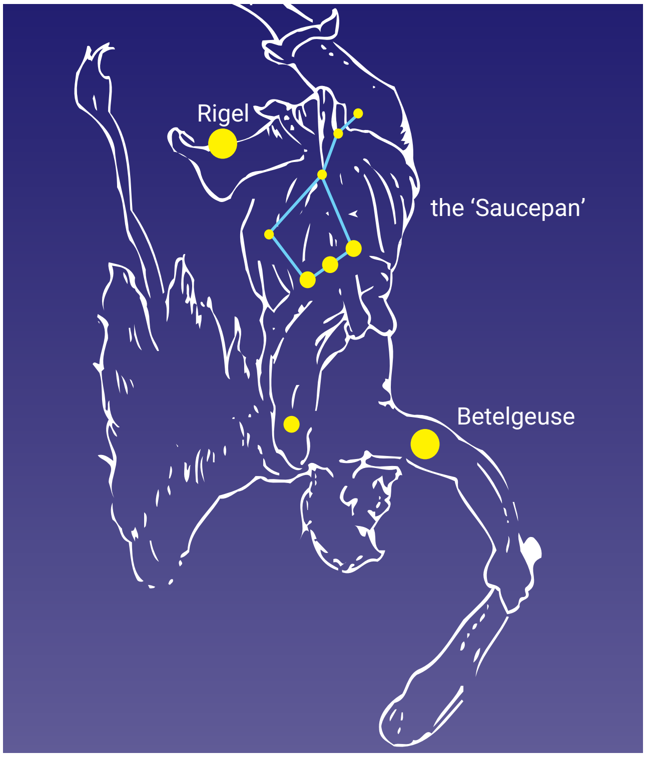

Figure 10.1 Ancient Greek astronomers named this constellation Orion after the mythological person who was a mighty hunter of great strength and beauty. The three bright stars that form Orion's belt are in a group of stars that we sometimes call the Saucepan.

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 a present-day spacecraft.) The next closest star is 41 000 000 000 000 km away, or 270 000 times the distance to 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 Figure 10.2.

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 1930s!

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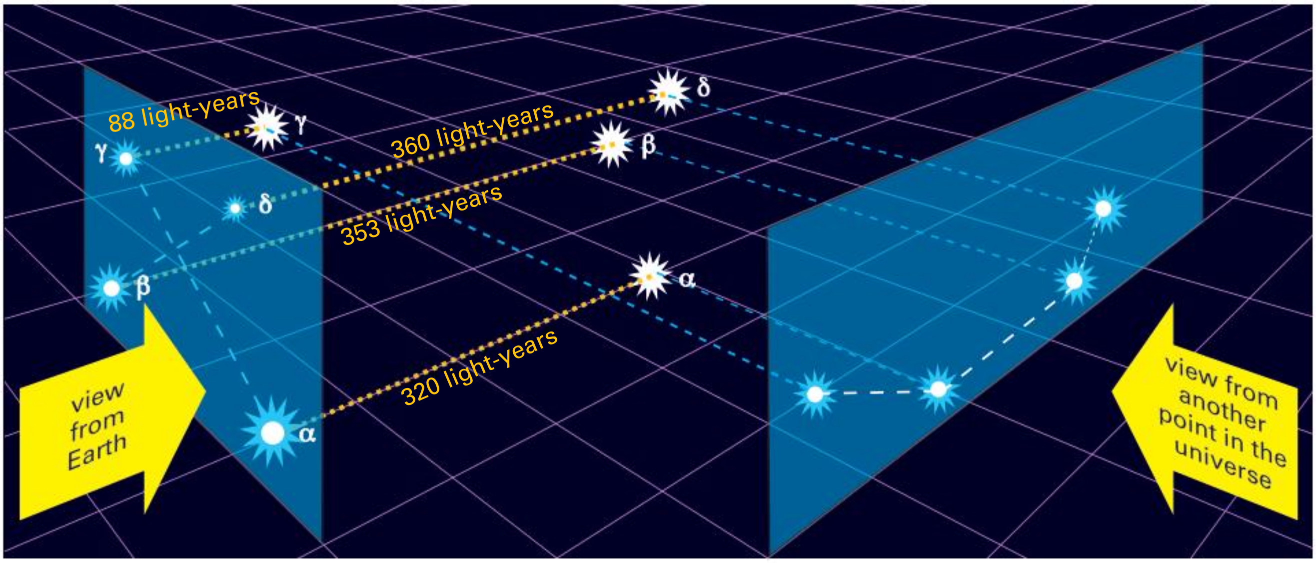

Figure 10.2 The four main stars in the Southern Cross appear to be in the same plane when viewed from Earth. However, you would not see the cross pattern if you looked at these stars from somewhere else in the universe.

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, 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).

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.

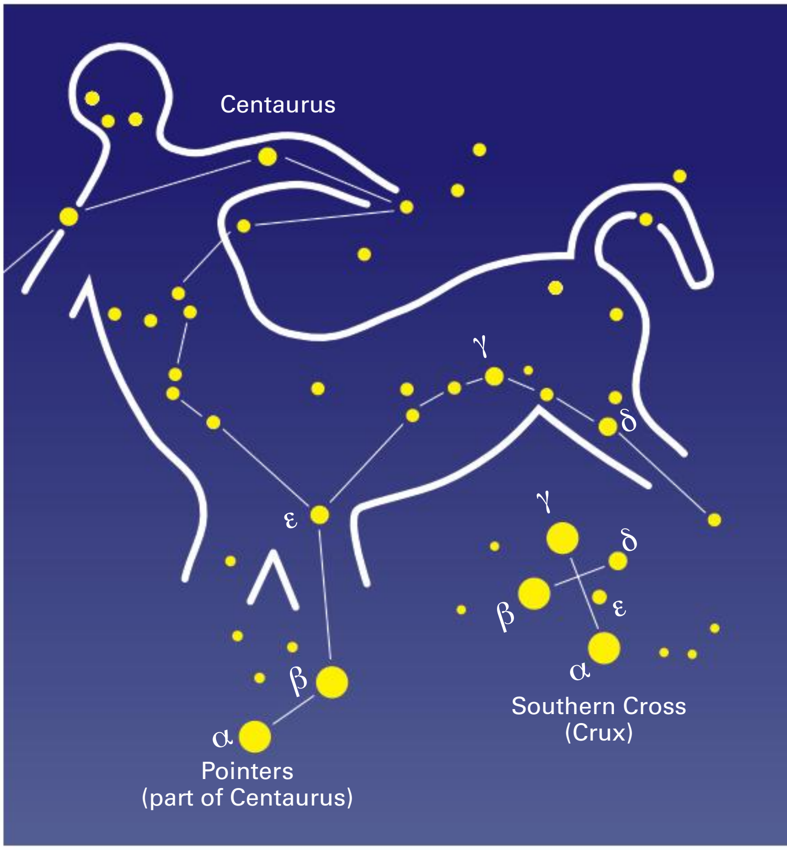

Figure 10.3 Stars in the constellations Crux and Centaurus

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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. Or you can use an app.

Using a star chart

If you are using a star chart, check the instructions and ensure you are pointing it the right way, and with the correct month set.

Using an app

Many apps are available to investigate the night sky and make it easier to identify stars and planets. Use an app such as ‘Star chart’ or ‘Sky map’.

1. Look at the Crux. Identify the α, β, γ, δ and ε stars in this constellation.
2. 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.
4. Can you identify any planets?

Figure 10.4 This star chart of the Southern Hemisphere may look complicated, but the apps now available make it easy to find the stars you are looking for.

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*.

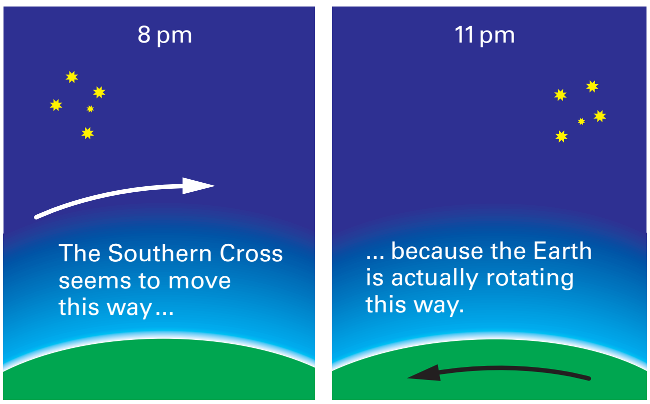

Figure 10.5 Earth’s rotation makes the stars appear to rotate around the Earth.

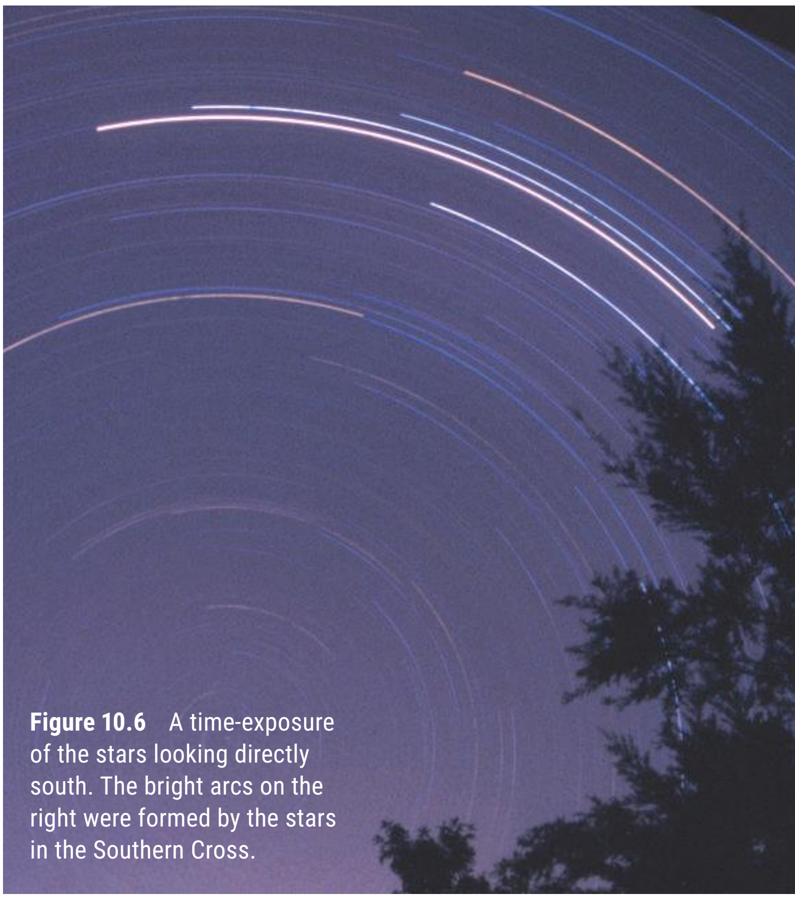

Figure 10.6 A time-exposure of the stars looking directly south. The bright arcs on the right were formed by the stars in the Southern Cross.

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INVESTIGATION 10.1 Locating stars

Aim

To locate and record the positions of various stars in the sky.

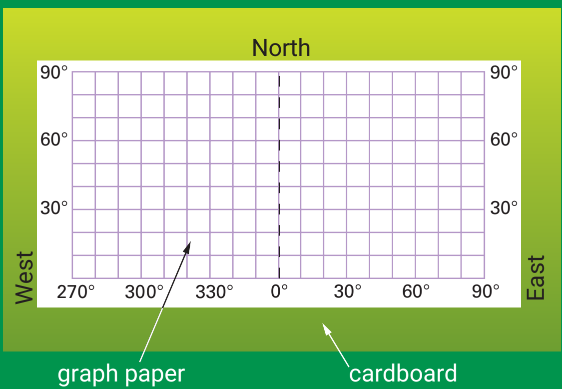
Materials

- sheet of graph paper
- piece of firm cardboard larger than the sheet of graph paper
- compass
- torch

Risk assessment and planning

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**.

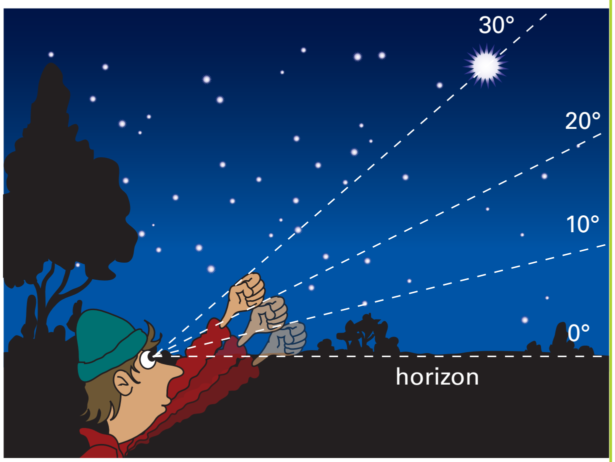
The vertical dotted line in the middle of the grid (0°) is the north–south line.

If you have time you can prepare a sky grid for locating the stars in the southern sky.

PART A

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, i.e. 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°.

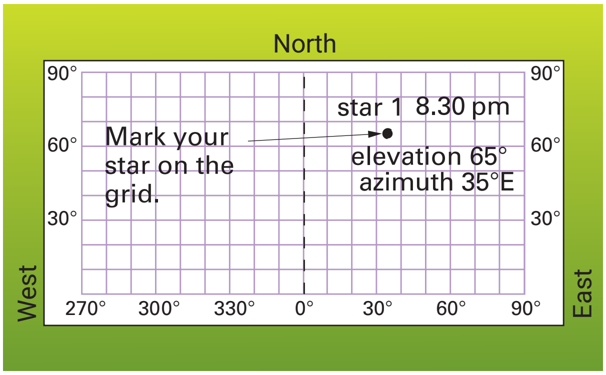


4. Measure how many 'fists' there are from the horizon (0°) to the star. Convert this to degrees. This is the star's elevation.

   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.

PART B 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 than 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.

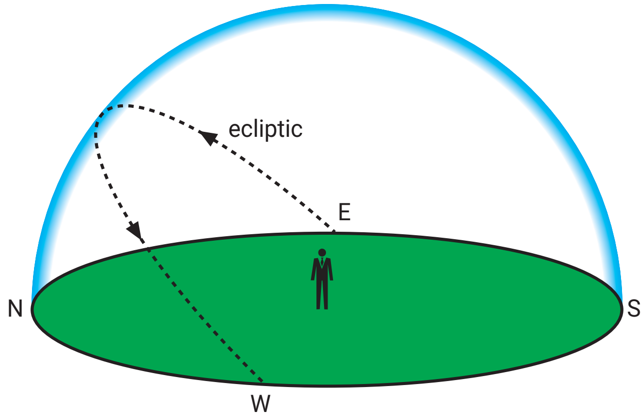


Figure 10.7 The ecliptic is the path followed by the sun, moon, planets and the twelve constellations in the zodiac.

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 astronomical objects other than the constellations do astrologers believe influence these characteristics?

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SCIENCE AS A HUMAN ENDEAVOUR

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.

Figure 10.8 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? A 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 a global firestorm. 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 the loss of many species of plants and algae.
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.

EXPLORE ONLINE

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

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SCIENCE AS A HUMAN ENDEAVOUR

Aboriginal astronomy

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?

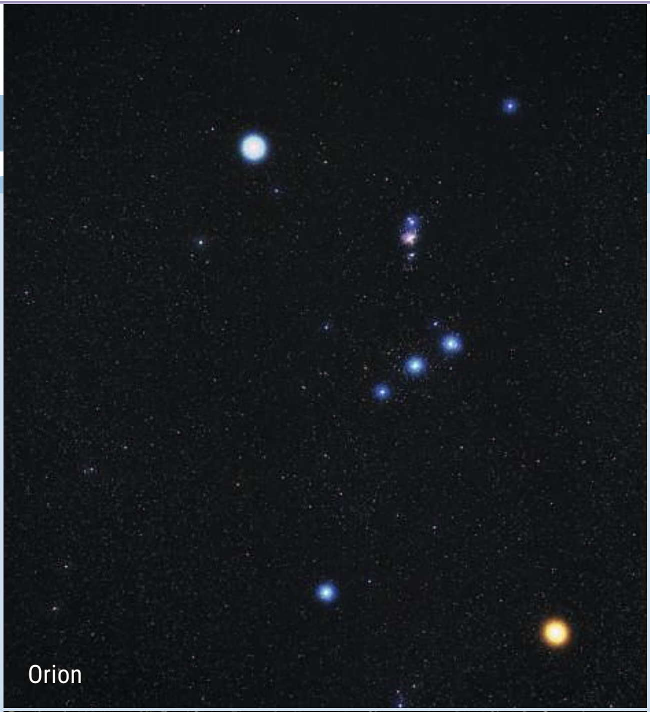
4 a Look at the photo of the Orion constellation. What is its common name in Australia?
 b What story did the ancient Greeks tell about Orion?
 c What stories did Australian Aboriginal people tell about it?

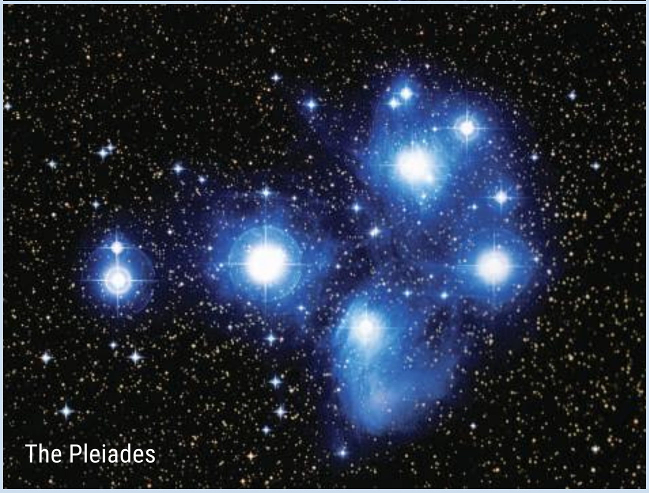
5 a What stories do Aboriginal people tell about the following star patterns?
 - the Southern Cross
 - the Pleiades (the Seven Sisters)
 - the Scorpion

 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.

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CHECK

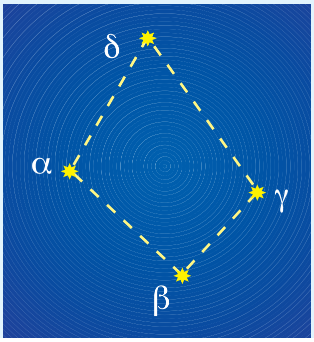
1 What is a light-year? Why do astronomers use this unit to measure distances?

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 Perth to Port Hedland?
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 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 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 and 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 and it is 900 light-years away. Yolanda then wondered whether Rigel still exists. What answer could Lim give Yolanda?

4 Figure 10.6 on page 266 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 Figure 10.2 on page 265.
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.


Pluto

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10.2 Stars and galaxies

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, and one of the largest stars, Canopus, is 80 000 times the size of our sun.

The enormous size of a star creates a huge gravitational force that squeezes the atoms of the gases together and creates immense pressure and heat. At this temperature electrons are stripped away from the atoms, leaving positively charged nuclei that are in constant rapid motion. The hot gases are in the state of matter called *plasma*, that 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 274.

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 Figure 10.10 on the next page.)

The **photosphere** is the visible part of the sun, the bright disc 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 waves 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.

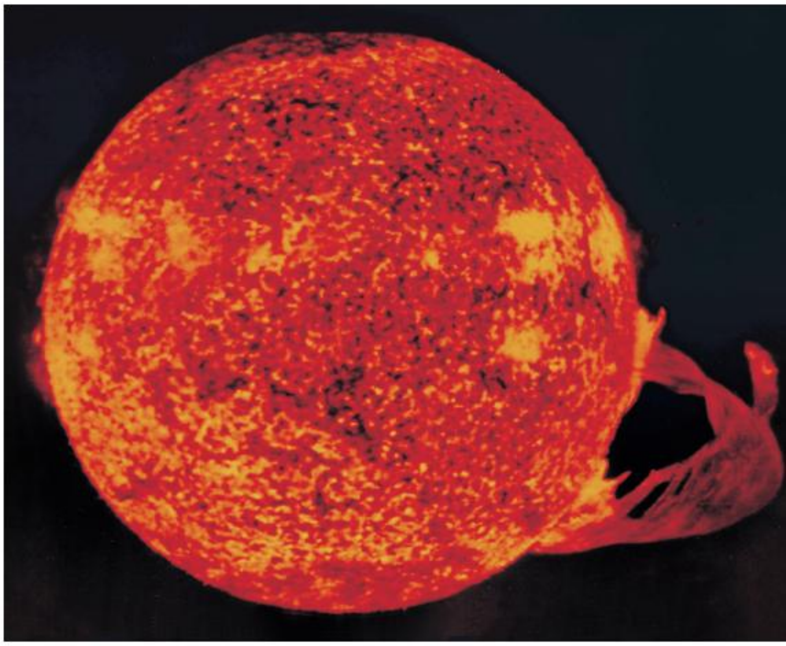

Figure 10.9 This photo of the sun was taken with special filters and shows the granules on the surface.

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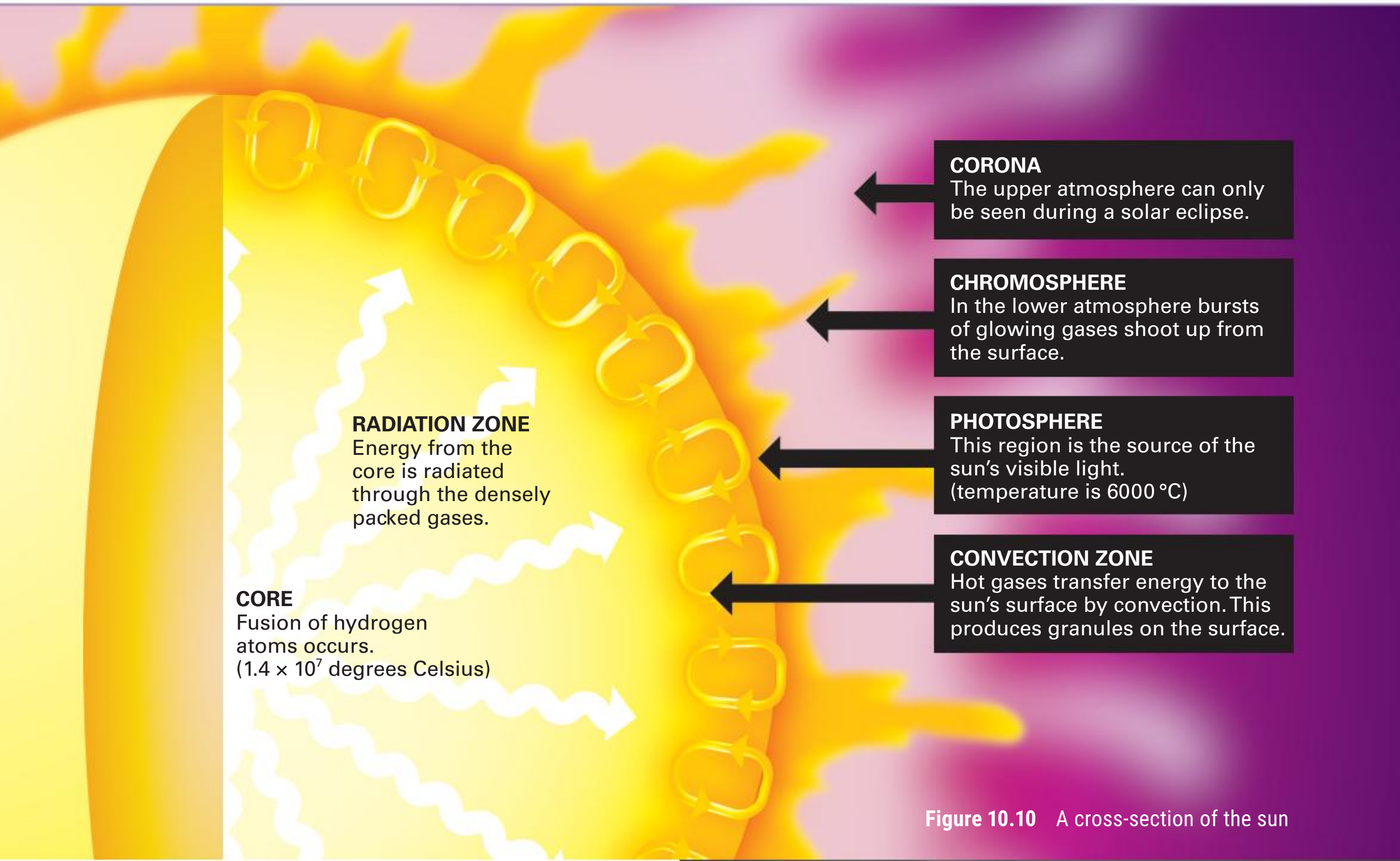

Figure 10.10 A cross-section of the sun

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 Figure 10.9 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 a solar eclipse 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.

Figure 10.11 The brightly glowing gases in the corona of the sun can be seen only during a total solar eclipse.

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SCIENCE AS A HUMAN ENDEAVOUR

$E = mc^2$

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.

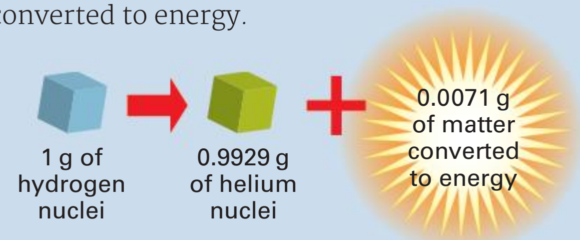
Special theory of relativity

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?

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Light from stars

Some stars 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 that would be given off by a star if it was a set distance from Earth.

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 that 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, and the coolest stars give off red light. Very hot stars such as 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. 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.

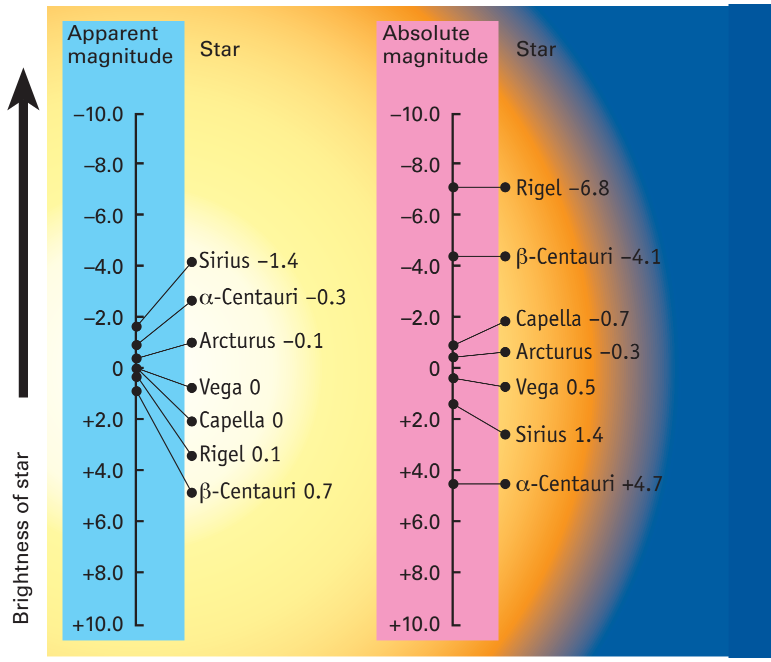
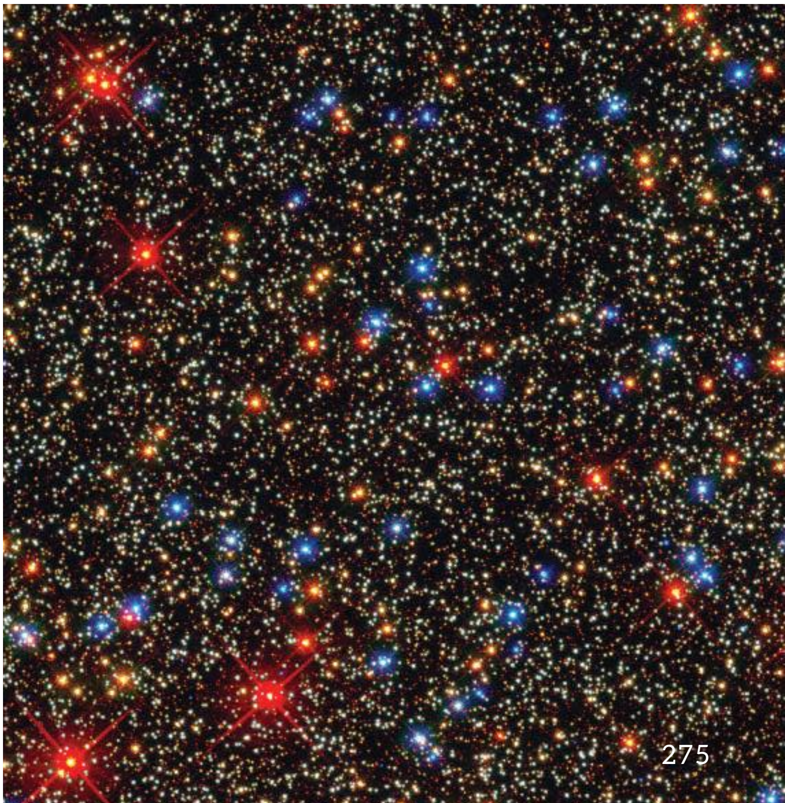


Figure 10.12 The apparent magnitude and absolute magnitude of some stars

Figure 10.13 This image from the Hubble telescope shows over 100 000 stars inside Omega Centauri. As well as showing the difference in brightness, the colours represent the different stages of the star life cycles (see Section 10.3).



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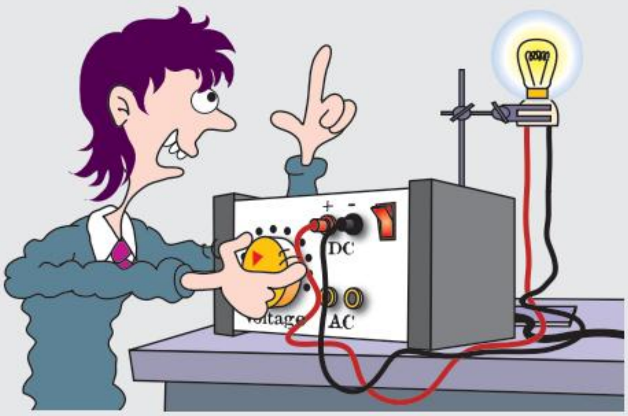
ACTIVITY

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:

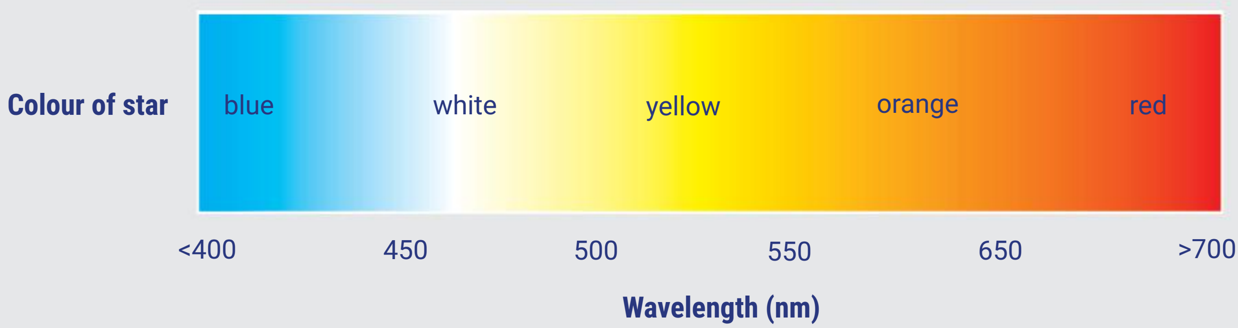
$$\text{temperature} = \frac{3 \times 10^6}{\text{wavelength}}$$

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 colour chart below to prepare a data table listing each of the five stars, its temperature and its colour.



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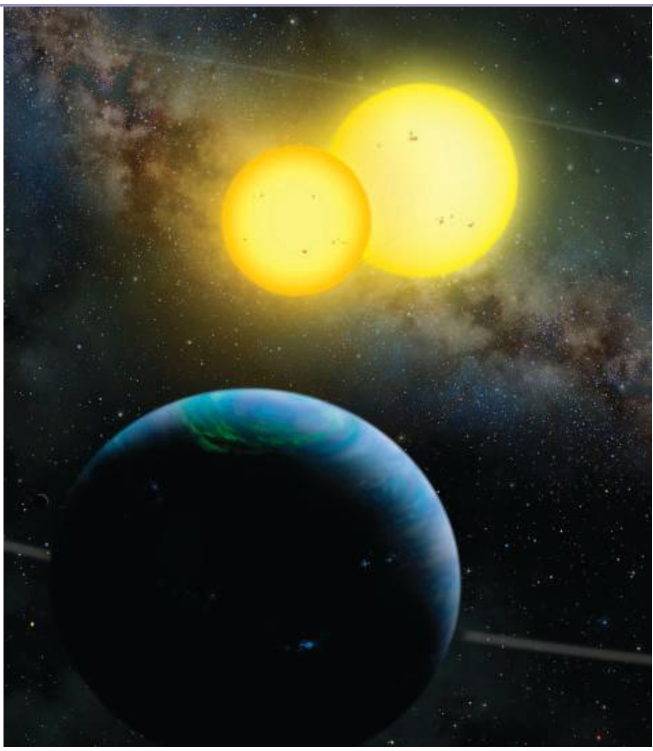

Figure 10.14 Representation of binary stars. This artist's rendition shows a recently discovered 'Saturn sized' planet named Keplar-35b orbiting a pair of binary stars in the Keplar-35 system. The planet orbits the stars once every 131 days.

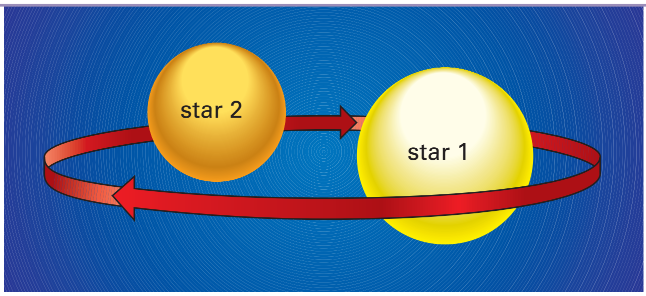

Figure 10.15 Star 1 is the brighter star in this binary. In the position shown, the binary appears bright from Earth.

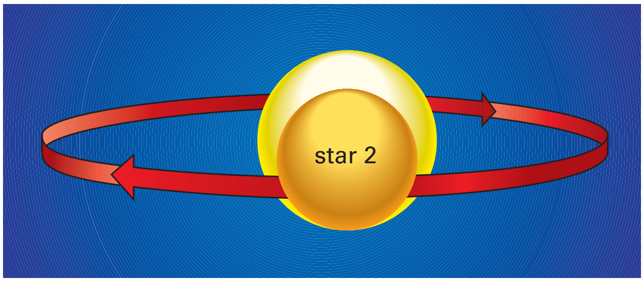

Figure 10.16 When star 2 passes in front of star 1, the brightness of the binary as seen from Earth decreases.

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).

Galaxies

Earth is in the Milky Way galaxy. The Milky Way appears as a band in our night sky because it is a disc, and we are looking at it from inside this disc. A **galaxy** is a massive collection of stars, interstellar gas, dust and other matter held together by gravity. The Milky Way contains between 200 and 400 billion stars and at least 100 billion planets! Do you think life can exist beyond our solar system? It is now estimated that the universe contains up to 200 billion galaxies.

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Figure 10.17 The Milky Way galaxy seen from Southern Chile

Types of galaxies

Galaxies can be classified in many ways, but one main way is by shape.

Spiral galaxies: These galaxies have a central core with arms spiralling outwards as they spin. Young stars form in the outer arms and older stars are found in the centre.

Barred spiral galaxies: These are like spiral galaxies but they have a 'bar' in the centre rather than a round core.

Elliptical galaxies: These are largely composed of mature stars and have less dust and gas than other types of galaxies. They are egg-shaped, although they may vary in shape and size.

Irregular galaxies: These galaxies are usually smaller and do not have enough gravity to pull everything into a regular shape.

Where is our solar system?

The Milky Way galaxy has spiral arms of giant stars that light up the interstellar gas and dust in between. The sun is in a finger called the Orion Spur. In Figure 10.19 the galaxy is overlaid with galactic longitude in relation to our sun.

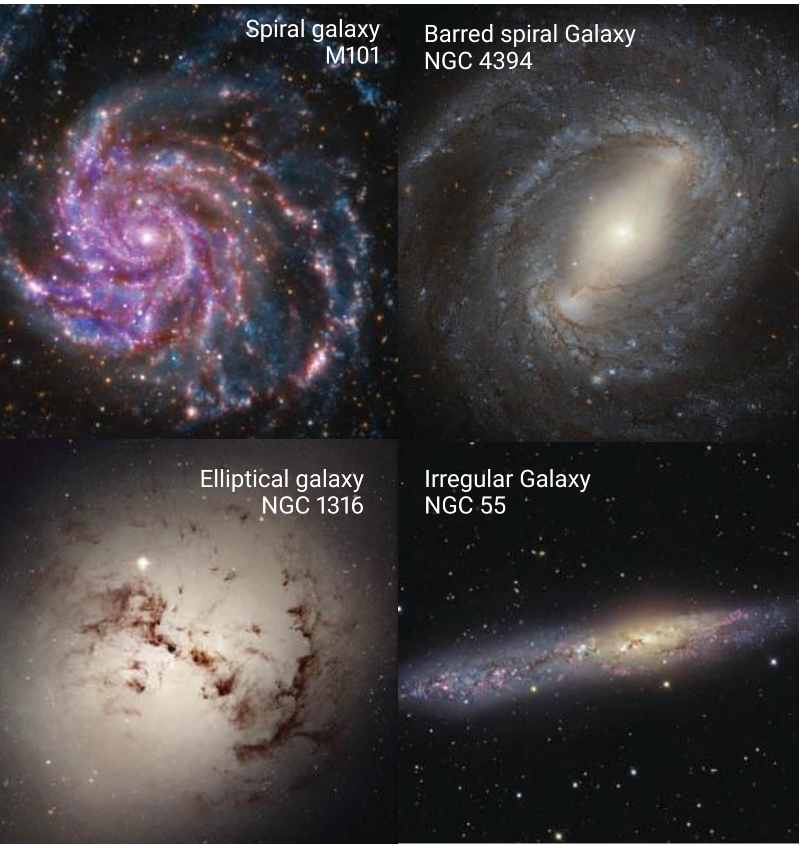

Figure 10.18 Types of galaxies

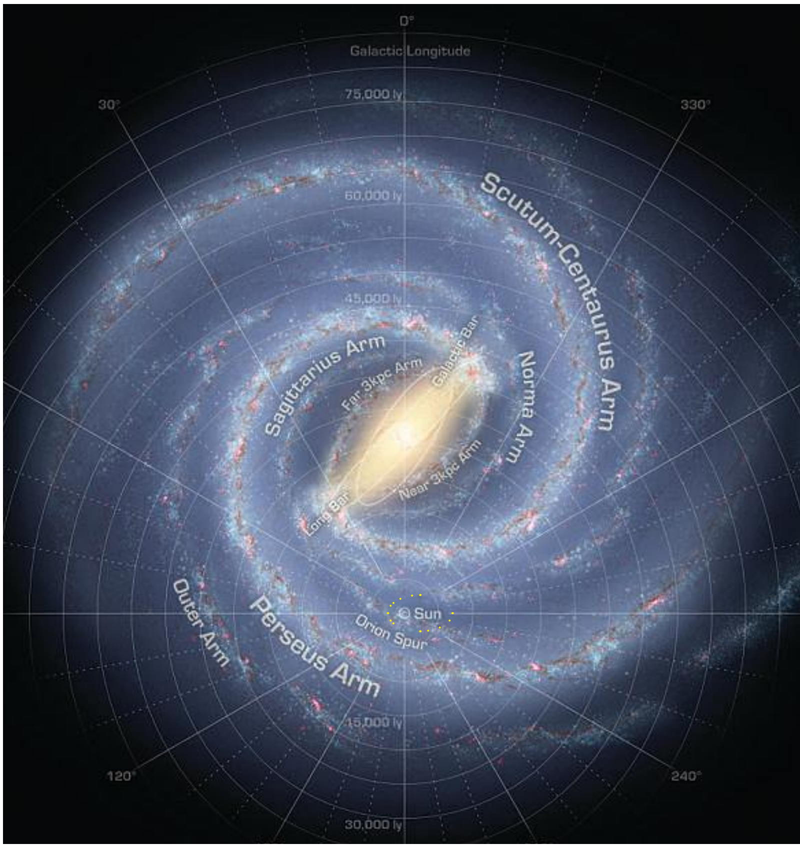

Figure 10.19 The location of the sun in our solar system

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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 in brightness.

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?

8 a What is a galaxy?
   b Draw a diagram of the four main galaxy shapes and label each one.
   c What type of galaxy is the Milky Way?

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 Figure 10.12 on page 275 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 in the core is different from that of 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 276 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.

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10.3 Life cycles of stars

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 Figure 10.20.

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 dying.

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

Figure 10.20 The Great Nebula of Orion is a huge expanding cloud of gas that resulted from a supernova.

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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.

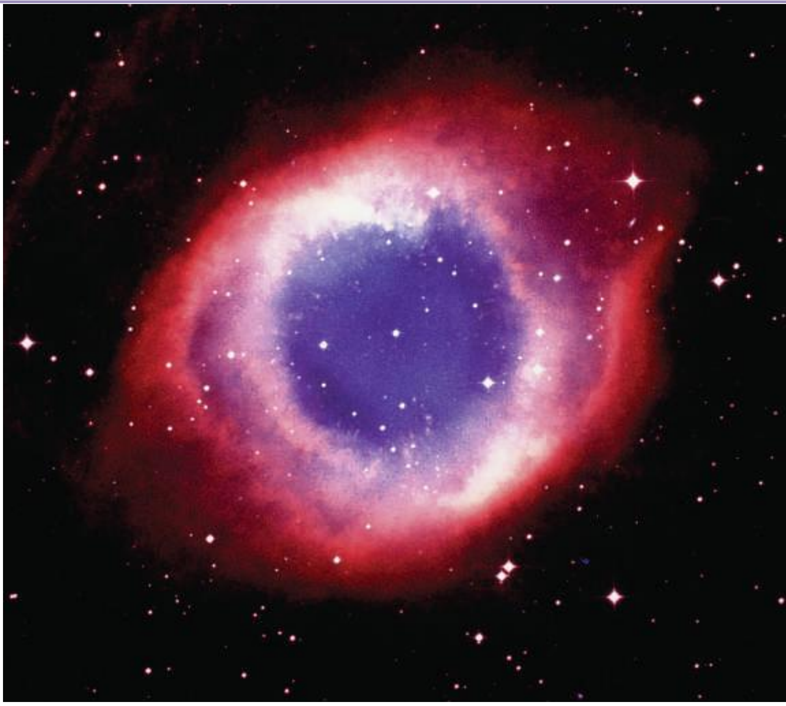

Figure 10.21 The Ring Nebula in Aquarius is expanding into space at 25 km/s. It has a central star that is probably forming into a white dwarf.

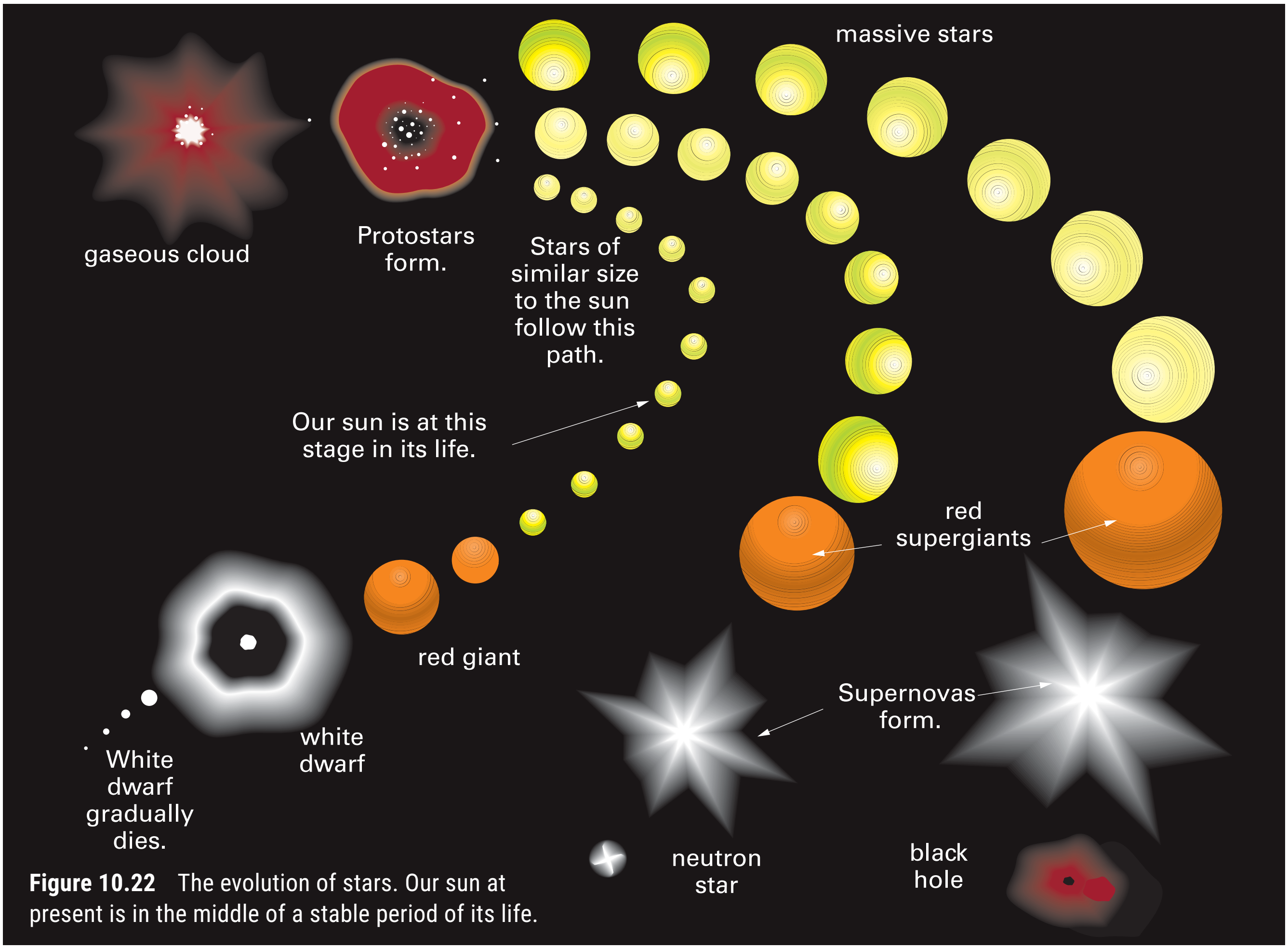

Figure 10.22 The evolution of stars. Our sun at present is in the middle of a stable period of its life.

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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 287) 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 smaller stars, these massive stars keep on collapsing. Nothing can halt this collapse, and the gravitational force that is created is so strong that not even light can 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.

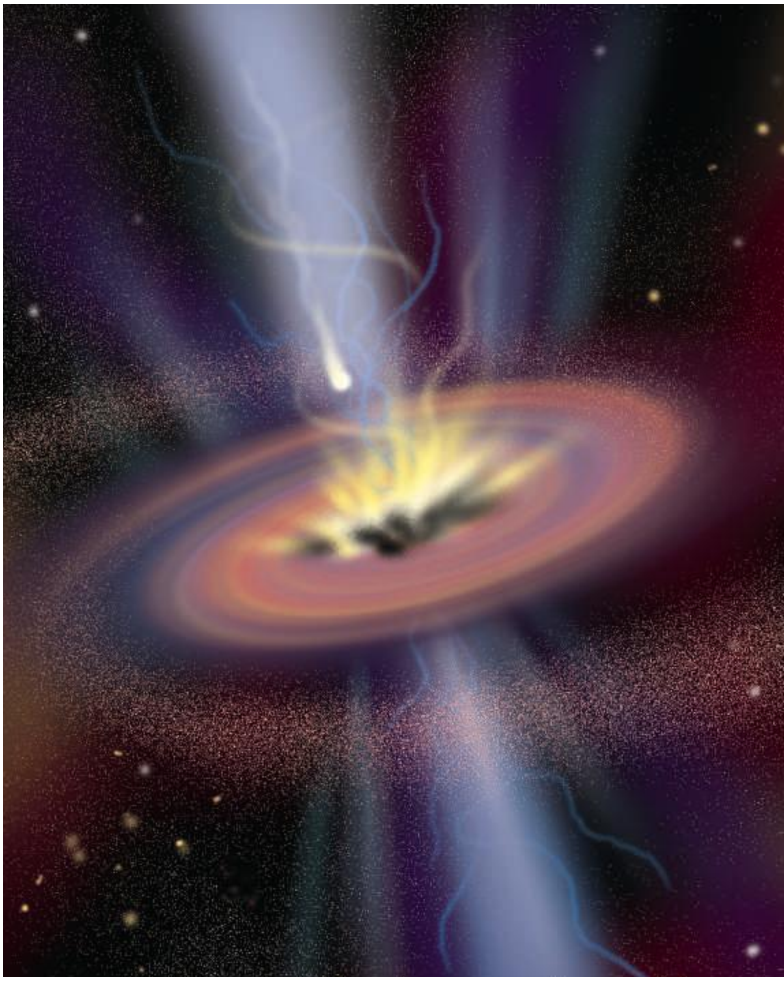

Figure 10.23 An artist's impression of a black hole. Gas and dust from a nearby star is being drawn towards the black hole where it circulates, heats up and gives out streams of X-rays.

EXPLORE ONLINE

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

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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 Figure 10.24). For years, astronomers 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.

If you would like to find out more about Bryan Gaensler's work, follow the links to **Bryan Gaensler**. There you will find links to many interesting articles written for science magazines and newspapers.

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 had run 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 inwards 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.

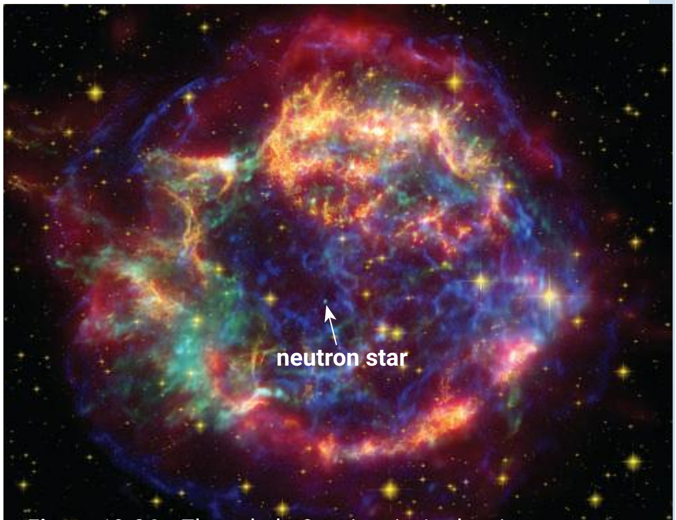

Figure 10.24 The nebula Cassiopeia A, showing a probable neutron star in the centre.

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.

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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 a small neutron star called a *magnetar* had 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.

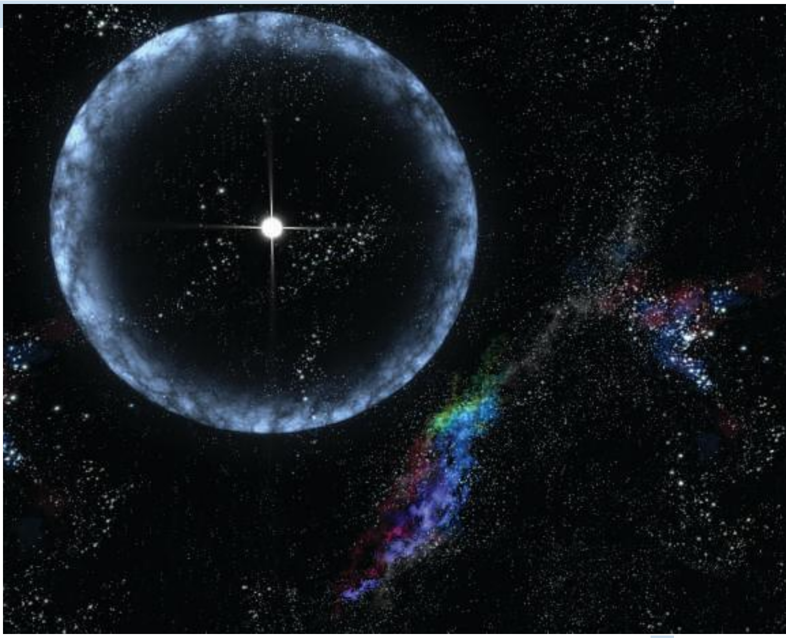

Figure 10.25 An artist's impression of the gamma-ray flare expanding outwards towards the Earth from the exploding magnetar SGR 1806-20.

Could a magnetar explosion closer to our solar system have been responsible for the mass extinction of organisms on Earth in the past?

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 such as 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'.

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The Big Bang theory

Astronomers who study the universe are called *cosmologists*. **Cosmology** is the study of the origin and structure of the universe.

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**. It suggests that about 13.8 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.

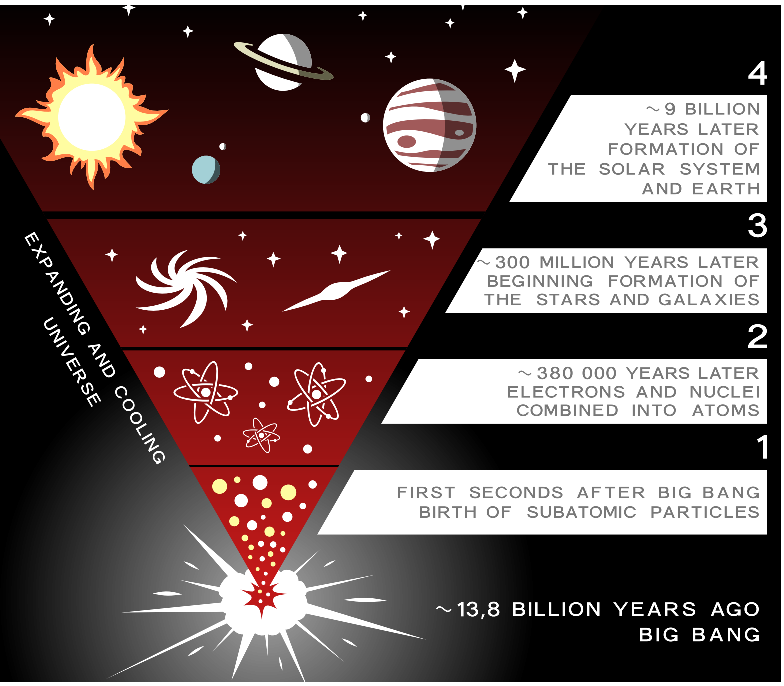

Figure 10.26 The Big Bang theory

On further expansion and 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 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.

Red shift—evidence for expansion

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.

As shown in Figure 10.27, if the galaxy is moving away from Earth (middle), the wavelength of the emitted radiation stretches and the absorption line shifts towards a longer wavelength in the red part of the spectrum (red shift). If the galaxy is moving towards Earth (bottom), the wavelength is compressed and the absorption line shifts into the blue part of the spectrum (blue shift).

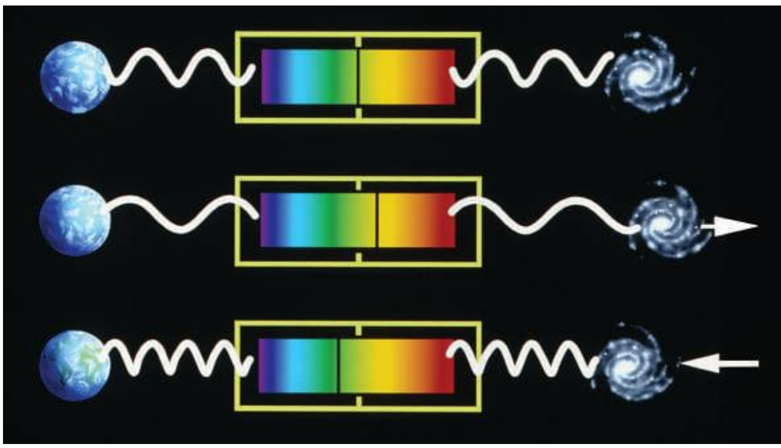

Fig 10.27 Red and blue shifts

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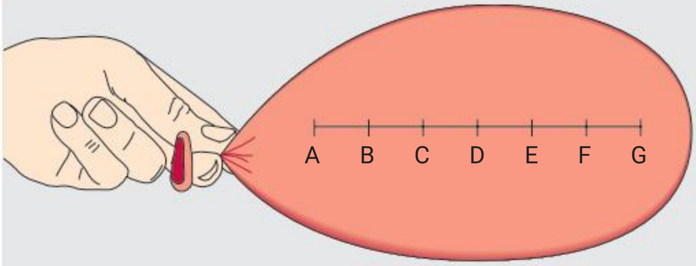
ACTIVITY

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.

How did the solar system form?

The solar system formed about 4.6 billion years ago, possibly started by a shockwave from a nearby supernova explosion that caused a cloud of dust and gas to collapse. As the cloud collapsed it compressed into a spinning disc, with material collecting at the centre gathering mass and gravity. When enough material had collected at the centre, nuclear fusion began and our sun was born. Due to its gravity, the sun attracted 99.8% of the matter available. The rest of matter collected into clumps that formed planets, dwarf planets, asteroids, meteorites and moons.

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 below 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.*

EXPLORE ONLINE

Follow the links to the websites below.

The Big Bang

History of the universe

This website has a more detailed animation of the events in the Big Bang.

Astronomy and the universe

This is a very easy-to-read website with comprehensive information on astronomy and 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 is in an Earth orbit. Suggest why this telescope has detected objects in space that were previously unknown.

Fig 10.28 The Hubble Space Telescope in orbit around the Earth

11 Using a flow chart, outline the steps in the Big Bang theory.

12 Explain the term red shift in relation to the expansion of the universe.

13 a What may have caused our solar system to form?

b What are believed to be the steps in forming our solar system?

CHALLENGE

1 The Crab Nebula is 6300 light-years from Earth. If the supernova was seen in CE 1064, 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 276 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 those furthest away, whereas the slowest galaxies 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, follow the links to **Frequently Asked Questions about quasars**.

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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 four main types of ______ : spiral, barred spiral, ______ and irregular.

8 The ______ theory explains the formation of the universe, and suggests that the universe is still ______.

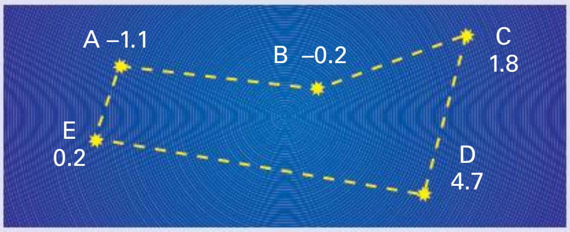
galaxies
elliptical
Big Bang
hydrogen
clouds
visible light
mass
convection
core
expanding
east to west
supernova
constellations
rotation
brightness

CH•10 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?



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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 The apparent magnitude of star A is −1.3 and that of star B is +3.5. The absolute magnitude of star A is +4.5 and that of star B is −5.2. Explain what this means.

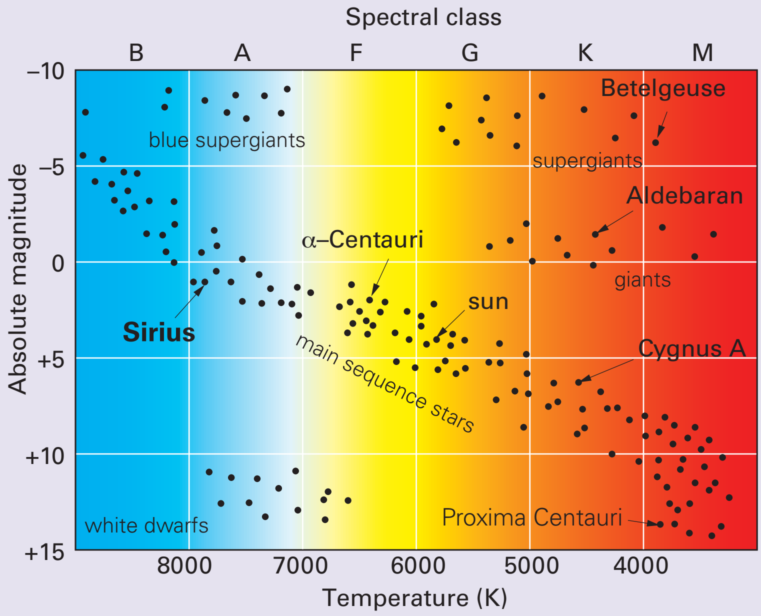
8 Explain why nuclear fusion reactions in the sun occur only in the core and not throughout the sun.

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 top 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.

12 Explain the following terms:
- **a** Big Bang
- **b** galaxy
- **c** red shift
- **d** solar system

13 Compare and contrast spiral galaxies and elliptical galaxies.

Check your answers on page 351.

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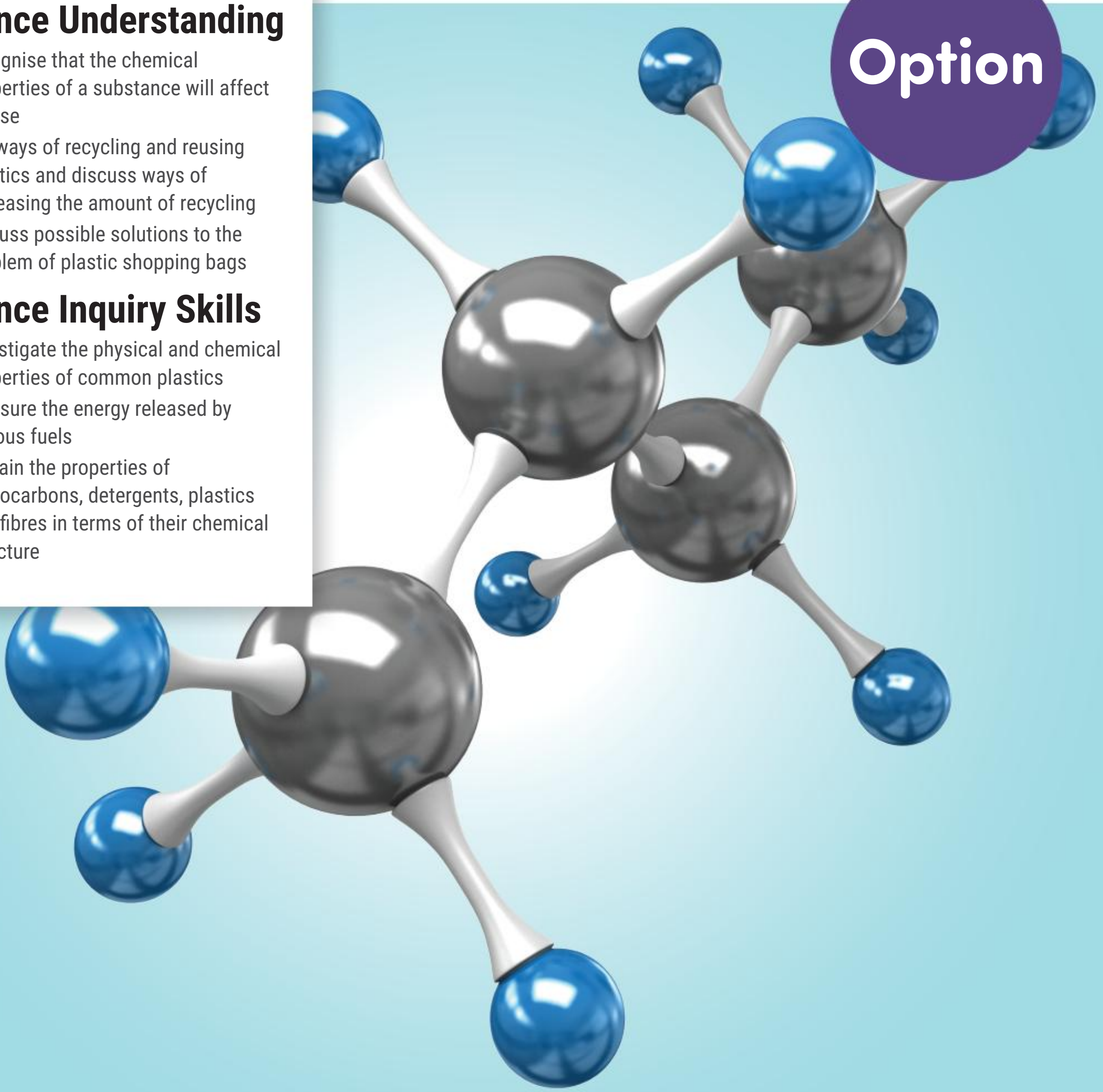
IN THIS CHAPTER

Science Understanding

- recognise that the chemical properties of a substance will affect its use
- list ways of recycling and reusing plastics and discuss ways of increasing the amount of recycling
- discuss possible solutions to the problem of plastic shopping bags

Science Inquiry Skills

- investigate the physical and chemical properties of common plastics
- measure the energy released by various fuels
- explain the properties of hydrocarbons, detergents, plastics and fibres in terms of their chemical structure



Option

CH•11 Carbon chemistry

ISBN 978 1 4202 3838 9

GET STARTED: *EXPLORE*

> Look at the image on the right. It shows coal, a rock made of up to 95% carbon. We use coal for energy and heat, and around two-thirds of all the coal mined is used to produce electricity in power stations all around the world.

1 Research coal mining in Western Australia and identify the composition of coal samples mined in WA.

2 Identify the products formed when coal is burnt, and research the environmental impact of those products.

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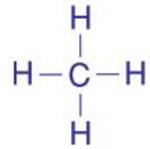
11.1 Carbon compounds

You walk into a shop selling freshly ground coffee. The aroma of coffee is due to hundreds of different chemical compounds all containing the element carbon. In fact, over 90% of all the compounds on Earth contain carbon. Carbon compounds are made up of carbon and a few other elements—mainly hydrogen, oxygen and nitrogen. All living things are made of carbon compounds; your food is made of them and your clothes are made from them.

The reason there are so many different carbon compounds is that carbon atoms can form four chemical bonds, due to the attractive forces between atoms. Carbon can bond (link) to other atoms such as hydrogen and oxygen. For example, methane is the main ingredient in natural gas, and is found in swamps when plant material decays. A methane molecule consists of a carbon atom bonded to four hydrogen atoms. Its *molecular formula* is CH_4, meaning there are four hydrogen atoms (H) for each carbon atom (C).

If you want to show how the atoms are bonded to each other you can use a **structural formula**. For example, the structural formula for methane is:



This is an easy way to draw a three-dimensional molecule in two dimensions. Each line represents a chemical bond.

The second reason there are so many carbon compounds is that carbon can bond to itself. For example, Figure 11.2 shows a molecule of ethanol (a type of alcohol), the most important ingredient in beer, wine and spirits. Notice that each carbon atom is bonded to four other atoms. Each hydrogen atom is bonded to only one atom, and oxygen is bonded to two atoms.

In the activity on the next page you can make models of carbon compounds for yourself.

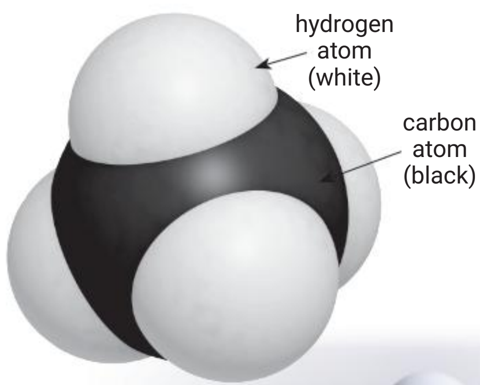


Figure 11.1 Two different molecular models for methane CH_4

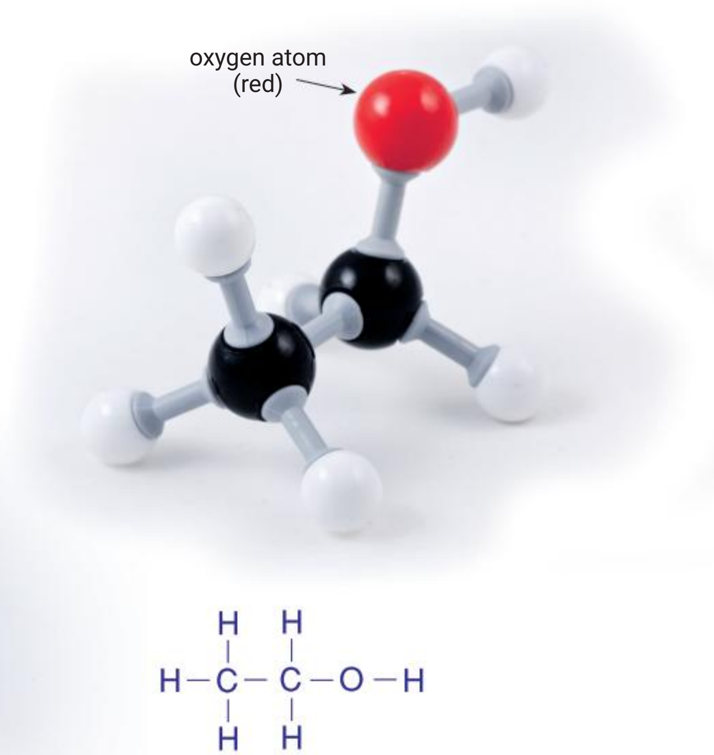


Figure 11.2 A molecular model of ethanol (C_2H_5OH), with its structural formula

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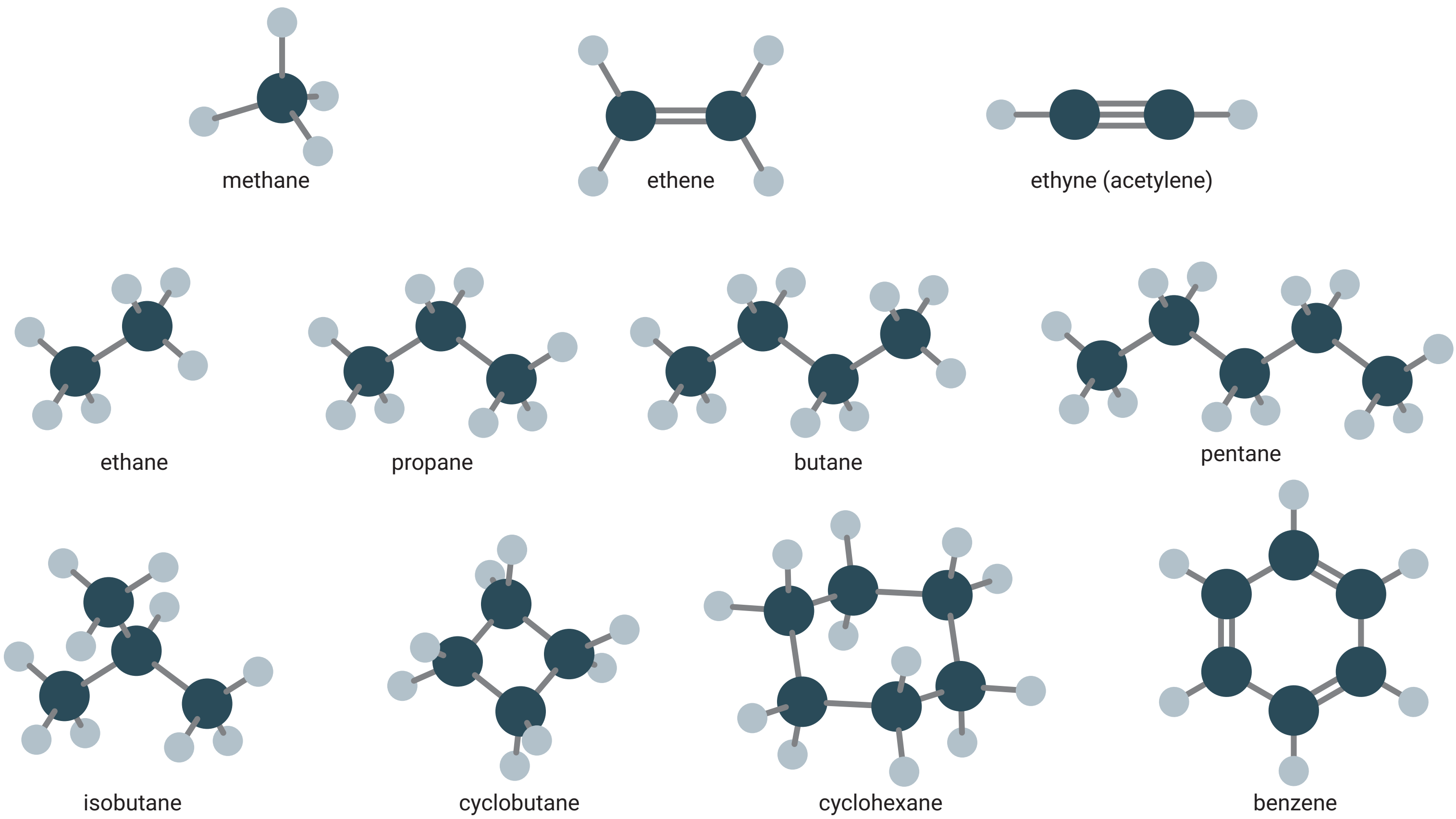

Figure 11.3 Some common carbon-based compounds. Carbon can also form double or triple bonds to itself, or rings.

ACTIVITY

You will need a molecular models kit.

1. Your teacher will show you how to use the kit, or you can read the instructions.
   - Which colour balls represent carbon atoms? Hydrogen atoms? Oxygen atoms?
   - How are the bonds between atoms represented?
   - How many bonds can carbon form?
   - How do you know?
   - How many bonds can hydrogen and oxygen form?
2. Make a model of a methane molecule CH_4 and sketch it with the different atoms labelled.
3. Join two carbon atoms with one bond then add as many hydrogen atoms as possible. This represents ethane—a gas similar to methane.
   - Write down the formula for ethane, and draw its structural formula.
4. Make models to represent propane, C_3H_8, and butane, C_4H_{10}. Compare your models with those made by other students.
   - Did you find that there are two different ways of making C_4H_{10}? Draw the two structural formulas.
5. You can use the models kit to have competitions. For example, how many different carbon compounds can you make using 4 carbon atoms, 2 oxygen atoms and 10 hydrogen atoms? You can use all of these atoms or only some of them—but you must obey the bonding rules by filling all the holes in each of the atoms. As you make each compound, write down its structural formula.

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Carbon compounds from oil

Crude oil is a liquid containing a mixture of hundreds of different carbon compounds. Most of these are hydrocarbons—compounds of carbon and hydrogen only. These different compounds can be separated by the process of **fractional distillation**.

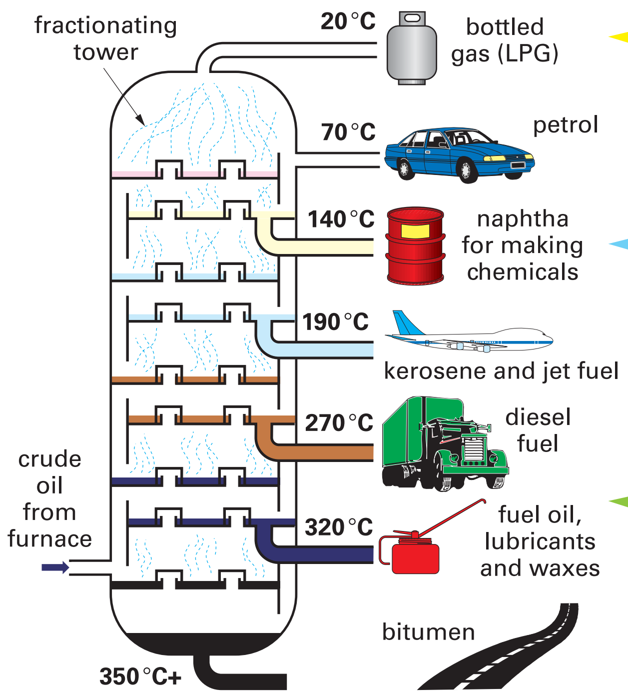
At an oil refinery the crude oil is heated in a furnace and passed into a large tower called a fractionating column, which is hot at the bottom and cooler at the top (see Figure 11.4). At the bottom almost all the hydrocarbons boil. Their vapours rise in the column, cooling all the way. When they have cooled down enough they condense back to liquids. Hydrocarbons with high boiling points condense in the lower, hotter part of the column. Hydrocarbons with lower boiling points condense further up, in the cooler part of the column. In this way the crude oil is separated into *fractions* with different boiling points.

Some of the fractions are gases, most are liquids, and some are solids. To explain these differences you need to consider the size of the molecules in the fractions. There are attractive forces between molecules, and the more atoms there are in a molecule, the stronger these attractive forces are. Therefore large, heavier molecules have very strong attractive forces between them, and are generally very close together.

The fractions from the top of the column consist of small, lighter molecules containing only a few carbon atoms. This is why these fractions are gases; for example, methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}), with low boiling points.

Most of the fractions from crude oil are liquids; for example, octane in petrol is C_8H_{18}. Their molecules are larger, with stronger forces between them, and closer together than the molecules in the gaseous fractions. As you go down the column, the molecules in the liquid fractions become larger, the molecular forces between them are stronger and hence the boiling points increase. The **viscosity** also increases. For example, petrol is quite runny (like water), but lubricating oil is thick (viscous). This is because of the stronger attractive forces between the molecules. The larger molecules also tend to get tangled up and cannot move about as easily as the smaller ones.

The solid fractions from the bottom of the column contain very large molecules, with very strong attractive forces, and packed close together. For example, the paraffin wax used to make candles contains molecules with 20–27 carbon atoms.



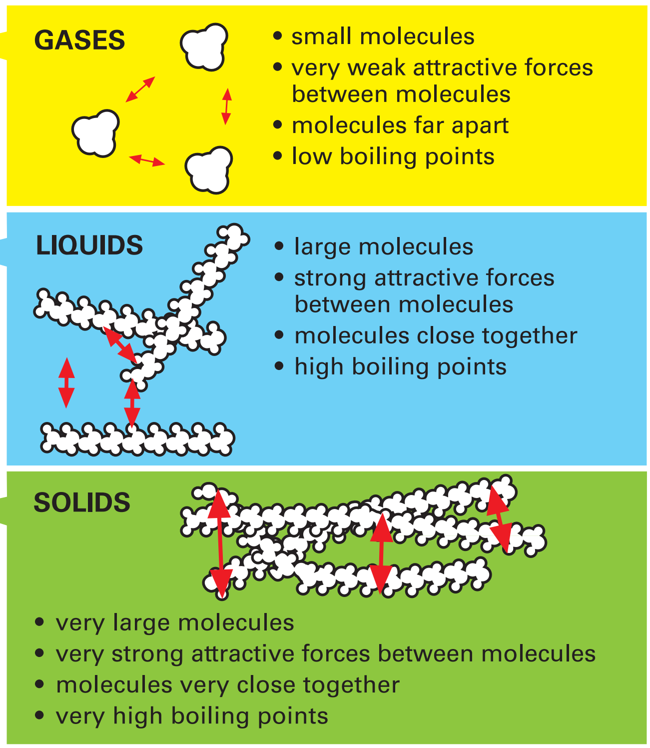


Figure 11.4 Fractional distillation of crude oil

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Soaps

Water has always been used to clean our bodies and clothing. However, water cannot remove oil and grease because these substances do not dissolve in water. You need a soap or a detergent to remove them.

It is thought that the first soap was made about 2500 years ago, probably by the Egyptians. Soaps are carbon compounds made by boiling vegetable or animal oils with caustic soda (sodium hydroxide). When salt is added to the mixture, hard lumps of the soap form on the surface. Dyes and perfumes can be added to make the soap look and smell better.

How soap works

Figure 11.5 shows what a typical soap molecule looks like. The 'tail' of the molecule is a long hydrocarbon chain, and the 'head' is negatively charged. The 'tail' has much the same structure as the compounds in grease and is attracted to and dissolves in the grease. This end is therefore called the grease-loving or water-hating end. The 'head' is attracted to water particles and is called the water-loving end. In Figure 11.6 the soap molecule has been simplified to .

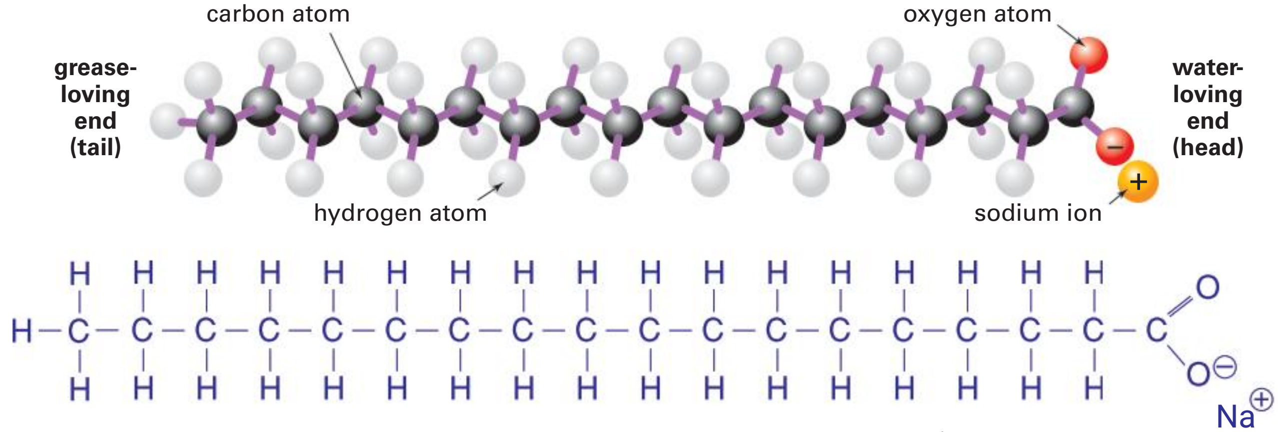
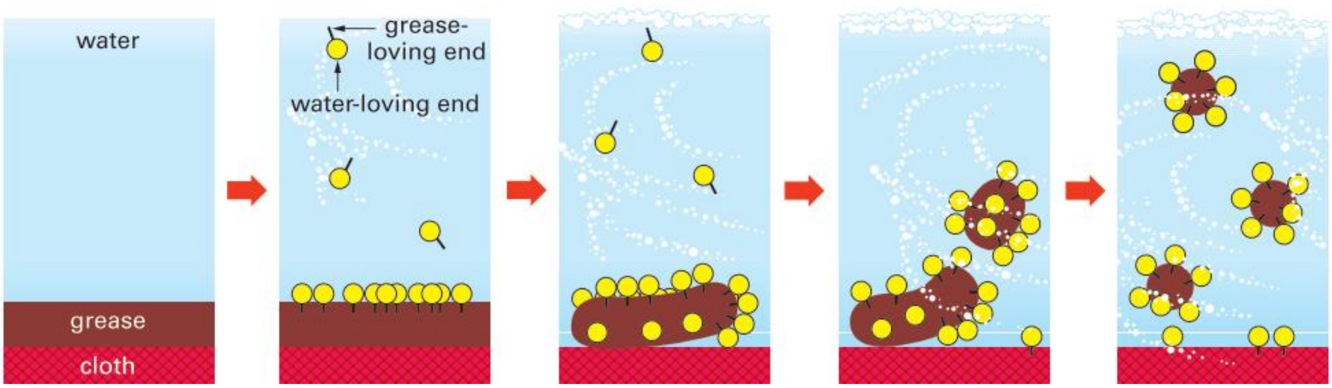


Figure 11.5 A typical soap molecule. Its chemical name is sodium stearate $C_{17}H_{35}COO^{-}Na^{+}$.



A piece of cloth is covered with grease. Water alone will not remove the grease.

When soap is added, the grease-loving 'tails' stick into the surface of the grease, leaving the charged 'heads' sticking out into the water.

Each droplet of grease becomes surrounded by a layer of soap molecules with their charged heads on the outside.

When the cloth is shaken in a washing machine, the large grease droplets break up into smaller droplets that can be removed from the cloth by further shaking.

The small grease droplets and attached soap molecules repel one another and do not re-attach themselves to the cloth. The excess soap molecules form a protective layer on the cleaned cloth.

Figure 11.6 How soap removes grease from a piece of cloth

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INVESTIGATION 11.1 Making soap

Aim

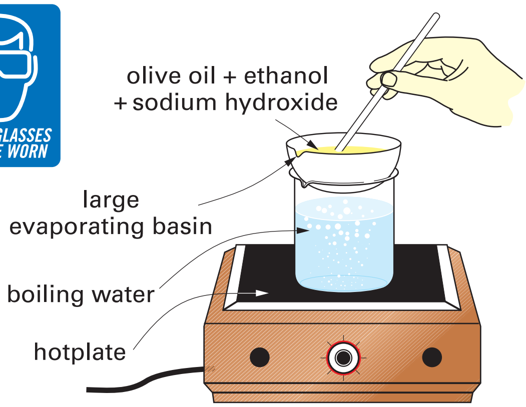
To make soap and test how well it works.

Materials

- hotplate (or burner, tripod and gauze mat)
- 2 beakers (approx. 400 mL)
- 2 test tubes with stoppers
- large evaporating basin
- stirring rod
- wash bottle
- spatula
- 90% **ethanol** (or **methylated spirits**)
- kerosene
- olive oil or castor oil
- 6 M **sodium hydroxide** solution (**caustic soda**)
- saturated sodium chloride solution
- piece of filter paper
- measuring cylinder (10 mL)

Risk assessment and planning

- Sodium hydroxide is very corrosive, especially when it is hot. So you will need to take special care that you do not spill any. What should you do if you do spill it? To protect your hands you could wear plastic gloves.
- Why is it safer to use a hotplate than a Bunsen burner in this investigation?
- You should not test the soap on your skin. Why not?



Method

1 Set up a steam bath as shown below left.

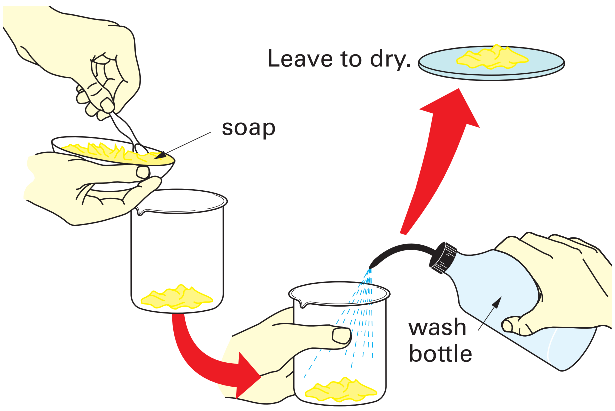
2 Add 5 mL of olive oil and 5 mL of ethanol to the evaporating basin. Then carefully add 5 mL of sodium hydroxide solution, while stirring. (The ethanol speeds up the reaction between the oil and the sodium hydroxide by dissolving the oil.)

3 Continue heating for about 30 min, while stirring. The olive oil should 'disappear' and the mixture become pasty.

4 Turn off the steam bath and add 5 mL of sodium chloride solution, while stirring. Soap is insoluble in this salt solution, and should float to the surface as a white curdy solid.

5 Use a spatula to skim off the soap into a beaker. Rinse it several times with a small amount of water, using a wash bottle.

6 Leave the soap to dry on a piece of filter paper.



7 One-third fill a test tube with water, and add some of your soap. Then put in a stopper and shake. Is a lather (froth) produced?

8 Add 2 or 3 drops of kerosene to water in a test tube, and shake. (Kerosene acts like grease.)

Describe what happens.

9 Now add some of your soap to the kerosene and water and shake it again.

What happens this time? Explain.

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Detergents

Detergents are synthetic compounds with a head and tail structure similar to that of soap. They are usually made from chemicals obtained from crude oil, and they are used as dishwashing liquids, washing powders and shampoos. They work better in hard water than soap does. (Hard water is water containing large amounts of dissolved solids that prevent soap from producing a lather.) This is why detergents are more effective cleaners than soaps.

The first detergents were not biodegradable. They were not broken down by microbes (micro-organisms) into simpler compounds. As a result they caused foam to appear in rivers and streams. In some polluted areas, even a glass of drinking water would have a head of foam on it. The problem was solved by changing the ingredients used to make the detergents. Detergents are now biodegradable and in most countries the law requires that all detergents be biodegradable.

Another problem is that many detergents contain chemicals called *phosphates*. These are used to 'soften' the water, allowing the detergents to remove more dirt from clothes. These phosphates are washed into drains and then into rivers and lakes where they are good fertilisers for algae and other water plants, which grow quickly and then die. The decay of these plants uses up the oxygen in the water and as a result fish and other aquatic animals may die. For this reason there are limits on how much phosphate manufacturers can put in detergents.

Figure 11.7 Detergents in waterways can be a pollutant.

CHECK

1. Explain why carbon forms so many different compounds.
2. Which elements do hydrocarbons contain?
3. How many bonds can each of these atoms form?
   - **a** carbon
   - **b** oxygen
   - **c** hydrogen
4. In what ways are soaps and detergents similar? In what ways are they different?
5. Describe in your own words how dishwashing detergent removes grease from dishes. Use a diagram if you wish.
6. What is the difference between fractional distillation and ordinary distillation?
7. A crude oil sample was separated into four fractions. These were collected in the temperature ranges shown in the table.

Fraction	Temperature range (°C)
A	5–70
B	70–115
C	115–200
D	200–380

Which fraction would you expect to:
- **a** be the most like petrol?
- **b** have molecules with the longest chains?
- **c** be the most viscous?
- **d** have the lowest boiling point?

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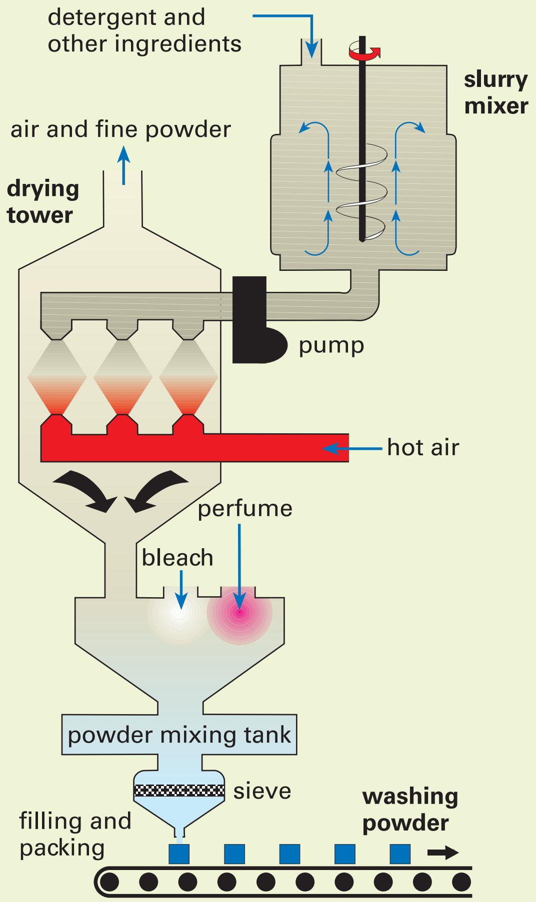
CHALLENGE

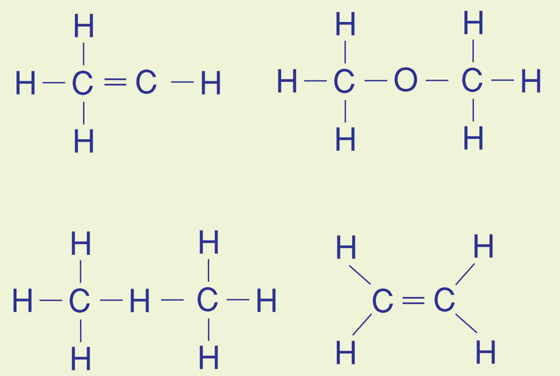
1 Look at the flow diagram below, which shows what happens in a factory making washing powder.
- a What raw materials are used by the factory?
- b What is the end product?
- c Are there any waste materials?
- d Why is a sieve used before packing the washing powder?
- e Suggest why the bleach and perfume are not added with the other ingredients at the start.



2 Methane gas burns in oxygen to produce carbon dioxide and water. Write a word equation for this reaction.

3 Suppose you had to wash in sea water. Which would be better to use—soap or detergent? Why?

4 Examine the following formulas. Which formulas are correct according to the bonding rules? For each one that is incorrect, say why. (You could try to construct the molecules using molecular models.)



= represents a double bond

5 CFC-11 (once used in aerosols) has the molecular formula CCl_3F.
- a Use the formula to work out what CFC stands for.
- b Draw the structural formula for CCl_3F.

6 Butane and isobutane both have the same formula C_4H_{10}. However, isobutane has a lower boiling point and lower density than butane. Use molecular models to explain these differences in properties.

EXPLORE

1 Suppose you are asked to test whether liquid detergents wash clothes better than powder detergents. Describe how you would do this, making sure you control variables.

2 Do a supermarket survey of laundry detergents. What does the P symbol mean? What other symbols are used on the packages?

3 Use a molecular models kit to build a soap molecule (Figure 11.5 on page 295). Use the internet to find out how detergent molecules are different from this.

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11.2 Plastics and fibres

In 1907, Leo Baekeland, a Belgian working in the United States, was trying to make an artificial substitute for shellac. (Shellac is a material obtained from tiny Indian lac bugs; it was used widely for making varnishes and waxes.) Instead, he made a new substance that kept clogging up his test tubes. Nothing would dissolve this dark brown substance, and on further investigation he found that it could be moulded into shapes. It was a good insulator of heat and electricity.

What Baekeland had done was to mix phenol and formaldehyde, which reacted to form a substance we now call *plastic*. (The word *plastic* means 'easy to mould'.) Baekeland called the new material *bakelite*, from his own name, and it was soon being used for saucepan handles and electrical fittings. Bakelite has now been replaced by newer plastics.

Polymers

Suppose you mix two different chemicals, A and B. Each contains small molecules and they can react together to form a bigger molecule, A–B. However, it is sometimes possible for the molecules to go on linking up to form giant long-chain molecules called **polymers**. (*Poly* means 'many' and *mer* means 'units'.)

All polymers contain big molecules that consist of many small molecules (or *monomers*) linked together. The chemical reaction in which small molecules link to form polymers is called **polymerisation** (pol-IM-er-eyes-AY-shun). Sometimes the monomers are all the same, and sometimes there are two different monomers.

Figure 11.8 Bakelite was used to make radios like these, as well as jewellery, telephones, billiard balls and board game pieces.

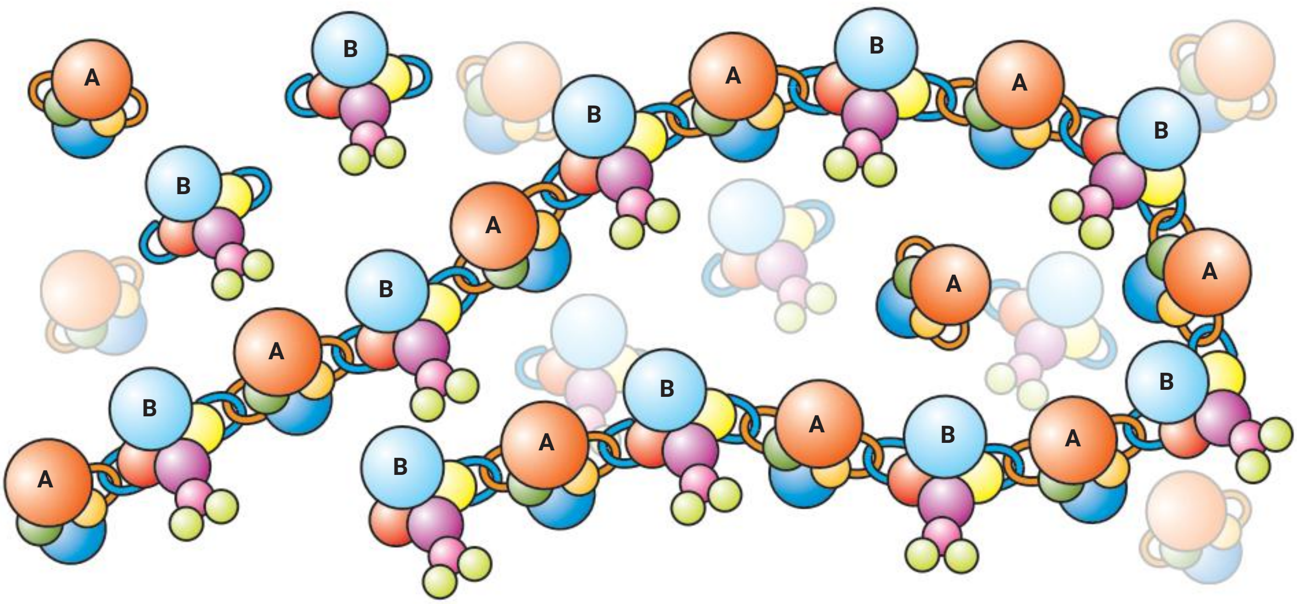

Figure 11.9 Two different small molecules join to form a long-chain molecule called a polymer. The process is a bit like linking paperclips together.

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Making polythene from ethene

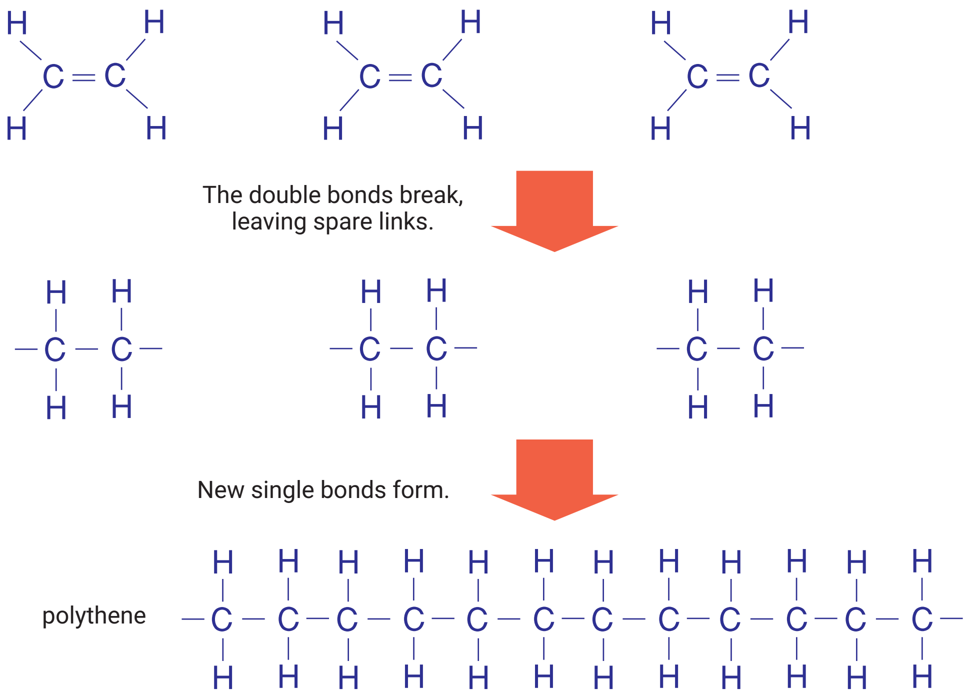

Figure 11.10 Formation of polyethene

Polythene (or polyethene) is formed by the polymerisation of ethene, one of the many chemicals obtained from crude oil. Ethene molecules contain a double bond (represented by a double line), which makes them very reactive. If the double bonds are broken and then linked to neighbouring molecules, a long chain polymer can form, as shown above. These chains can contain up to 50 000 carbon atoms.

Many other monomers besides ethene can be polymerised. For example, vinyl chloride is the same as ethene except that one hydrogen atom in each ethene molecule has been replaced by a chlorine atom. It can be polymerised to form polyvinyl chloride or PVC. Similarly, styrene can be polymerised to form polystyrene.

Natural polymers

Many polymers occur naturally. For example, cellulose and starch in plants are both polymers made from glucose units. If we represent a glucose molecule by the symbol g, then the structure of starch is −gggggggggg−, and the structure of cellulose is −gƃgƃgƃgƃgƃ−. In cellulose, every second glucose molecule is upside down.

The cells and tissues in your body are made of proteins, which are polymers made from smaller molecules called *amino acids*. These contain carbon, hydrogen, oxygen, nitrogen and sulfur atoms. Figure 11.11 shows part of a protein molecule made from five different amino acids. Different proteins are made by joining the amino acids in different sequences. With 20 amino acids to choose from, the number of different proteins that can be made is almost limitless. The protein insulin contains 51 amino acid units, but most proteins contain 500 or more.

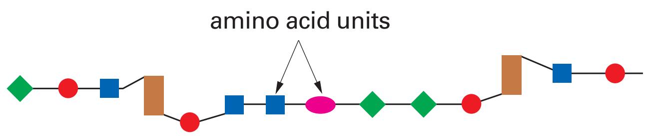

Figure11.11 This piece of protein chain is formed from five different amino acids.

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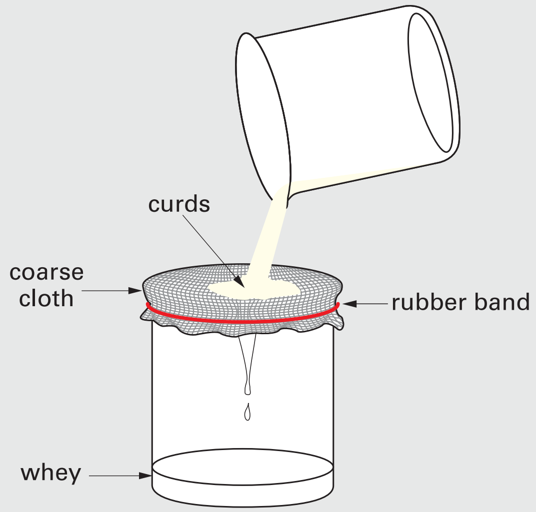
ACTIVITY

Milk contains a protein called casein (KAY-seen). It can be extracted by adding about 5 mL of vinegar to about 100 mL of warm milk, in much the same way that cheese is formed.

Separate the curds (white solid) from the whey (yellowish liquid) by pouring the mixture through some coarse cloth. Squeeze the cloth with your fingers to remove the whey. Knead the casein (curds) in warm water, and shape it into a ball or some other shape.

Leave the plastic to dry for a day or two.

- Describe the properties of your plastic.
- Suggest what you could use casein plastic for.



Properties and uses of plastics

There are two different types of plastics. One type contains long thin molecules which form tangled chains. In these plastics there are strong bonds between the atoms along the chain, but much weaker forces between neighbouring chains. Because of this, the chains can slide over each other easily (Figure 11.12). Hence these plastics stretch and bend easily and soften on heating. Such plastics are called **thermoplastics**. Examples are polythene, polystyrene, PVC and nylon.

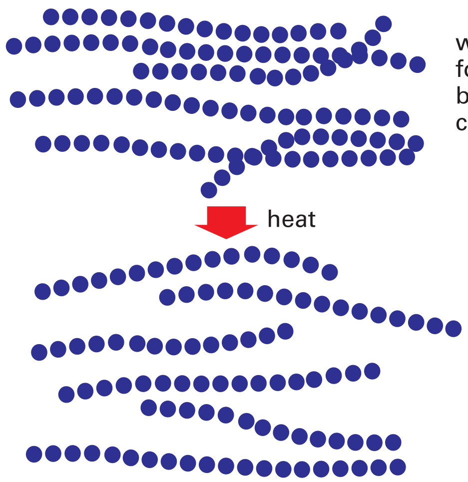


Figure 11.12 The chains of a thermoplastic move apart when the plastic is melted.

Thermoplastics can be shaped in a number of different ways. Each method involves heating the plastic so that it becomes soft, shaping it and then cooling it.

The second type of plastic is made from molecules whose atoms form strong bonds *between* chains as well as along the chains (Figure 11.13). These plastics are called **thermosets**. They are much harder than thermoplastics and less flexible. They do not melt when heated. Instead they char (blacken) as the cross-links are broken and the polymer starts to decompose. Examples of thermosets are bakelite, fibreglass resin and epoxy glues.

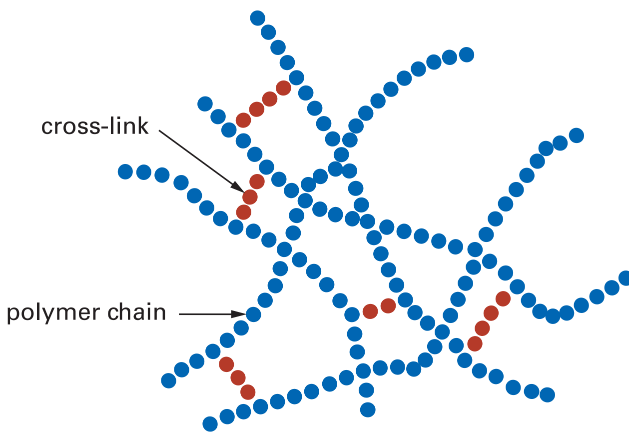


Figure 11.13 The structure of a thermoset

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Name of plastic	Identification code		Common uses
polyethylene terephthalate	1	PETE	soft drink, water and juice bottles
polythene (high density)	2	HDPE	milk bottles, various household containers, black polypipe
polyvinyl chloride (PVC or vinyl)	3	V	fruit juice bottles, raincoats, electrical conduits, garden hoses, plumbing pipes
polythene (low density)	4	LDPE	shopping bags, food wrap film, squeeze bottles
polypropene (polypropylene)	5	PP	ice-cream containers, take-away containers, chip packets, bumper bars, bank notes
polystyrene	6	PS	yoghurt containers, refrigerator linings, foam packaging

EXPLORE ONLINE

Follow the links to the websites below.

Macrogalleria
A cyberwonderland where you can explore five levels of information on how plastics and fibres are used and made. Includes many photographs.

Plastipedia
Comprehensive information on the history of plastics, plastics processes and applications.

Learning Centre
Information on the uses of plastics and recycled plastics in Australia.

Figure 11.14 This Plantic plastic tray is made from corn starch and degrades rapidly in water.

Recycling and reusing plastics

There are two problems with our increasing use of plastics (more than one million tonnes per year in Australia). First, most plastics are made from oil, a non-renewable resource which will become scarce in the future. Second, what do we do with plastic objects when we have finished with them? There are many different ways of reusing them. For example, you can use old ice-cream containers to store things in. However, most councils now collect plastic items from homes for recycling.

There are three different ways of recycling plastics.

1 Thermoplastics can be melted and remoulded. However, because there are so many different types of plastic, they must first be washed and sorted, otherwise the recycled plastics will not have the properties you want. This costs money, and the recycled plastic may be more expensive than new plastic. However, a number of manufacturing plants in Australia now use recycled plastic. For example, milk bottles are recycled to make products such as garbage bins and detergent bottles, and plastic banknotes are recycled to make compost bins.

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2 Mixed plastic waste can be crushed and moulded into a range of products such as plastic posts, plant pots and park benches. It can also be mixed with wood to make a composite material. For these uses the lower-quality product is not a problem.

3 Because plastics burn, they can be used as fuel. So far this has proved difficult because of the toxic gases produced and the sticky nature of many plastics as they burn. However, technologists have found a way of converting waste plastics into oil. In the system shown in Figure 11.15, some of the gases formed as the plastic decomposes are condensed to give valuable oil products. The rest of the gases are used to heat the plastic waste. Such a system can handle 8000 tonnes of plastic waste in a year. It is an expensive process but a useful way of saving our non-renewable oil reserves.

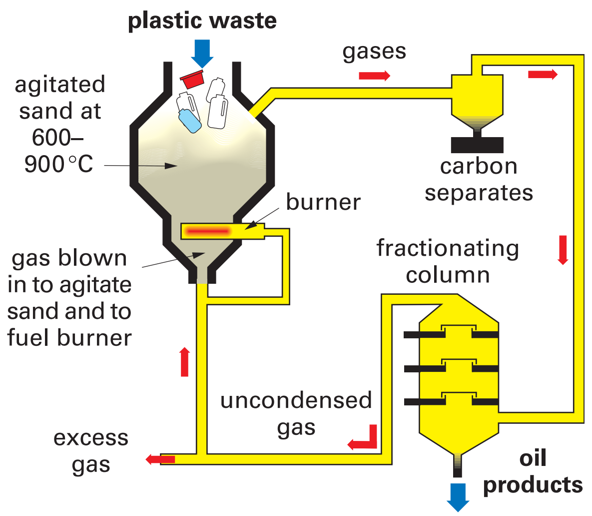


Figure 11.15 Recycling plastic waste into oil

Figure 11.16 Blocks of crushed plastic ready for recycling

Figure 11.17 The crushed plastic (left) and the oil obtained from it

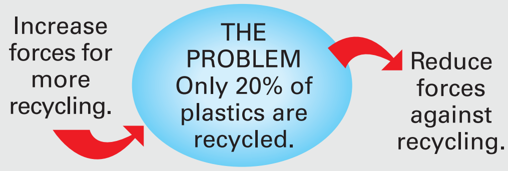
ACTIVITY

At present we recycle only about 20% of the plastics we use. How can we increase the proportion recycled? Discuss this problem in a group using the steps below.

1 Brainstorm all the forces in favour of more plastics recycling. For example, most people are environmentally conscious at present.

2 Brainstorm the forces opposed to recycling. For example, it's too much trouble to separate plastics from other rubbish.

3 Decide which of the forces could be changed. Is it easier to strengthen the 'for' forces or weaken the 'against' forces?



4 On the basis of step 3, write out a plan to solve the problem.

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EXPERIMENT 11.1 Properties of plastics

Planning guide

1. Use the identification codes in the table on page 302 to collect a range of commonly used plastics.
2. Read through the six properties of plastics on this page, then select the properties you want to test. **Don't burn the plastics, since the fumes released pollute the laboratory and cause breathing difficulties for some students.**
3. You will need to work out for yourselves how to do each test. Write down a plan, which should include:
   - how you will do the test, with a diagram if necessary
   - what you will measure, and how you will record and display your data
   - a list of the equipment you will need
   - any safety precautions you will need to take.

   Your teacher must approve your plan before you can start.
4. Write a report of your test, noting the properties you think are useful and those that are not so useful for objects made of the plastics you tested.

Resistance to chemicals

Are plastics affected by acids and bases? You could try to dilute hydrochloric acid and caustic soda. Do the plastics dissolve in solvents such as turpentine or alcohol?

Resistance to heat

Put the plastic on a heatproof mat. Heat the end of a screwdriver in a burner, then press it against the plastic. Does the plastic melt?

Insulating properties

Set up a simple electric circuit to test whether the plastics are insulators or conductors. Compare them with metals.

Degradability

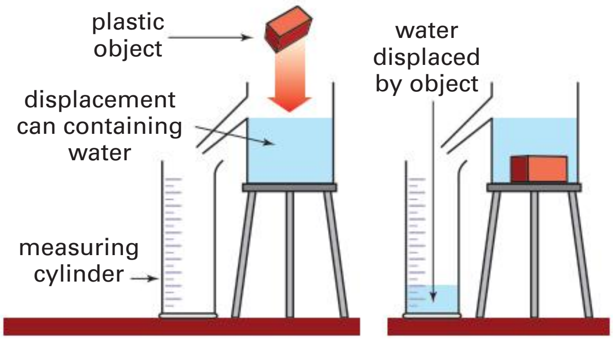
Do the properties of the plastic change when it is exposed to air, sunlight and water or buried for some time? Is this a good thing or a bad thing?

Density

If a plastic floats in water, it is less dense than water—its density is less than 1 g/cm³. If it sinks, its density is more than 1 g/cm³. To calculate the density of a plastic sample, you use the formula:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

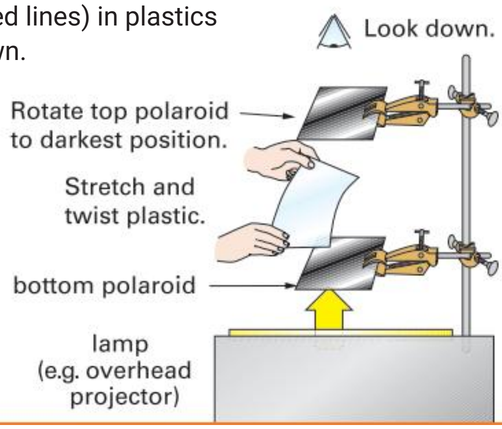
To measure the volume of a plastic object, use a displacement can as shown. If the plastic floats, you will need to hold it under water with a thin piece of wire.



Flexibility and stress

Can the plastic be bent or stretched, and if so does it return to its original shape? To what angle can it be bent before it breaks? Does its flexibility change when the plastic is warmed in hot water?

You can check for strained areas (coloured lines) in plastics as shown.



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SCIENCE AS A HUMAN ENDEAVOUR

The plastic bag problem



Answer the questions below. For some, you will need to search on the internet. For others, you will need to discuss them in a small group.

1 What are the advantages and disadvantages of the thin plastic shopping bags that you receive at supermarkets?
2 What are these bags made from? What raw material is used to make them?
3 How many shopping bags do Australians use each year?
4 Most plastic bags end up in landfill. How long do they take to break down?
5 Planet Ark estimates that plastic bags littering the ocean kill at least 100 000 birds (including penguins), whales, seals and turtles every year. However, the Plastics and Chemicals Industries Association (PACIA) says 'there is no credible evidence to support the claim that hundreds of seabirds and mammals die each year from ingesting plastic bags'. Why do these two groups disagree so much? What is the truth?
6 How can plastic shopping bags be reused around the home?
7 Ireland had a major litter problem, so in 2002 they introduced a levy of 15 cents per plastic shopping bag. This reduced the use of the bags by 90% in 6 months, but at the same time the use of plastic bin liners increased. Try to explain what happened.
8 Can plastic shopping bags be recycled? How?
9 Many people are now using reusable 'green' shopping bags made of polypropylene or calico. Are these a solution to the problem of our overuse of plastic shopping bags? Explain your answer.
10 Following disastrous floods in 1988 and 1998, which were due in part to drains being blocked by plastic bags, the country of Bangladesh banned plastic bags. South Australia also banned them in 2009. Do you think it would be a good idea to ban plastic shopping bags throughout Australia? Why or why not?
11 What are biodegradable, photodegradable and compostable shopping bags?
12 Scientists first made polythene in 1933, and in 1974 it was used to make plastic shopping bags. Since then the use of these bags has skyrocketed. However, these plastic bags have become a major problem for the environment. From what you have learnt by answering the questions on this page, what do you suggest we do about the problem?

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Fibres

Clothes are made from fabrics which, in turn, are made from threads spun from fibres.

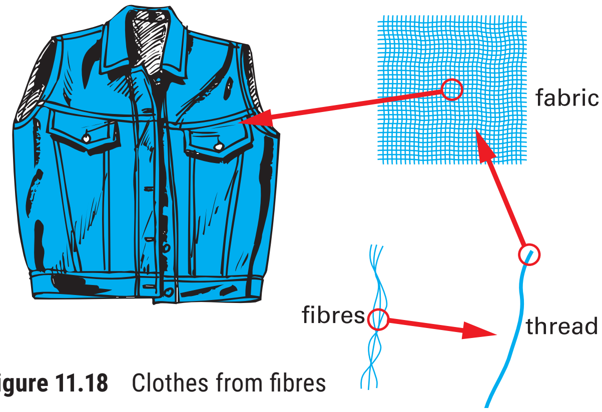

Figure 11.18 Clothes from fibres

All fibres are polymers, and they may be natural or synthetic. Cotton and wool are natural materials obtained from plants and animals. Cotton is made of cellulose polymers, and wool is made of protein molecules. Synthetic fibres such as nylon and polyester are polymers made from chemicals obtained from oil and coal. The key below shows the different types of fibres.

Properties of fibres

The polymer chains in fibres are very long. They are lined up close to each other and attract each other strongly. This makes the fibre very strong and difficult to break. Stretching the fibre helps to line up the molecules, making it even stronger.

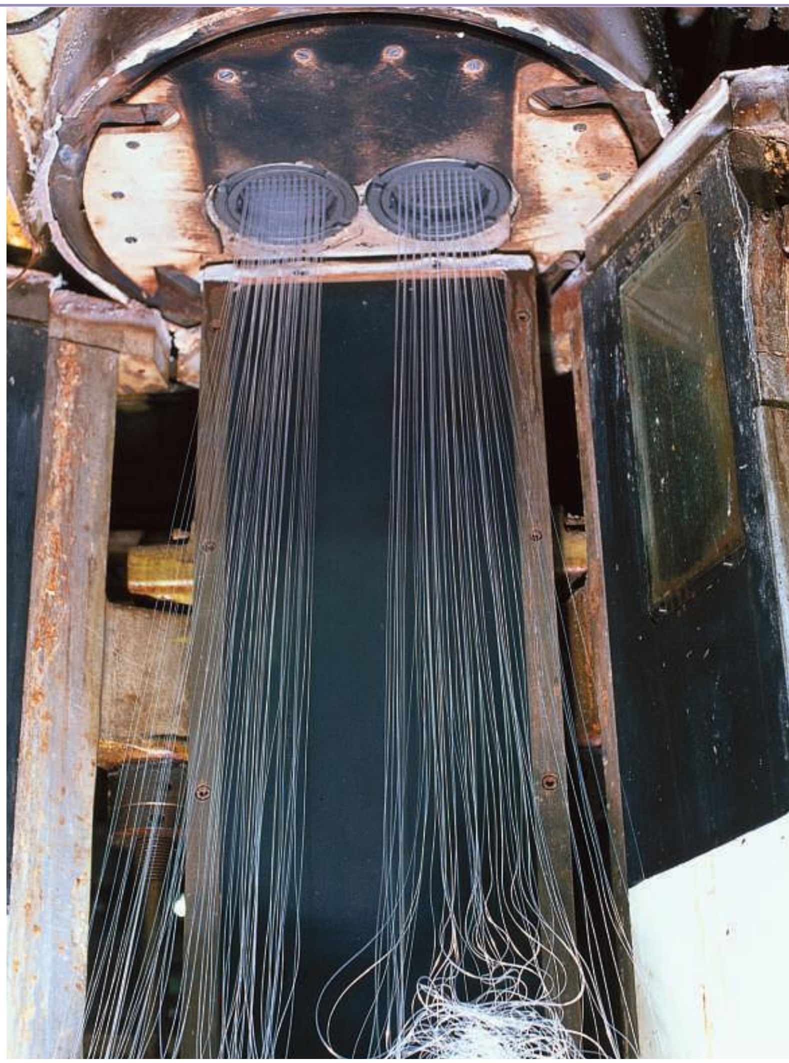

Figure 11.19 Synthetic fibres like nylon are made by forcing the melted material through holes in a metal plate called a spinneret, named after the organ through which a spider spins the silk for its web.

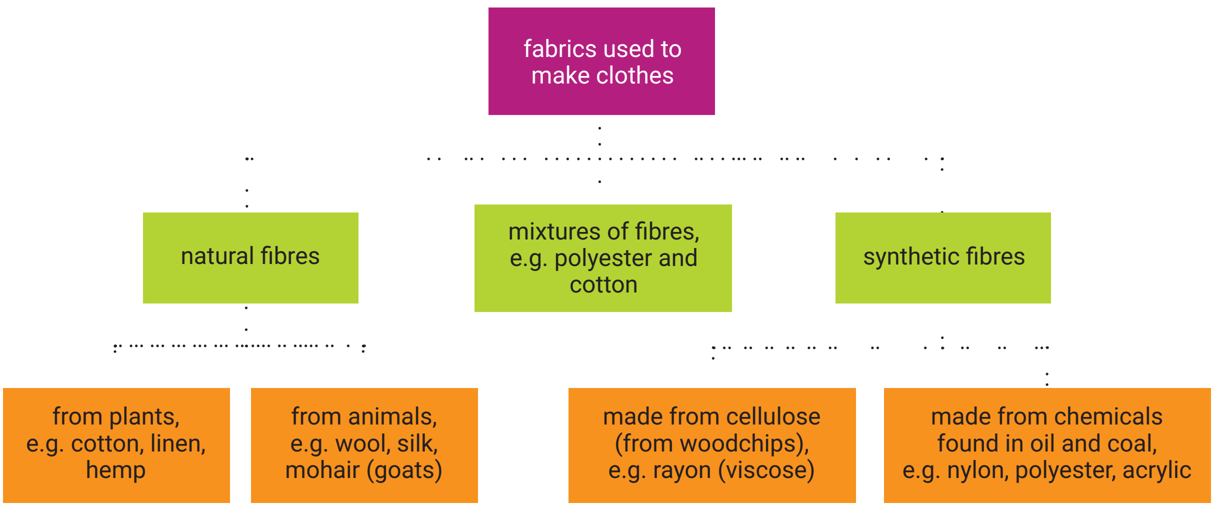

Figure 11.20 A key for classifying fibres

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Stretchy fibres like nylon or wool have molecules that are normally closely curled like a telephone cord. When you pull on the fibre, it stretches by straightening out the loops, but when you release it, the molecules curl up again.

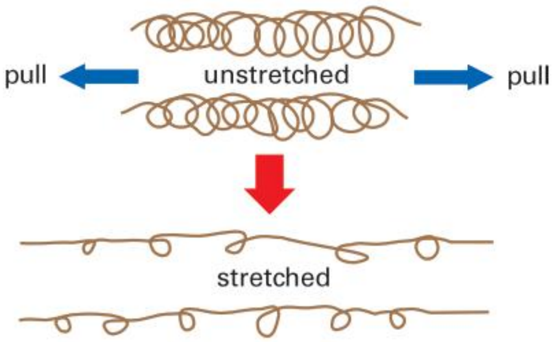

Figure 11.21 How a fibre can be stretched

Many of the properties of synthetic fibres are different from those of natural fibres. Cotton absorbs moisture and allows sweat to evaporate. It is therefore comfortable to wear on hot days. Synthetic polyester does not wear out as easily as cotton, but does not absorb moisture. This makes it sticky and uncomfortable on hot days. By making clothes from a *mixture* of cotton and polyester, you have the properties of both fibres. For example, 65% polyester and 35% cotton is a common mixture. Clothes made from this blend are hard-wearing, comfortable in summer and drip-dry (non-iron).

Perming hair and creasing wool

Each strand of your hair contains many long chains of the protein keratin. These long polymer chains are held together by different types of chemical bonds. The strongest of these bonds is made up of two sulfur atoms.

In curly hair, the S–S bonds between the protein polymer chains hold the strands of hair in a curly shape. If you have your hair chemically straightened, solutions are added to your hair that break and re-form the S–S bonds, as in Figure 11.22.

In step 1, the hair is moistened, causing some of the bonds between the protein chains to break.

In step 2, the straightening solution is added. This causes a chemical reaction in which the remaining S–S bonds are broken. Because the cross-links have been broken, the hair is relaxed and can be combed straight. Unfortunately, the straightening solution has the ‘rotten egg’ smell of sulfur compounds.

In step 3, a neutraliser is added to reverse the reaction and re-form the S–S cross-links. As the hair dries it becomes strong again, with the cross-links now holding the strands straight.

Wool fibres are also made of protein polymer chains. Australian scientists from CSIRO developed a process to make permanent creases in wool. It works in much the same way as permanent waving of hair, which is the reverse of chemical straightening. Permanent crease skirts or trousers don’t lose their crease when worn or washed.

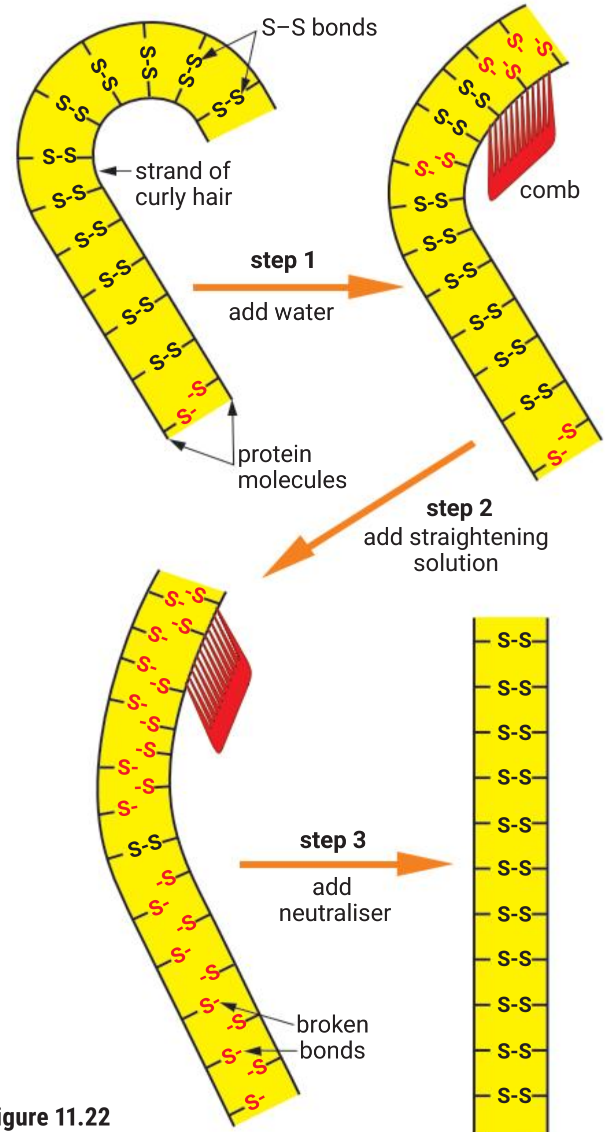

Figure 11.22
How the chemical straightening of hair works

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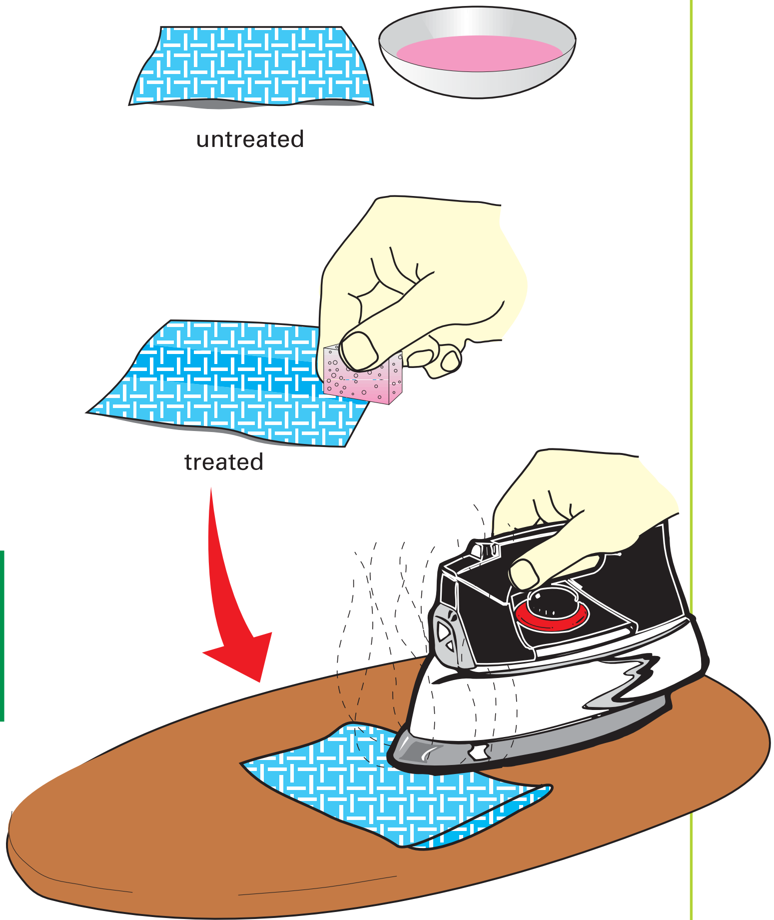
INVESTIGATION 11.2 Permanent crease

Aim

To make a permanent crease in a piece of woollen fabric.

Materials

- permanent crease solution (3% **sodium hydrogen sulfite** or **sodium metabisulfite** solution containing a little detergent)
- 2 pieces of woollen fabric
- sponge
- evaporating basin (or similar container)
- container for washing wool samples
- detergent
- hot water
- steam iron



Risk assessment and planning

Read the investigation carefully.

What safety precautions will be necessary?

PART A

Method

1 Pour some of the permanent crease solution into the evaporating basin. Sponge a line of solution down the centre of one of the wool samples.

2 Crease the sample along the sponged line and press the crease in with the steam iron for about 30 seconds. Using the steam iron again, press a similar crease in the untreated sample.

3 Wash both samples in hot water (about 70 °C) containing a small amount of detergent.

4 Take the samples out of the water and allow them to dry.

Compare the two samples.

Write a conclusion for the investigation.

PART B Inquiry

Design an experiment to answer one of these questions.

1 Does the temperature of the washing water in step 3 have any effect?

2 Does this permanent creasing method work for other fabrics, e.g. polyester?

3 What effect do different washing solutions have? Some you could try are liquid and powder detergent, ammonia solution, vinegar, wool wash and fabric softener.

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SCIENCE AS A HUMAN ENDEAVOUR

Goodyear and rubber

Rubber is a natural polymer consisting of long tangled molecules. Over the years scientists have learnt how to modify its properties and to make synthetic rubbers. But this process has not been straightforward, as this story shows.

For many centuries the native people of Central and South America used a milky liquid (latex) from certain trees to make elastic bouncing balls. The early European explorers used this latex to waterproof their clothes. This worked well until the sun melted the rubber, making it soft and sticky. And during cold weather the rubberised material became hard and brittle.

Charles Goodyear, an American inventor, became interested in finding a process to make rubber that would have the same properties in hot and cold weather. However, his experimenting soon used up the little money he had and he was put in prison more than once for owing people money. At one time he sold to the government a large order of mailbags that had been coated with his modified rubber to make them waterproof. But the mailbags turned sticky and shapeless from heat even before they left the factory.

Centuries ago, South American people discovered the essential properties and uses of the rubber tree.

After 10 years of unsuccessful experimenting, Goodyear accidentally spilt a mixture of rubber and sulfur on a hot stove. To his surprise the rubber didn't melt, and when he scraped it off and let it cool he found that it was not sticky. To test the rubber he left it outside in the cold overnight, and in the morning it hadn't become hard and brittle.

Goodyear continued experimenting and found the right amounts of rubber and sulfur to use and the best conditions for heating. He applied for a patent for a process he called *vulcanisation*, after Vulcan the Roman god of fire.

Goodyear didn't live happily even after his discovery. He had to defend his patent many times against people who wanted to steal his process. He was a poor businessman and never recovered from his huge debts. Not long before he died, he said:

Life should not be estimated exclusively by the standard of dollars and cents. I am not disposed to complain that I have planted and others have gathered the fruits. A man has cause for regret only when he sows and no one reaps.

Questions

1. What was wrong with the first rubber made from rubber trees?
2. What did Charles Goodyear mix with rubber to vulcanise it?
3. What is a patent?
4. Suggest how Goodyear could have avoided the disaster with the mailbags.
5. Read carefully what Goodyear said before he died. Rewrite this more clearly in your own words.
6. Using what you have learnt about polymers, explain why rubber is so elastic.

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CHECK

1 Why is it that the names of so many plastics start with P?

2 In some cars about 30% of the components used are made from plastics. Why do car manufacturers use so much plastic?

3 For each of the items below, list the properties of plastic that make it suitable for making that particular object.
  a hand-held hair dryer
  b packaging foam
  c stackable chairs

4 List the advantages and disadvantages of making drinking cups from plastic.

5 What is the monomer for the natural polymers cellulose and starch?

6 It is possible to recycle thermoplastics but not thermosets. Why is this?

7 a Look at Figure 11.15 on page 303. Explain in your own words how this process works.
  b How could this process be used to generate electricity?

8 Give at least one example of each of the following:
  a a natural fibre from a plant
  b a natural fibre from an animal
  c a synthetic fibre made from oil or coal

9 Which properties would be particularly important in choosing a fibre for each of the following uses?
  a fishing line
  b laboratory coat
  c non-iron shirt or blouse
  d swimwear
  e towel

10 Compare and contrast chemical straightening of hair and perming of hair.

11 Most synthetic fibres are thermoplastic. What does this mean? Why must a cool iron be used on clothes made from synthetic fibres?

12 Some people think that the cost of plastics will rise as the world's oil resources diminish. Why?

CHALLENGE

1 The casein polymer you made in the activity on page 301 is soft at first, but it hardens if you leave it for a day or so. Infer what causes this hardening. Draw a diagram.

2 Why do curls in hair tend to disappear when the hair becomes wet?

3 The table opposite compares the properties of wool and polyester (a synthetic competitor).
  a Make a list of the properties in which wool is clearly superior to polyester.
  b If you were employed by the wool industry to find ways to improve some of the properties of wool, which ones would you choose to work on? Why?
  c Design an experiment which could be used to measure a fabric's resistance to shrinkage.
  d How would you expect the crease resistance of wool to change in humid conditions? Why?
  e Suggest why polyester is so much better than wool at resisting insect attack.

4 In South Australia there is a returnable deposit on plastic drink bottles. Do you think this would significantly reduce the litter created by these items in your state? Explain.

Property	Wool	Polyester
strength	★★	★★★★
ability to accept a dye	★★★★	★
ease of use	★★★	★★
crease resistance	★★	★★★
resists insect attack	★	★★★★
low flammability	★★★★	★
resists shrinking	★	★★★★
does not show dirt	★★★★	★
moisture absorbency	★★★★	★
takes permanent crease	★	★★★
feel	★★★★	★

★ poor ★★ fair ★★★ good ★★★★ best

5 Suppose you have the five different amino acid units shown below. How many different protein fragments could you make by putting these five units together, using each one only once? Draw them.

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EXPLORE

1 a Various processes are used to shape plastics, e.g. injection moulding, extrusion and blow moulding. Use library resources to find out about these processes. To get you started follow the links to **Plastic processes**.

b The photo below shows how thin plastic film is made. Explain how you think this is done, starting from solid pellets of plastic.

2 Stretch a rubber band around a block of wood and put it in the freezer for about 10 minutes. Predict what you think will happen when you remove the rubber band from the block. Do it and observe what happens. Then try to explain what happened.

3 Check plastic containers on supermarket shelves or at home. Use the recycling symbols in the table on page 302 to identify the type of plastic in each.

a Add more uses to the right-hand column of the table.

b Which are the most common plastics?

c Are plastics recycled in your area? Which types?

4 Use the internet to research one or more of the following:

- What are conducting plastics? When were they first discovered? How are they different from normal plastics? What can they be used for?
- What are bulletproof vests made of? Follow the links to **How body armour works**.
- How do shampoos and conditioners keep your hair soft and shiny?
- What research is being done into spider-web fibres?

5 When you add hardener to a resin, it sets to form a thermosetting plastic. Use a resin kit to embed an insect in resin, like the mosquito in amber in *Jurassic Park*.

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11.3 Carbon in fuels

Carbon-based substances are commonly used as fuels all over the world. Coal is used in many power plants, including the power plants in Collie and Kwinana in Western Australia. Carbon is also present in the oil and natural gas that is extracted from deep underground in offshore wells on the North West Shelf.

Figure 11.23 Oil and gas platform on the North West Shelf

We use carbon-based compounds as fuels because of their availability, cost and partly because of the infrastructure that is already in place to use these materials as fuels. These fuels are non-renewable, so eventually will run out. They also produce harmful by-products, such as carbon dioxide, as they burn.

Extracting oil and gas

Carbon-based compounds can be extracted from various resources such as coal, crude oil and natural gas. These three are the major resources being mined in Western Australia. The petroleum industry, which controls the mining of oil and gas, is largely based in the north-west of the state, with Carnarvon, Port Hedland and other coastal towns having large offshore and onshore reserves.

Figure 11.24 Crude oil

Crude oil is transported to Kwinana (south of Perth) for refining, before being exported. The processing of fuels involves fractional distillation (see page 294), which separates the substances by boiling point (or chain length), and cracking, where less valuable long-chain hydrocarbons are broken into smaller molecules. **Cracking** involves breaking a long carbon chain (which can have 30 or more carbon atoms) into shorter chains of between two and 10 carbons. From there, the shorter hydrocarbons are sold as fuels for cars, planes and jet engines, and as liquid petroleum gas (LPG).

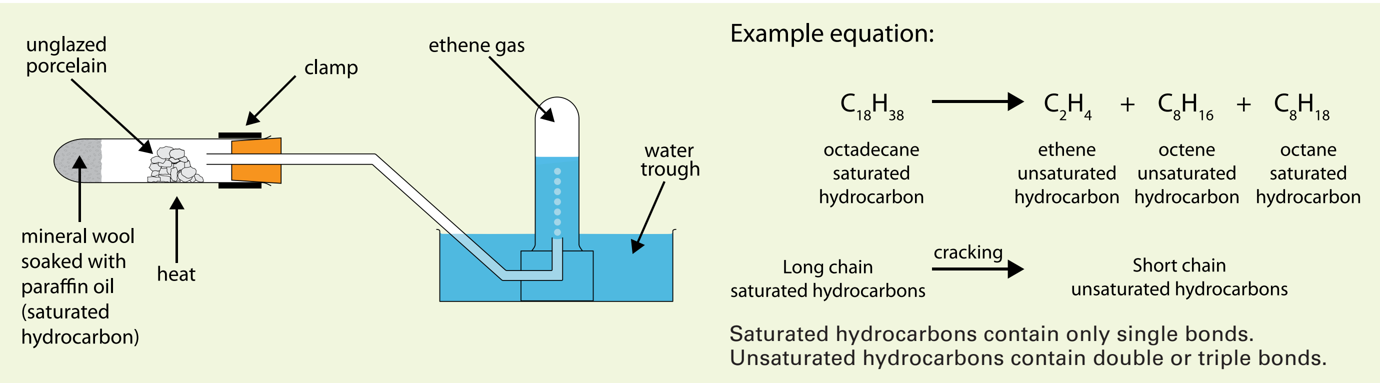

Figure 11.25 Laboratory cracking of paraffin oil

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Fuels

During combustion, fuels burn to release heat (as these reactions are exothermic) and produce carbon dioxide and water. As the length of the carbon chain increases, the amount of heat released during combustion also increases, as do the amounts of greenhouse gases.

The main greenhouse gas released from hydrocarbons is carbon dioxide, and impurities in different fuels can cause sulphur and nitrogen compounds to be formed during combustion. A common reaction that you may have observed is the burning of petrol, which contains octane (C_8H_{18}).

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

The equation above shows that when two molecules of octane burn, 16 molecules of carbon dioxide are released. Because each fuel contains a hydrocarbon with a different number of carbons, the amount of heat and CO_2 produced varies. With any fuel that we use, it is a compromise between how much the fuel costs, how much heat it releases and how much product forms.

Different fuels are used for different types of machinery and in different industries. Coal is a low-purity fuel, often used in power plants. It releases a large amount of heat energy, so is ideal for the production of electricity. Octane is used in cars, and butane (C_4H_{10}) is used in portable stoves. These are fuels that burn at much lower temperatures.

Biofuels

Biofuels are renewable, and are produced from the glucose ($C_6H_{12}O_6$) in grain and plants. The process of fermentation, which occurs naturally in some instances, forms bioethanol, which can be used as a petrol additive. The equation for this reaction is:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Biodiesel is another common renewable fuel, made from oils or fats, and can be catalysed by sodium hydroxide or lipase, which is a type of enzyme or natural catalyst. Biodiesel has a similar structure to longer-chain fuels like diesel and aviation fuel. But due to a different structure in the carbon chain of bio-compounds, they burn to release less carbon dioxide than traditional fuels. This, combined with their sustainable nature, makes them an increasingly common alternative to fossil fuels.

Figure 11.26 A factory producing biodiesel from rapeseed

Fuels and the environment

Carbon dioxide is the main greenhouse gas and is contributing to the climate change that is occurring in our world. The average concentration of carbon dioxide in our atmosphere is around 400 parts per million, but can be up to 10 times higher in cities and heavily industrialised areas. The concentration of CO_2 has been steadily increasing due to industrialisation and deforestation.

The increasing levels of carbon dioxide and other greenhouse gases is not only contributing to climate change, but is also causing *ocean acidification*. Carbon dioxide dissolves in water to form carbonic acid, which can change the pH of the oceans and affect the ability of coral and other organisms to grow.

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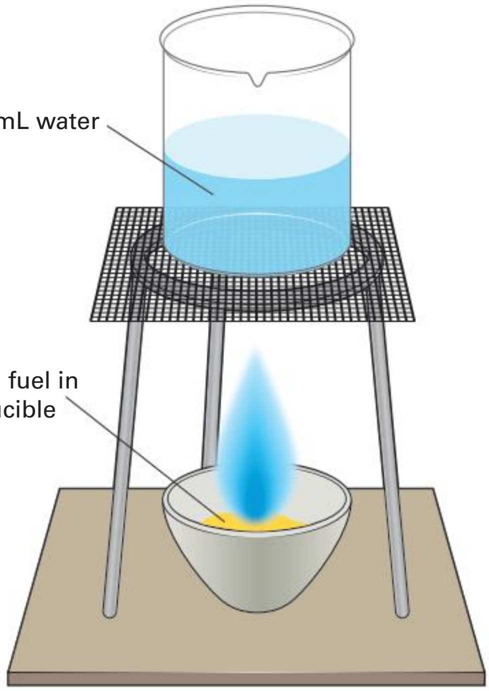
INVESTIGATION 11.3 Energy in fuels

Aim

To identify which fuel releases the most energy during combustion.

Materials

- 5 g ethanol
- 5 g propanol
- 5 g butanol
- 3 crucibles
- tripod
- gauze mat
- three 250 mL beakers, each containing 100 mL of water
- 3 thermometers
- matches



Risk assessment and planning

What safety precautions will be necessary?
Draw up a data table to record your results.

Method

1. Place 5 g of each fuel into the crucibles, labelling which fuel goes into which crucible.
2. Place the first crucible on a heatproof mat and put the tripod and gauze mat over it, placing the first beaker on top of the tripod.
3. Record the initial temperature of the water in your data table and then ignite the first fuel.
4. Observe the water temperature increase, and record the temperature at its highest point.
5. Repeat the experiment using the second and third fuels.

Discussion

1. Write balanced equations for the combustion of each of the three fuels.
2. Which fuel produced the most heat energy? Represent your data on a graph.
3. Which fuel would you choose to use as a fuel?
4. Predict whether hexanol, which has a longer carbon chain, will produce more or less heat.
5. State three variables that were controlled in this experiment, and then determine another three variables that could have been controlled to give more reliable results.
6. Explain the difference between reliable results and valid results, with reference to this experiment.
7. Explain three errors that were made in this experiment, and suggest how you could minimise these errors if you repeated the investigation.

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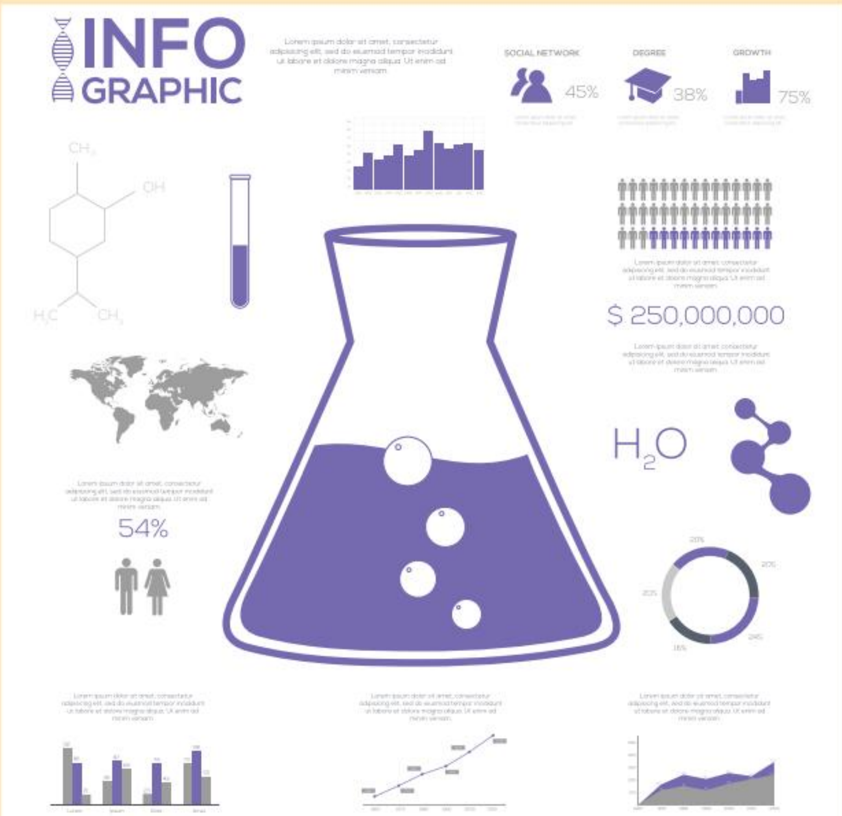
SKILLBUILDER

Designing an infographic

Infographics can be used to show data in attractive and informative ways. By representing information in different colours and graph types, we can attract the eye to important information. When designing an infographic, it is important to know your target audience, and create something that will appeal to them. The design should attract people and encourage them to read and respond to the data presented.

Infographic 1



Infographic 2

1 Infographic 1 has been designed for young children and so uses bright colours and minimal text. Infographic 2 uses much less colour and more complex language and diagrams. Who might it have been designed for?

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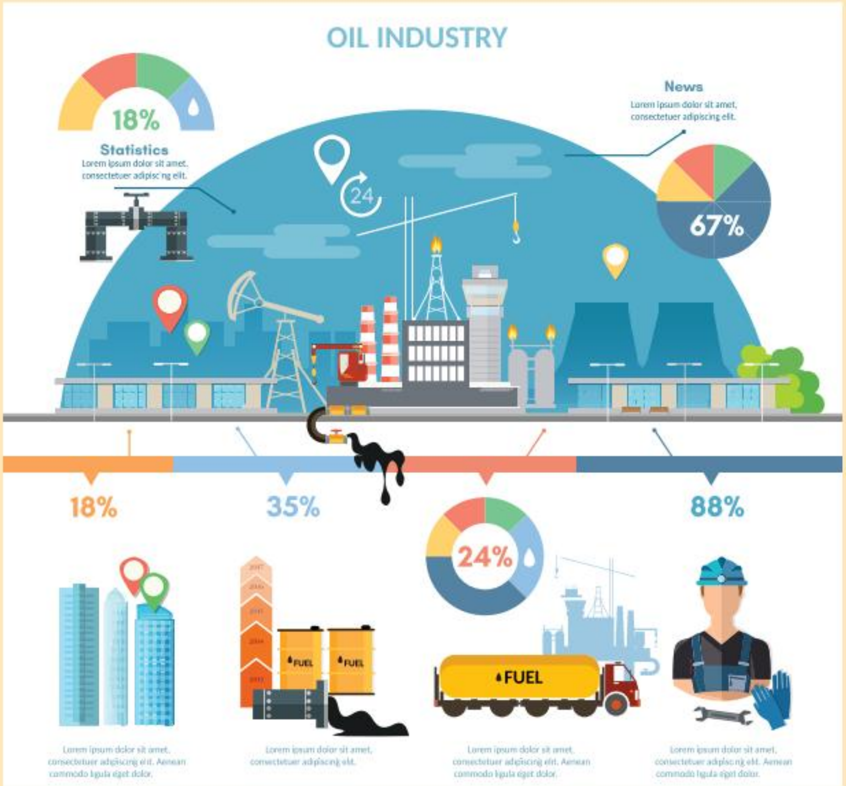
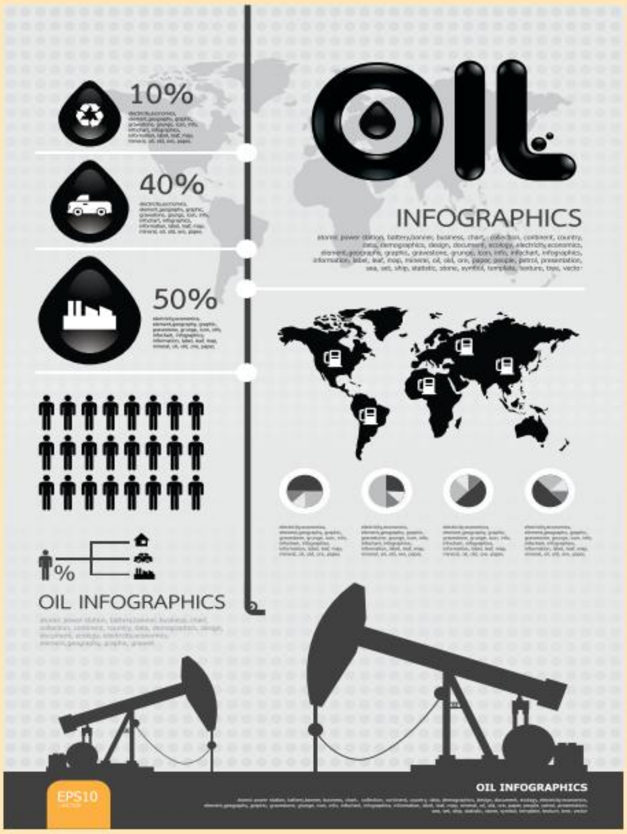
2 When you compare the infographics 1 and 2, you can see obvious differences in the target audience. By manipulating the presentation, information can be highlighted or hidden. Look at infographics 3 and 4. They both present information on the oil industry. Which one do you think makes the industry look more appealing? Why?



Infographic 3



Infographic 4

3 Design an infographic that compares biofuels and fossil fuels. Your design should be targeted towards people your own age, and should present them with information about the availability, renewability, cost and polluting emissions of the two fuel types. The infographic should not be designed to overly present an opinion, but as you have seen with other infographics, it is possible to highlight one fuel source over the other. Present your infographic to the class and reflect on whether biofuels or fossil fuels are the better source of energy.

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CHECK

1 What are the main fuels mined in Western Australia?

2 Where are Western Australia's gas reserves?

3 What are some of the impurities that are mined with coal?

4 When coal burns, what are the products?

5 a State the names and formulas of four gases that are formed from the combustion of fuels.
  b What are some of the harmful ways that these gases can affect us?

6 Research the change in greenhouse gas emissions from the start of the industrial revolution until the present day.

7 What are the components of E10 fuel? How does this differ from 91-octane petrol?

Figure 11.27 E10 fuel is available at some petrol stations.

CHALLENGE

1 a Research the difference between black and brown coal.
  b Research the main areas of coal mining in Western Australia.
  c Research the contribution that the oil and gas industry makes to the Australian economy, and comment on whether you expect that to increase or decrease over the next 20 years.

2 Research the methods used to produce biodiesel, and compare and contrast the base-catalysed and lipase-catalysed methods.

3 Compare the production of biofuels with other sources of renewable energy and comment on their efficiency, usefulness and renewability. Explain why some situations are better suited to the use of biofuels than other forms of renewable energy.

Figure 11.28 Renewable energy sources

MAIN IDEAS

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

1 Crude oil is a mixture of ______ (compounds containing hydrogen and carbon) that can be separated by fractional ______.

2 ______ is the process where the long chain hydrocarbon molecules in crude oil are broken down into ______ , more useful molecules.

3 Soaps and ______ both contain long molecules with a water-loving end and a grease-loving end.

4 Polymers are very large molecules made by joining many small molecules together in a process called ______.

5 Plastics are synthetic polymers that can be ______ into various shapes.

6 ______ melt when heated, but ______ do not (due to cross-links between the polymer chains).

7 Fibres consist of natural or ______ polymers. Their properties depend on the type of polymer they contain.

8 Oil and gas are common _________ compounds used as fuels. When they burn they release heat and form _________ gas.

9 Renewable _________ such as _________ and biodiesel are increasingly being used to replace _________ fossil fuels.

ethanol
distillation
moulded
synthetic
detergents
carbon
cracking
polymerisation
carbon dioxide
biofuels
hydrocarbons
thermosets
thermoplastics
non-renewable
smaller

CH•11 REVIEW

1 Soap works as a cleaning agent because:
- **A** it has long chain-like molecules.
- **B** it is made from grease.
- **C** it dissolves in water.
- **D** its molecules have a water-loving end and a grease-loving end.

2 A polymer is a substance that is:
- **A** made up of many small molecules linked together.
- **B** formed when two or more chemicals react together.
- **C** made soft by heating.
- **D** like bakelite.

3 Ryan and Aiden wanted to know how the heat of combustion of an alcohol is related to the number of carbon atoms in the alcohol molecule. They did an investigation like the one on page 314 and recorded their results in a data table.

Alcohol	Formula	Heat of combustion (kJ/mol)
methanol	CH_4O	726
ethanol	C_2H_6O	1367
propanol	C_3H_8O	2021
butanol	$C_4H_{10}O$	2676

a Plot Ryan and Aiden's data and draw a line of best fit.
b Write a generalisation linking the heat of combustion to the number of carbon atoms in the alcohol.
c Use your graph to predict the heat of combustion of pentanol $C_5H_{12}O$.

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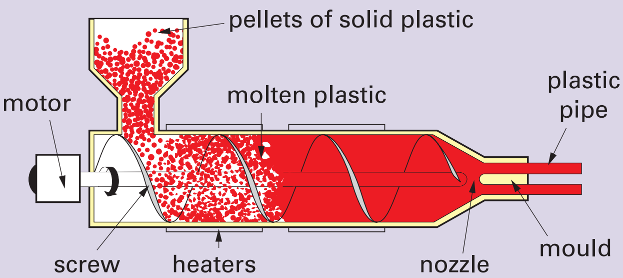
4 Which of the following statements are true and which are false? Rewrite the false ones to make them correct.

- **a** Carbon atoms form four chemical bonds.
- **b** Hydrocarbons contain carbon, hydrogen and oxygen atoms.
- **c** Only thermoplastics can be recycled.
- **d** Hair and wool are both protein polymers.
- **e** Petrol has a higher boiling point than diesel fuel.
- **f** Long-chain hydrocarbons can be broken down by fractional distillation.
- **g** When petrol burns it forms carbon dioxide and water.
- **h** The correctly balanced equation for the combustion of butane (C_4H_{10}) is:
  $C_4H_{10} + O_2 \rightarrow 4CO_2 + 5H_2O$

5 The diagram shows how plastics are shaped by the process of extrusion.

- **a** Use the diagram to explain how this process works.



- **b** Which one of the following products could *not* be produced by this method?
  - **A** PVC pipes
  - **B** detergent bottles
  - **C** roof guttering
  - **D** biro casings

6 The boiling points of four liquids are as follows:

	Boiling point (°C)
acetic acid	118
acetone	56
propanol	97
water	100

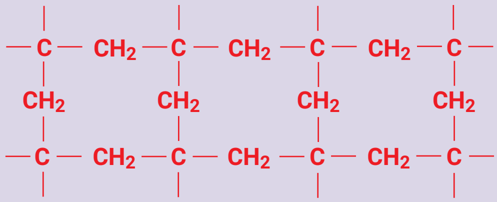
Suppose you had a mixture of these liquids, and you distilled it.

- **a** Which would be the first substance to distil? Which would be the last?
- **b** Two of the liquids are very difficult to separate by fractional distillation. Which are they, and why are they difficult to separate?

7 Polymer A consists of carbon atoms bonded like this:

$— CH_2 — CH_2 — CH_2 — CH_2 — CH_2 — CH_2 — CH_2 —$

Polymer B consists of carbon atoms bonded like this:



- **a** Which polymer, A or B, is a thermoplastic? Give a reason.
- **b** Which polymer would not melt on heating?
- **c** Which polymer would be stronger? Why?
- **d** Which polymer could be recycled?
- **e** Which polymer is polythene?

8 A major manufacturer of school uniforms is concerned by reports that their windcheater jackets develop holes in the elbows after only a few weeks wear. They insist that threads of the fabric used are able to support very large loads without breaking.

- **a** Write a short explanation of why the breaking strength of the thread is not the problem.
- **b** Describe a test that could be used to decide whether the jackets were any better or worse than those of their competitors.

Check your answers on page 352.

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IN THIS CHAPTER

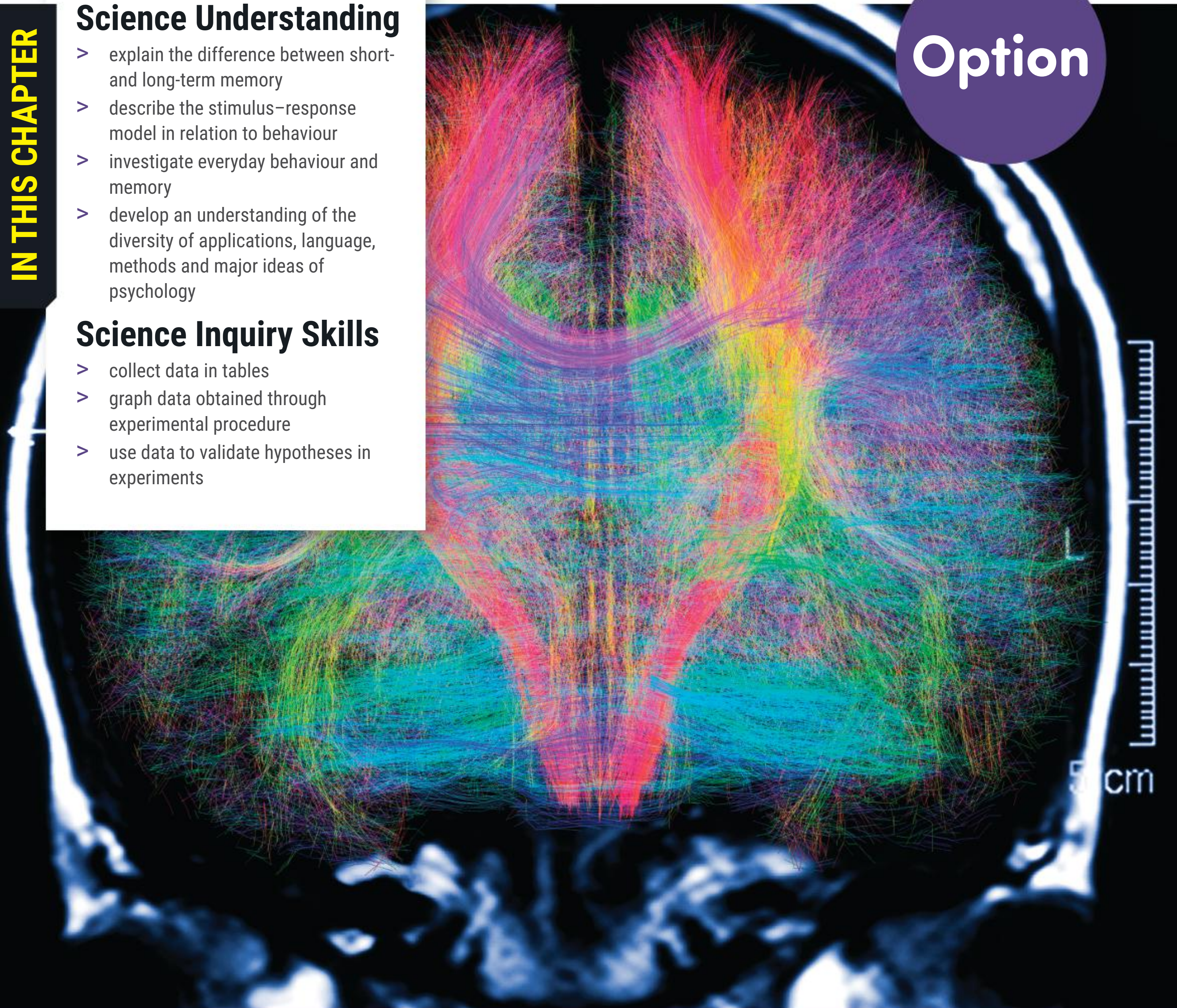
Science Understanding

- explain the difference between short- and long-term memory
- describe the stimulus–response model in relation to behaviour
- investigate everyday behaviour and memory
- develop an understanding of the diversity of applications, language, methods and major ideas of psychology

Science Inquiry Skills

- collect data in tables
- graph data obtained through experimental procedure
- use data to validate hypotheses in experiments

Option



CH•12 Psychology

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GET STARTED: *EXPLORE*

One aspect of psychology is investigating how our memory works. On the right are two lists of words. List A is made up of nonsense words (words that don't make sense) and List B has common everyday words.

1 Allow your partner 10 seconds to look at the words in List A.
2 Cover up the list and get your partner to write down as many words as they can remember in 30 seconds.
3 Repeat with List B.

From which list did they remember the most words?

Explain why you think it was easier to remember the words from that list instead of the other list.

List A Nonsense words	List B Common words
ator	alligator
botam	apple
crov	arrow
difim	baby
firap	bird
glimoc	book
gricul	butterfly
hilnim	car
jolib	corn
kepwin	flower
eptav	hammer
lumal	house
mib	lemon
natpem	microscope
peyrim	ocean
rispaw	pencil
stiwin	rock
tubiv	shoes
vopec	table
yapib	window

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12.1 What is psychology?

Have you ever wondered why you remember certain events in your life but not others? Why is everyone different in what they do and how they react? Scientists have studied the human mind and how people behave since the time of ancient Greece. However, the official scientific study of psychology is relatively new—only just over a hundred years old.

Psychology is a branch of science, because it deals with human behaviours and cognitive functions. It also involves scientific investigations to confirm or dismiss hypotheses about behaviours. Today, psychological research into human and animal behaviour is driven by six common approaches: psychodynamic, behavioural, cognitive, humanistic, evolutionary and sociocultural.

Approaches to psychology

The *psychodynamic approach* to psychology originated in the works of Sigmund Freud. It deals with the behaviour and mental processes of people as an unconscious struggle. Its basis is that a person's subconscious plays a major part in their actions and behaviours.

The *behavioural approach* stemmed from the research of John Watson. Its focus is on what is observable behaviour and, from these observations, how behaviour is learnt. It also includes a study of how rewards and punishments affect people's behaviour.

The *cognitive approach* focuses on how information is taken in, represented mentally and stored. It also examines how information is perceived and processed.

Behaviour is the result of people choosing how they think and act, and this is the basis for the *humanistic approach*. A person's experiences will guide their thoughts and actions, and their choices are affected by the individual's perspective.

Charles Darwin had specific ideas on both evolution and natural selection. The *evolutionary approach* assumes that a person's behaviour and mental processes are a result of evolution and their genes.

The *sociocultural approach* is very common in a multicultural society. It studies how people's beliefs and cultural background influence their behaviour.

Psychologists tend to use a combination of these approaches. For example, clinical psychologists use *cognitive behaviour therapy*, which is a combination of the behavioural and cognitive approaches.

In this chapter we will examine two main areas of study: memory and behaviour. How we remember events and information is a factor in how we behave in different circumstances. Both these things make us the people that we are. Many of the above approaches are applied throughout the chapter.

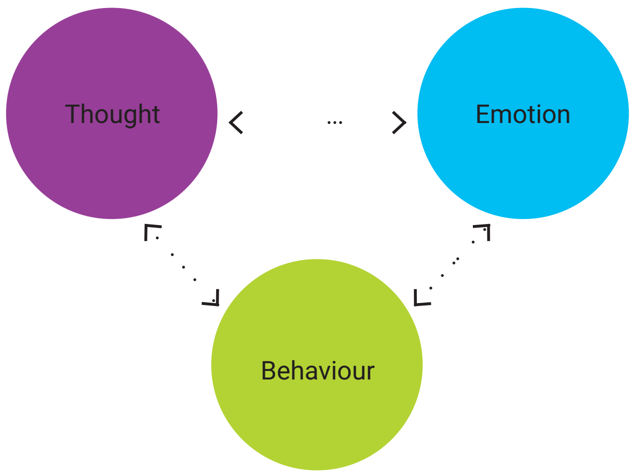

Figure 12.1 Three major areas of psychology

Types of psychologists

Psychologists are scientists, and there is a large variety of fields in which they can work. These include:

- counselling
- clinical
- neuro
- educational and developmental
- sports and exercise
- forensic

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All these fields use aspects of modern psychology in their treatment and research techniques. For psychologists to be effective, they must understand how the mind works and how people behave.

Figure 12.2 Note-taking is essential for a psychologist.

Counselling psychology focuses on a variety of mental health issues, such as depression, anxiety and family or social problems. Counselling psychologists focus on the wellness and strengths of their patients to assist them with their problems. Counselling psychologists encourage their patients to work through their own problems and provide them with strategies to assist them.

As children develop from early childhood to adulthood they may encounter problems with their development or learning. *Educational psychologists* are skilled in diagnosing people with learning difficulties. They are also trained to work with children as they transition through school, and help them with peer relationships.

Forensic psychology requires psychologists to apply their knowledge and skills to the legal and criminal systems. This is a growing field within psychology, largely due to the increase in criminal profiling. A psychological profile is a description of the likely character, behaviour and interests of a violent criminal.

ACTIVITY

Could you be a witness?

One of the most important parts of a prosecuting team is an eyewitness. The memory of an eyewitness to a crime can be used to convict someone of committing that crime. However, people aren't like video cameras, and in a stressful situation their memory is not as reliable.

1. As a class, role-play a crime. Give everyone a role: witness, criminal, crowd. Nobody in the class should know who the 'criminal' is.
2. Have the criminal commit a fake crime. Make it a maximum of 10 seconds and get the crowd to cause a diversion.
3. After the 'crime', get the witness to give a detailed description of the criminal (not just the name of the person who was the criminal). Focus on things like their height, build, clothes, hair length, colour and so on.

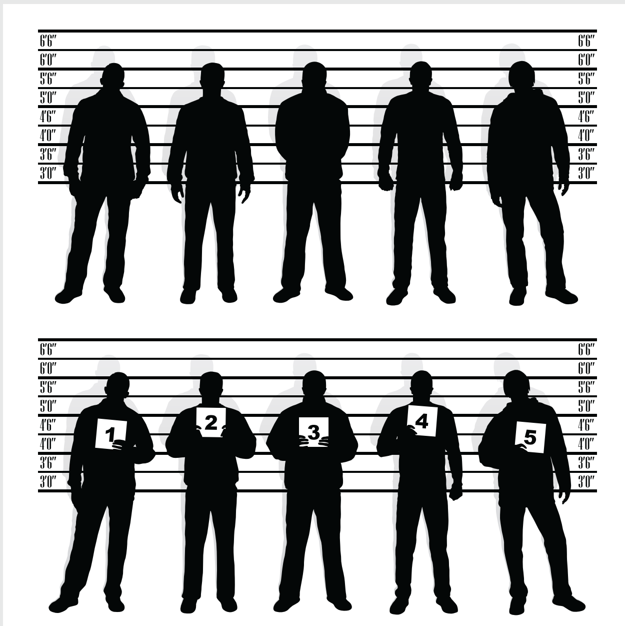

Figure 12.3 A police line-up

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SCIENCE AS A HUMAN ENDEAVOUR

Sports psychology

Sports psychologists have a diverse field of expertise. As well as working with professional athletes to help them attain their best, they also help non-athletes improve their sense of wellbeing through various forms of exercise. Sometimes people reach a mental barrier that they feel they can't overcome. This may be due to negative self-talk after experiencing 'failure' that causes them to believe that they won't succeed before they even start. They may also suffer anxiety or stress that causes them to become fearful of failure and resistant to attempting tasks.

Some of the major techniques sports psychologists use are:

- *visualisation*, where they work with people on visualising a task or an event and attaining success
- *motivation*, where people learn to use both intrinsic and extrinsic motivators in their training
- *mindfulness*, where the person focuses on an object, moment or feeling and ignores any surrounding problems.

ACTIVITY

1 Using the technique of visualisation, devise a plan for a professional athlete to improve their focus during a game.

Visualisation is a primary technique used by sports psychologists and sometimes also by other psychologists. It is a technique where you program your subconscious brain with positive thoughts. Most people, especially during times of failure or stress, will have programmed their subconscious with negative thoughts. By practising visualisations, the athlete will be able to visualise success and also to reprogram their subconscious.

2 Another technique that can be used is mindfulness.

Choose a natural object from within your immediate environment and focus on watching it for a minute or two. This could be a flower or an insect, or even the clouds or the moon. Don't do anything except observe the thing you are looking at. Simply relax into a harmony for as long as your concentration allows. Look at it as if you are seeing it for the first time. Visually explore every aspect of the object. Allow yourself to be consumed by its presence. Allow yourself to connect with its energy and its role and purpose in the natural world.

At the completion of this activity you should feel a sense of calm. This is a technique that requires practice.

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ACTIVITY

Dyslexia

A specific learning difficulty is where a student has a significant difficulty in one academic area, while they cope well in other areas. The most common specific learning difficulty is **dyslexia** (dis-LEXI-a). Students with dyslexia experience difficulties with reading accuracy, reading rate and comprehension. They also struggle with phonological coding, which is to do with the sound structure of language as distinct from its meaning. Dyslexia affects people in different ways. The link below to an online simulation will help you understand what it feels like to read with dyslexia.

Describe how dyslexia affects a person's learning.

Experience it:
Reading issues

CHECK

1 What are the six modern approaches to psychology?

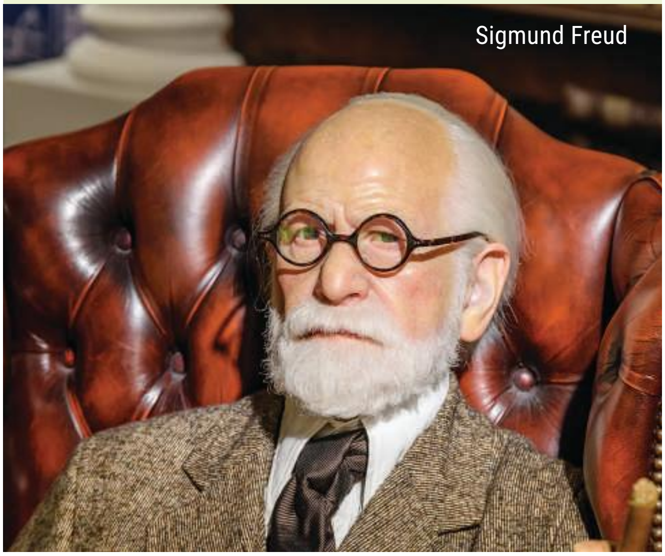
2 List four branches of psychology.

3 Describe what areas a forensic psychologist would focus on to profile a criminal.

4 Research some of the techniques that a psychologist may use to assist a person with anxiety.

CHALLENGE

1 As described previously, psychology has its roots in ancient Greece. As with all sciences, there were—and still are—opposing and different viewpoints. The science of psychology has also changed over the years. Research these psychologists and explain how their approaches have had an influence on modern psychology.
- Wilhelm Wundt
- Ivan Pavlov
- William James
- Sigmund Freud


Sigmund Freud

EXPLORE

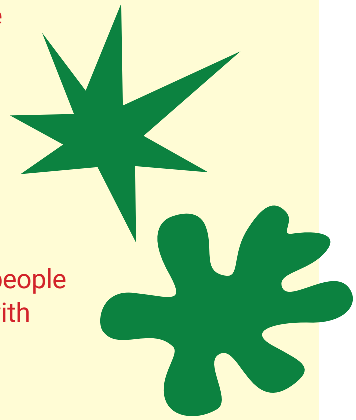
Do shapes prompt our memory?

With their ability to use language to communicate, humans are different from other animals. As humans have evolved, our language has moved from symbols and gestures to actual words. Below are two shapes. Study the shapes, then name one shape 'Bouba' and the other shape 'Kiki'. Take a photocopy (or redraw them) and ask a sample of 20 people which one they think is 'Bouba' and which one is 'Kiki'.

a Before you conduct the experiment, describe what you think your results will be.

b Compare the actual results with what you originally thought.

c Explain why you think people identified the shapes with certain names.



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12.2 Memory

Our memory is the process that enables us to recall past experiences and information. It is an essential aspect of our life. Without memory, we wouldn't be able to remember what we had for breakfast, the names of our family or how to get to school. For psychologists, the process of memory can be broken down into the five stages shown below.

The five stages of memory

Input ▶ Encoding ▶ Storage ▶ Retrieval ▶ Output

- *Input* is the information coming into the memory through the senses (sight, touch, sound, smell and taste).
- *Encoding* is putting the information into a format that the memory can recognise. When we view an object in 3-D, it is converted to a 2-D image as our memory cannot keep it as a 3-D image.
- *Storage* is filing away information so we can use it later.
- *Retrieval* is searching for the information that has been encoded previously and accessing it so we can use it.
- *Output* is responding to or using the information somehow.

Input

The input of information can come via any of the senses. As a young child you may have smelt biscuits baking, and now as a teenager, when you smell that aroma, your memory will make you think that biscuits are baking. There are many psychologists who believe that our senses influence our decisions and behaviours more than we realise. Proof of this theory is the fact that smelling a vanilla scent will increase our appetite.

Another example of input is sound. If you hear a clap of thunder, you will assume that there is lightning and possibly a storm coming. This is due to the fact that previously, when you heard that sound, lightning followed and possibly also heavy rain.

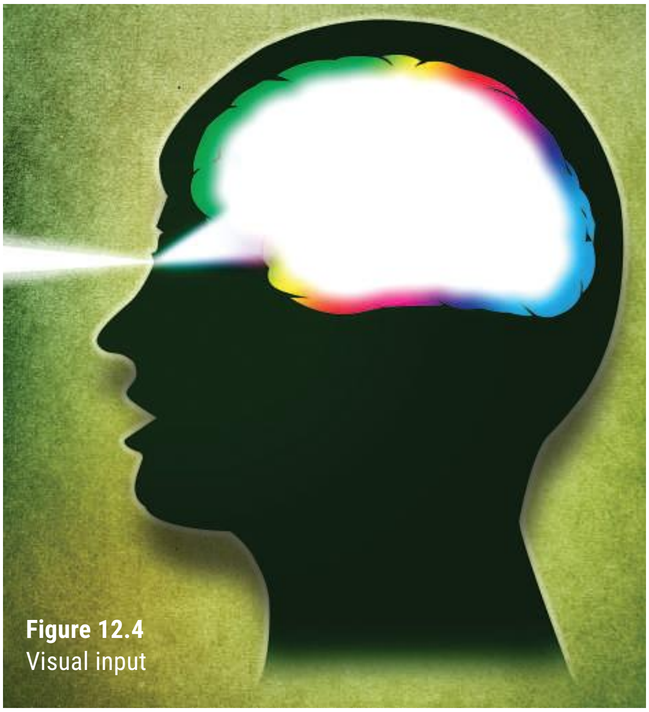

Figure 12.4
Visual input

Encoding

When information is obtained from a sensory input, it needs to be changed into forms that the brain can process. There are three main ways in which the information can be encoded:

- visual (in the form of a picture)
- acoustic (in the form of a sound)
- semantic (in the form of a meaning).

To ensure a memory is encoded properly you must first be paying attention, and since we can't be paying attention all the time, most input is never encoded and made into a memory. If everything we saw, felt or heard became encoded, our memory would be filled very quickly. Therefore, if you want information to be stored, you must make sure that you are paying attention.

Storage

The way the information is stored determines how long the memory will last for, how much is stored and what information is stored. If we think of the storage as 'slots', our memory has certain slots for **short-term memory**, which only lasts 10 to 30 seconds, and more slots for **long-term memory**, which can last a lifetime.

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Short-term memory has only limited slots and that is why the memory will last only a short period of time. For example, to make sense of the previous sentence, you must remember the first part of the sentence. However, after a period of time, you will have forgotten what the start of the sentence was. For you to convert this to long-term memory, you need to rely on alternative methods, such as repetition, giving it meaning or linking it to previously acquired knowledge.

The capacity of short-term memory can be increased using a technique called 'chunking'. Chunking is where the information is broken into smaller, relatable information 'chunks' so it can fit into a single slot. Short-term memory is sometimes also referred to as working memory.

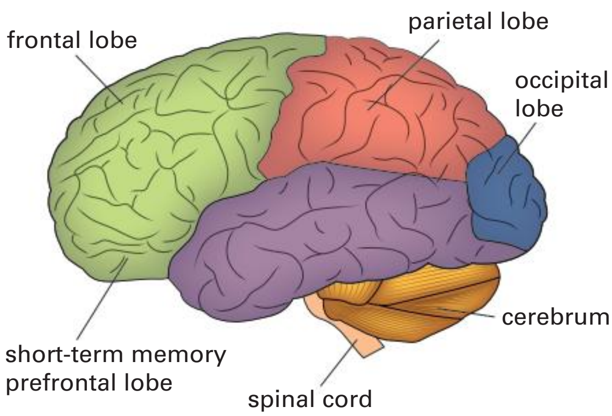

Figure 12.5 It is generally thought that the prefrontal lobe of the brain is used as a short-term memory store.

Retrieval

If we can't remember the information, we cannot retrieve the information. Short- and long-term memory are retrieved in different ways.

The way short-term memory is stored means it must be retrieved sequentially. An example is when you memorised the words in Get Started on page 321. To recall the fourth word, you would have had to go through the list sequentially until you remembered it.

The way long-term memory is stored means it must be retrieved by association. There are two main methods to do this: recall and recognition.

Recall is simply remembering a fact or an event; for example, remembering your phone number. Recognition is the association of an event, fact or sense with something that you may have encountered previously; for example, remembering the name of someone from primary school. You can link that person to something you did together at primary school, which helps you to remember their name.

All of us have forgotten things, names or events. There are many reasons for forgetting a memory, including trauma, ineffective coding, ageing or retrieval failure. It has been found that linking an event to an emotion will increase the chances of it being stored in long-term storage. Are you able to recall events at times when you were happy, in pain or sad better than events that occurred on a standard day?

Output

The output of memory is the final action—how you react verbally, physically or emotionally to a certain stimulus. If you see a dog running towards you and you turn and run away or climb onto something, the output may be a reaction to a past memory or experience that tells you the dog is dangerous and likely to act in a vicious manner.

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Factors that can affect your memory

As mentioned earlier, humans have both short- and long-term memory. First, things are stored in our short-term memory, which has a limited storage capacity and can only be stored for no longer than 30 seconds. Information is either lost, or transferred from short-term to long-term memory, where it can be retained. There are many factors that have been proven to affect our memory. Some of these are discussed below.

Excessive alcohol use has been proven to cause memory loss. The damage isn't caused to the brain cells; it is the dendrites—the nerve connections between brain cells—that are mostly affected by alcohol use. It is this damage that causes a loss in memory.

Sleep deprivation also affects memory. That is why it is important that you sleep well before an exam or test. It is not just the quantity of sleep that is important, but also the quality. Waking up throughout the night and having a disturbed sleep affects our capacity to recall information.

There are other factors that inhibit memory retention, and the problem often occurs at the encoding stage. For example, stress and anxiety often affect our memory and concentration. When we are experiencing periods of stress our brain can become overstimulated, so our ability to transfer to long-term memory is affected. Excessive stress can also lead to complete memory loss. Another issue can be distraction—if we aren't focusing fully, the information is unlikely to be encoded.

Head injuries that involve an injury to the brain can cause significant and immediate loss of memory. This will cause both short- and long-term memory loss, although in some cases the memory may improve over time.

There are symptoms and disorders that will affect memory. Many of these are common in the elderly, but they can occur at all ages. **Dementia** (de-MEN-sha) is the name of a group of symptoms that causes the loss of cognitive ability and other disorders affecting the brain. People experiencing dementia have problems with both short- and long-term memory. Disorders that have dementia as a symptom include Alzheimer's, Huntington's and Parkinson's.

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Memory techniques

It is important for the recall of information that items and facts in short-term memory are transferred to long-term memory. This is crucial when you are studying. One of the best techniques for transferring information is rehearsal, where you practise something over an extended length of time. That is why it is best to study small amounts of information over a long time, rather than 'cramming' for an exam. It is also important that you carry out your study in the correct way with the correct information. If you are practising in the wrong way, this can affect your encoding and how you store information in your long-term memory.

There are many other helpful studying techniques to improve memory. For example, you could use more than one sense: reading things out loud can sometimes help retention and retrieval, or putting the information into a song, or even giving it a rhythm. When you learn new information, making connections or associations with previously learnt information can also help with remembering. When an association is made, it makes it easier to retrieve the new information.

There is also a strong link between emotions and memory retention. This is demonstrated by memories surrounding trauma or enjoyment, as the memory is attached to the emotion. However, memories associated with an emotion are not always accurate because at an emotional time our perceptions may influence our memory. Sometimes memories of a traumatic event are remembered as being a lot worse than the actual experience.

INVESTIGATION 12.1 Effects of exercise

Aim

To investigate whether exercise or other activity has an immediate effect on memory.

Materials

- obstacle course in playground, or board game
- tray with 20 random objects with different colours
- tray with 20 random objects, all the same colour

Method

1. Do an initial memory test by looking at the first tray with random objects on it for 30 seconds and then trying to remember as many as possible in 2 minutes.

   Record your results in a data table like the one shown here.
2. Complete the obstacle course or play the board game for 10 minutes.
3. Go back to the memory tray for 30 seconds and again try to remember as many objects as possible in 2 minutes.
4. Repeat the whole exercise with a tray of 20 objects, all the same colour.
5. Compare your results with the rest of the class, and calculate averages.

Discussion

Did the obstacle course affect people's memory? What about the board game?

Name	Initial number remembered	Number remembered after obstacle course/board game	Difference in number remembered
Different-colour objects			
Same-colour objects			

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SCIENCE AS A HUMAN ENDEAVOUR

Alzheimer's disease

Can you remember a time when you saw someone you know but couldn't remember their name? Or a time when you'd forgotten where you put your keys or your phone? For people suffering from Alzheimer's disease this can be an everyday occurrence. **Alzheimer's** (ALTZ-heim-ers) is the most common form of dementia, accounting for around 70% of dementia diagnoses. Dementia is a term that describes a wide range of diseases associated with a decline in memory or thinking skills. Alzheimer's was first recorded in 1907 by Dr Alois Alzheimer, who reported a case of a middle-aged woman who had dementia, with various changes in her brain. Initially the condition was only considered to be in patients over 60 years of age, and it wasn't until the 1970s when Dr Robert Katzman, a neurologist, reported that it was a disease that could affect adults of any age.

The early stages of Alzheimer's can be very hard to detect as it usually begins with forgetting things, such as where you placed personal items, and having difficulty finding the right words that you use every day. The symptoms may vary from day to day or even across a day, and some patients demonstrate an increased level of dementia in the afternoon. Other symptoms include:

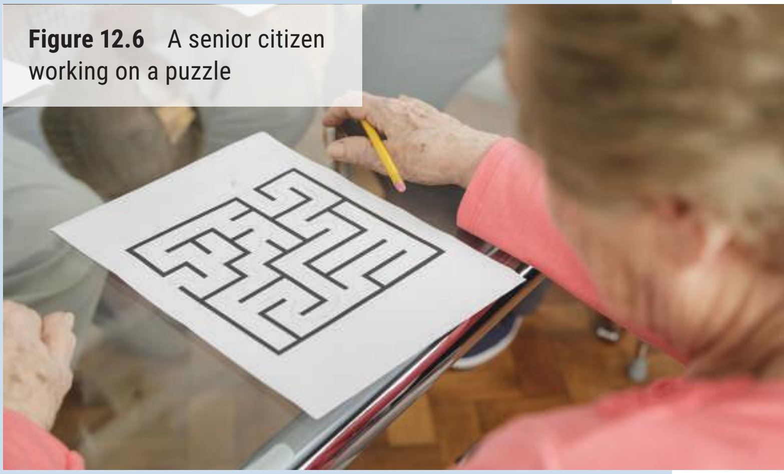
- loss of social skills
- emotional changes
- increased vagueness in conversations
- decreased memory, even of recent events.

Through the research done into Alzheimer's, several risk factors have been identified:

- Age: the incidence increases with age
- Mental activity: challenging the brain can lower the risk
- Being connected in the community can lower the risk
- Alcohol consumption: over-consumption causes damage to the brain
- Physical activity increases brain function and lowers the risk
- High blood pressure increases the risk.

Alzheimer's is what is called a progressive disease, which means it gets worse over time. Although there is currently no cure for Alzheimer's, a large amount of research is being conducted.

Figure 12.6 A senior citizen working on a puzzle



Questions

1 In groups, research activities that are helpful to delay the onset of dementia.
2 Examine what options of care are available for patients with dementia.
3 Alzheimer's isn't the only dementia disease. List some other dementia diseases.
4 Research whether or not there has been an increase in the number of cases of dementia, and explain the results.

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INVESTIGATION 12.2 Music and memory

Aim
To find out how listening to music affects concentration.

Materials
- online 'Concentration' game
- laptop or ipad (if not available, use a memory game with cards)
- students' favourite songs

Method
1. Download Concentration or a similar memory game (or use cards).
2. Play the game and record your scores.
3. Listen to your chosen song with earphones while playing the game. Once again record your score.
4. Compare your results with the rest of the class, and calculate averages.

Discussion
1. Did listening to music while you played the game improve your score?
2. Do you think the type of music would make any difference? Explain.
3. Discuss with your classmates whether they listen to music when they study, and why they choose to do this.

CHECK

1. What are the five stages in the process of memory?
2. Review the data you obtained memorising the common and nonsense words on page 321. Which one of the five stages do you think caused the delay in memorising the nonsense words?
3. Alzheimer's is a form of dementia. How does dementia affect a person's memory?
4. List three ways of making it easier to remember people's names.
5. Describe an event from your early childhood that you remember vividly. Explain why you think you remember this event so well.
6. Choose a partner and, with your eyes closed, describe the items in the room to your partner. What things did you remember and what couldn't you remember?

EXPLORE ONLINE

One of the recent recommendations to avoid loss of memory is to exercise the brain, in the same way you would exercise any other muscle. These activities are called 'brain training'. Some examples include crossword puzzles and sudoku. Today, many brain-training activities are completed online and are performed daily in short sessions. They are suitable for all ages and are promoted to improve memory. Below are some examples.

Brain games

Brain training

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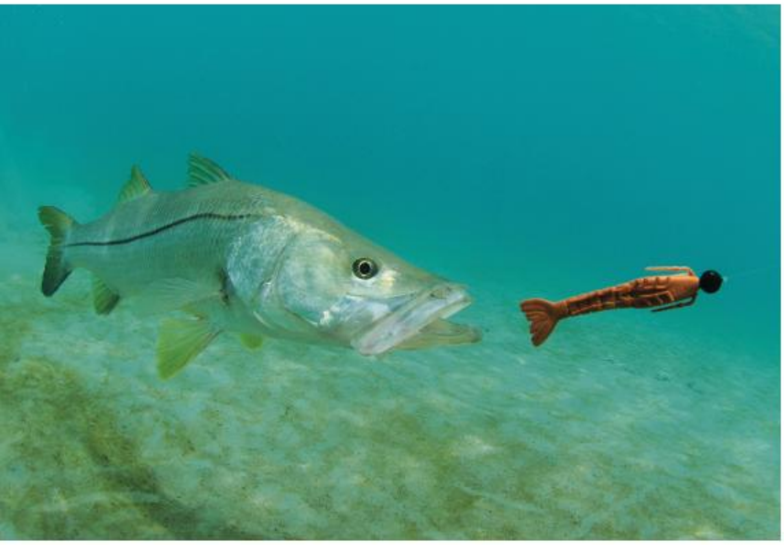
12.3 Behaviour

Behaviour is how we act and what we do. It is the way living things respond to the changes in their environment. Behavioural analysis using the **stimulus–response model** is one scientific method used to look at both animal and human behaviour.

For a response or a behaviour to occur, we must first have a **stimulus**. A noise, an action, a sensation or words are all examples of a stimulus. The stimulus is received by the receptor (a sense organ), which then uses the nervous system to convey the message to the muscles or glands that produce a response. Take for example someone scaring you. You hear the person shout 'Boo!' and the message travels through nerves to the muscles, which produces the response of you jumping.

Another example of stimulus–response is a fish seeing a lure and opening its mouth to swallow it. This is an automatic response as the fish sees the lure as a food source.



Reflex actions

A **reflex action** is a rapid response to a stimulus that occurs when the nerve impulse from the receptor travels to the muscle or gland and doesn't get processed by the brain. An example is shutting your eyes when you sneeze. Here's another one: try to keep your eyes open as a partner touches your eyelid. Why do you think you reacted this way?

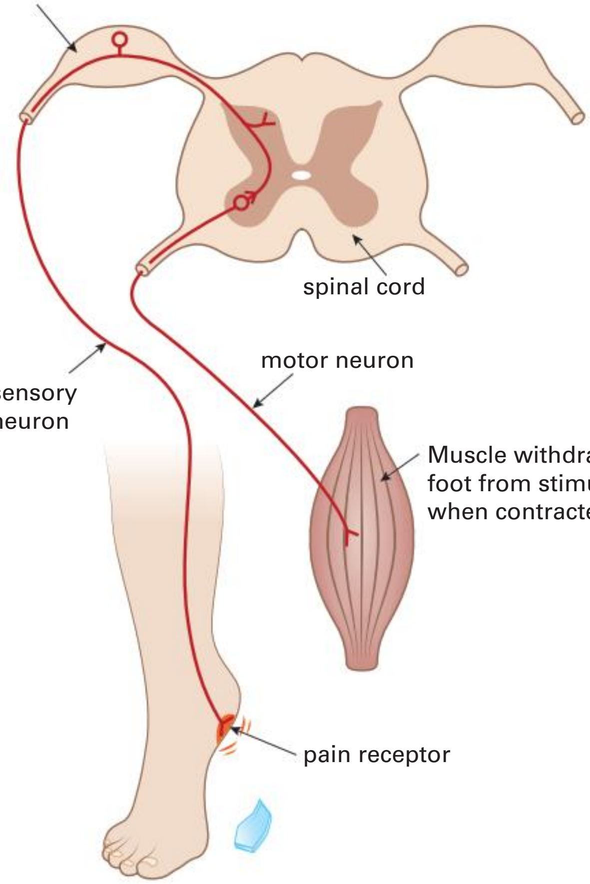


Figure 12.8 How a reflex action works

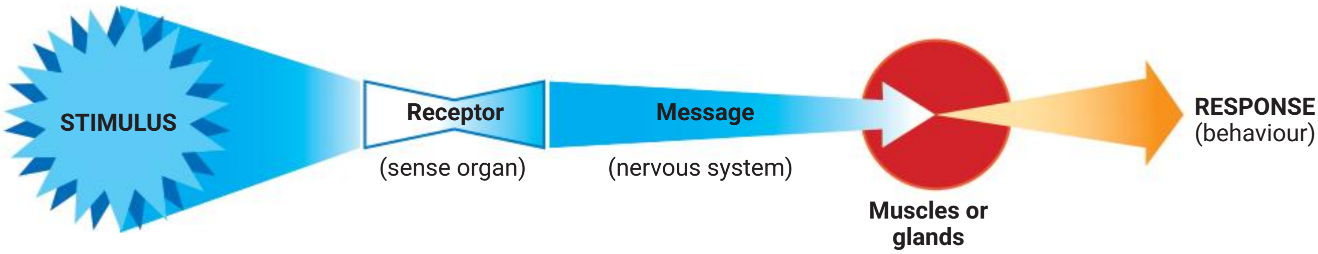


Figure 12.7 The stimulus–response model

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Reflex actions also occur when you may be in danger of getting injured. For example, if a ball is coming towards your face, you will raise your arms to protect yourself. Doctors also use reflex action tests as part of a medical examination.

Instinctive behaviours are primitive responses that an organism is born with and that are built into its nervous system. An example is the palmar grasp reflex, which is the tendency for babies to close their hands around anything such as your finger. Yawning is another behaviour that can occur—and it is thought to be contagious.

Figure 12.9 The palmar grasp reflex

Conditioning

Have you ever been told 'You learn from your mistakes'? This statement is true because learning occurs when behaviour is changed due to an experience. If you touch something hot and get burnt, you will remember not to do that next time. Throughout our lives we change our behaviours due to learnt experiences, whether they were experienced personally or through something we observed. This process is called **conditioning**.

There is a field of behavioural psychology that deals with changing people's and animals' behaviour through a variety of techniques. For example, it has been found that negative reinforcement doesn't work as well as positive reinforcement. That is why dog trainers use the stimulus–response reinforcement model to train a dog. If an owner throws a ball and the dog fetches it and brings it back to the owner, the dog is rewarded with a treat or pat. The stimulus is the ball being thrown, the response is the dog bringing the ball back, and the reinforcement is the treat or praise. Through this model it is hoped the dog will change its behaviour and always bring the ball back.

Figure 12.10 Giving a dog a reward for good behaviour

Conditioning occurs when we respond to certain stimuli. If we receive something pleasant or rewarding we are likely to repeat that response. This type of learning is the basis of most behaviour management with children. If we positively reward good behaviour, the child is likely to repeat this behaviour to receive a reward.

Ivan Pavlov was a Russian scientist who did conditioning experiments on dogs. One of his experiments was to ring a bell every time he fed meat powder to the dogs, then measure the amount of saliva they produced. After a while the dogs produced saliva when they heard the bell even though they weren't fed. The dogs had transferred their response (salivating) from an old stimulus (food) to a new stimulus (bell).

Many phobias we experience are the result of conditioning. For example, some people are fearful of heights. This may have started when they were children and had an experience

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where they nearly fell from a height or were afraid of falling. Now when they experience heights, this memory is recalled and they experience fear.

Figure 12.11 This man is struggling with his fear of heights.

Figure 12.12 Pavlov and his dog

Learning

Every day we learn something new or we learn from an experience. When you were a toddler, you may have touched a hot oven door. From this you learnt that the oven would burn you and you didn't touch the door again. Learning occurs when we change our behaviour because of something we experience, and as a result there is also a change in our memory.

There are at least three different types of learning: habituation, trial-and-error learning, and problem-solving.

Habituation

Habituation is the simplest type of learning where we learn *not* to respond to a stimulus. We form the habit of not responding. An example is where you have a new alarm clock that makes a loud ticking noise. For the first few nights you hear the noise, but eventually you become unaware of it. Your body has learnt not to respond to the stimulus of the ticking. This type of learning is very important as it helps us to ignore unimportant stimuli that could disrupt our daily activities.

Trial-and-error learning

Trial and error is a problem-solving method in which multiple attempts are made to reach a solution: you try one method, observe whether it works, and if it doesn't, you try another method. This process is repeated until success or a solution is reached.

Trial and error is also called 'guess and check'. It is a basic method of learning that all humans and animals use for learning new behaviours.

Problem-solving

Humans have the ability to solve problems without having to use trial and error. Problem-solving is a process that involves discovering, analysing and solving problems.

Problem-solving can also involve using your memory. For example, memory helps you solve difficult maths problems and can also assist you when you experience a situation that you haven't encountered before. To solve a problem, you use a strategy that will help you with the process, and choosing an appropriate strategy is where you need to use your memory.

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SCIENCE AS A HUMAN ENDEAVOUR

Wibbly Wobbly Bridge

Behaviourists such as John Watson believed that psychology should be the study of observable behaviours. He believed behaviours were the results of conditioning. An example of human behaviour is a phenomenon that occurred on the day that the Millennium Bridge in London was opened to the public in 2000. The modern steel suspension bridge was designed for pedestrians crossing the Thames River between Bankside and the City of London. As thousands of people streamed across the bridge, at first it slowly began to sway then gradually the swaying increased. The swaying was so extreme that the bridge was deemed unsafe. After only a few days the bridge was closed for two years while engineers worked at modifying it.

Following extensive investigations, it was discovered that the swaying was due to the synchronised way people walk. This phenomenon is called resonance. It was discovered that someone walking behind another person would unconsciously alter their step to become in step with that person. This would then be followed by the person behind them and so on. You can imagine the effect that up to 2000 people walking in a synchronised manner would have had on the bridge. Alterations were made to the bridge to take this effect into account.

Question

Describe another situation where people subconsciously 'copy' what another person is doing.

Figure 12.13 The Millennium Bridge in London

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CHECK

1 What is a stimulus?

2 Give an example of a simple reflex action and use the stimulus–reflex model to explain it.

3 Describe the difference between a learnt behaviour and an instinctive behaviour.

4 When you eat with a knife and fork, you place the fork directly into your mouth without thinking. Do you think this is learnt behaviour, a reflex action or instinct? Why?

5 Form groups of two to three to discuss the type of behaviour involved in the situations below. Explain how the behaviour helps the animal survive.
  a Cockroaches react to light. When lights are switched on they scurry to a dark place.
  b A tuning fork is placed near a cage of mosquitoes. When it is struck, only the male mosquitoes are attracted to it.
  c Whales migrate from the Southern Ocean to the northern waters off Australia during winter.

6 What is the difference between problem-solving and trial and error?

7 Explain the advantage of habituation to animals.

8 Why do you think animals such as worms and caterpillars don't have problem-solving abilities, but dogs and cats do?

9 Name the type of learning that is occurring in each of the following examples.
  a Five-year-olds are doing a puzzle where they need to place pegs of certain shapes into holes of the same shape.

  b Dolphins at Sea World are trained to balance a ball on their nose.
  c Babies learn to get attention by crying.
  d Mice are put in a maze with only one small opening. It takes a long time for them to find the exit.

10 Explain why at dinner time a dog will come to its owner, wagging its tail.

11 Sociocultural psychology is a branch of psychology that examines how cultural and ethnic similarities and differences influence the behaviour of humans. An example of this is sneezing. In some cultures, a sneeze is a good omen, but in other cultures it is regarded as a sign of illness. In countries where there is a mixture of cultures, conflicts can sometimes arise due to these differences. A sociocultural psychologist looks for ways to resolve or minimise these conflicts.
  a Describe ways in which a sociocultural psychologist could help resolve cultural conflicts.
  b List other psychological approaches that could be used.

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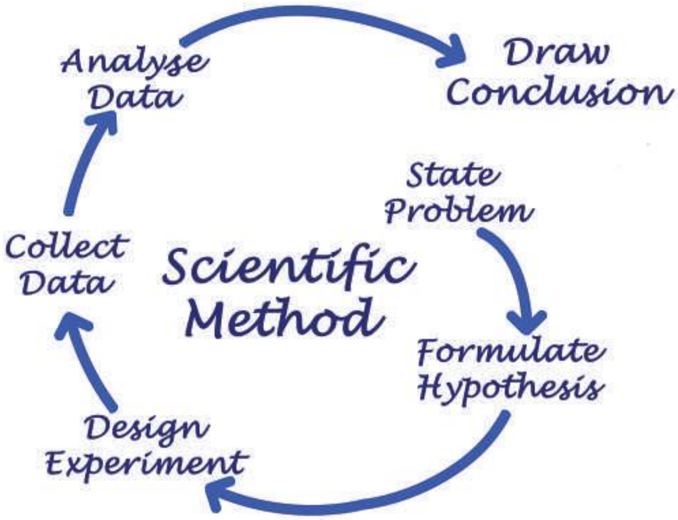
12.4 Research methods in psychology

Psychologists use the **scientific method** when working with clients and when conducting research to validate their theories. This method is a way of making observations, gathering data, forming theories, testing predictions, and then interpreting results. Psychologists may make observations based on a person's memory, their feelings or behaviour. From these observations, they will come up with a theory to explain their observations. However, without having data the theory remains a theory. Therefore, experiments are conducted to confirm, modify or dismiss the theory. As with all investigations, it is important that the investigation has a good sample size before drawing a conclusion.

All psychological research methods start with a question; for example: 'Are people happier on the weekend than during the week?' This question can then be turned into a hypothesis: 'People are happier on the weekend because they are spending more time with loved ones.'

As with all experiments, a procedure must be developed to confirm or dismiss the hypothesis. When completing the procedure, it is important that there is a dependent and independent variable, with all other variables controlled. With this example, the independent variable (the one you purposely change) is the working week or the weekend, and the dependent variable is the subject's happiness. The variables that need to be controlled include the age, gender and occupation of the subjects. The subjects' happiness could be measured using a rating scale or a survey.

Once the data has been gathered, it is then presented in a table and/or a graph so that the data can be interpreted and the hypothesis confirmed, modified or dismissed.



The scientific method

When doing experiments in psychology you need to follow the series of steps outlined below.

Question

Your research question should be focused on human behaviours, as these can be observed and/or measured directly. For example: 'Does playing music affect your memory when studying?'

Hypothesis

Write a hypothesis around the question. Remember that a hypothesis is an educated guess that states a relationship between the independent variable and the dependent variable.

Research

A hypothesis needs to be confirmed by doing research. A variety of research methods can be used to test a hypothesis; for example:

- interviews, which can be questionnaires or formal, structured interviews
- observations—natural or controlled
- experiments
- rating scales
- surveys.

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Analysing results

Examine the results and determine what they mean. You should look for patterns and relationships in the data. This can be done using tables and/or graphs.

Discussion

Are your results reliable and valid?

Reliability is when an experiment can be duplicated and you get the same results. Reliability can be improved by doing several trials and calculating an average, or using different subjects.

Validity is how well an experiment measures what it is supposed to measure. The results must be logical and relevant to what you are trying to find out, and the variables must be properly controlled. To make your results valid, you need to select your subjects carefully and make sure your method is likely to get the results you are looking for.

If your results aren't reliable or valid, you will need to repeat or redesign your experiment.

Conclusion

Relate your results back to your hypothesis. Do they confirm it or do you need to modify it, or dismiss it?

SCIENCE AS A HUMAN ENDEAVOUR

Is it ethical?

Psychology investigations involve human or animal subjects. Because of this, today's researchers must abide by the ethical standards set by their professional body. In 1963, Stanley Milgram, a qualified psychologist, conducted an experiment on obedience to authority in which he gave painful electric shocks to his subjects to validate his hypothesis. Because of the pain suffered by the people who took part in this experiment it would now be deemed unethical.

Question

Work in small groups to compile a list of ethical standards that psychologists should abide by when they are conducting experiments on humans or animals.

EXPERIMENT 12.1 Do your own research

1 Work in groups and design an investigation to answer one of the questions/hypotheses listed below, or choose one of your own.
   - Do people who are rushing around notice people in need?
   - People are happier when listening to songs that have happy lyrics.
   - Does music help you study?
   - Red M&Ms are more popular than other colours.
   - How much information can a person remember in 10 minutes?
   - Does using different-coloured paper help you remember information better?
   - You need to eat breakfast to concentrate in the morning.
   - Colour improves people's moods.
   - Do action films make people eat more popcorn?
   - Is social media addictive?

2 Discuss your design with your teacher before you start your investigation.

3 Present your findings as a movie, poster or report. Your investigation and report must include the following:
   - **a** Question
   - **b** Hypothesis
   - **c** Research
   - **d** Results
   - **e** Discussion
   - **f** Conclusion

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MAIN IDEAS

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

1 Psychology has developed over the years with psychodynamic, ______, cognitive, humanistic, evolutionary and ______ approaches used in research into human and animal behaviour.

2 Memory is an important function in our everyday behaviour. The input is the information coming through our five ______.

3 There are two types of memory: ______-term and ______-term.

4 In the stimulus–response model, the response is our ______.

5 To verify a hypothesis on human behaviour, a psychologist would conduct an ______.

6 In an experiment, the ______ will confirm, modify or dismiss the hypothesis.

short
behaviour
experiment
conclusion
behavioural
sociocultural
long
senses

CH•12 REVIEW

1 A certain stimulus is identified and placed into memory. Which stage of the memory process is this?
A encoding
B retrieval
C output
D storage

2 A person moves from the country to an inner-city house. At first she cannot sleep because of the traffic noise. After some time she doesn't notice the noise anymore. This is an example of:
A conditioning
B problem solving
C habituation
D a reflex action

3 You conduct an experiment to determine if music helps people to study. Half the people study with music for 30 minutes and the other half study without music for 30 minutes.
a What is the independent variable?
b What variables need to be controlled?

4 Joan saw her cat on the roof of the house. The cat was distressed and couldn't get down. Joan took a ladder from the garage and climbed onto the roof to save the cat. This is an example of:
A trial and error learning
B a reflex action
C conditioning
D problem solving

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5 What is the stimulus for each of the following behaviours?
a Birds roost in trees at night.
b Blowflies come into the kitchen at lunchtime.
c A bird fluffs up its feathers.
d A driver puts her foot on the brake at traffic lights.
e A cat arches its back, raises its fur and hisses.

6 Some birds, particularly in the southern parts of Australia, migrate north just before winter.
a What type of behaviour is this?
b Suggest what stimulus might trigger this behaviour.
c Design an experiment to show that your suggested stimulus triggers this behaviour.

7 Describe the differences between short- and long-term memory.

8 a Use the analogy of a filing cabinet to explain memory.
b Do you think this is a good analogy? Explain your answer.

9 Guinea pigs kept in cages were fed each day by a person wearing a white laboratory coat. Each time this person with the food came near the cages, the guinea pigs would squeak with excitement. After some time, the guinea pigs would squeak when anyone wearing white clothes approached their cages. How do you account for this?

10 Identify a situation you have encountered where positive reinforcement has been used to change the behaviour of an animal or person, or to create a new behaviour.

Check your answers on page 353.

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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.

CH•1 Periodic table

1 **D**

2 **A**

3 **D**—contains 8 non-metal atoms

4 **B**—see page 16

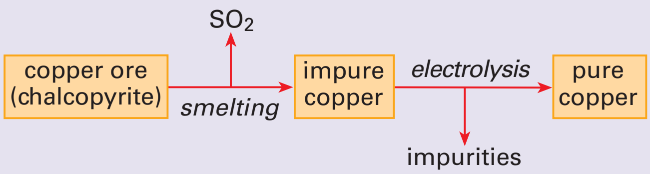
5 **a** cerium 58 (dwarf planet)
uranium 92
neptunium 93
plutonium 94
b scandium 21 (Scandinavia)
gallium 31 (Latin name for France)
germanium 32
europium 63
polonium 84 (Poland)
francium 87
americium 95
californium 98
tennessine 117 (US state of Tennessee)
c neon, and sometimes helium, argon, krypton and xenon
d nitrogen and oxygen
e arsenic
f iron, aluminium, copper, lead, zinc, nickel, titanium

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 is the most reactive, then copper and then platinum which is the least reactive.
b Platinum would make the best mirror because it does not corrode and hence its surface stays shiny.

8 Element 119 would start a new row on the left of the periodic table—in Group 1. So you would expect it to be a reactive metal, like the other alkali metals. Element 120 would be an alkaline earth metal like the other metals in Group 2.

9 Using the flow chart on page 19 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 11). 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 23). 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

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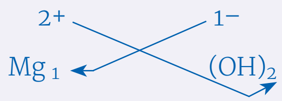
CH•2 Rearranging atomss

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**



$Mg(OH)_2$

4 **a** three—Cu, S and O
b Cu^{2+} and SO_4^{2-} ions (see page 40)
c ionic

5 **a** Ionic compounds are held together by the attraction between oppositely charged ions (see page 33).
b Covalent compounds are held together by the sharing of electrons (see page 36).

6 **a** $C + \mathbf{2}Br_2 \rightarrow CBr_4$
b $Fe_2O_3 + \mathbf{3}C \rightarrow \mathbf{2}Fe + \mathbf{3}CO$
c $P_4 + \mathbf{6}H_2 \rightarrow \mathbf{4}PH_3$
d $C_4H_8 + \mathbf{6}O_2 \rightarrow \mathbf{4}CO_2 + \mathbf{4}H_2O$
e $Al_2(SO_4)_3 + \mathbf{3}Pb(NO_3)_2 \rightarrow \mathbf{3}PbSO_4 + \mathbf{2}Al(NO_3)_3$

7 **a** $MgSO_4 \rightarrow Mg^{2+} + SO_4^{2-}$
$KOH \rightarrow K^+ + OH^-$
(See the table on page 40.)

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. As 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)

12 **a** combination, combustion, decomposition, precipitation, acid–metal, acid carbonate, neutralisation, metal-displacement
b Examples will vary. See the chapter.
c Examples will vary. See the chapter.

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CH•3 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 74)

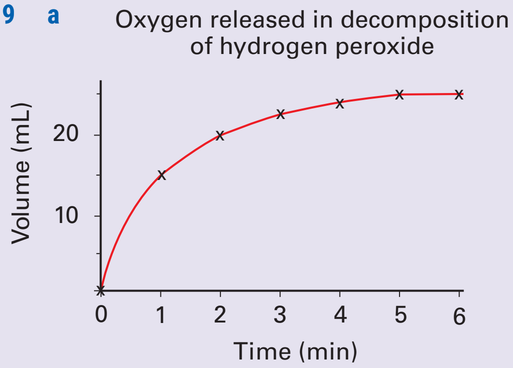
6 The reaction in test tube A will be faster than the reaction in tube B. This is because the acid in tube A is more concentrated (less water) than that in B.

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 74.)

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 and 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.

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CH•4 Road science

1 **D**

2 $v_{av} = \frac{d}{t}$

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 forwards 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 wheels '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 anti-lock 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.

$a_{av} = \frac{v - u}{t} = \frac{0 - 15 \text{ m/s}}{3 \text{ s}} = -5 \text{ m/s}^2$

$F = ma$

$= 80 \text{ kg} \times -5 \text{ m/s}^2$

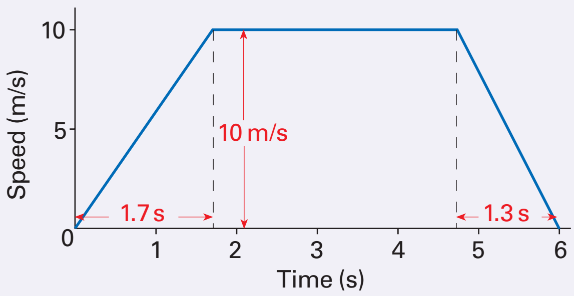
$= -400 \text{ newtons}$

(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 $= \frac{0 - 10 \text{ m/s}}{1.3 \text{ s}}$

$= -7.7 \text{ m/s}^2$

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CH•5 Space engineering

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 125.)

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 re-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)—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.

$W = mg$,

so $m = \frac{W}{g}$

$= \frac{88\text{ N}}{1.6\text{ m/s}^2}$

$= 55\text{ kg}$

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:

$W = 75\,000\text{ kg} \times 3.9\text{ m/s}^2$

$= 292\,500\text{ N}$

Net force accelerating rocket:

$F = 75\,000\text{ kg} \times 5\text{ m/s}^2$

$= 375\,000\text{ N}$

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:

$W = 75\,000\text{ N} \times 8.9\text{ m/s}^2$

$= 667\,500\text{ N}$

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.

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10 **a** On Earth the weight of the astronaut is $110\ \text{kg} \times 9.8\ \text{m/s}^2 = 1078\ \text{N}$

b $a = \dfrac{F}{m} = \dfrac{9\ \text{N}}{110\ \text{kg}}$

$= 0.08\ \text{m/s}^2$

c The total thrust developed by the 24 rockets is $24 \times 9 = 216$ 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 $110 \times 1.6 = 176$ N. This is less than the total thrust developed by the rockets, so she would lift off from the moon's surface.

CH•6 Using electricity

1 A

2 When you turn the switch on, electric current flows in the coil and the electromagnet works. It attracts the L-shaped piece of metal attached to the spring, pulling the bolt out of the door. When you turn the switch off, the electromagnet no longer attracts the metal bar, which is pulled up by the spring, locking the door again.

3 **a** The earth pin is the bottom slightly longer one.

b The earth wire connects the metal case of an appliance to the ground. If there is a short circuit, the electric current travels to the ground instead of through your body.

c Appliances that are double-insulated do not need an earth wire. They are surrounded by plastic (an insulator) and have no external metal parts (conductors).

4 **a** alternating current

b 12 watts

c six D-sized batteries

d The ⧈ symbol indicates that the radio is double-insulated. It therefore needs only a two-pin plug.

e The radio operates on 9 volts DC, so it would need a step-down transformer to reduce the voltage from 240 V to 9 V.

5 **a** High-pressure steam spins the turbines.

b In the electric generators, kinetic energy is converted to electrical energy.

c C contains step-up transformers to increase the voltage before it is transmitted to our homes.

d Before the electricity is supplied to our homes the voltage must be decreased to 240 volts, using step-down transformers.

e Everything would be the same, except that instead of burning coal to heat the boiler you use a nuclear reactor.

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6 energy (kW-h) = power (kW) × time (h)

$$= \frac{1500}{1000} \times 3$$

$$= 4.5 \text{ kW-h}$$

cost of energy = 4.5 × 15 cents

= 68 cents

7 **a** 2 amps
b 4 volts
c $R = \frac{V}{I} = \frac{4 \text{ volts}}{2 \text{ amps}} = 2 \text{ ohms}$

8 **a** voltage, current and resistance
b resistance—kept at 6 ohms
c The voltage doubled.
d The voltage doubled.
e The voltage stayed the same.
f $V = IR$

CH•7 Inheritance

1 **B**

2 **C**

3 **C**

4 **a** 32 pairs
b 32 single chromosomes
c Sperm have 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 type A blood.

father

mother	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).

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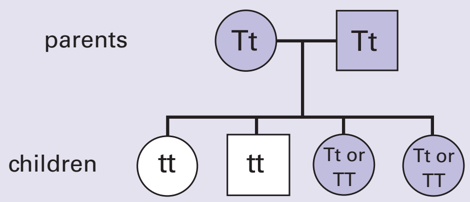
9 Suppose the gene for tongue rolling is T and the gene for non-tongue rolling is t. Then the phenotype for the daughter and son who cannot roll their tongues is tt. The father and mother must have genotypes Tt because they can both roll their tongues and have children who cannot.

The shaded circles and squares indicate those who can roll their tongues.

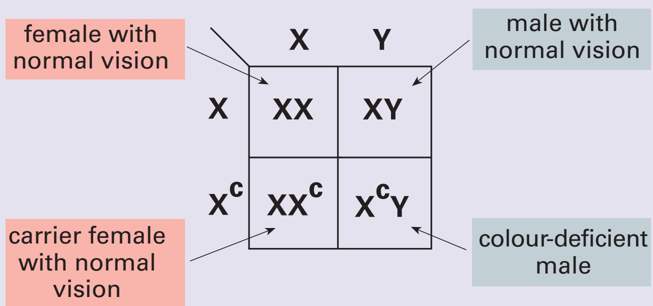


10 a The genotypes of the parent plants are TT and Tt. They are both tall.

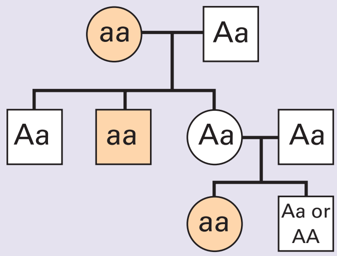
	T	**T**
t	Tt	Tt
T	**TT**	TT

b All the plants are tall.

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 below shows (in theory) that the female children will have normal vision but half of them will carry the colour-deficiency gene, and 50% of male children 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.



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CH•8 Evolution of life

1 **B**—see page 218

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 and 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 the finches 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 231. 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 the groups are isolated from each other for a long period of time, trees at X and Z could form two different species. In contrast, trees at Y are not totally isolated from the trees at Z and might still interbreed.

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CH•9 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 253.
d True—see pages 250 and 252.

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

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 240.

8 **a** Global warming heats the Earth's atmosphere, and in turn is increasing the melting of the polar ice caps. This raises sea levels.
b Global warming could affect biodiversity in various ways. It could cause changes in an ecosystem which could favour certain characteristics of organisms, leading to them being better adapted to the ecosystem. This changed environment would in turn drive evolution and cause more mutations, and produce more variation and therefore more biodiversity over time.

Alternatively, global warming could cause a change in an ecosystem that reduces the chance of survival of an organism, and hence reduces its population and distribution, leading to reduced biodiversity.

Examples will vary. See the Activity on page 254 for some examples.

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CH•10 Origin of 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 282

5 Einstein's equation, $E = mc^2$, means that, under conditions of extreme heat and pressure, such as in a star's core, matter 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.

12 **a** The Big Bang is a theory to explain the origin of the universe. It suggests that the universe was formed about 13.8 billion years ago and is still expanding.

b A galaxy is a massive collection of stars, interstellar gas, dust and other matter held together by gravity.

c 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, and therefore the red shift is considered evidence that the universe is expanding.

d A solar system is a collection of planets, moons, asteroids and other bodies rotating around a star and held in orbit by the star's gravity.

13 Spiral galaxies have a central core with arms spiralling outwards as they spin. Young stars form in the outer arms and older stars are found in the centre. Elliptical galaxies are largely composed of mature stars and have less dust and gas than spiral galaxies. They are egg-shaped, although they may vary in shape and size.

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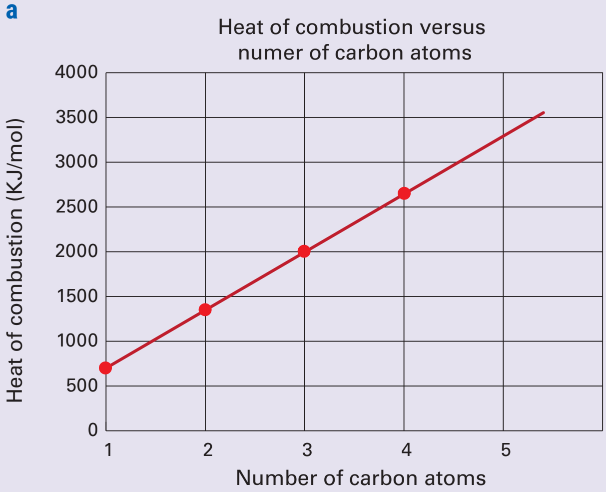
CH•11 Carbon chemistry

1 **D**

2 **A**

3 **a**



b The heat of combustion of alcohols increases in direct proportion to the number of carbon atoms in the alcohol molecule.

c Extrapolating from the graph, the heat of combustion for pentanol (with five carbon atoms) is approximately 3250 kJ/mol.

4 **a** true

b false—Hydrocarbons contain carbon and hydrogen only.

c true

d true

e false—Petrol has a *lower* boiling point than diesel fuel (see Figure 11.4 on page 294).

f false—Long-chain hydrocarbons can be broken down by *cracking*.

g true

h false—The oxygens are not balanced. The correct equation is:

$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

5 **a** The plastic pellets are forced along by the turning screw and melted by the heaters. The molten plastic is then forced into the nozzle where it cools and takes the shape of the mould, in this case a pipe.

b **B**

6 **a** Acetone would distil first, because it has the lowest boiling point. Acetic acid would distil last.

b Propanol and water are difficult to separate. They distil together because their boiling points are very close.

7 **a** **A** is a thermoplastic since there are no crosslinks between the chains (see page 301).

b **B** would not melt on heating since it is a thermoset.

c **B** would be stronger because of all the crosslinks.

d **A**—since only thermoplastics can be recycled.

e **A** is likely to be polythene (see page 300).

8 **a** The holes in the elbows are caused by rubbing rather than stretching. The fact that the thread is strong is not relevant in this situation.

b You would need to test the different fabrics by rubbing them, e.g. pulling strips of fabric backwards and forwards across the edge of a bench 100 times. You could then compare the wear in the different fabrics.

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CH•12 Psychology

1 D

2 C

3 a The independent variable is people studying with or without music.
b The controlled variables are the music and the study material.

4 D

5 a the time of the day
b the scent of food
c weather and coldness
d seeing the red traffic lights
e seeing a perceived threat approaching

6 a instinctive
b a change in the season
c You would need to change the season, which is not possible—unless you were somehow able to change the sunlight hours, which indicates a change in the season. You could also observe whether the birds migrate if the change of season is earlier or later than normal.

7 Memory is the capacity to encode, store and retrieve information. Short-term memory lasts only a short period of time (10 to 30 seconds). Long-term memories can be stored and retrieved over an extended period of time.

8 a Memories are like files you create (input and encoding) and store alphabetically in the different drawers of a filing cabinet (your brain). These memories can then be retrieved at a later date, just as you can retrieve a file from a filing cabinet and use the information in it (output).
b Memory is much more complex than this. For example, there are many links between the information in different files.

9 The guinea pigs were conditioned to being fed by someone in a white coat. They then associated someone in white with being fed. The guinea pigs had transferred their response from an old stimulus (food) to a new stimulus (white clothes).

10 Answers will vary. An example is when a dog being trained receives a treat when it returns a ball in a game of catch. After a period of time it associates the expected behaviour with a treat. Another example is where a child is rewarded for good behaviour (positive reinforcement) and as a result tends to repeat this good behaviour.

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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 95

activity series: a list of the metals with the most reactive at the top and the least reactive at the bottom 53

alkali metals: very reactive elements in Group 1 of the periodic table, e.g. sodium and potassium 13

alkaline earth metals: reactive elements in Group 2 of the periodic table, e.g. magnesium and calcium 13

alleles (a-LEELs): different forms of the same gene; each allele produces variations in inherited characteristics, e.g. eye colour 191

allotropes: different forms of the same element; e.g. diamond, graphite and buckyballs are allotropes of carbon 23

Alzheimer's (ALTZ-heim-ers): a progressive mental deterioration due to degeneration of the brain 330

artificial selection: the selection and breeding of particular organisms to produce offspring with desired characteristics 224

atmosphere: the thin layer of gases surrounding the Earth (or any other planet) 236

atomic number: the number of protons in the nucleus of an atom, which is equal to the number of electrons 6

average speed: the total distance travelled, divided by the time it takes to go that distance; usually measured in m/s or km/h 93

Avogadro's number: the number of atoms or molecules in one mole of a substance, equal to 6.022×10^{23} 58

azimuth: the direction of a star measured clockwise around the observer's horizon from the north; so a star due north has an azimuth of 0°, one due east 90°, south 180° and west 270° 267

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 285

binary stars: two stars that revolve around each other 277

biodegradable: able to be broken down or decayed by biological means (bacteria and fungi) 243

biodiversity: the combination of all life on Earth; the plants and animals, the genetic information they contain and the ecosystems they live in and interact with 206

biofuels: liquid fuels that have been produced from other materials such as waste plant and animal matter 313

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 243

biomagnification: the build-up in concentration of a chemical as it moves from organism to organism in a food chain 244

biosphere: the thin layer where life exists on Earth 236

black holes: invisible objects in space that emit X-rays and are thought to form when the most massive stars explode 282

carbon cycle: the cycling of the element carbon between the atmosphere, biosphere, hydrosphere and lithosphere 240

catalysts (CAT-a-lists): substances that speed up chemical reactions, without being used up themselves 77

chemical bonds: attractive forces between atoms that hold them together 32

chromatid (CRO-ma-tid): one of two identical strands into which a chromosome splits during mitosis 185

chromosomes: objects found in the nucleus of a cell that carry the genetic information 185

chromosphere: the lower atmosphere of the sun in which bursts of glowing gas shoot out from the surface 273

circuit-breakers: safety devices that break electric circuits when they carry too much current 151

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clones: organisms that have identical genes to their parents 229

co-dominance: the genes for a particular characteristic combine to give features of both the individual genes 196

collision theory: theory that says for a reaction to occur the atoms, ions or molecules must collide with the correct orientation and with sufficient energy 64

combustion (burning): a rapid chemical reaction that occurs when a substance reacts with oxygen in the air, producing heat and light energy 81

concentration: the amount of solute dissolved in a certain volume of solution 74

conditioning: a learning process where a response becomes more frequent or predictable in a given environment as a result of reinforcement 333

conservation of energy: this law says that energy cannot be created, destroyed or lost—it can only be changed from one form to another 115

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 86

constellations: groups of stars that form unchanging patterns in the sky 264

corona: the upper atmosphere of the sun, which can be seen only during a solar eclipse 273

correlation: how closely two variables depend on each other 255

cosmology: the study of the origin and structure of the universe 285

covalent bond: a chemical bond formed by the sharing of electrons between two or more atoms 36

cracking: a process in which large molecules of a hydrocarbon are broken down into smaller molecules by heat, pressure or catalysts 312

decomposition: a chemical reaction in which a substance breaks down to simpler substances 50

dementia (de-MEN-sha): the loss of cognitive ability and function 328

detergents: synthetic compounds usually made from chemicals obtained from crude oil; used as dishwashing liquids, washing powders and shampoos; more effective cleaners than soaps 297

DNA (deoxyribonucleic acid): the complex chemical compound found in chromosomes that contains the genetic code 176

dominant gene: a gene for a particular characteristic that completely hides or masks the alternative (recessive) gene 191

dyslexia (dis-LEXI-a): a disorder when people have difficulty in learning to read or interpret words, letters and other symbols 325

earth wire: a wire connecting the metal case of an appliance to the ground 152

ecliptic (ek-CLIP-tick): the path followed by the sun, moon, planets and a number of constellations in their apparent movement across the sky 268

ecosystem diversity: the variety of ecosystems that exist 206

electrolysis (ee-lek-TROL-e-sis): the process of passing an electric current through an electrolyte to produce chemical reactions at the electrodes 18

electron configuration: a shorthand way of showing the arrangement of electrons around an atom; for example oxygen's electron configuration is 6,2 9

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 7

electroplating: depositing a thin layer of metal on another using electrolysis 81

elevation: the angle of a star measured upwards from the observer's horizon 267

endothermic reaction: a reaction during which energy is absorbed; energy must be supplied to keep the reaction going 81

enhanced greenhouse effect: an increase in the natural greenhouse effect, brought about by increased levels of greenhouse gases in the atmosphere 252

enzymes (EN-zimes): biological catalysts that speed up (or control) chemical reactions in organisms 77

equilibrium (e-kwil-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 252

eutrophication (YOU-tro-fi-KAY-shun): a reduction in the oxygen concentration in water caused by decomposing organisms following excess plant growth 243

evolution: a process in which species change over time and develop into new species 218

exothermic reaction: a reaction that releases energy 81

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fractional distillation: distillation process used to separate a mixture of liquids into 'fractions', based on their different boiling points 294

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* 105

fuse: a safety device containing a piece of wire that melts and breaks the circuit if too great an electric current passes through it 150

galaxy: a massive collection of stars, interstellar gas, dust and other matter held together by gravity 277

gene pool: the sum of all genes in a population of a particular organism 218

generators (electric): devices that use electromagnetic induction to convert kinetic energy into electrical energy 166

genes: segments of DNA that carry genetic information from one generation to the next 176

genetic diversity: the range of genes a species contains 206

genetic engineering: the common term for a technique in biotechnology of inserting desired genes from one species into the chromosomes of another species 225

genome: the total genetic material in an organism 181

genotype (GEN-o-type): the type of genes in an organism 193

geostationary orbits: satellite orbits at a particular altitude so that the satellite remains over the same point on the Earth's surface 133

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 252

greenhouse effect: the trapping of heat energy by gases in the atmosphere, causing its temperature to rise; carbon dioxide is the main greenhouse gas 250

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) 250

groundwater: water that has soaked underground through soil and rocks 244

halogens: very reactive non-metals in Group 17 of the periodic table, e.g. chlorine and iodine 22

heterozygous (HET-er-o-ZYE-gus): where the genes for a particular characteristic are different, resulting in a hybrid 193

homozygous (HO-mo-ZYE-gus): where the genes for a particular characteristic are the same, resulting in a pure breeder 193

hydrocarbons: covalent compounds containing only the elements hydrogen and carbon 26

hydrosphere: all the water on Earth; this includes oceans, lakes, rivers, groundwater and water in the atmosphere 236

incomplete dominance: the genes for a particular characteristic are neither dominant nor recessive but combine to give a mixture or blend of characteristics 196

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 109

ions (EYE-ons): atoms or groups of atoms that have a positive or negative charge, caused by the loss or gain of electrons 32

ionic bond: a chemical bond resulting from the attraction between ions of opposite charge 33

ionosphere (eye-ON-os-fear): the top layer of the atmosphere; it contains ions formed from collisions of cosmic rays with gas molecules 249

kilowatt-hour (kWh): the unit used to measure electrical energy; it is 1000 watts used for 1 hour 159

light-year: an astronomical unit that is used to measure the huge distances between stars; it is the distance light travels in one year 264

lithosphere: the rigid outer layer of the Earth; it includes the crust and the upper part of the mantle 236

long-term memory: the phase of memory responsible for the storage of information for an extended period of time 326

meiosis (my-OH-sis): the process of cell division that produces sex cells, which have half the number of chromosomes of body cells 186

metallic bond: type of bond formed from the attraction between mobile electrons and fixed positively charged metal atoms 36

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microgravity: a term that describes the apparent weightlessness of an object that is in orbit 136

minerals: metal compounds found in the Earth 16

mitosis (my-TOE-sis): a process in which a single cell divides to produce two identical daughter cells 185

molar mass: the mass of one mole of an element or compound 60

mole: the amount of an element or compound containing the same number of atoms as there are in 12.0 grams of carbon-12 (6.022×10^{23}) 58

momentum: the mass of a moving body multiplied by its speed 109

mutations: permanent changes in genes; they may be caused by exposure to radiation or chemicals 179

natural selection: the process in which the best-adapted individuals survive in a particular habitat (often called survival of the fittest) 212

nebula (NEB-you-la): a huge expanding cloud made up of dust and gases formed after a massive star explodes (supernova) 280

neutralisation: the reaction of an acid and a base to form salt and water 52

neutron star: a small star made of extremely dense matter and formed from the remaining matter after a massive star explodes 282

noble gases (or inert gases): unreactive gases in Group 18 of the periodic table, e.g. helium and neon 22

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 272

ohm (Ω): the unit of electrical resistance 155

Ohm's law: the current (I) flowing through a resistor is proportional to the voltage difference (V) between its ends; the equation for Ohm's law is $V = IR$, where R is the resistance 156

orbit: the path followed by an object in space as it moves around another object 130

ores: mineral-containing rocks that are suitable for mining and mineral extraction 16

organic chemistry (carbon chemistry): the branch of chemistry that studies carbon compounds 26

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 256

pedigrees: family trees, showing the inheritance of particular characteristics from one generation to later generations 194

periodic table: a listing of the elements in order of their atomic numbers; elements are grouped according to their chemical properties 6

phenotype (FEE-no-type): the physical appearance or characteristics of an organism 193

photosphere: the visible part of the sun 272

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 239

polymerisation (pol-IM-er-eyes-AY-shun): a chemical reaction in which many small molecules link up to form a giant molecule (polymer) 299

polymers: substances composed of giant molecules formed by linking many smaller molecules (monomers) together 299

power (electrical): the rate at which an appliance uses electrical energy; it is measured in watts 159

precipitation: a chemical reaction that results in the formation of a precipitate when two clear solutions are mixed 51

psychology: a branch of science that deals with human behaviour and cognitive functions 322

reaction rate: the speed of a chemical reaction 70

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 103

recessive gene: a gene for a particular characteristic that is completely hidden or masked by the alternative (dominant) gene 191

recombination: during meiosis when chromosome pairs line up, a section of a chromosome overlaps and swaps with its pair, resulting in a different arrangement of genes; this leads to new combinations of traits in offspring 209

reflex action: a rapid response to a stimulus that occurs when a nerve impulse travels straight to the muscle or gland without getting processed by the brain 332

relative atomic mass: the weighted average of the masses of the isotopes in a naturally occurring element relative to the mass of an atom of the carbon-12 isotope which is taken to be exactly 12; sometimes called atomic weight 5

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reliable: results are reliable if they are the same when the experiment is repeated many times 75

replication: the process during cell division by which DNA makes identical copies of itself 178

satellite: a natural or man-made object that orbits a planet 130

scientific method: a process of systematic observation, measurement and experiment and the forming, testing and modification of hypotheses 337

sewage (SUE-idge): water and wastes that come from kitchen sinks, bathrooms, laundries, toilets and industries 243

short circuit: a fault that allows current to flow along an unintended low-resistance path in an electric circuit 150

short-term memory: the capacity for holding a small amount of information in the mind for a short period of time 326

smelting: the process of extracting metals from their ores through melting 16

solar cells (or photovoltaic cells): devices containing a semiconductor, which absorb solar energy and convert it directly to electrical energy 164

species: a population of organisms that has similar features and can interbreed 217

species diversity: the variety of species, each with their own genetic diversity, that exist within a habitat or ecosystem 206

stimulus: something that is detected by an organism's receptors and causes a response 332

stimulus–response model: theory that says that when a sense is stimulated, a message is sent through the central nervous system to a part of the body that will produce a response 332

stratosphere: the middle layer of the atmosphere; its upper region contains the ozone layer 249

structural formula: a chemical formula which shows the structure of a molecule—how the atoms are linked together 292

supernova: occurs when a massive star explodes, scattering most of its matter into space 280

thermoplastics: plastics that can be melted or remoulded repeatedly 301

thermosets: plastics that cannot be remoulded after the initial heating and moulding process 301

thrust: the force created by a rocket's engines to move it forwards 127

transformer: a device designed to increase (step up) or decrease (step down) the voltage of alternating current 170

transition metals: the elements found in the middle of the periodic table; they include common metals such as iron and copper 14

troposphere (TROP-os-fear): the layer of the atmosphere closest to the Earth 249

valency: the number of electrons an atom gains, shares or loses when combining with other atoms 39

valence electrons: the electrons in the outer shell of an atom; these electrons participate in chemical reactions 8

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 75

viscosity: a measure of a fluids' ability to flow, sometimes referred to as the 'thickness' of a fluid 294

voltmeter: an instrument used to measure voltage, in volts (V) 155

watt (W): the unit of power, equal to 1 joule per second 159

X-linked: genes that are found on the X chromosome but have no equivalent on the Y chromosome 198

zenith: the point in the sky directly above an observer 267

zodiac: the twelve constellations that follow the same path as the sun, moon and planets across the sky 268

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